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MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 31/91

Halbgruppentheorie

21. bis 27. Juli 1991

Vom 21.-27. Juli 1991 fand am Mathematischen Forschungsinstitut Oberwolfach die vierte Tagung über Halbgruppentheorie statt. Sie wurde von den Herren J. M. Howie (St. Andrews), W. D. Munn (Glasgow) und H. J. Weinert (Clausthal-Zellerfeld) geleitet; die 46 Teilnehmer kamen aus insgesamt 15 Ländern.

Die Vorträge betrafen recht unterschiedliche Gebiete der algebraischen Theorie der Halbgruppen und vorwiegend Gegenstände, die sowohl für die weitere Entwicklung der Halbgruppentheorie als auch für die verschiedensten Anwendungen in anderen mathematischen Disziplinen aktuelle Bedeutung haben. Als Beispiele erwähnen wir einmal Zusammenhänge zur Gruppentheorie, wo geometrische, topologische und graphentheoretische Techniken der Halbgruppentheorie zu neuen Ergebnissen geführt haben und auch weitere Lösungen offener Fragen erwarten lassen. Ähnliches gilt für die Ringtheorie und für die universelle Algebra, im letzteren Falle insbesondere durch erhebliche Fortschritte unserer Kenntnisse über Varietäten und Pseudovarietäten von Halbgruppen. Ebenso führen bessere Einsichten in die Struktur von Transformationshalbgruppen zu entsprechenden Resultaten in der Kombinatorik. Schließlich erwähnen wir zahlreiche Anwendungen der Halbgruppentheorie in der Theorie der Automaten und der Kodierungstheorie.

Neben den Vorträgen und persönlichen Gesprächen und Kontakten fanden drei kleinere Zirkel zu bestimmten Fragestellungen statt, z.B. über profinite Topologien über freien Gruppen und über die Darstellung singulärer Endomorphismen. In diesem Zusammenhang sei erwähnt, daß einige Ergebnisse bereits direkt während der Konferenz entstanden sind oder verbessert werden konnten.

Wie bei den Halbgruppentagungen von 1978, 1981 und 1986 wird auch für diese Tagung ein Proceeding-Band erscheinen.

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Die Tagungsleiter möchten schließlich noch einmal ihr Bedauern darüber ausdrücken, daß trotz der großzügig bemessenen Teilnehmerzahl zahlreiche interessierte Fachkollegen nicht eingeladen und auch viele entsprechende Anfragen nicht mehr berücksichtigt werden konnten.

Vortragsauszüge

K. AUINGER

Free products in the variety of all combinatorial strict inverse semigroups

Combinatorial strict inverse semigroups (that is, inverse subdirect products of combinatorial Brandt semigroups) can be characterized by the following construction (see e.g. M. Petrich, Inverse semigroups).

Let X be a partially ordered set, for each $\alpha \in X$ let I_α be pairwise disjoint non-empty sets and for $\alpha \geq \beta$ let $f_{\alpha,\beta} : I_\alpha \to I_\beta$ be mappings such that (i) $f_{\alpha,\alpha} = id_{I_\alpha}$, (ii) $f_{\alpha,\beta} f_{\beta,\gamma} = f_{\alpha,\gamma}$ whenever $\alpha \geq \beta \geq \gamma$ and (iii) $\delta(i,j) = \max\{\gamma \leq \alpha, \beta \mid i f_{\alpha,\gamma} = j f_{\beta,\gamma}\}$ exists for arbitrary $i \in I_\alpha$, $j \in I_\beta$, $\alpha, \beta \in X$. Put $S = \bigcup I_\alpha \times I_\alpha$, endowed with multiplication $(i,j)(k,l) = (i f_{\alpha,\delta}, l f_{\beta,\delta})$, where $\delta = \delta(j,k)$. The parameters $X, I_\alpha, f_{\alpha,\beta}$ are obtained as follows: $X = S/\mathcal{J} = S/\mathcal{D}$, $I_\alpha = E(\alpha)$, that is, the idempotents of the $\mathcal{D}$-class α and for $e \in I_\alpha$, $e f_{\alpha,\beta}$ denotes the uniquely determined idempotent in β such that $e \geq e f_{\alpha,\beta}$. The c.s.i. semigroup S is uniquely determined by the parameters X, I_α, $f_{\alpha,\beta}$.

Let $S_i = (X_i; I_{\alpha^i}, f_{\alpha^i,\beta^i})$, $i \in I$, be a collection of c.s.i. semigroups and let $S = (X; I_\alpha, f_{\alpha,\beta})$ be the c.s.i.-free product of the semigroups S_i. The parameters X, I_α, $f_{\alpha,\beta}$ will be expressed in terms of the ingredients of the semigroups S_i.

A. CHERUBINI (WITH M. PETRICH)

Linear congruences on a free monoid

The main purpose of this talk is to study the behaviour of linear congruences, which are defined by:

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There exist integers $s_1, ..., s_k$, where $X = \{a_1, \ldots, a_k\}$ such that:

$$u\varrho v \iff u_1 s_1 + \ldots + u_k s_k = v_1 s_1 + \ldots + v_k s_k \quad (u, v \in X^*)$$

where u_i stands for the number of occurences of a_i in u.

The principle result is the characterization theorem for linear congruences. Unions and intersections of linear congruences are described for certain special families of linear congruences.

