MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 2/1982

Modell-Theorie

10.1. bis 16.1.1982

Die Modelltheorie-Tagung 1982 in Oberwolfach wurde von den Herren W. Baur (Zürich), A. Macintyre (New Haven) und A. Prestel (Konstanz) geleitet.

Die Arbeitstagung hatte zum Thema "Entscheidbare und unentscheidbare Körpertheorien". In einer Reihe von ausführlichen Vorträgen wurden aktuelle Ergebnisse dieses im Schnittbereich von Algebra und Modelltheorie liegenden Gebietes dargestellt. Wie auch schon auf früheren Modelltheorietagungen wurde nicht nur über neueste Ergebnisse informiert, sondern anhand der Vorträge sollte sowohl interessierten Modelltheoretikern als auch Algebraikern die Möglichkeit der Einarbeitung in dieses Gebiet geboten werden.

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Vortragsauszüge

W. Baur:

Undecidability of $\mathbb{Q}$ and $\mathbb{R}(T)$

The following well-known theorems are proved:

1. (Julia Robinson) The integers are first order definable in the field of rational numbers
2. (A. Malcev, A. Tarski) There exists a formula in the language of field theory defining the natural numbers in any rational function field $R(T)$, R real closed.

In particular, $Th(\mathbb{Q})$ and $Th(\mathbb{R}(T))$ are undecidable.

A. MacIntyre:

Decidability of the theory of finite fields

Ax's theorem on the decidability of the theory of finite fields was proved. First one considers infinite ultraproducts F^* of finite fields, and isolates the following properties of F^* :

(i) F^* perfect ;
(ii) $G(F^*) \simeq \hat{\mathbb{Z}}$;
(iii) every absolutely irreducible variety over F^* has a point in F^*.

That (iii) holds is a consequence of Weil's Riemann Hyphothesis for curves over finite fields. It is important (iii) is a first-order property and is axiomatized by:

(iv) Every absolutely irreducible plane curve has infinitely many points.

Fields satisfying (iii) are now called PAC fields. Fields satisfying (i), (ii) and (iii) are called pseudofinite.

Following a method of Jarden we proved pseudofinite fields are determined up to elementary equivalence by their absolute numbers. Next one characterizes the possible fields of absolute numbers, using Cebotarev's Density Theorem. This, together with another use of the Riemann Hyphothesis, yields the main theorem.

N. Klingen:

The embedding lemma

Das Einbettungslemma stellt einen wichtigen Teilschritt im Beweis der Entscheidbarkeit der Theorie der endlichen Körper dar. Es besagt grob, daß ein abzählbarer Körper E in einen $\aleph_1$-saturierten perfekten PAC-Körper F eingebettet werden kann, wenn beide einen geeigneten gemeinsamen Teilkörper haben und die absolute Galoisgruppe $G_F = G(\tilde{F}/F)$ in G_E abgebildet werden kann. Aus diesem Einbettungssatz gewinnt man ein Kriterium für die elementare Äquivalenz perfekter PAC-Körper. Insbesondere ergibt sich der im Vortrag über die Entscheidbarkeit der Theorie der endlichen Körper bereits benutzte Satz:
K,L pseudo-endlich. Dann sind K und L elementar äquivalent genau dann, wenn Abs(K) (:= algebraischer Abschluß des Primkörpers) isomorph ist zu Abs(L) .

M. Jarden:

Ax-fields of bounded corank

A perfect field E is said to be an Ax-field if every non-empty absolutely irreducible variety defined over E has an E-rational point. For a countable hilbertian field K and a positive integer e we define $Ax(\leq e,K)$ to be the class of all Ax-fields E that contain K such that rank $G(E) \leq e$. We also define $F\,L\,Alg\,Ax(e,K)$ to be the class of all Ax-fields E algebraic over K such that G(E) has rank e and with an order divisable by only finitely many primes. Denote by L(K) the language of the theory of fields augmented by constant symbols for the elements of K . We prove:

Theorem: a) A sentence θ is true in all fields $E \in Ax(\leq e,K)$ if and only if it is true in all $F\,L\,Alg\,Ax(e,K)$.

b) If K is a field with elimination theory (e.g. $K = \mathbb{Q}$), then the theory of $Ax(\leq e,K)$ is recursively decidable.

