

## ON EMBEDDING PROPERTIES OF $SD$ -GROUPS

VAHAGN H. MIKAELIAN

Received 19 November 2002

*To the memory of Professor Alexey Ivanovich Kostrikin*

Continuing our recent research on embedding properties of generalized soluble and generalized nilpotent groups, we study some embedding properties of  $SD$ -groups. We show that every countable  $SD$ -group  $G$  can be subnormally embedded into a two-generator  $SD$ -group  $H$ . This embedding can have additional properties: if the group  $G$  is fully ordered, then the group  $H$  can be chosen to be also fully ordered. For any nontrivial word set  $V$ , this embedding can be constructed so that the image of  $G$  under the embedding lies in the verbal subgroup  $V(H)$  of  $H$ . The main argument of the proof is used to build continuum examples of  $SD$ -groups which are not locally soluble.

2000 Mathematics Subject Classification: 20F14, 20F19, 20E10, 20E15, 20F60.

### 1. Results and background information

**1.1. Background information and the main result.** In [7] Kovács and Neumann considered some embedding properties of  $SN^*$ - and  $SI^*$ -groups (see definitions and references below). They, in particular, showed that every countable  $SN^*$ - or  $SI^*$ -group is embeddable into a two-generator  $SN^*$ - or  $SI^*$ -group, respectively. The consideration of such embeddings of generalized soluble and generalized nilpotent groups was very natural after a series of results on embeddings into two-generator groups for soluble and nilpotent groups (see [1, 18, 19, 20, 23] and the references therein). And, in general, interest in embeddings of countable groups into two-generator groups (with some additional properties or conditions) is explained by the famous theorem of Higman, B. H. Neumann, and H. Neumann about the embeddability of an arbitrary countable group into a two-generator group [5].

In [13, 15] we considered the embedding properties of a few other classes of generalized soluble and generalized nilpotent groups. In particular, we saw that (a) every countable  $SN$ -,  $SI$ -,  $SN^2$ , or  $SI^2$ -group is embeddable into a two-generator  $SN$ -,  $SI$ -,  $SN^2$ , or  $SI^2$ -group, respectively; but (b) *not* every countable  $ZA$ - or  $N$ -group is embeddable into a two-generator  $ZA$ - or  $N$ -group, respectively.

The first aim of the present paper is to consider similar problems for another popular class of generalized soluble groups: for  $SD$ -groups; that is, for groups in which the series of commutator subgroups,

$$G = G^{(0)} \geq G^{(1)} \geq G^{(2)} \geq \dots \geq G^{(\sigma)} \geq \dots, \quad (1.1)$$

reaches unity:  $G^{(\rho)} = \{1\}$  for some finite or infinite ordinal  $\rho$ . As we will see, for any countable  $SD$ -group, such an embedding into a two-generator  $SD$ -group is possible.

Moreover—and this is the second aim of this paper—the mentioned embedding can satisfy a few additional properties: the embedding can be *subnormal*, *verbal*, and *fully ordered*. To have our statements in a precise form, we first state our main theorem, and then turn to the background information about each of these three properties.

**THEOREM 1.1.** (A) *Every countable  $SD$ -group  $G$  is subnormally embeddable into a two-generator  $SD$ -group  $H$ : there exists  $\gamma: G \rightarrow H$  such that  $G \cong \gamma(G)$ ,  $\gamma(G) \triangleleft \triangleleft H$ .*

(B) *For every nontrivial word set  $V \subseteq F_\infty$ , the two-generator  $SD$ -group  $H$  and the embedding  $\gamma$  can be chosen so that  $\gamma(G)$  lies in the verbal subgroup  $V(H)$  of the group  $H$ .*

(C) *Moreover, if the group  $G$  is fully ordered, then the group  $H$  can be chosen to be also fully ordered such that  $G$  is order-isomorphic to its image  $\gamma(G)$ . Also, if the group  $G$  is torsion-free, the group  $H$  can be chosen to be torsion-free.*

**1.2. The additional properties for embeddings.** That the embedding of a general countable group into a two-generator group can be subnormal is proved by Dark in [1] (see also the paper of Hall [4]). In [14, 15, 16] we combined the subnormality of the embeddings of countable groups with other properties (see below).

The consideration of the verballity of embeddings (of countable groups into two-generator groups) was initiated by B. H. Neumann and H. Neumann in [20], where they proved that every countable group  $G$  can be embedded not only into a two-generator group  $H$  but also into the second commutator subgroup  $H^{(2)} = H''$  of the latter (the commutator subgroups are simply the special cases for verbal subgroups). In fact, here the second commutator subgroup can be replaced by any verbal subgroup  $V(H)$  [14]. If the group  $G$  is an  $SN$ -,  $SI$ -,  $SN^\triangleright$ , or  $SI$ -group, then the group  $H$  can be constructed to belong to the same class as  $G$  [15]. And as Theorem 1.1 shows now, the analog of this fact is also true for the class of  $SD$ -groups. Moreover, all these embeddings can be subnormal.

The problem whether a fully ordered countable group can be embedded into a fully ordered two-generator group was posed by Neumann, and he solved it in [18]. In [16] this property was combined with subnormality and verballity of embeddings. Moreover, if the fully ordered countable group  $G$  is an  $SN$ -,  $SI$ -,  $SN^\triangleright$ , or  $SI$ -group, then the fully ordered group  $H$  can be chosen in the same class [15]. Again, Theorem 1.1 shows that the analog of this is true for the class of  $SD$ -groups.