D. EASDOWN

Presentations of the symmetric inverse semigroup and full transformation semigroup on a finite set

We use the presentation of the symmetric group on a finite set as a Coxeter group to find a presentation of the symmetric inverse semigroup and to conjecture a presentation for the full transformation semigroup on a finite set. These are different from known results (Aizenstat 1958, Jónsson 1961).

J. B. FOUNTAIN (SEE ALSO V. A. R. GOULD)

Stability of S-sets II

In the study of stable first order theories, superstable and totally transcendental theories are of particular interest. For the theory T_S, that is the model companion of a right coherent monoid S, one can find necessary and sufficient conditions on S in order for T_S is superstable. In fact, T_S is superstable if and only if S satisfies the maximal condition for right ideals.

The situation for total transcendence is more complicated but a usable result is obtained for the case when U-rank coincides with Morley rank.

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S. M. GOBERSTEIN (WITH M. V. SAPIR)

On quasivarieties of inverse semigroups

Let B_n denote the combinatorial Brandt semigroup with n nonzero idempotents ($n \geq 2$) and let $\mathrm{var}\, B_2$ denote the variety of inverse semigroups generated by B_2. We show that for any $n \geq 2$ the quasivariety $\mathrm{qvar}\, B_n$ generated by B_n is determined by a single quasiidentity within $\mathrm{var}\, B_2$. Certain properties of the lattice of subquasivarieties of $\mathrm{var}\, B_2$ are established.

G. M. S. GOMES

Embedding proper left type-A monoids into semidirect products

Let S be a semigroup and $a, b \in S$. We say that a and b are *$\mathcal{R}^*$-related* iff they are $\mathcal{R}$-related in an oversemigroup $T \supseteq S$. A monoid M is said to be *left type*-A if $E(M)$ is a semilattice, each $\mathcal{R}^*$-class R_a^* of M contains an idempotent a^+ (necessarily unique) and M can be $\mathcal{R}^*$-embedded into an inverse monoid. Also, M is said to be *proper*, if $\mathcal{R}^* \cap \sigma = \iota$, where σ is the least right cancellative monoid congruence on M.

Theorem. Let M be a left type-A monoid. Then M is proper iff M can be $\mathcal{R}^*$-embedded into the submonoid $W = \{(t, at) \mid a \in E, t \in T\}$ of a semidirect product $T * E$ of a right cancellative monoid T acting injectively and downwards on a semilattice E.

Note. The study of a proper left type-A category over which a right cancellative monoid acts injectively and downwards is the main tool used in the proof of this theorem.

V. A. R. GOULD (SEE ALSO J. B. FOUNTAIN)

Stability of S-sets I

Let L_S denote the language of (right) S-sets over a monoid S and let Σ_S be a set of sentences in L_S which axiomatises S-sets. A general result of model theory says that Σ_S has a model companion, denoted by T_S,

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precisely when the class $\mathcal{E}$ of existentially closed S-sets is axiomatisable and in this case, T_S axiomatises $\mathcal{E}$. We show that T_S exists if and only if S is right coherent, that is, every finitely generated S-subset of any finitely presented S-set is finitely presented. If S is right coherent, so that T_S exists, then T_S is a theory suitable for the application of techniques from stability theory. We describe types over T_S algebraically and use our result to show that T_S is a stable theory.

K. Henckell

Type-V and local complexity

Let **G**=Groups and **A**=Aperiodics. We define "Type-**V**" subsemigroups of a finite semigroup S for any pseudo-variety **V**, generalizing the earlier "Type-II" (=Type-**G**) and "Type-I" (=Type-**A**). Type-**G** is decidable by Ash, and we give a characterization for (absolute) Type-**A** semigroups (generated by an $\mathcal{L}$-chain). We then define $l(S)$, the local complexity of S, as the largest alternating I/II-chain of subsemigroups of S. $l(S)$ can be axiomatically characterized as the largest local complexity function, and is decidable. However, there exist semigroups S_n with complexity n and local complexity 1.

P. M. Higgins

Eventually regular semigroups determined by certain pseudo-random sets

A class of pre-images of the free monogenic inverse monoid is introduced in ono-to-one correspondence with the irrational numbers greater than one. Each member of the class is an eventually regular semigroup with generator a, the regular powers of which form a pseudo-random set. This then affords an example of a finitely generated semigroup U which is eventually regular, yet $U \times U$ is not. This shows that the class of eventually regular semigroups is not closed under finite direct products, thus answering a question posed by P. M. Edwards.

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H.-J. Hoehnke

On the internal structure of fractal categories

Fractal categories appear as adequate abstract descriptions of those subcategories K of Par, the category of sets and partial mappings between sets, which are closed with respect to the subidentities belonging to $\mathrm{Dex}\, f$, the domain of existence of any mapping $f : A \to B \in K$. They are at the same time an axiomatic approximation of the categories of fractions in the sense of Verdier-Gabriel-Zisman-Happel, omitting universality.

The axioms imply, that each Hom-set $K(A, A)$ ($A \in |K|$ = the object class of K) is a type $SL2$ γ-monoid in the sense of Batbedat-Fountain (also called γ-monoid by Batbedat, 1978/81). We assume K to be small and are interested on structural properties of the lattice $\mathrm{Con}\, K$ of all congruences on K. A key role plays the notion of a perfect congruence. It is related to a functorial variant of a subvariety and its generation by certain free partial algebras in the subvariety.

K. H. Hofmann

On a subsemigroup of $SL(2,\mathbb{C})$

We let $G = SL(2,\mathbb{C})$ act on the Rieman sphere via Möbius transformations and define the semigroup S to consist of all g in G preserving the upper half-plane (plus infinity). Let W be the invariant cone in $sl(2,\mathbb{R})$ whose determinant is nonpositive and which is above the plane spanned by the matrices $\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$, $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$.