Part a) of the theorem is announced in the paper "Decidability and undecidability theorems for PAC-fields", Bulletin of AMS (1981). The proof of both parts of the theorem relies on the elementary equivalence theorem of Jarden and Kiehne and on extensive use of properties of Frattini-covers and projective groups.

M. Ziegler:

Undecidable subtheories of the theory of $(\mathbb{R}, +, \cdot)$.

Satz: Zu jeder Primzahl q gibt es einen formal reellen Körper K mit

i) $\mathbb{N}$ ist in K definierbar

ii) Der Grad jeder endlichen formal reellen algebraischen Erweiterung ist 1 oder durch q teilbar.

Folgerung: Jede endliche Teiltheorie von $Th(\mathbb{R})$ ist erblich unentscheidbar.

Ähnliche Sätze liefern die Folgerungen

Sei p eine Primzahl (oder = 0):

Jede endliche Teiltheorie der Theorie der algebraisch abgeschlossenen Körper der Charakteristik p ist erblich unentscheidbar.

Jede endliche Teiltheorie der Theorie der p-adischen Körper ist erblich unentscheidbar.

Y.L. Ershov:

Galois stratification

Let K be a field, U(K) is an universal domain over K. If $\xi_1, \ldots, \xi_n \in U(K)$ then an element $0 \neq \eta \in K[\bar{\xi}] = K[\xi_1, \ldots, \xi_n]$ is a smoothing for $K[\bar{\xi}]$ iff $K[\bar{\xi}, \eta^{-1}]$ is integrally closed.

n-Galois strat is a system $\mathcal{T} = \langle \bar{\xi}; \eta ; \alpha ; H \rangle$ such that:

1. $\bar{\xi} = \xi_1, \ldots, \xi_n, \eta, \alpha \in U(K)$
2. η is a smoothing element for $K[\bar{\xi}]$
3. $K(\bar{\xi}, \alpha)$ is a Galois extension of $K(\bar{\xi})$ and $H \leq G(K(\bar{\xi},\alpha)/K(\bar{\xi}))$
4. α is integral over $K[\bar{\xi}, \eta^{-1}]$ and $d(\alpha)$ – the discriminant of α – is invertible in $K[\bar{\xi}, \eta^{-1}]$.

Connected with an n-Galois strat $\mathcal{T}$ is some new n-placed predicate $P_{\mathcal{T}}$ on every K-field L as follows:

For $\bar{\xi}' \in L^n$

$\bar{\xi}' \in P_{\mathcal{T}}(L) \iff \bar{\xi}'$ is a specialization of $\bar{\xi}$ and the K-homomorphism $\varphi : K[\bar{\xi}] \to K[\bar{\xi}']$ can be extended to some homomorphism $\psi : K[\bar{\xi}, \eta^{-1}, \alpha] \to L(\alpha')$ into an algebraic extension of L in such a way that the decomposition group of ψ over φ is H .

There is an elimination of quantifier procedure in this new language for the theory of Frobenius (Iwasawa) fields.

D. Haran:

Undecidability of the theory of PAC fields

The theory of PAC fields, or any other family of fields whose Galois groups constitute the family of all profinite projective groups, admitts codification of a certain theory $T\mathcal{G}$ in a "language of profinite groups" $L\mathcal{G}$. Following the idea of G. Cherlin it is shown that the theory of graphs can be coded in the theory of $T\mathcal{G}$. Therefore the theory of all profinite groups is indecidable, and, thus, the theory of PAC fields is undecidable.

G. Cherlin:

Undecidability of Global fields

Theorem (Rumely) The theory of global fields is essentially undecidable.

This improves results of J. Robinson, Y. Ershov und Y. Penzin. Rumely's proof uses the general theory of norms from cyclic extensions and the Dirichlet theorem on primes in arithmetic progressions.