**1.3. An application of the argument.** In [13] we used the embedding construction of [15] to build sets consisting of continuum of not locally soluble  $SI^*$ -groups. The reason why we devoted a paper to that topic was that so far in the literature there was only one example of the mentioned type. To be exact, there were two examples (independently built by Hall [3] and by Kovács and Neumann [7]) presenting the *same* group. The examples built in [13] were not only pairwise distinct groups but, moreover, groups generating pairwise distinct varieties of groups.

Turning back to  $SD$ -groups, there is no lack of examples of  $SD$ -groups and, in particular, of not locally soluble  $SD$ -groups (consider, e.g., any absolutely free group of rank greater than 1). However, we include here a scaled-down version of the construction of

[13] as an illustration of what can be obtained by means of the verbal embeddings of groups.

**THEOREM 1.2.** *There exists a continuum of torsion-free, not locally soluble two-generator  $SD$ -groups which generate pairwise different varieties of groups.*

**1.4. References to the basic literature.** An  $SN^*$ -group or an  $SI^*$ -group is a group possessing a soluble ascending subnormal or normal series, respectively. In analogy with this, an  $SN^\natural$  or  $SI^\natural$ -group is a group possessing a soluble descending subnormal or normal series respectively [12]. More generally, an  $SN$ - or  $SI$ -group is a group possessing a soluble subnormal or normal (not necessarily well ordered) system, respectively. A  $ZA$ -group is a group with central ascending series. Finally, an  $N$ -group is a group in which every subgroup can be included in an ascending subnormal series. For information on the theory of generalized soluble and generalized nilpotent groups, we refer to the original articles of Kurosh and Chernikov [9] and of Plotkin [24, 25], as well as to the books of Robinson [26, 27] and of Kurosh [8]. For general information on varieties of groups, we refer to the basic book of Neumann [21]. Information on linearly (or fully) ordered groups can be found in the book of Fuchs [2] or in the papers of Levi [10, 11] and of Neumann [17, 18].

## 2. The main embedding constructions

**2.1. The subnormal embedding into a two-generator group.** We begin with a simple but still very useful construction (see, e.g., [3, 20]). Assume the given group  $G$  to be countable and its elements to be indexed by the set of nonnegative integers:

$$G = \{g_0, g_1, \dots, g_n, \dots\}. \quad (2.1)$$

Then consider in the Cartesian wreath product  $GWr\langle f \rangle$  of the group  $G$  and of the infinite cyclic group generated by the element  $f$  the following element  $\omega$  of the base subgroup  $G^{\langle f \rangle}$ :

$$\omega(f^i) = \begin{cases} g_k, & \text{if } i = 2^k, k = 0, 1, 2, \dots, \\ 1, & \text{if } i \in \mathbb{Z} \setminus \{2^k \mid k = 0, 1, 2, \dots\}. \end{cases} \quad (2.2)$$

Clearly, the element  $f$  acts on the base subgroup as a “right-shift” operator. In particular, for arbitrary  $g_n$ , we have  $\omega^{f^{-2^n}}(1) = g_n$ . Thus, for each pair  $g_n, g_m \in G$ , we have

$$\left[ \omega^{f^{-2^n}}, \omega^{f^{-2^m}} \right](1) = [g_n, g_m]. \quad (2.3)$$

Furthermore, for arbitrary  $j \neq 0$ ,

$$\left[ \omega^{f^{-2^n}}, \omega^{f^{-2^m}} \right](f^j) = 1. \quad (2.4)$$

Define  $H = H(G) = \langle \omega, f \rangle$ . Using this construction, we can prove the following lemma.

**LEMMA 2.1.** *Let  $H = H(G)$  be the above-constructed two-generator group. Then there is an isomorphic embedding  $\alpha : G' \rightarrow H$  of the commutator subgroup  $G'$  into  $H$  such that  $\alpha(G')$  is subnormal in  $H$ . Moreover, if the group  $G$  has any one of the properties*

- (1)  $G$  is an  $SD$ -group,
- (2)  $G$  is a fully ordered group,
- (3)  $G$  is a torsion-free group,

*then the group  $H$  also has the same properties (and if the group  $G$  is fully ordered, then  $G'$  is order-isomorphic to  $\alpha(G')$ ).*

**PROOF.** For understandable reasons, we can omit the case when  $G$  is a trivial group. For any pair  $g_n, g_m \in G$ , the embedding  $\alpha$  can be defined as

$$\alpha([g_n, g_m]) = [\omega^{f^{-2^n}}, \omega^{f^{-2^m}}] \in H. \tag{2.5}$$

Equalities (2.3) and (2.4) show that this can be continued to an injection.

(1) Assume that  $G$  is an  $SD$ -group:  $G^{(\delta)} = \{1\}$ . Evidently,  $H'$  lies in the normal closure  $T = \langle \omega \rangle^H$  of  $\langle \omega \rangle$  in  $H$ . As it is known (and can be calculated based on equalities (2.3) and (2.4)), the commutator  $T'$  is equal to the direct power  $\overline{G'}^{(f)}$  of the commutator  $G'$ . The direct power  $T'$  is an  $SD$ -group of length  $\delta - 1$ . Thus (taking into account the fact that the subgroups of  $SD$ -groups are  $SD$ -groups) we get that  $H$  is an  $SD$ -group of length  $2 + \delta - 1 = \delta + 1$ .