Theorem. The function $f : SL(2,\mathbb{R}) \times W \to G$; $f(g, X) = g \cdot \exp iX$ maps its domain analytically diffeomorphically onto S.

Remark. Let T denote the simply connected covering semigroup of S. Then T is an analytic semigroup (with boundary) which cannot even algebraically be embedded into a group. The discussion of this example serves as an introduction of an audience of experts in the algebraic theory of semigroups into the recent field of Lie semigroups. A reference is J. Hilgert, K.H. Hofmann and J.D. Lawson, Lie Groups, Convex Cones and Semigroups, Oxford 1989, another K.H. Hofmann, J.D. Lawson and J. Pym, Eds., The Analytical and Topological Theory of Semigroups, Berlin 1990.

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E. HOTZEL

On the structure of the dual Baer-Levi semigroup

If X is a set and q an infinite cardinal $\leq |X|$ then the semigroup $T = DBL_X(q) = \{f : X \to X; |f^{-1}(y)| = q \text{ for all } y \in X\}$ (the dual Baer-Levi semigroup associated with X and q) is a right simple right cancellative semigroup without idempotent. T is not isomorphic to any Baer-Levi semigroup $BL_{X'}(q')$ or any factor semigroup thereof. The relation $\delta^r = \{(f,g); |D(f^{-1},g^{-1})| < r\}$ where $D(f^{-1},g^{-1}) = \{x \in X; f^{-1}(x) \neq g^{-1}(x)\}$ is easily seen to be a congruence of T, for any infinite cardinal r. The converse also holds: The relations δ^r with $\aleph_0 \leq r \leq |X|$ are the only nontrivial congruences of T. This is a counterpart to Lindsey and Madison's determination of the congruences of the Baer-Levi semigroup $BL_X(q)$ (1976) as well as to Schreier, Ulam and Baer's findings about the congruences of the infinite symmetric group (1933/34). A main step of the proof in the case of T is to demonstrate, within every congruence κ, the existence of standard pairs, i.e. pairs (f,g) such that $|f^{-1}(y) \cap g^{-1}(z)| = 0$ or $= q$ for all $x, y \in X$ and such that $g * f^{-1}$ is an equivalence relation on X with sufficiently many sufficiently large nontrivial classes.

J. M. HOWIE

Order-preserving transformation semigroups: rank properties

The semigroup $\mathcal{AO}_n$ of all singular order-preserving selfmaps of $\{1,2,...,n\}$ has been shown by Gomes and Howie to have rank n. It is generated by its idempotents, and its idempotent rank (the smallest number of idempotent generators) is $2n-2$. For the semigroup $\mathcal{RAO}_n$ of all partial singular order-preserving selfmaps of $\{1,2,...,n\}$ the rank is $2n-1$ and the idempotent rank is $3n-2$. For $r \leq n-2$ the rank and idempotent rank of $\{\alpha \in \mathcal{AO}_n : |\operatorname{im}\alpha| \leq r\}$ have been shown by Garba to be both equal to $\binom{n}{r}$, while for $\{\alpha \in \mathcal{RAO}_n : |\operatorname{im}\alpha| \leq r\}$ the rank and the nilpotent rank are both equal to $\sum_{k=r}^{n} \binom{n}{k}\binom{k-1}{r-1}$.

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P. R. JONES

A kernel for category morphisms, with applications to locality

B. Tilson defined the derived category of a morphism, in fact of a relational morphism, of monoids. Tilson and Rhodes defined a "two-sided" version - the kernel - of such morphisms. Each has proved very useful in describing category varieties associated with a monoid variety **W**. The smallest and largest category varieties whose monoids are those of **W** are g**W** and l**W** respectively. **W** is local if g**W**=l**W**. We define a derived category D_Φ and a kernel K_Φ of a relational morphism Φ of categories, extending the definitions for monoids. A "derived category theorem" and a "kernel theorem" are proved. We use this to prove that **DS** is local and that a large new class of completely regular varieties is local.

H. JÜRGENSEN

Hierarchien von Codes

Zahlreiche Klassen von Codes und verwandten Sprachen können als Klassen von solchen Sprachen charakterisiert werden, deren Elemente bezüglich einer endlich-stelligen Relation auf dem freien Monoid X^* unvergleichbar sind. Wir entwickeln eine allgemeine Erklärung dieses Zusammenhangs, die insbesondere zu vereinfachten Hierarchiebeweisen für Klassen von Codes führt.

A. KISIELEWICZ

All varieties of commutative semigroups

We describe all equational theories of commutative semigroups in terms of certain well-quasi-ordering on the set of finite sequences of nonnegative integers. This description yields many old and new results on varieties and pseudovarieties of commutative semigroups. In particular, we describe the lattice of varieties of commutative semigroups; we give an explicit uniform solution to the word problems for free objects in all varieties of commutative semigroups; we also describe all pseudovarieties of commutative semigroups.

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U. Knauer

Hereditary endomorphism monoids of acts and graphs

A monoid is called *left/right (semi)hereditary* if all its left/right (finitely generated) ideals are projective. R denotes a monoid.

Theorem (together with P. Normak). The endomorphism monoid of a projective right R-act P fulfills any of the above properties
iff all its principal left ideals form a tree, i.e. $\operatorname{End} P$ has PLIT,
iff all its principal right ideals form a tree, i.e. $\operatorname{End} P$ has PRIT,
iff P has not more than two indecomposable isomorphic components eR and eRe is a group.