Main Lemma: There is a formula $\varphi(x,\bar{y})$ so that for each (nonarchimedian) prime p of a global field F, there are parameters a_1,a_2,a_3,a_4,a_5 so that

$$\varphi(F,\bar{a}) = O_p \cap F$$

To construct the formula φ, let q be a rational prime, p a prime of F not dividing q, and let $a \to x$ mean that x is a norm from $F[a^{1/q}]$. Let $(a_1,a_2) \to x$ mean:

$\exists y[a_1 \to y \wedge a_2 a_1 \to a_2 y \wedge y \to x]$. Let $(a_1,a_2,a_3,a_4) \to x$ mean:

$\exists x'x'' [(a_1,a_2) \to x' , (a_3,a_4) \to x'' , x = x'x'']$

Technical Lemma: Given F, p, q as above, there are

$$a_1,a_2,a_3,a_4 \text{ in } F \text{ such that:}$$

$$\forall x : (a_1,a_2,a_3,a_4) \to x \text{ iff } q \mid v_p(x) .$$

Finally, $\varphi(x,y_1,y_2,y_3,y_4,y_5) =$ "$(y_1,y_2,y_3,y_4) \to 1 + y_5 x^q$ "

[The relevant y_s satisfy $v_p(y_s) = 1$]

Y. Ershov:

Multiply valued fields

Using the notion of coherently complete n-valued field it is possible to find theorems for such fields which are similar to well-known theorems for Henselian fields.

A. Prestel:

Pseudo real closed fields

A field is called pseudo real closed (PRC) if every absolutely irreducible K-variety which has a simple rational point in each real closure $\overline{(K,P)}$ of K already has a K-rational point. The class of PRC-fields contains all PAC-fields (e.g. ultraproducts of finite fields), all fields K such that (K,P) is pseudo real closed in the sence of Basarab or McKenna, and all fields K such that $(K,P_1,\ldots,P_n)$ is a model of van den Dries' axioms (for some orderings $P_1,\ldots,P_n$ of K). A PRC-field K is called maximal if it does not admit a totally real extension which is algebraic (i.e. K is pythagorean and each odd degree polynomial over K has a zero in K). It was proved that the theory T of preordered fields (K,S) where K is a maximal PRC-field whose space X_K of orderings does not have any isolated points and $S = K^2$, is model complete. Moreover it was shown that T is decidable.

S. Basarab:

Hilbertian prc fields

Let $F|K$ be a field extension, and G a finite group. Then the following are equivalent:

a) For every algebraic extension L of K and every finite Galois extension $M|L$ with $G(M|L)$ a factor group of G, $M \cap LF = L$

b) For every finite Galois extension $N|K$, for every factor group H of G, $F \cap N$ is contained in the fixed field N_H of some normal subgroup $(G(N|K))_H$ of $G(N|K)$ canonically associated to $G(N|K)$ and H in some technical way.

Denote by $\mathcal{G}(F|K)$ the family of all finite groups G subject to the above equivalent conditions. Given a family $\mathcal{G}$ of finite groups, we say that $F|K$ is a $\mathcal{G}$-extension if $\mathcal{G} \subset \mathcal{G}(F|K)$. The fields and $\mathcal{G}$-extensions from a category $C_{\mathcal{G}}$ with good properties. In particular $C_{\mathcal{G}}$ has AP. The category $C_{\mathcal{G}}$ can be presented as the category of models of some theory $\mathcal{G}FL$ extending by definitions the usual theory FL of fields. Consider also the theory $\mathcal{G}OF_n = \mathcal{G}FL \cup OF_n$ with $n \in \mathbb{N}$, whose models are n-ordered fields, and whose morphisms are extensions of n-ordered fields which are also $\mathcal{G}$-extensions.

Theorem 1: $\mathcal{G}OF_n$ has a model companion $\overline{\mathcal{G}OF}_n$ which is decidable if $\mathcal{G}$ is recursive.

Theorem 2: $(K,P_1,\ldots,P_n) \models \overline{\mathcal{G}OF}_n$ iff

a) K is $\mathcal{G}$-prc (i.e. for every regular totally real field extension $F|K$, F can be embedded over K into an elementary extension $^*K$ in such a way that $K|F$ is a $\mathcal{G}$-extension

b) $P_i \neq P_j$ for $1 \leq i < j \leq n$ and K has only n-orderings

c) There are no proper totally real algebraic $\mathcal{G}$-extensions of K.