(2) Assume that the full-order relation “ $<$ ” is defined on  $G$ , and “lift” it to the group  $H$ . It is easy to see that for any element  $f^i \tau \in H$ , where  $f^i \in \langle f \rangle$  and  $\tau \in H \cap G^{(f)}$ , there necessarily exists a corresponding maximal index  $z_0(\tau) \in \mathbb{Z}$  such that  $\tau(f^i) = 1$  for any  $i \leq z_0(\tau)$ . Thus we can compare any two distinct elements of  $H$ ,

$$f^{i_1} \tau_1 < f^{i_2} \tau_2, \tag{2.6}$$

if and only if  $i_1 < i_2$ , or if  $i_1 = i_2$  and  $\tau_1(f^{z_0+1}) < \tau_2(f^{z_0+1})$ , where  $z_0$  is the minimum of  $z_0(\tau_1)$  and  $z_0(\tau_2)$ .

(3) If the group  $G$  is torsion-free, then the group  $H$  is also torsion-free. □

**2.2. The verbal subnormal embedding.** Let  $\mathfrak{A}$  be the variety of all abelian groups and let  $\mathfrak{V}$  be any variety different from the variety of all groups  $\mathfrak{O}$  (for now the properties of this variety are immaterial, but later it will be replaced by special varieties).

**LEMMA 2.2.** *For any variety  $\mathfrak{V} \neq \mathfrak{O}$ , there exists a group  $N$  with the following properties:*

- (1)  $N$  is a torsion-free  $SD$ -group;
- (2)  $N$  generates a product variety  $\mathfrak{V}_1 \mathfrak{A}$ , where  $\mathfrak{V}_1 \neq \mathfrak{O}$  and  $\mathfrak{V}_1$  is not properly contained in  $\mathfrak{V}$  (in particular,  $N \notin \mathfrak{V} \mathfrak{A}$ );
- (3)  $N$  can be fully ordered.

**PROOF.** There are many methods to construct such a group. We outline one of them. Consider the relatively free nilpotent group  $S = F_k(\mathfrak{N}_c)$  of some rank  $k$  and class  $c \leq k$ , such that  $S \notin \mathfrak{V}$  (we are always able to find such a group because the set of all nilpotent groups, and even the set of all finite  $p$ -groups, generates  $\mathfrak{O}$ ). The group  $N$  we need can be constructed for  $S$  in a way rather similar to the construction of the group  $H(G)$

for the group  $G$  in Section 2.1. Consider in the infinite Cartesian power  $S^{\langle z \rangle}$ , that is, in the base subgroup of the Cartesian wreath product  $SWr\langle z \rangle$  (of the group  $S$  and of the infinite cyclic group  $\langle z \rangle$ ) an element  $\lambda_s$  for each  $s \in S$ :

$$\lambda_s(z^i) = \begin{cases} s, & \text{if } i \geq 0, \\ 1, & \text{if } i < 0, \end{cases} \tag{2.7}$$

and define  $N = \langle \lambda_s, z \mid s \in S \rangle$ . The group  $N$  contains the first copy  $S_0$  of  $S$  in  $S^{\langle z \rangle}$ . In the sequel, we identify  $S$  with  $S_0$  and use the same notations for their elements if no misunderstanding arises.

(1) The group  $N$  is clearly a torsion-free soluble group.

(2) The group  $N$  belongs to  $\mathfrak{V}_1\mathfrak{A} = \mathfrak{N}_c\mathfrak{A}$ , and  $N$  contains a subgroup isomorphic to the direct wreath product  $Swr\langle z \rangle$ . Thus,  $\text{var}(N) = \mathfrak{V}_1\mathfrak{A} = \mathfrak{N}_c\mathfrak{A}$ .

(3) Since the verbal subgroup  $V(S)$  is not trivial ( $V$  is the word set corresponding to the variety  $\mathfrak{V}$ ), we can choose an element  $a \in V(S)$  of infinite order. On the free nilpotent group  $S$ , a full-order relation “ $<$ ” can be defined as in [10, 11, 17]. Moreover, since in any group the full order can be replaced by its converse full order “ $<^{-1}$ ” ( $x <^{-1} y$  if and only if  $y < x$ ), we can, without loss of generality, assume that the element  $a$  is positive:  $1 < a$ . Then, according to the definition of full order, all the powers  $a^2, a^3, \dots, a^n, \dots$  will also be positive elements. (This element  $a$  will be used later.) We “lift” the full-order relation “ $<$ ” of  $S$  to the group  $N$ . As in the proof of Lemma 2.1, for any element  $z^i\tau \in N$ , where  $z^i \in \langle z \rangle$  and  $\tau \in N \cap S^{\langle z \rangle}$ , there necessarily exists a maximal index  $z_0(\tau) \in \mathbb{Z}$  such that  $\tau(z^i) = 1$  for any  $i \leq z_0(\tau)$ . Thus, for any two distinct elements of  $N$ , we can put

$$z^{i_1}\tau_1 < z^{i_2}\tau_2 \tag{2.8}$$

if and only if  $i_1 < i_2$  or if  $i_1 = i_2$  and  $\tau_1(z^{z_0+1}) < \tau_2(z^{z_0+1})$ , where  $z_0$  is the minimum of  $z_0(\tau_1)$  and  $z_0(\tau_2)$ . □