The endomorphism monoid of any right R-act as well as the monoid of strong endomorphisms of a finite graph can be represented as a wreath product S wr K of a monoid S with a small category K. A characterization of S wr K having PRIT (together with V. Fleischer) generalizes the above Theorem and admits a description of finite graphs whose strong endomorphism monoid has any of the above mentioned properties.

G. J. Lallement

Completely regular finite prefix codes

A prefix code $C \subseteq A^*$ is said to be completely regular if the syntactic monoid $\operatorname{Synt} C^*$ is a union of groups. An algorithmic construction of all finite codes of this type can be obtained, based on earlier results for various special cases.

In case $\operatorname{Synt} C^*$ is a group, then $C = A^n$ and $\operatorname{Synt} C^* \cong \mathbb{Z}_n$.

In case $\operatorname{Synt} C^*$ is a completely simple semigroup with 1 adjoined, C is obtained from special directed graphs called team tournaments (see *Inf. and Control*, 48, (1981), 11 - 29).

In case $\operatorname{Synt} C^*$ is a union of groups with a nontrivial group of units, then $\operatorname{Synt} C^*$ can be obtained by constructing transformations on the set $\{0, 1, ..., n-1\}$ based on factorizations of $\mathbb{Z}_n$ given by sequences of divisors of n (see *Discrete Math.*, 24, (1978), 19 - 36).

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The general case combines the two techniques above to yield all monoids Synt C^* as chains of completely simple semigroups (see *J. of Pure and Applied Alg.*, 26, (1982), 203 - 218, for the case when Synt C^* has 2 $\mathcal{D}$-classes).

A. DE LUCA (WITH S. VARRICCHIO)

Finiteness conditions for semigroups

The study of "unavoidable" regularities on very long words in a finite alphabet is of great interest in combinatorics on words both for the importance of the subject itself and for the applications in many areas of algebra and theoretical computer science. We recall the bi-ideal sequences, i.e. sequences of words such that each term is both a prefix and a suffix of the next term. M. Coudrain and M. P. Schützenberger proved that for any positive integer n all sufficiently long words contain a subword which is the n-term of a bi-ideal sequence. Another interesting unavoidable regularity was discovered by A. I. Shirshov in 1957. His famous theorem states that for any positive integers n and p every sufficiently long word contains a subword which is either a p-power of a nonempty word or n-divisible. In 1984 A. Restivo and C. Reutenauer proved, as an application of the Shirshov theorem, a finiteness condition for semigroups of interest for the Burnside problem.

We prove some new combinatorial properties of uniformly recurrent infinite words which can be expressed in terms of "bi-ideal" and "n-divided" sequences. A consequence of these results is an improvement of a theorem of Shirshov and a new finiteness condition for finitely generated semigroups which generalizes both the theorem of Restivo and Reutenauer and a theorem of de Luca and Restivo.

S. W. MARGOLIS

The closed rational sets in profinite topologies on free groups and free monoids and the Theorem of Ash

Let M be a finite monoid. Let $K(M) = \bigcup 1\tau^{-1}$ over all relational morphisms $\tau : M \to G$ for any finite group G. Ash has proved the Rhodes

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type-II conjecture, that is, $K(M) = D(M)$, where $D(M)$ is the smallest submonoid of M containing the idempotents of M and closed under the implication $aba = a \in M \Rightarrow aD(M)b \cup bD(M)a \subseteq D(M)$. This has a number of important consequences. In particular, if $\mathbf{V}$ is a decidable variety, so is the Malcev product $\mathbf{V}$ m **Groups**. Pin has provided a connection with profinite topologies on free monoids and free groups. As a consequence, let L be a rational subset of A^* and $\eta : A^* \to M(L)$ the syntactic morphism. Then L is closed in the profinite topology of A^* if and only if $P = L\eta$ satisfies the implication $\forall s,t \in M(L) \forall e = e^2 \in M(L), set \in P \Rightarrow st \in P$. A rational subset L of the free group $FG(A)$ is closed in the profinite topology if and only if L is a finite union of sets of the form $gH_1...H_n$ where $g \in FG(A)$ and H_i is a finite generated subgroup of $FG(A)$ for $i = 1, ..., n$. It is decidable whether a rational set is closed in both cases.

L. Márki

Fountain-Gould left orders in rings

Characterizations of left orders are presented in turn in division rings, simple artinian rings, simple rings with minimum condition on principal one-sided ideals, and primitive rings with non-zero socle. At each step we have a notion of ring of quotients which is more general than the previous one but which reduces to the previous one in that special case. The first and the second step are due to Ore and Goldie, respectively, the last two steps to Ahn and Márki. The third step uses Fountain-Gould orders, the idea of which has come from semigroup theory. Left orders in simple rings with minimum condition on principal one-sided ideals can also be characterized in terms of Rees matrix rings as well as by properties of some of their "local subrings".

