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Abstract: The work has begun to study the structure of pseudofinite acts over a monoid. A theorem on the finiteness of an arbitrary cyclic subacts of S -act is proved under the condition that this S -act is pseudofinite and the number of types of isomorphisms of finite cyclic S -acts is finite. It is shown that the coproduct of finite S -acts is pseudofinite. As a consequence, it is shown that any S -act, where S is a finite group, is pseudofinite.

Keywords: pseudofinite act, pseudofinite theory, coproduct, act over monoid.

Introduction

Recently, the model theory of pseudofinite structures is an actively developing area of mathematics. The concept of pseudofiniteness was first introduced by J. Ax to show the solvability of the theory of all finite fields [1]. Subsequently, the theory of pseudofinite fields received great development (see, for example, [2], [3]). A large review of the theory of models of finite and pseudofinite groups is presented in [4]. In [5] the characterization of pseudofinite groups is given in terms of Szmielw's invariants. The results

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related to the model theory of finite and pseudofinite rings can be found in [6]. In [7] the structure of pseudofinite acyclic graphs is studied. In [8] the authors of this work considered the issues of pseudofiniteness of connected unars without cycles.

An acts over monoids are a generalization of unars. In this work we study pseudofinite S -acts. A theorem on the finiteness of an arbitrary cyclic subacts of S -act is proved under the condition that this S -act is pseudofinite and the number of types of isomorphisms of finite cyclic S -acts is finite. It is shown that the coproduct of finite S -acts is pseudofinite. As a consequence, it is shown that any S -act, where S is a finite group, is pseudofinite.

1 Preliminaries

Let us recall some definitions and facts from act theory and model theory (see [9, 10, 12]). Throughout this paper S will denote a monoid with identity 1. An algebraic system $\langle A; s_{s \in S} \rangle$ of the language $L_S = \{s \mid s \in S\}$ consisting of unary operation symbols is a (left) S -act if $s_1(s_2a) = (s_1s_2)a$ and $1a = a$ for all $s_1, s_2 \in S$ and $a \in A$. An S -act $\langle A; s_{s \in S} \rangle$ is denoted by ${}_S A$. An S -act ${}_S A$ is called *cyclic* if there exists $a \in A$ such that $A = \{sa \mid s \in S\}$. The cyclic act that generated by a is denoted by ${}_S Sa$. Elements x, y of an S -act ${}_S A$ are called *connected* (denoted by $x \sim y$) if there exist $n \in \omega$, $a_0, \dots, a_n \in A$, $s_1, \dots, s_n \in S$ such that $x = a_0$, $y = a_n$, and $a_i = s_i a_{i-1}$ or $a_{i-1} = s_i a_i$. An S -act ${}_S A$ is called *connected* if we have $x \sim y$ for any $x, y \in {}_S A$. It is easy to check that \sim is a congruence relation on the S -act ${}_S A$. The classes of this relation are called *connected components* of the S -act ${}_S A$. A *coproduct* of S -acts ${}_S A_i$ is a disjunctive union of this S -acts. The coproduct of S -acts ${}_S A_i$ is denoted by $\coprod_{i \in I} {}_S A_i$. It is known (see [9]) that every S -act ${}_S A$ can be uniquely represented as a coproduct of connected components.

A structure \mathfrak{M} of the language L is *pseudofinite* if any sentence of language L true in \mathfrak{M} is true in some finite of language L .

Fact 1. [13] *A structure \mathfrak{M} of language L is pseudofinite if and only if it is elementarily equivalent to the ultraproduct of finite structures of language L .*

Fact 2. [11] *Let D be filter on the set I . Then D is ultrafilter iff for any $K \subseteq I$ either $K \in D$ or $I \setminus K \in D$.*

If ${}_S A$ is an S -act, then writing $\bar{a} \in A$ means that $a_1, \dots, a_n \in A$, where $\bar{a} = \langle a_1, \dots, a_n \rangle$. If $\bar{u} = \langle u_1, \dots, u_n \rangle$, then $l(\bar{u})$ will denote the length of the tuple \bar{u} and the notation $v \in \bar{u}$ means that v is an element of the tuple \bar{u} .

2 Necessary condition for pseudofiniteness

Theorem 1. *Let the number of isomorphism types of finite cyclic S -acts be finite and S -act ${}_S A$ be pseudofinite. Then any cyclic subact of ${}_S A$ is finite.*

Proof. Let the conditions of Theorem be satisfied and l be the maximum of the cardinalities of all finite cyclic S -acts. By Fact 1, ${}_S A \cong {}_S B$, where ${}_S B = \prod_{i \in I} {}_S B_i / D$, ${}_S B_i$ are the finite S -acts and D is ultrafilter on I .