Now take a group  $G$ , a nontrivial word set  $V$ , and the group  $N$  constructed as above for the given  $V$ . Consider the Cartesian wreath product  $GWrN$  and select the following elements,  $\chi_g$ , in the base group  $G^N$  of this wreath product:

$$\chi_g(n) = \begin{cases} g, & \text{if } n = a^i, \text{ for some positive integer } i \in \mathbb{N}, \\ 1, & \text{if } n \notin \{a^i \mid i \in \mathbb{N}\}, \end{cases} \tag{2.9}$$

where  $a$  is the element chosen above. Denote by  $K = K(G, V)$  the following subgroup of  $GWrN$ :

$$K = \langle \chi_g, N \mid g \in G \rangle. \tag{2.10}$$

Denote by  $U$  the word set corresponding to the variety  $\mathfrak{VA}$ . In these notations, the following lemma holds.

**LEMMA 2.3.** *Let  $K = K(G, V)$  be the above-constructed group for the group  $G$  and for the nontrivial word set  $V$ . Then there is an isomorphic embedding  $\beta : G \rightarrow K$  of the*

group  $G$  into  $K$  such that  $\beta(G)$  is subnormal in  $K$  and lies in the verbal subgroup  $U(K)$ . Moreover, if the group  $G$  has any one of the properties

- (1)  $G$  is an  $SD$ -group,
- (2)  $G$  is a fully ordered group,
- (3)  $G$  is a torsion-free group,

then the group  $K$  also has the same properties (and if the group  $G$  is fully ordered, then it is order-isomorphic to  $\beta(G)$ ).

**PROOF.** Let  $\pi_g$  be the element of the first copy of  $G$  in  $G^N$  corresponding to  $g \in G$ :

$$\pi_g(n) = \begin{cases} g, & \text{if } n = 1, \\ 1, & \text{if } n \in N \setminus \{1\}. \end{cases} \quad (2.11)$$

The embedding  $\beta$  can be defined as

$$\beta(g) = \pi_g, \quad \forall g \in G. \quad (2.12)$$

Then  $(\chi_g^{-1})^a \chi_g = \pi_g$  because it is easy to calculate that

$$\left[ (\chi_g^{-1})^a \chi_g \right](n) = \begin{cases} 1, & \text{if } n \in N \setminus \{a^i \mid i = 0, 1, 2, \dots\}, \\ g, & \text{if } n = 1 = a^0, \\ 1, & \text{if } n = a, a^2, a^3, \dots \end{cases} \quad (2.13)$$

Since

$$a \in V(S) \subseteq U(N) \subseteq U(K), \quad (2.14)$$

we have  $\pi_g = a^{-1} a^{\chi_g} \in U(K)$ . Thus the mapping  $g \rightarrow \pi_g$  defines an isomorphic embedding of  $G$  onto the first copy  $\beta(G)$  of  $G$  in  $G^N$  and in  $U(K)$ . Clearly,  $\beta(G)$  is subnormal in  $K$  (and, in fact, even in  $G\text{Wr}N$ ).

(1) If  $G$  is an  $SD$ -group:  $G^{(v)} = \{1\}$ , then  $K^{(v+c+1)} = \{1\}$ , where  $c$  is the nilpotency class of  $S$  (in fact,  $c$  could be replaced by a smaller integer, but it is immaterial for our purposes) for, clearly,  $K' \subseteq \langle G^N, S^{(z)} \rangle$ ,  $K^{(c+1)} \subseteq G^N$ , and  $(G^N)^{(v)} \leq (G^{(v)})^N = \{1\}$ . Notice that we could use this argument in the proof of [Lemma 2.1\(1\)](#). However, there we used a somewhat different argument to stress that in that case we deal with a direct (not Cartesian) product.

(2) Assume that a full-order relation “ $<$ ” is defined on  $G$ . From the definition of the elements  $\chi_g$  (and of the operation of elements of  $N$  on  $\chi_g$ ), it is clear that for any nontrivial element  $n\theta \in K$ , where  $n \in N$  and  $\theta \in K \cap G^N$ , there necessarily exists an element  $n_0(\theta) \in N$  with the following property:

$$\theta(n) = 1, \quad \forall n < n_0(\theta), \theta(n_0(\theta)) \neq 1. \quad (2.15)$$

Now the full orders available on the groups  $G$  and  $N$  can be “continued” to the group  $K$ . Let  $n_1\theta_1$  and  $n_2\theta_2$  be any two distinct elements of  $K$ . Then

$$n_1\theta_1 < n_2\theta_2 \quad (2.16)$$

if and only if  $n_1 < n_2$  or if  $n_1 = n_2$  and  $\theta_1(n_0) < \theta_2(n_0)$ , where  $n_0$  is the minimum of  $n_0(\theta_1)$  and  $n_0(\theta_2)$ .