J. C. Meakin

Subgroups of free groups - the Hanna Neumann conjecture

In 1954, Howson showed that if H and K are finitely generated subgroups of a free group F, the $H \cap K$ is also finitely generated. The question is:

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what is a reasonable bound on $r(H \cap K)$? In 1955, H. Neumann showed that (if $H \cap K \neq \{1\}$ then)

$$r(H \cap K) - 1 \leq 2(r(H) - 1)(r(K) - 1)$$

and expressed the "hope" that "2" can be replaced by "1" in this inequality. According to Gersten (1983), this has become known as the Hanna Neumann conjecture:

(HNC) $$r(H \cap K) - 1 \leq (r(H) - 1)(r(K) - 1).$$

This has been proved in many special cases (e.g. if H or K is of finite index or if H and K have rank 2). Of course one may assume that F has rank 2. In 1983, Stallings showed how finitely generated subgroups of F may be represented by finite immersions over the bouquet of 2 circles (i.e. finite inverse automata). Recently J. Meakin and P. Weil have used this to study many more special cases (e.g. (HNC) is true if either H or K is positively generated) and to suggest a general proof scheme.

H. Mitsch

The natural partial order on semigroups

Generalizing the well-known natural partial order on regular semigroups we can define on any semigroup: $a \leq b$ iff $a = xb = by$, $xa = a(= ay)$ for some $x, y \in S^1$. The semigroups which are totally ordered with respect to $\leq$ are characterized, and in the class of E-inverse semigroups those are found for which $\leq$ is the identity relation. Extending the theorem of Green it is proved that for any $\mathcal{D}$-related elements a, b in any semigroup, $|H_a \cup (a]| = |H_b \cup (b]|$, where $(a] = \{x \in S \mid x \leq a\}$. For regular semigroups it is shown that if $a\mathcal{D}b$ then $(a]$ and $(b]$ are even order-isomorphic(*). This result holds also in semigroups for which $\leq$ is compatible with multiplication on both sides; for example: commutative or centric semigroups or strong semilattices of trivially ordered monoids. As an application, retract extensions are characterized by order-theoretical properties, and for strong semilattices of semigroups the natural partial order is described.

(*) During the meeting this result has been generalized by P. R. Jones to arbitrary semigroups!

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W. D. MUNN

Prime inverse semigroup rings

Let F be a field, let S be an inverse semigroup (with semilattice $E(S)$) and let $F[S]$ denote the semigroup ring of S over F. Under what circumstances is $F[S]$ a prime ring?

Consider the following conditions on S: (a) S is bisimple, (b) for each maximal subgroup G of S, the group ring $F[G]$ is prime. Note that, by Connell's theorem (1963), (b) is equivalent to (b'): for each maximal subgroup G of S, G contains no nonidentity finite normal subgroup.

If $E(S)$ satisfies a certain finiteness condition, introduced by Teply, Turman and Quesada (1980), then $F[S]$ is prime if and only if (a) and (b) hold (WDM, 1987). In the absence of any restriction on $E(S)$, (a) and (b) are together sufficient for $F[S]$ to be prime (WDM, 1990): However, examples show that neither (a) nor (b) is a necessary condition for the primeness of $F[S]$.

J. OKNINSKI

Krull dimension of semigroup algebras satisfying polynomial identities

Let $K[S]$ denote the semigroup algebra of a monoid S over a field K. We define $\mathrm{rk}(S)$ as the supremum of the ranks of the free commutative subsemigroups of S. The proof of the following conjecture, extending the well known result on commutative semigroup algebras (due to Gilmer in cancellative case, and to the author in the general commutative case) is outlined:

If $K[S]$ satisfies a polynomial identity, then the classical Krull dimension $\mathrm{clKdim}\, K[S]$ of $K[S]$ coincides with $\mathrm{rk}(S)$.

As a surprising consequence we note that $\mathrm{clKdim}\, K[S] \geq \mathrm{clKdim}\, K[T]$ for every subsemigroup T of S. Moreover, $\mathrm{rk}(S)$ does not grow under homomorphic images of S. The latter is a crucial step in the proof of the above result. The techniques used involve recent results on PI-algebras and PI-semigroup algebras, the Gelfand-Kirillov dimension, and recent techniques in semigroup algebras of linear semigroups.

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J. E. Pin

The influence of automata theory on semigroup theory

In this lecture, we present several results and concepts of finite semigroup theory that were first motivated by automata theory, after Schützenberger pionneering work in the sixties. The first example is I. Simon's result on piecewise testable languages, which leads to several nice characterizations of $\mathcal{J}$-trivial finite semigroups, due to Straubing and Straubing-Thérien, and which can be summarized as follows. A monoid M is *ordered* if there exists a total order $\leq$ on M which is compatible with the multiplication and such that the identity is the greatest element of M. Let $\mathcal{C}_n$ be the monoid of all increasing and extensive functions on the set $\{1, 2, ..., n\}$, let $\mathcal{R}_n$ be the monoid of all reflexive relations on $\{1, 2, ..., n\}$, and let U_n be the monoid of boolean unitriangular matrices of size n. If M is a finite monoid, then the following conditions are equivalent: (1) M is $\mathcal{J}$-trival, (2) There exists $n > 0$ such that M divides $\mathcal{C}_n$, (3) There exists $n > 0$ such that M divides $\mathcal{R}_n$, (4) There exists $n > 0$ such that M divides $\mathcal{U}_n$, (5) M is a quotient of an ordered monid.

Second, the results of McNaughton and Brzozowski-Simon on locally testable languages, the result of Knast on dot-depth one languages and the work of Schützenberger, Straubing and Thérien on concatenation hierarchies led to the systematic study of the varieties of finite semigroups (or pseudo-varieties) of the form $\mathbf{V*LI}$, where $\mathbf{LI}$ is the variety of locally trivial semigroups (= nil extensions of rectangular bands), and * denotes the semidirect product of varieties. This study ultimately led to the general concept of derived category, that was brought to light by Tilson by polishing the proofs of the results mentioned above.