Let us show that any cyclic subact of ${}_S B$ contains at most l elements. Let $b/D \in B$. Since ${}_S B_i$ are finite S -acts, the S -acts ${}_S S b(i)$ are also finite for any $i \in I$. By assumption, the number of isomorphism types of finite cyclic S -acts is finite. Let ${}_S S a_0, \dots, {}_S S a_{m-1}$ be representatives of all isomorphism types of finite cyclic S -acts. Then $K_0 \cup \dots \cup K_{m-1} = I$, where

$$K_j = \{i \in I \mid {}_S S b(i) \cong {}_S S a_j\} \quad (0 \leq j < m).$$

By Fact 2, there exists $j \in I$ such that $K_j \in D$. Since $|S a_j| \leq l$, then $K_j \subseteq \{i \in I \mid |S b(i)| \leq l\} \in D$. Then by Łoś Theorem ([11], Theorem 3.3.5) $|S b/D| \leq l$. Therefore, any cyclic subact of ${}_S B$ contains at most l elements.

Let us show that any cyclic subact of ${}_S A$ is finite. Assume the opposite, namely, that there exists $a \in A$ such that $|S a| \geq \omega$. Let a_0, \dots, a_l be arbitrary distinct elements of $S a$. Then $a_i = t_i a$ ($0 \leq i \leq l$) for some $t_0, \dots, t_l \in S$. Let Φ denote the formula

$$\exists x \exists x_0 \dots \exists x_l \left(\bigwedge_{0 \leq i < j \leq l} x_i \neq x_j \wedge \bigwedge_{0 \leq i \leq l} x_i = t_i x \right). \quad (1)$$

Then ${}_S A \models \Phi$. Since S -acts ${}_S A$ and ${}_S B$ are elementarily equivalent, then ${}_S B \models \Phi$, i.e. S -act ${}_S B$ has a cyclic subact containing more than l elements. This is a contradiction. \square

In [14], an example is given showing that the condition for the finiteness of any cyclic subact of an S -act in Theorem 1 is not sufficient for the pseudofiniteness of S -act, and also an example of a pseudofinite S -act over a finite monoid is constructed, all of whose cyclic subacts are finite.

3 Pseudofiniteness of the coproduct of finite S -acts

Lemma 1. *Let ${}_S A = \coprod_{\alpha < \kappa} {}_S A_\alpha$, κ be an infinite ordinal, ${}_S A_\alpha$ be the connected components of ${}_S A$,*

$${}_S D_\beta = \prod_{\alpha < \beta} {}_S A_\alpha, \quad (\beta < \kappa),$$

$${}_S D = \prod_{\beta < \kappa} {}_S D_\beta / F,$$

where F is an ultrafilter on κ containing a Fréchet filter, i.e. filter $\{\alpha \in \kappa \mid |\kappa \setminus \alpha| < \kappa\}$. For any $a \in A$, by a' we denote an element of $\prod_{\beta \in \kappa} D_\beta$ such that $a'(\alpha) = a$ if $\alpha \geq \alpha_0$, and $a'(\alpha)$ is an arbitrary element of D_α , if $\alpha < \alpha_0$, for some $\alpha_0 < \kappa$; by \bar{A} we denote a set $\{a'/F \mid a \in A\}$. Then ${}_S A \cong {}_S \bar{A}$ and ${}_S \bar{A} \preccurlyeq {}_S D$.

Proof. The map $\theta : A \rightarrow \bar{A}$ such that $\theta(a) = a'/F$ is an isomorphism from ${}_S A$ to ${}_S \bar{A}$, so ${}_S A \cong {}_S \bar{A}$. We show that ${}_S \bar{A} \preccurlyeq {}_S D$. Let $n \in \omega$, $\bar{x} = \langle x_1, \dots, x_n \rangle$, $\bar{a} = \langle a_1, \dots, a_n \rangle \in A$, $\bar{a}' = \langle a'_1/F, \dots, a'_n/F \rangle \in \bar{A}$, $\Phi(\bar{x})$ be a formula of

language L_S , $L_{S'}$ be a language of formula $\Phi(\bar{x})$, ${}_S\bar{A} \models \Phi(\bar{a}')$. It is necessary to prove that ${}_S D \models \Phi(\bar{a}')$.