(3) It is easy to see that if the group  $G$  is torsion-free, then the group  $GWrN$  and its subgroup  $K$  also are torsion-free.  $\square$

**2.3. Proof of Theorem 1.1.** Lemmas 2.1 and 2.3 already allow us to prove the statements of Theorem 1.1.

**PROOF OF STATEMENT (A).** Assume that  $G = G_0$  is a countable  $SD$ -group and  $\mathfrak{V} = \mathfrak{E}$  is the trivial variety consisting of the group  $\{1\}$  only. By Lemma 2.3, the group  $G$  can be subnormally embedded into an  $SD$ -group  $G_1$  such that  $\beta(G) \subseteq U(G_1) = G'_1$ , where this time the word set  $U$  corresponds to the variety of the abelian groups  $\mathfrak{A} = \mathfrak{VA} = \mathfrak{A}$ . It is easy to see that the group  $G_1$  is also countable. Thus, by Lemma 2.1, the commutator subgroup  $G'_1$  can be subnormally embedded into a two-generator  $SD$ -group  $G_2 = H(G_1)$ ,  $\alpha: G'_1 \rightarrow G_2$ . The subnormal embedding we are looking for can be defined as the composition  $\beta \cdot \alpha$ .  $\square$

**PROOF OF STATEMENT (B).** Assume that  $V \subseteq F_\infty$  is any nontrivial word set corresponding to the variety  $\mathfrak{V}$ . Again, by Lemma 2.3, the group  $G$  can be subnormally embedded into an  $SD$ -group  $G_1 = K(G, V)$  such that  $\beta(G) \subseteq U(G_1)$ , where  $U$  corresponds to  $\mathfrak{VA}$ . By Lemma 2.1, the commutator subgroup  $G'_1$  can be subnormally embedded into some two-generator  $SD$ -group  $G_2 = H(G_1)$ ,  $\alpha: G'_1 \rightarrow G_2$ .

If we now show that

$$\beta(G) \subseteq V(G'_1), \tag{2.17}$$

the statement will be proved because

- (a)  $\alpha(\beta(G))$  is subnormal in  $G_2$  (for  $\beta(G)$  is subnormal in  $G'_1$ , and the latter is subnormal in  $G_2$ );
- (b)  $\alpha(\beta(G))$  lies in  $V(G_2)$  (for  $\alpha(\beta(G)) \subseteq \alpha(V(G'_1)) \subseteq V(G_2)$ ).

To prove (2.17), we first notice that

$$S_0 \subseteq N' (\subseteq G'_1), \tag{2.18}$$

where under  $S_0$  we understand the first copy of  $S$  in  $S^{(z)}$ . Indeed, we should simply apply the argument of the proof of Lemma 2.3 to see that  $S_0$  lies in  $N'$ . We have

$$a \in V(S_0) \subseteq V(G'_1). \tag{2.19}$$

Therefore, for any  $g \in G$ ,

$$\pi_g = \beta(g) = a^{-1} a^{x_g} \in V(G'_1), \tag{2.20}$$

and we can again take  $\gamma = \beta\alpha$ .  $\square$

**PROOF OF STATEMENT (C).** This statement follows directly from Lemmas 2.1 and 2.3 and from the fact that a subgroup—in this case the commutator subgroup  $G'_1$ —of an  $SD$ -group (of a fully ordered group) is an  $SD$ -group (a fully ordered group). Also, if  $G$  is torsion-free, evidently, the groups  $G_1$  and  $G_2$  also have that property. Theorem 1.1 is then proved.  $\square$

### 3. Continuum two-generator $SD$ -groups

**3.1. Bisections.** We need a special set of groups constructed by Ol'shanskii in [22]. Namely, let  $\{L_n \mid n \in \mathbb{N}\}$  be a countable set of finite groups with the following properties:

- (1)  $L_n \in \mathcal{L}$ , where  $\mathcal{L} \neq \mathcal{O}$  is a soluble variety of finite exponent;
- (2)  $L_n \notin \text{var}(L_1, \dots, L_{n-1}, L_{n+1}, \dots)$  for an arbitrary  $n \in \mathbb{N}$ .

In fact, as variety  $\mathcal{L}$ , one can take the variety  $\mathcal{C}_5 \cap \mathfrak{B}_{8qr}$ ,  $n = 1, 2, \dots$ , where  $\mathcal{C}_5$  is the variety of soluble groups of length at most 5;  $q, r$  are distinct primes; and  $\mathfrak{B}_{8qr}$  is the Burnside variety of groups of exponents dividing  $8qr$  [22].

We define a *bisection* (B) as follows. The set  $\mathbb{N}$  of positive integers can be split as

- (B)  $\mathbb{N}' \cup \mathbb{N}'' = \mathbb{N}$ , where  $\mathbb{N}' \cap \mathbb{N}'' = \emptyset$  and  $\mathbb{N}', \mathbb{N}'' \neq \emptyset$ .

Then denote the group  $L_{(B)}$  to be the direct product of the groups  $L_n$ ,  $n \in \mathbb{N}'$ , the variety  $\mathfrak{V}_{(B)}$  to be the variety generated by the groups  $L_n$ ,  $n \in \mathbb{N}'' = \mathbb{N} \setminus \mathbb{N}'$ , and the word set  $V_{(B)}$  to be that corresponding to  $\mathfrak{V}_{(B)}$ .