Finally, we mention an important open problem that arises naturally in language theory. Its semigroup counterpart can be stated as follows. Let $\mathbf{V}$ be the variety of finite monoids generated by the monoids T_n of boolean upper-triangular matrices of size n. One can show that $\mathbf{V} = \mathbf{PJ}$ where $\mathbf{PJ}$ denotes the variety of finite monoids generated by the monoids of the form $\mathcal{P}(M)$ where M is $\mathcal{J}$-trivial. **Open problem**: Is $\mathbf{V}$ decidable? That is, given a finite monoid M, is there an algorithm to decide whether M belongs to $\mathbf{V}$ or not?

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L. POLÁK

Varieties of unary semigroups

Notation:
$RI = \mathrm{Mod}((xy)' = y'x', x'' = x, xx'x = x)$ - *-regular semigroups
$CR^* = RI \cap \mathrm{Mod}(xxx'x' = xx')$ - completely regular *-regular semigroups
$CR = \mathrm{Mod}(x'' = x, xx'x = x, xx' = x'x)$ - completely regular semigroups
$OCR = CR \cap \mathrm{Mod}(xyy'xx'y = xy)$ - orthogroups
U - the free unary semigroup on $X = \{x_1, x_2, ...\}$
$L(V)$ - the lattice of all subvarieties of a variety V
$\sim_V$ - the corresponding fully invariant congruence on U.
The following topics will be discussed:

1. The word problem for free objects in RI.
2. The interchangeability of $\sim_{OCR}$ and $\sim_{RI}$.
3. Relationships between $L(CR)$ and $L(CR^*)$.

J. S. PONIZOVSKII

On two questions of Sverdlovskaya Tetrad

In what follows $k \subset K$ are fields, $M(n, K)$ is a multiplicative semigroup of all $n \times n$ matrices over K, W is an n-dimensional linear space over K in which matrices from $M(n, K)$ act as right operators. A subsemigroup S of $M(n, K)$ is basic iff (i) $W \cdot L(S) = W$ (here $L(S)$ is a K-linear envelope of S) and (ii) if $w \in W$, $w \cdot S = 0$ then $w = 0$.

Theorem. Let T be a periodic semigroup with a completely 0-simple ideal U, and let G be a maximal nonzero subgroup of U. Let $f : T \to M(n, K)$ be a matrix representation such that $f(U)$ is basic. If $f(G)$ is conjugate to a group over k, then $f(T)$ is conjugate to a semigroup over k.

We show that Theorem gives a positive answer to a question 3.39 (Sverdlovskaya Tetrad, third issue, Sverdlovsk, 1989). We also give a positive answer to a question 3.38 (same journal).

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N. R. Reilly

The representation of completely regular semigroups by semigroups of partial transformations

A recurring theme throughout the study of groups and semigroups is the representation of various classes by particular kinds of groups or semigroups of mappings. Good examples of results of this ilk are the Cayley representation of groups by permutation groups, the Cayley representation of semigroups as semigroups of transformations and the Wagner/Preston representation of inverse semigroups by one-to-one partial transformations. These results provide a good source of examples of the members of the class under investigation and at the same time illustrate that the class is, in some sènce, natural. Although a great many papers have been written about the class of completely regular semigroups, no natural class of transformation semigroups has been found that represents them in the way that permutation groups, transformation semigroups and partial one-to-one transformations represent groups, semigroups and inverse semigroups. The purpose of the present work is to attempt to fill that void for completely regular semigroups.

L. E. Renner

$B \times B$ orbits on reductive monoids

For a large class of monoids, known as reductive monoids, there is a precise relationship among three objects: M, B and $\mathcal{R}$. We illustrate the theory for $M = M_n(k)$ the matrix monoid, $B = T_n(k)$ the upper triangular group, and $\mathcal{R} = \mathcal{I}_n$, the symmetric inverse semigroup. Here we view $\mathcal{I} \subseteq M_n(k)$ in the usual way as the set of submonomial matrices. Our main results are:

(1) $M = \bigsqcup_{r\in\mathcal{I}_n} BrB$, disjoint union.

(2) There is a set of generators S of $\mathcal{I}_n^* \cong S_n$ such that $\rho Br = BrB \cup B\rho rB$ if $r \in \mathcal{I}_n$ and $\rho \in S$.

(3) For each $\mathcal{J}$-class J of $\mathcal{I}_n$ there is a unique $v \in J$ such that $Bv = vB$.

(4) If $\mathcal{O} = \{r \in \mathcal{I}_n \mid rBr^* \subseteq rr^*B\}$ then $\mathcal{O}$ is an inverse semigroup such that $|\mathcal{O} \cap H| = 1$ for each $\mathcal{H}$-class of $\mathcal{I}_n$.

(5) If $r \in \mathcal{I}_n$ then $r = r_+ r_0 r_-$ where $r \mathcal{J} r_+ \mathcal{J} r_0 \mathcal{J} r_-$; $r_+, r_- \in \mathcal{O}$ and $r_0 \mathcal{H} v$ (v as in (3)). r_+, r_0 and r_- are unique.

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(6) $BrB = Br_+ Br_0 Br_- B$.
(7) If $r = e\sigma = \sigma f \in \mathcal{I}_n$ then $E(Be) \times H_r \times E(fB) \longrightarrow_{\cong} BH_rB$ where H_r is the $\mathcal{H}$-class of r in M.

Several other results were mentioned, in particular, concerning the lenght function $l : \mathcal{I}_n \to I\!N$.