For an arbitrary formula $\Psi(\bar{x})$ of a language L we will use standard notation: $(\Psi(\bar{x}))^1 \Leftrightarrow \Psi(\bar{x})$, $(\Psi(\bar{x}))^0 \Leftrightarrow \neg\Psi(\bar{x})$. For $m \in \omega$, let $E^{(m)}$ denote the set $\{\varepsilon \mid \varepsilon : (S')^2 \times \{1, \dots, m\}^2 \rightarrow \{0, 1\}\}$; for $\varepsilon \in E^{(m)}$ let $\Psi_\varepsilon(x_1, \dots, x_m)$ denote the formula $\bigwedge_{(i,j) \in \{1, \dots, m\}^2} \bigwedge_{(s,t) \in (S')^2} (sx_i = tx_j)^{\varepsilon((s,t), (i,j))}$.

Since θ^{-1} is an isomorphism from ${}_S\bar{A}$ to ${}_S A$, then ${}_S A \models \Phi(\bar{a})$. In addition, $\Phi(\bar{x}) \equiv \Phi'(\bar{x})$, where

$$\Phi'(\bar{x}) \Leftrightarrow \forall y_1 \exists z_1 \dots \forall y_k \exists z_k \bigvee_{\varepsilon \in E} \Psi_\varepsilon(\bar{x}, \bar{y}, \bar{z}),$$

$\bar{y} = \langle y_1, \dots, y_k \rangle$, $\bar{z} = \langle z_1, \dots, z_k \rangle$, $E \subseteq E^{(n+2k)}$. We can assume that $\Phi(\bar{x}) \Leftrightarrow \Phi'(\bar{x})$. Since ${}_S A \models \Phi(\bar{a})$, then there are functions $f_i : A^i \rightarrow A$ ($1 \leq i \leq k$) such that

$${}_S A \models \forall y_1 \dots y_k \bigvee_{\varepsilon \in E} \Psi_\varepsilon(\bar{a}, y_1, \dots, y_k, f_1(y_1), \dots, f_k(y_1, \dots, y_k)).$$

For an arbitrary $\bar{b} = \langle b_1, \dots, b_k \rangle \in A$ there is unique $\varepsilon_{\bar{b}} \in E^{(n+2k)}$ such that ${}_S A \models \Psi_{\varepsilon_{\bar{b}}}(\bar{a}, b_1, \dots, b_k, f_1(b_1), \dots, f_k(b_1, \dots, b_k))$. Since the set $E^{(n+2k)}$ is finite, then there is a finite number of different $\varepsilon_{\bar{b}_1}, \dots, \varepsilon_{\bar{b}_m}$ such that for any $\bar{c} \in A$ there is $\bar{b}_i \in \{\bar{b}_1, \dots, \bar{b}_m\}$, satisfying the equality $\varepsilon_{\bar{c}} = \varepsilon_{\bar{b}_i}$. We denote the set $\{\bar{b}_1, \dots, \bar{b}_m\}$ by M . For $|J|$ -element set $J = \{j_1, \dots, j_l\} \subseteq \{1, \dots, k\}$, $j \in \{1, \dots, k\}$ and arbitrary $\bar{c} = \langle c_1, \dots, c_k \rangle \in A$, we introduce some more notations:

$$\bar{c}^j = \langle c_1, \dots, c_j \rangle,$$

$$K_{\bar{b}}^J = \{(\alpha_{j_1}, \dots, \alpha_{j_l}) \in \kappa^l \mid \exists \bar{c} \in A \forall j \in J (f_j(\bar{c}^j) \in A_{\alpha_j}, \varepsilon_{\bar{b}} = \varepsilon_{\bar{c}})\}.$$

Consider an S -act ${}_S D_{\alpha_0}$, where $\alpha_0 \in \kappa$, such that $a_1, \dots, a_n \in D_{\alpha_0}$ and for any $\bar{b} \in M$, $J = \{j_1, \dots, j_l\} \subseteq \{1, \dots, k\}$ ($l = |J|$) the following conditions are satisfied:

(1) if $|K_{\bar{b}}^J| > p$, where $p = l \cdot (n + 2k - l)$, then $({}_S A_{\alpha_{j_1}^1}, \dots, {}_S A_{\alpha_{j_l}^1}), \dots, ({}_S A_{\alpha_{j_1}^p}, \dots, {}_S A_{\alpha_{j_l}^p})$ are l -tuples of the connected components of S -act ${}_S D_{\alpha_0}$ for some different $(\alpha_{j_1}^1, \dots, \alpha_{j_l}^1), \dots, (\alpha_{j_1}^p, \dots, \alpha_{j_l}^p) \in K_{\bar{b}}^J$;