In the case $n = 0$, the models K of $\overline{\mathcal{G}OF}_o$ are the perfect Frobenius fields such that the closure of $\mathcal{G}$ (defined in a technical way) coincides with the class of all finite groups realizable over K. For $n = 0$ we get also that $\overline{\mathcal{G}OF}_o$ has elimination of quantifiers. Extending suitably by definitions $\overline{\mathcal{G}OF}_n$ we get also elimination of quantifiers.

F. Delon:

Henselian fields of characteristic $p > 0$

The works of Ax-Kochen and Ershov tell us that if K is an henselian valued field such that $ch(\overline{K}) = 0$, its theory is determined by those of $\overline{K}$ and val K. Ershov proved a result concerning the case where $ch(K) = p > 0$. We generalize this result and give a new formulation, which is much simpler:

Let K be a henselian valued field of ch. $p > 0$ with no finite separable extension of degree divisible by p; then its theory is determined by those of $\bar{K}$, of val K, and by its degree of inseparability. In particular K is decidable iff $\bar{K}$ and val K are.

Our proof is done in two steps: First we study the valued fields with no immediate separable finite proper extension, and then we use a property equivalent to Kaplansky's condition over the residue field.

M. Jarden:

On e-ordered fields

An e-ordered field is a structure $\mathcal{E} = (E, Q_1, \ldots, Q_e)$ that consists of a field E with e orderings $Q_1, \ldots, Q_e$. We start from some fixed e-ordered field $\mathfrak{K} = (K, P_1, \ldots, P_e)$, such that K is a countable Hilbertian field. For each $1 \leq i \leq e$ we choose a real closure $\bar{K}_i$ of K_i with respect to P_i. Then we consider e-tuples $(\sigma_1, \ldots, \sigma_e) \in G(K)^e$ and denote $K_\sigma = \bar{K}_i^{\sigma_1} \cap \ldots \cap \bar{K}_e^{\sigma_e}$, let $P_{\sigma i}$ be the ordering of K_σ which is induced by $\bar{K}^{\sigma_i}$ and finally let $\mathfrak{K}_\sigma = (K_\sigma, P_{\sigma 1}, \ldots, P_{\sigma e})$. We prove:

<u>Theorem</u>: For almost all $\sigma \in G(K)^e$ we have:

a) If V is an absolutely irreducible variety over K_σ with a function field F and if $P_{\sigma 1}, \ldots, P_{\sigma e}$ extend to F, then V has a K-rational point.

b) $G(K_\sigma) \cong \hat{D}_e$ = the free product (in the category of profinite groups) of e copies of $\mathbb{Z}/2\mathbb{Z}$.

Part b) of this theorem is due to W.-D. Geyer. Therefore, e-ordered fields that satisfy a) and b) are called Geyer-fields (of rank e). We prove next for the theory $L_e(\mathfrak{K})$ of e-ordered fields over K:

<u>Theorem</u>: A sentence Θ of $L_e(\mathfrak{K})$ is true in all Geyer fields of rank e that contain K if and only if Θ is true in almost all $\mathfrak{K}_\sigma$.

Then we define $A(\Theta) = \{\sigma \in G(K)^e \mid \mathfrak{K}_\sigma \models \Theta\}$ and prove for the Haar measure μ of $G(K)^e$:

Theorem: If Θ is a sentence of $L_e(\mathfrak{K})$, then $\mu(A(\Theta))$ is a rational number that can be computed if, e.g. $K = \mathbb{Q}$. Hence the theory of Geyer-fields of rank e is decidable.

As the next step we define an e-ordered field $(E,Q_1,\ldots,Q_e)$ to be a v.d.Dries-field (of corank e) if it satisfies:

a) If V is an absolutely irreducible variety defined over E, with a function field F and if $Q_1,\ldots,Q_e$ extend to F, then V has an E-rational point.

b) $G(E) \cong \hat{D}_e(2)$ = the free product (in the category of pro-2-groups) of e copies of $\mathbb{Z}/2\mathbb{Z}$.