**3.2. Construction of  $SD$ -groups with bisections (B).** Take any torsion-free insoluble  $SD$ -group  $G$  not generating the variety  $\mathcal{O}$  and put

$$G_{(B)} = F_\infty(\text{var}(G) \text{var}(L_{(B)})). \quad (3.1)$$

It is easy to see that  $G_{(B)}$  is an  $SD$ -group. Also, it is a torsion-free group by the theorem of Kovács about torsion-free relatively free groups of product varieties [6]. Since  $V_{(B)}$  is clearly a nontrivial word set, we are in a position to apply Theorem 1.1 to subnormally embed  $G_{(B)}$  into an appropriate two-generator  $SD$ -group

$$H_{(B)} = H(G_{(B)}, V_{(B)}). \quad (3.2)$$

Since the set of all the bisections (B) is of continuum cardinality, to prove Theorem 1.2, it is sufficient to find many continuum bisections which determine groups  $H_{(B)}$  generating pairwise distinct varieties of groups.

Consider another bisection,

- ( $\tilde{B}$ )  $\tilde{\mathbb{N}}' \cup \tilde{\mathbb{N}}'' = \mathbb{N}$ , where  $\tilde{\mathbb{N}}' \cap \tilde{\mathbb{N}}'' = \emptyset$  and  $\tilde{\mathbb{N}}', \tilde{\mathbb{N}}'' \neq \emptyset$ ,

different from (B) and consider the groups  $G_{(\tilde{B})}$  and  $H_{(\tilde{B})} = H(G_{(\tilde{B})}, V_{(\tilde{B})})$  corresponding to this bisection ( $\tilde{B}$ ). Here the inequality (B)  $\neq$  ( $\tilde{B}$ ), of course, simply means that  $\mathbb{N}' \neq \tilde{\mathbb{N}}'$  (or, equivalently,  $\mathbb{N}'' \neq \tilde{\mathbb{N}}''$ ). Clearly,  $\text{var}(L_{(B)}) \neq \text{var}(L_{(\tilde{B})})$ . Moreover, we have the following lemma.

**LEMMA 3.1.** *If (B)  $\neq$  ( $\tilde{B}$ ), then  $\text{var}(G_{(B)}) \neq \text{var}(G_{(\tilde{B})})$ .*



**PROOF.** We have

$$\begin{aligned} \text{var}(G_{(B)}) &= \text{var}(G) \text{var}(L_{(B)}), \\ \text{var}(G_{(\tilde{B})}) &= \text{var}(G) \text{var}(L_{(\tilde{B})}). \end{aligned} \tag{3.3}$$

Then, by [21, Theorem 23.23], if  $\text{var}(G_{(B)}) = \text{var}(G_{(\tilde{B})})$ , we have  $\text{var}(L_{(B)}) = \text{var}(L_{(\tilde{B})})$ . This contradicts the fact that  $(B) \neq (\tilde{B})$  and the selection of the group set  $\{L_n \mid n \in \mathbb{N}\}$ .  $\square$

The next step of our construction is the group  $K_{(B)} = K(G_{(B)}, V_{(B)})$  that we built for the group  $G_{(B)}$  and the word set  $V_{(B)}$ . The set of all possible word sets (as well as the set of all varieties of groups) is of continuum cardinality. In fact, the continuum of distinct bisections  $(B)$  already provide us with continuum of distinct word sets  $V_{(B)}$ . This, however, does not mean that building the groups  $K_{(B)}$  for continuum distinct word sets  $V_{(B)}$ , we will get *continuum* examples of distinct  $SD$ -groups  $H_{(B)}$ . The point is that the role of the word set  $V$  in  $K$  (and, thus, in  $H$ ) is in the determination of the class  $c$  and of the rank  $k$  of the free nilpotent group  $S = F_k(\mathfrak{N}_c)$ , which we are using to build the appropriate group  $N$ . The set of such integers is *countable*. This means that there exist many (in fact, continuum) word sets  $V_{(B)}$  for which the same nilpotent group  $S_{(B)}$  should be chosen. This also means that the construction, that we have at our disposal at the current moment, does not yet allow us to build a continuum of  $SD$ -groups using the fact about continuum set of words  $V_{(B)}$  only.

But this observation also allows us to modify and shorten one of the segments of our proof. Namely, we restrict ourselves to such a set (of continuum cardinality) of word sets  $V_{(B)}$  which correspond to a fixed pair of integers  $c$  and  $k$ . It will be sufficient to prove that this set can already give rise to continuum two-generator (torsion-free)  $SD$ -groups.

**LEMMA 3.2.** *Assume that  $(B)$  and  $(\tilde{B})$  are two distinct bisections of the type mentioned:  $S_{(B)} = S_{(\tilde{B})}$ . If  $\text{var}(G_{(B)}) \neq \text{var}(G_{(\tilde{B})})$ , then  $\text{var}(K_{(B)}) \neq \text{var}(K_{(\tilde{B})})$ .*

**PROOF.** As we saw in the proof of Lemma 2.3, for the given bisection  $(B)$ , the group  $K_{(B)}$  contains the first copy of  $G_{(B)}$ . That copy, together with  $N_{(B)}$ , generates the direct wreath product  $G_{(B)} \text{wr} N_{(B)}$ . Since the group  $N_{(B)}$  discriminates the variety  $\mathfrak{N}_c \mathfrak{A}$ , the group  $G_{(B)} \text{wr} N_{(B)}$  generates  $\text{var}(G_{(B)}) \text{var}(N_{(B)}) = \text{var}(G_{(B)}) \mathfrak{N}_c \mathfrak{A} = \text{var}(K_{(B)})$ . Thus, taking another bisection  $(\tilde{B})$ , we would get  $\text{var}(K_{(\tilde{B})}) = \text{var}(G_{(\tilde{B})}) \mathfrak{N}_c \mathfrak{A}$  (recall that according to the remark preceding this lemma, we can use the same variety  $\mathfrak{N}_c$  for both bisections). The latter is distinct from  $\text{var}(G_{(B)}) \mathfrak{N}_c \mathfrak{A}$  whenever the bisections are distinct.  $\square$

The final step of our argument is the construction of the two-generator group  $H_{(B)} = H(K_{(B)})$ .