(2) if $|K_{\bar{b}}^J| \leq p$ and $K_{\bar{b}}^J = \{(\alpha_{j_1}^1, \dots, \alpha_{j_l}^1), \dots, (\alpha_{j_1}^p, \dots, \alpha_{j_l}^p)\}$, then

$$({}_S A_{\alpha_{j_1}^1}, \dots, {}_S A_{\alpha_{j_l}^1}), \dots, ({}_S A_{\alpha_{j_1}^p}, \dots, {}_S A_{\alpha_{j_l}^p})$$

are l -tuples of the connected components of S -act ${}_S D_{\alpha_0}$.

Let $\alpha \geq \alpha_0$. Then $D_{\alpha_0} \subseteq D_\alpha$. We show that ${}_S D_\alpha \models \Phi(\bar{a})$. For this we construct functions $g_i : D_\alpha^i \rightarrow D_\alpha$ ($1 \leq i \leq k$) such that

$${}_S D_\alpha \models \forall y_1 \dots y_k \bigvee_{\varepsilon \in E} \Psi_\varepsilon(\bar{a}, y_1, \dots, y_k, g_1(y_1), \dots, g_k(y_1, \dots, y_k)).$$

Let $\bar{c} = \langle c_1, \dots, c_k \rangle \in D_\alpha$. By the definition of $\varepsilon_{\bar{c}}$, we have

$${}_S A \models \Psi_{\varepsilon_{\bar{c}}}(\bar{a}, c_1, \dots, c_k, f_1(c_1), \dots, f_k(c_1, \dots, c_k)).$$

By the definition of the set M , there exists $\bar{b} \in M$ such that $\varepsilon_{\bar{b}} = \varepsilon_{\bar{c}}$. Let $J = \{j \in \{1, \dots, k\} \mid f_j(\bar{c}^j) \notin D_\alpha\}$. If $J = \emptyset$, then

$${}_S D_\alpha \models \Psi_{\varepsilon_{\bar{c}}}(\bar{a}, c_1, \dots, c_k, f_1(c_1), \dots, f_k(c_1, \dots, c_k))$$

and we set $g_i(\bar{c}^i) = f_i(\bar{c}^i)$ for all i , $1 \leq i \leq k$.

Suppose that $J = \{j_1, \dots, j_l\}$ and $J \neq \emptyset$. Then in the formula $\Psi_{\varepsilon_{\bar{b}}}(\bar{x}, \bar{y}, \bar{z})$ there is no subformulas of the form $(sz_j = tu)^1$, where $s, t \in S'$, $j \in J$, and $u \in \{x_i \mid i \in \{1, \dots, n\}\} \cup \{y_i \mid i \in \{1, \dots, k\}\} \cup \{z_i \mid i \in \{1, \dots, k\} \setminus J\}$.

If $|K_{\bar{b}}^J| \leq p$ and $K_{\bar{b}}^J = \{(\alpha_{j_1}^1, \dots, \alpha_{j_l}^1), \dots, (\alpha_{j_1}^p, \dots, \alpha_{j_l}^p)\}$, then by (2), $(SA_{\alpha_{j_1}^1}, \dots, SA_{\alpha_{j_l}^1}), \dots, (SA_{\alpha_{j_1}^p}, \dots, SA_{\alpha_{j_l}^p})$ are l -tuples of the connected components of S -act ${}_S D_{\alpha_0}$, hence there is $(\alpha_{j_1}^i, \dots, \alpha_{j_l}^i) \in K_{\bar{b}}^J$ such that $f_j(\bar{c}^j) \in A_{\alpha_{j_l}^i} \subseteq D_\alpha$ for all $j \in J$, contradiction.