Using a theorem of Prestel we show that it is possible to choose for every $\sigma \in G(K)^e$ such that $\mathfrak{K}_\sigma$ is a Geyer-field, an algebraic v.d. Dries extension $\mathfrak{K}'_\sigma$. We prove:

Theorem: a) A sentence Θ is true in all v.d.Dries fields that contain $\mathfrak{K}$ if and only if it is true in almost all $\mathfrak{K}'_\sigma$.

b) The theory of v.d. Dries fields that contain $(Q,P_1,\ldots,P_e)$ is the model companion $\overline{OF}_e$ of the theory of e-ordered fields.

Corollary: If $(E,Q_1,\ldots,Q_e)$ is a model of $\overline{OF}_e$, then $G(E) = \hat{D}_e(2)$.

Peter Roquette:

Skolem Diophantine problems

Report on a joint paper with D. Cantor on Diophantine problems. There exists a local-global principle (over the field of all algebraic numbers and the ring of all algebraic integers) for the class of those Diophantine equations whose associated variety is irreducible and unirational. Using results of A. Robinson on the decidability etc. of algebraically closed fields with valuations, there results a decision procedure for the said class of Diophantine problems (called Skolem problems). Several results and problems connected with Skolem problems were discussed, as well as possible generalizations to other classes of Diophantine problems.

E. Becker:

Generalized real closed fields

Sei K formal-reeller Körper, $P \subset K$ heißt Ordnung der Stufe n, wenn gilt: $P + P \subset P$, $PP \subset P$, $K^{2n} \subset P$, $-1 \notin P$, $K^{\times} | P^{\times}$ zyklisch. Diese Ordnungen treten auf beim Studium der Summen 2n-ter Stufe Potenzen, denn es gilt: $\Sigma K^{2n} = \bigcap P$, P Ordnung n-ter
Wir betrachten Paare (K,P), wobei K ein Körper und P eine Ordnung irgendeiner Stufe ist. (L,P') heißt Erweiterung von (K,P), wenn gilt: $K \subset L$, $P' \cap K = P$; im allgemeinen gilt: $[K^{\times} : P^{\times}] \leq$ $\leq [L^{\times} : P'^{\times}]$ die Erweiterung heißt treu, wenn $[K^{\times} : P^{\times}] = [L^{\times} : P'^{\times}]$ ist.

Definition: $(R,\tilde{P})$ reeller Abschluß von (K,P) = maximale algebraisch treue Erweiterung von (K,P) ; (K,P) reell abgeschlossen, wenn (K,P) keine echten algebraischen treuen Erweiterungen besitzt. R heißt verallgemeinerter reell-abgeschlossener Körper, wenn R eine Ordnung höherer Stufe P besitzt, so daß (R,P) reell-abgeschlossen ist.

Theorem 1: R ist verallgemeinerter reell-abgeschlossener Körper genau dann, wenn gilt: R besitzt henselschen Bewertungsring V mit folgenden Eigenschaften:

i) der Restklassenkörper ist reell-abgeschlossen im üblichen Sinne,
ii) die Wertegruppe Γ von V ist p-divisibel für fast alle p,
iii) ist $\Gamma \neq p\Gamma$, dann $[\Gamma : p\Gamma] = p$.

Die in Satz 1 auftretenden p's mit $[\Gamma : p\Gamma] = p$ sind allein durch R bestimmt. $S(R) := \{p \quad \Gamma \neq p\Gamma\}$ heißt der Typ von R .

Theorem 2: Die Klasse $\mathcal{H}(S)$ der verallgemeinerten reell-abgeschlossenen Körper von Typ S ist elementar.

Theorem 3: Sei R ein verallgemeinerter reell-abgeschlossener Körper. Dann ist seine Theorie Th(R) entscheidbar.

Zum Beweis werden verwendet: 1) Ershov, Ax-Kochen-Sätze über die elementare Äquivalenz henselsch bewerteter Körper,
2) die modelltheoretischen Untersuchungen von Kargapoloff über geordnete abelsche Gruppen.

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