**LEMMA 3.3.** *If  $\text{var}(K_{(B)}) \neq \text{var}(K_{(\tilde{B})})$ , then  $\text{var}(H_{(B)}) \neq \text{var}(H_{(\tilde{B})})$ .*

**PROOF.** The proof immediately follows from the fact that

$$\text{var}(H_{(B)}) = \text{var}(K_{(B)} \text{wr} \langle f \rangle) = \text{var}(K_{(B)}) \mathfrak{A}. \tag{3.4}$$

We take any nonidentity  $w = w(x_1, \dots, x_n)$  for the variety  $\text{var}(K_{(\mathbb{B})})\mathfrak{A}$  and show that  $w$  can be falsified on some elements of  $H_{(\mathbb{B})}$ , as well. This will prove the point because  $H_{(\mathbb{B})}$  evidently belongs to  $\text{var}(K_{(\mathbb{B})})\mathfrak{A}$ . Take  $c_1, \dots, c_n \in K_{(\mathbb{B})} \text{wr} \langle f \rangle$  such that  $w(c_1, \dots, c_n) = 1$ . Clearly,  $c_i = f^{m_i} \rho_i$ , where  $\rho_i$  belongs to the base subgroup  $K_{(\mathbb{B})}^{(f)}$ ;  $i = 1, \dots, n$ . Finitely many elements  $\rho_i$  in this direct wreath product have only finitely many nontrivial “coordinates”  $\rho_i(f^j)$ ,  $i = 1, \dots, n$ ,  $j \in \mathbb{Z}$ . This means that there is a big enough positive integer  $n^*$  such that if we replace (trivial) “coordinates”  $\rho_i(f^j)$ ,  $|j| > n^*$  of each  $\rho_i$ , by arbitrarily chosen values from the group  $K_{(\mathbb{B})}$ , and denote these new strings by  $\rho'_i$  correspondingly, then we will still have

$$w(f^{m_1} \rho'_1, \dots, f^{m_n} \rho'_n) \neq 1. \quad (3.5)$$

Since all the powers  $f^{m_1}, \dots, f^{m_n}$  already belong to  $H(K_{(\mathbb{B})})$ , the proof will be completed if we show the following rather more general fact: for arbitrary positive integer  $n_0$  and arbitrary pregiven values  $d_j \in K_{(\mathbb{B})}$ ,  $j = -n_0, \dots, n_0$ , the group  $H(K_{(\mathbb{B})})$  contains such an element  $\rho'' \in H(K_{(\mathbb{B})}) \cap K_{(\mathbb{B})}^{(f)}$  for which  $\rho''(f^j) = d_j$ ,  $j = -n_0, \dots, n_0$ .

Taking into account the “shifting” effect of the element  $f$ , it will be sufficient to show that for any pregiven  $d \in K_{(\mathbb{B})}$ , there is an element  $\rho'''_d \in H(K_{(\mathbb{B})}) \cap K_{(\mathbb{B})}^{(f)}$  such that

$$\rho'''_d(f^j) = \begin{cases} d, & \text{if } j = 0, \\ 1, & \text{if } -2n_0 \leq j \leq 2n_0, j \neq 0. \end{cases} \quad (3.6)$$

(Notice that we did not put any requirements on  $\rho'''(f^j)$  for  $j > 2n_0$  or for  $j < -2n_0$ .) The elements  $\rho''$  will then be products of elements of type  $\rho'''_d$  (for various  $d$ 's) and of their conjugates by powers of  $f$ . It remains to construct elements  $\rho'''_d$  (for any  $d$  and  $n_0$ ) by means of two generators  $\omega_{(\mathbb{B})}$  and  $f$ . We have

$$\omega_{(\mathbb{B})}(f^i) = \begin{cases} g_k, & \text{if } i = 2^k, k = 0, 1, 2, \dots, \\ 1, & \text{if } i \in \mathbb{Z} \setminus \{2^k \mid k = 0, 1, 2, \dots\}, \end{cases} \quad (3.7)$$

where this time the countable group  $K_{(\mathbb{B})}$  is presented as  $K_{(\mathbb{B})} = \{g_0, g_1, \dots\}$ . The element  $d$  can be presented as a product  $g_i \cdot g_j$  for infinitely many pairs  $g_i, g_j \in K_{(\mathbb{B})}$ . On the other hand, the number of all possible pairs  $g_i, g_j$  with a common upper bound on  $|i|$  and  $|j|$  is clearly finite. Thus, there necessarily exists a pair  $g_i, g_j$  such that  $d = g_i \cdot g_j$  and  $2^i, 2^j > 2n_0$ . Then

$$\rho'''_d = \omega^{f^{-2^i}} \omega^{f^{-2^j}}. \quad (3.8)$$

□

Lemmas 3.1, 3.2, and 3.3 prove [Theorem 1.2](#) because the continuum of two-generator torsion-free  $SD$ -groups we constructed do generate pairwise distinct varieties of groups.