Therefore $|K_{\bar{b}}^J| > p$, where $p = l \cdot (n + 2k - l)$. By (1), $(SA_{\alpha_{j_1}^1}, \dots, SA_{\alpha_{j_l}^1}), \dots, (SA_{\alpha_{j_1}^p}, \dots, SA_{\alpha_{j_l}^p})$ are l -tuples of the connected components of S -act ${}_S D_\alpha$, where $(\alpha_{j_1}^1, \dots, \alpha_{j_l}^1), \dots, (\alpha_{j_1}^p, \dots, \alpha_{j_l}^p)$ are the different elements of $K_{\bar{b}}^J$. Then there is $(\alpha_{j_1}, \dots, \alpha_{j_l}) \in \{(\alpha_{j_1}^1, \dots, \alpha_{j_l}^1), \dots, (\alpha_{j_1}^p, \dots, \alpha_{j_l}^p)\}$ such that $SA_{\alpha_{j_1}} \cup \dots \cup SA_{\alpha_{j_l}}$ does not contain elements from the set

$$\{a_i \mid i \in \{1, \dots, n\}\} \cup \{c_i \mid i \in \{1, \dots, k\}\} \cup \{f_i(\bar{c}^i) \mid i \in \{1, \dots, k\} \setminus J\}.$$

By definition of $K_{\bar{b}}^J$, l -tuple $(\alpha_{j_1}, \dots, \alpha_{j_l})$ corresponds to $\bar{d} \in A$ such that $\varepsilon_{\bar{d}} = \varepsilon_{\bar{b}}$ and $f_j(\bar{d}^j) \in A_{\alpha_{j_l}}$ for all $j \in J$. Since in the formula $\Psi_{\varepsilon_{\bar{b}}}(\bar{x}, \bar{y}, \bar{z})$ there is no subformulas of the form $(sz_j = tu)^1$, where $s, t \in S'$, $j \in J$,

$$u \in \{x_i \mid i \in \{1, \dots, n\}\} \cup \{y_i \mid i \in \{1, \dots, k\}\} \cup \{z_i \mid i \in \{1, \dots, k\} \setminus J\}$$

and

$${}_S A \models \Psi_{\varepsilon_{\bar{d}}}(\bar{a}, d_1, \dots, d_k, g_1(d_1), \dots, g_k(d_1, \dots, d_k)),$$

then

$${}_S D_\alpha \models \Psi_{\varepsilon_{\bar{b}}}(\bar{a}, c_1, \dots, c_k, g_1(c_1), \dots, g_k(c_1, \dots, c_k)),$$

where $g_i(\bar{c}^i) = f_i(\bar{c}^i)$ if $i \notin J$, and $g_i(\bar{c}^i) = f_i(\bar{d}^i)$ if $i \in J$.

Thus, we construct functions $g_i : D_\alpha^i \rightarrow D_\alpha$ ($1 \leq i \leq k$) such that

$${}_S D_\alpha \models \forall y_1 \dots y_k \bigvee_{\varepsilon \in E} \Psi_\varepsilon(\bar{a}, y_1, \dots, y_k, g_1(y_1), \dots, g_k(y_1, \dots, y_k)).$$

So ${}_S D_\alpha \models \Phi(\bar{a})$ for any $\alpha \geq \alpha_0$. Since the ultrafilter F contains Fréchet filter, then by Łoś's Theorem ${}_S D \models \Phi(\bar{a}')$. \square

Corollary 1. *Let ${}_S A = \coprod_{\alpha < \kappa} {}_S A_\alpha$, κ be an infinite ordinal, ${}_S A_\alpha$ be the connected components of ${}_S A$, Φ be a sentence of language L_S , and ${}_S A \models \Phi$. Then there is a finite set $\{{}_S B_1, \dots, {}_S B_m\} \subseteq \{{}_S A_\alpha \mid \alpha < \kappa\}$ such that ${}_S B_1 \sqcup \dots \sqcup {}_S B_m \models \Phi$.*

Proof. Let the conditions of Corollary be satisfied. We will use the notation introduced in the proof of Lemma 1. As in Lemma 1, we can assume that

$$\Phi \Leftrightarrow \forall y_1 \exists z_1 \dots \forall y_k \exists z_k \bigvee_{\varepsilon \in E} \Psi_\varepsilon(\bar{y}, \bar{z}),$$

where $\bar{y} = \langle y_1, \dots, y_k \rangle$, $\bar{z} = \langle z_1, \dots, z_k \rangle$, $E \subseteq E^{(2k)}$. As the desired S -act ${}_S B_1 \sqcup \dots \sqcup {}_S B_m$ we take an S -act ${}_S D_{i_0}$, constructed in the proof of Lemma 1 for $n = 0$. \square

Theorem 2 follows directly from Corollary 1.

Theorem 2. *The coproduct of finite S -acts is a pseudofinite S -act.*

Since any S -act over a group is a cyclic S -act, we get

Corollary 2. *Any S -act, where S is a finite group, is a pseudofinite S -act.*

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