J. L. RHODES

On semigroups (applied to infinite group theory)

Given a finitely generated group (G, A) an expansion $(G, A)^M$ is applied giving an infinite **inverse** semigroup which is finite-$\mathcal{J}$-above having subgroups the **finite** subgroups of G. Further expansions are applied giving $(G, A)^{M\wedge}$ or $(G, A)^{MBR}$ which is still finite-$\mathcal{J}$-above, subgroups still the **finite** subgroups of G, but the $\mathcal{L}$ order is now an (upsidedown) **tree**. By taking a variation of the right regular representation (using a generalized version of the Chiswell-Lyndon lenght functions for semigroups) we obtain $\mathcal{O} = (G, A)^{M\wedge}$ acting on a tree T. $\mathcal{O}$ is an orthodox semigroup. We now consider the hyperbolic boundary of ends and apply ergodic-like theory via Fürstenberg to obtain information about G.

T. SAITO

Maximal inverse subsemigroups of the full transformation semigroup

M. Kunze and S. Crvenkovic (1986, 1987) determined the maximal subsemilattices of the finite full transformation semigroup. They used a new order, called a transitivity order, on a finite set X. In this talk, by using the transitivity order, we study the maximal inverse subsemigroups of the full transformation semigroup $T(X)$.

We first generalize the results of them to show that every subsemilattice of $T(X)$ is represented by a pair of transitivity order and a class of subsets of X, called admissible sets of F-ideals. Next we determine, for any given subsemilattice L, the maximum inverse subsemigroup S whose semilattice of idempotents is L. If L is a maximal subsemilattice, then S is clearly a maximal inverse subsemigroup. However, the converse is not true. There are maximal inverse subsemigroups of $T(X)$ whose semilattice of idempotents is not maximal.

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B. M. Schein

The minimal degree of an inverse semigroup

Every inverse semigroup S admits faithful (that is, isomorphic) representations by one-to-one partial transformations of various sets A. The cardinality $|A|$ of A is called the *degree* of the representation. If S is infinite, then A is infinite and $|A| \geq |S|^-$, where $|S|^-$ is the cardinal number which is the predecessor of $|S|$ (if such a predecessor exists) or $|S|$ (if no predecessor exists). The situation is much more complicated for finite inverse semigroups. We give an exact formula for the minimal degree of a faithful representation of a finite inverse semigroup S and show how this formula can be used in various specific situations. The formula gives the minimal degree of S in terms of the minimal degrees of certain finite groups associated with S. Probably, this is the best result to be expected, as the problem of describing the minimal degree of a finite group is a very complicated one, it is solved only for very special classes of finite groups.

L. N. Shevrin

On two longstanding problems concerning nilsemigroups

The talk was devoted to a discussion of the following questions arisen 30 years ago in author's work and written down in "The Sverdlovsk Tetrad".

Question 1. Will any nilsemigroup whose proper subsemigroups are nilpotent be itself nilpotent?

Question 2. Will any semigroup whose proper subsemigroups are distinct from their idealizers be a semigroup with an ascending annihilator series?

In publications of several authors a number of conditions were considered under which these questions have positive answers. These conditions as well as properties of a (hypothetic) counter-example for the Question 1 were presented. Such a counter-example would at the same time be a counter-example for the Question 2.

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I. Simon

On the pseudovariety of $\mathcal{J}$-trivial semigroups

We present a topological proof of the characterization of finite $\mathcal{J}$-trivial semigroups in terms of their languages. This proof is inspired by the work of J. Almeida who determined the structure of the topological semigroup $\overline{\Omega}_n\mathbf{J}$ of all n-ary implicit operations on $\mathbf{J}$. The main characteristics of this proof are the substitution of combinatorial ideas by topological ones. The arguments become simpler but the constructive aspects are lost. Related open problems will also be mentioned.

J. B. Stephen

A graphical approach to the word problem for presentations of monoids

Let $M = \mathrm{Mon}\langle A|T\rangle = A^*/\tau$ be a presentation of a monoid. The graph of M is the labeled directed graph $\Gamma(M;A;T)$ with vertex set M and edge set $\{(m,a,n) \in M \times A \times M \mid m(a\tau) = n\}$. For $m \in M$, the triple $(1, \Gamma(M;A;T), m)$ may be considered as an automaton with initial state 1 and accepting state m. The trim component of this automaton is denoted $B\Gamma(m)$; the language of $B\Gamma(m)$ is $(m\tau^{-1}) \subseteq A^*$.

A proceedure for constructing $B\Gamma(w\tau)$, $w \in A^*$, is outlined, and used to give an alternative to the approach of L. Polák for the solution of the word problem for free *-regular semigroups.

H. Straubing

Programs over finite monoids and circuit complexity

Let A be a finite alphabet, M a finite monoid, $X \subseteq M$, $n > 0$. A *program* over M is a sequence $(i_1, f_1), \ldots, (i_r, f_r)$; $1 \leq i_j \leq n$, $f_j : A \to M$. The program accepts the set

$$\{a_1 \ldots a_n \in A^n \mid f_1(a_{i_1}) \ldots f_r(a_{i_r}) \in X\} \subseteq A^n.$$

A family of programs π_n over a monoid M (one for each input length n) thus accepts a language $L \subseteq A^+$. The principal question we address

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is: What languages can be accepted by families of programs over M in which the length of the program grows polynomially in the length of the input? This is motivated by close connections with complexity of boolean circuits. (See D. Barrington and D. Thérien, *J. Assoc. Comp. Mach.* 35 (1988).) We survey some recent progress on this question.