And none of these groups is locally soluble because it would be then a soluble group, and, thus, it could not contain the initial group  $G_{(B)}$  that was chosen to be insoluble.

**ACKNOWLEDGMENTS.** The author is very much thankful to Prof. Alexander Yu. Ol'shanskii, Moscow State University and Vanderbilt University, for an advice (included in the paper as [Lemma 3.3](#)) that allowed him to shorten the initial proof in [Section 3](#), as well as to the referee for very valuable comments to the manuscript.

## REFERENCES

- [1] R. S. Dark, *On subnormal embedding theorems for groups*, J. London Math. Soc. **43** (1968), 387–390.
- [2] L. Fuchs, *Partially Ordered Algebraic Systems*, Pergamon Press, New York, 1963, Russian translation by I. V. Streletski under edition of A. G. Kurosh, Mir, Moscow, 1965.
- [3] P. Hall, *The Frattini subgroups of finitely generated groups*, Proc. London Math. Soc. (3) **11** (1961), 327–352.
- [4] ———, *On the embedding of a group in a join of given groups*, J. Aust. Math. Soc. **17** (1974), 434–495.
- [5] G. Higman, B. H. Neumann, and H. Neumann, *Embedding theorems for groups*, J. London Math. Soc. **24** (1949), 247–254.
- [6] L. G. Kovács, *The thirty-nine varieties*, Math. Sci. **4** (1979), no. 2, 113–128.
- [7] L. G. Kovács and B. H. Neumann, *An embedding theorem for some countable groups*, Acta Sci. Math. (Szeged) **26** (1965), 139–142.
- [8] A. G. Kurosh, *The Theory of Groups*, 3rd ed., Nauka, Moscow, 1967 (Russian), English translation of the 2nd ed. by K. A. Hirsch, Chelsea Publishing, New York, 1960.
- [9] A. G. Kurosh and S. N. Chernikov, *Soluble and nilpotent groups*, Uspehi Mat. Nauk. **2** (1947), 18–59 (Russian).
- [10] F. W. Levi, *Ordered groups*, Proc. Indian Acad. Sci. Sect. A **16** (1942), 256–263.
- [11] ———, *Contributions to the theory of ordered groups*, Proc. Indian Acad. Sci. Sect. A **17** (1943), 199–201.
- [12] O. V. Mel'nikov, V. N. Remeslennikov, V. A. Roman'kov, L. A. Skorniyakov, and I. P. Sheshtakov, *General Algebra. Vol. 1*, Mathematical Reference Library, Nauka, Moscow, 1990 (Russian).
- [13] V. H. Mikaelian, *Infinitely many not locally soluble  $SI^*$ -groups*, to appear in Ricerche Mat.
- [14] ———, *Subnormal embedding theorems for groups*, J. London Math. Soc. (2) **62** (2000), no. 2, 398–406.
- [15] ———, *On embeddings of countable generalized soluble groups into two-generated groups*, J. Algebra **250** (2002), no. 1, 1–17.
- [16] ———, *An embedding construction for ordered groups*, J. Aust. Math. Soc. **74** (2003), no. 3, 379–392.
- [17] B. H. Neumann, *On ordered groups*, Amer. J. Math. **71** (1949), 1–18.
- [18] ———, *Embedding theorems for ordered groups*, J. London Math. Soc. **35** (1960), 503–512.
- [19] ———, *Embedding theorems for groups*, Nieuw Arch. Wisk. (3) **16** (1968), 73–78.
- [20] B. H. Neumann and H. Neumann, *Embedding theorems for groups*, J. London Math. Soc. **34** (1959), 465–479.
- [21] H. Neumann, *Varieties of Groups*, Springer-Verlag, New York, 1967.
- [22] A. Yu. Ol'shanskiĭ, *The finite basis problem for identities in groups*, Izv. Akad. Nauk SSSR Ser. Mat. **34** (1970), 376–384 (Russian).
- [23] ———, *Efficient embeddings of countable groups*, Vestnik Moskov. Univ. Ser. I Mat. Mekh. (1989), no. 2, 28–34 (Russian).
- [24] B. I. Plotkin, *Generalized soluble and generalized nilpotent groups*, Uspehi Mat. Nauk. **13** (1958), no. 4, 89–172 (Russian).

- [25] ———, *Generalized soluble and generalized nilpotent groups*, Amer. Math. Soc. Transl. Ser. 2 **17** (1961), 29–115.
- [26] D. J. S. Robinson, *Finiteness Conditions and Generalized Soluble Groups. Part 1*, Ergebnisse der Mathematik und ihrer Grenzgebiete, vol. 62, Springer-Verlag, New York, 1972.
- [27] ———, *Finiteness Conditions and Generalized Soluble Groups. Part 2*, Ergebnisse der Mathematik und ihrer Grenzgebiete, vol. 63, Springer-Verlag, New York, 1972.

Vahagn H. Mikaelian: Department of Computer Science, Yerevan State University, 375025 Yerevan, Armenia

*E-mail address:* [mikaelian@e-math.ams.org](mailto:mikaelian@e-math.ams.org)