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**A SEMIGROUP UNION OF DISJOINT LOCALLY FINITE
SUBSEMIGROUPS WHICH IS NOT LOCALLY FINITE**

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The semigroup S of the title is the free semigroup F on four generators factored by the congruence generated by the set of relations $\{w^2 = w^3 \mid w \in F\}$. The following lemma is proved by examining the elements of a given congruence class of F :

LEMMA. **If $x, y \in S$ and $x^2 = y^2$, then either $xy = x^2$ or $yx = x^2$.**

From the Lemma it then easily follows that the (disjoint) subsemigroups $\{y \in S \mid y^2 = x^2\}$ of S are locally finite.

This note answers in the negative a question raised by Shevrin in [2].

THEOREM. *There exists a semigroup S with disjoint locally finite subsemigroups S_e such that $S = \cup S_e$ and S is not locally finite.*

Let F be the free semigroup with identity on four generators. Let \sim denote the smallest congruence on F containing the set $\{(x^2, x^3) \mid x \in F\}$. That is, for $w, w' \in F$, $w \sim w'$ if and only if a finite sequence of "transitions", of either of the types $ab^2c \rightarrow ab^3c$ or $ab^3c \rightarrow ab^2c$, transforms w into w' .

The equivalence classes of F with respect to \sim are taken as the elements of S , and multiplication in S is defined in the natural way.

There is given in [1] a sequence on four symbols in which no block of length k is immediately repeated, for any k . Thus the left initial segments of this sequence give elements of F containing no squares. Since no transition of the form $ab^2c \rightarrow ab^3c$ or $ab^3c \rightarrow ab^2c$ can be applied to an element of F containing no squares, the equivalence classes containing these elements consist of precisely one element each; thus the semigroup S is infinite, and hence not locally finite.

In what follows, the symbols $\alpha, \alpha_1, \alpha_2, \dots$ refer to transformations (on elements of F) of the form

$$ab \rightarrow ayb, \quad \text{where } a \sim ay, \quad \text{and } a, b, y \in F.$$

The symbols $\beta, \beta_1, \beta_2, \dots$ refer to transformations of the type

$$axb \rightarrow ab, \quad \text{where } a \sim ax, \quad \text{and } a, b, x \in F.$$

Note that $ab^2c \rightarrow ab^3c$ is an α , and $ab^3c \rightarrow ab^2c$ is a β .

LEMMA 1. *If $w, w' \in F$, and $w\beta\alpha = w'$, then there are α_1, β_1 such that $w\alpha_1\beta_1 = w'$.*

Proof. Let

$$w = axb, \quad w\beta = ab, \quad \text{where } a \sim ax.$$

Let

$$w\beta = AB, \quad w\beta\alpha = AyB, \quad \text{where } A \sim Ay.$$

There are two cases:

(i) A is contained in a . That is,

$$a = Aa' \quad \text{and} \quad w' = wba = a\beta\alpha = Aa'ba = Aya'b.$$

Here let

$$w\alpha_1 = axb\alpha_1 = Aa'xb\alpha_1 = Aya'xb.$$

Now since

$$Aya' \sim Aa' = a \sim ax = Aa'x \sim Aya'x,$$

we may let

$$w\alpha_1\beta_1 = Aya'xb\beta_1 = Aya'b = w'.$$

(ii) A is not contained in a . That is,

$$b = b_1b_2, \quad A = ab_1, \quad A \sim Ay,$$

and

$$w' = w\beta\alpha = aba = ab_1b_2\alpha = Ab_2\alpha = Ayb_2 = ab_1yb_2.$$

Since

$$axb_1 \sim ab_1 = A \sim Ay = ab_1y \sim axb_1y,$$

we may let

$$w\alpha_1 = axb\alpha_1 = axb_1b_2\alpha_1 = axb_1yb_2,$$

and

$$w\alpha_1\beta_1 = axb_1yb_2\beta_1 = ab_1yb_2 = w'.$$

LEMMA 2. *If $w, w' \in F$, $w\gamma_1\gamma_2 \cdots \gamma_m = w'$, where each γ_i is either an α or a β , then there are $\alpha_1, \dots, \alpha_n, \beta_1, \dots, \beta_k$ such that $w\alpha_1 \cdots \alpha_n\beta_1 \cdots \beta_k = w'$.*

This follows immediately from Lemma 1 by induction.

LEMMA 3. *The word aba contains a left initial segment which is equivalent to a .*

Proof. Let $ab = AB$, $aba = AyB$, where $A \sim Ay$. Again there are two cases:

(i) A is contained in a . That is, $a = Aa'$, $aba = Aa'ba = Aya'b$.

Since $A \sim Ay$, the left initial segment Aya' of aba is equivalent to a .

(ii) A is not contained in a . That is, $b = b_1b_2$, $A = ab_1$, $aba = ab_1b_2a = ab_1yb_2$.

Here, a itself is a left initial segment of aba , and is certainly equivalent to a .

LEMMA 4. *If $x, y \in F$ and $x^2 \sim y^2$, then either $y \sim xa$ for some $a \in F$, or $x \sim yb$ for some $b \in F$.*

Proof. By Lemma 2, there are α_i and β_j such that $xx\alpha_1 \cdots \alpha_m \beta_1 \cdots \beta_n = yy$. Let $w = xx\alpha_1 \cdots \alpha_m = yy\beta_n^{-1} \cdots \beta_1^{-1}$. By Lemma 3, w contains a left initial segment A equivalent to x . Similarly, since each β_i^{-1} is an α , w also contains a left initial segment B equivalent to y . Depending on which segment contains the other, either $B = Aa$ for some a , or $A = Bb$ for some b . In the first case, $y \sim B = Aa \sim xa$; in the second, $x \sim A = Bb \sim yb$.

LEMMA 5. *In this lemma, “=” will denote equality in S . Let e be an idempotent element of S : $e = e^2$. Let $S_e = \{x \in S \mid x^2 = e\}$. Then S_e is a locally finite subsemigroup of S .*

Proof. First, we note that $z \in S_e$ implies $ez = ze = e$. For $ez = z^2z = z^2 = e$, and similarly $ze = e$. Now let $x, y \in S_e$, that is, $x^2 = y^2 = e$. By Lemma 4, either $y = xa$ or $x = yb$. In the first case, we obtain $xy = x^2a = x^3a = x^2y = ey = e$. In the second case, we obtain similarly that $yx = e$. Thus $x, y \in S_e$ implies $xy = e$ or $yx = e$. In either case, $(xy)^2 = e$, that is, $xy \in S_e$. Thus S_e is a semigroup.

Now let $x_1, \dots, x_n \in S_e$, and let $\langle x_1, \dots, x_n \rangle$ denote the subsemigroup of S_e generated by x_1, \dots, x_n . If $n = 1$, then $\langle x_1 \rangle$ is clearly finite; so suppose $n > 1$. Then every element of $\langle x_1, \dots, x_n \rangle$ may be expressed as a product of not more than n of the x_i 's. For any product z of more than n x_i 's must contain some x_i twice: $z = ax_i b x_i c$, where $a, b, c \in S_e$. Since either $x_i b = e$ or $b x_i = e$, it follows that $x_i b x_i = e$ and $z = a e c = e c = e = x_1 x_1$. This shows that $\langle x_1, \dots, x_n \rangle$ is finite, and hence that S_e is locally finite.

The theorem follows immediately from Lemma 5, since clearly $e \neq e'$ implies that S_e and $S_{e'}$ are disjoint, and

$$S = \cup S_e .$$

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