M. SZENDREI

Embeddability in semidirect products

We present two results connected to the author's open problem whether each E-unitary regular semigroup is embeddable in a semidirect product of a band by a group.

We call an E-unitary regular semigroup S *strongly embeddable* if it is embeddable in a semidirect product of a band B by a group where B is from the band variety generated by the band of idempotents of S.

Theorem 1. Each orthodox semigroup has an embeddable E-unitary cover.

Theorem 2. Let S be an orthodox semigroup whose kernel modulo the least group congruence belongs to a regular orthogroup variety $\mathbf{V}$. Then S is embeddable in a semidirect product of a member in $\mathbf{V}$ by a group.

P. G. TROTTER

On e-varieties of regular semigroups

An e-variety is a class of regular semigroups that is closed under the taking of homomorphic images, direct products and regular subsemigroups. This concept was introduced by T. E. Hall in 1989 and independently, for orthodox semigroups, by J. Kadourek and M. Szendrei in 1990. Various results on e-varieties will be summarized.

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M. V. VOLKOV

Avoidable words and lattice universal semigroup varieties

The talk will summarize some recent research of M. V. Sapir and myself devoted to semigroup varieties with "large" subvariety lattice. A variety V is said to be *lattice universal* if its subvariety lattice contains an interval which is dual to the partition lattice over a countable set. First examples of lattice universal semigroup varieties were constructed by Burries and Nelson in 1971 and by Jezek in 1976. These examples used the well known sequences of words avoiding squares (i.e. having no subwords of the form ww). Bean, Ehrenfeucht and McNulty in 1979 and Zimin in 1982 developed the general theory of avoidable words which enables, as we prove, to describe lattice universal semigroup varieties under quite weak additional conditions. Namely, if V has axiomatic rank n and contains no infinite finitely generated periodic groups, then it is lattice universal iff Zimin's word Z_{n+1} is an isoterm relative to V (Zimin's words are defined by $Z_1 = x_1$, $Z_{n+1} = Z_n x_{n+1} Z_n$).

P. WEIL (WITH B. LE SAEC AND J. E. PIN)

Finite semigroups with idempotent stabilizers

Let S be a finite semigroup and $p \geq J - depth(S)$. We show that there exists (and we effectively construct) a finite semigroup ${}^p\hat{S}$ and a surjective morphism $\pi : {}^p\hat{S} \rightarrow S$ with the following properties:

1) Each right stabilizer in ${}^p\hat{S}$ is an idempotent R-trivial semigroup (=right-normal band).

2) For each idempotent e of S, the inverse image of e by π divides the direct product of a rectangular band by a finite number of copies of the cyclic group of order p. Furthermore, π factors through the Rhodes expansion of S.

The semigroup ${}^p\hat{S}$ arises as the transition semigroup of a finite automaton whose construction is inspired by the construction of the Rhodes expansion, to which mod p counters have been adjoined.

Some remarkable applications are: a new and purely algebraic proof of McNaughton's theorem on the determinization of finite automata for infinite words; and a new proof of Brown's lemma on locally finite semigroups.

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H. J. WEINERT

Generalized semigroups of right quotients

Let $S = (S, \cdot)$ be a semigroup and Σ a subsemigroup of S. Then a semigroup $T = (T, \cdot)$ with identity is called a generalized semigroup of right quotients (briefly: a GQ_r-semigroup) of S by Σ iff there is a homomorphism $\phi : S \to T$ which satisfies: (1) In T exists $(\alpha\phi)^{-1}$ for each $\alpha \in \Sigma$. (2) T coincides with $\{(a\phi)(\alpha\phi)^{-1} \mid a \in S, \alpha \in \Sigma\} \subseteq T$. (3) For all $a, b \in S$, from $a\phi = b\phi$ it follows $a\sigma = b\sigma$ for some $\sigma \in \Sigma$.

This concept has been considered by P. Lefebvre, A. Bouvier and A. Faisant about 1968. The purpose of the talk is to reduce statements on GQ_r-semigroups and on correspondingly defined GQ_r-seminearrings $(T, +, \cdot)$ of seminearrings (and hence rings and semirings) $(S, +, \cdot)$ by Σ to classical Q_r-semigroups $(T, \cdot)$ of $(S, \cdot)$ by Σ. The latter, due to K. Murata 1950, are defined choosing ϕ above as the identical injection. The simply proved key results are that (1)-(3) imply, for all $a, b \in S$ and $\alpha \in \Sigma$, $a\Sigma \cap \alpha S \neq \emptyset$ and $\alpha a = \alpha b \Rightarrow a\sigma = b\sigma$ for some $\sigma \in \Sigma$, and that the latter both yield the existence of a least congruence κ_Σ on $(S, \cdot)$ for which each $\overline{\alpha} \in \overline{\Sigma}$ is cancellable in $\overline{S} = S/\kappa_\Sigma$. Since $a\Sigma \cap \alpha S \neq \emptyset$ implies $\overline{a}\overline{\Sigma} \cap \overline{\alpha}\overline{S} \neq \emptyset$ trivially, each GQ_r-semigroup of S by Σ is obtained by an epimorphism $\kappa_\Sigma^\sharp : S \to \overline{S}$ and an extension of $\overline{S}$ to a classical Q_r-semigroup of $\overline{S}$ by $\overline{\Sigma}$, and conversely.

Berichterstatter: C. Dönges

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