

6. Further Applications

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The t -sequence t^n is interesting because the adjunction problem is already proved (without the torsion-free hypothesis) for words with this t -shape [L]. However the methods discussed here do not extend this result to t -sequences in normal form based on t^n . An example is $t^3 t^{-1} t^3 t^{-1}$.

Another interesting case is the sequence tt^{-1} which is not amenable. However a simple trick (substitute u^2 for t) makes it suitable. Hence theorem 5.1 implies a solution to the adjunction problem (over torsion-free groups) for words of the form $gtg't^{-1}$. For words of this shape, torsion-free is a necessary condition as the example in the introduction shows!

We do not yet have a simple test for amenability though it is easy from the definition to write down large classes of amenable sequences. However it can be seen that, speaking very roughly, a sequence is amenable unless it has a uniform slope, like $t^5 t^{-3} t^5 t^{-3}$ or $t^3 t^{-3} t^3 t^{-3}$ (slope zero).

6. FURTHER APPLICATIONS

We give here the other applications from [Kl] of the crash theorems, not covered above.

THEOREM 6.1 (Application to free products). *Let A, B be groups and suppose each (cyclic) factor of $u \in A * B - A$ has infinite order. Then the natural homomorphism $A \rightarrow \langle A * B \mid [A, u] = 1 \rangle$ is injective.*

Proof. Suppose not. Then the conditions of the first transversality lemma apply and there is a non trivial element $a \in A$ such that $a \in \langle\langle [A, u] \rangle\rangle$. So we have a cell subdivision K of the 2-sphere such that reading round from the base point $*$ for every 2-cell in K spells out the word

$$w(a) = (c_0^{-1} a c_0) c_1 \cdots c_{n-1} (c_n^{-1} a^{-1} c_n) c_{n-1}^{-1} \cdots c_1^{-1}$$

for some $a \in A$, see figure 8. Note that if this 2-cell has the opposite orientation then the word spelt out is $w(a^{-1})$.

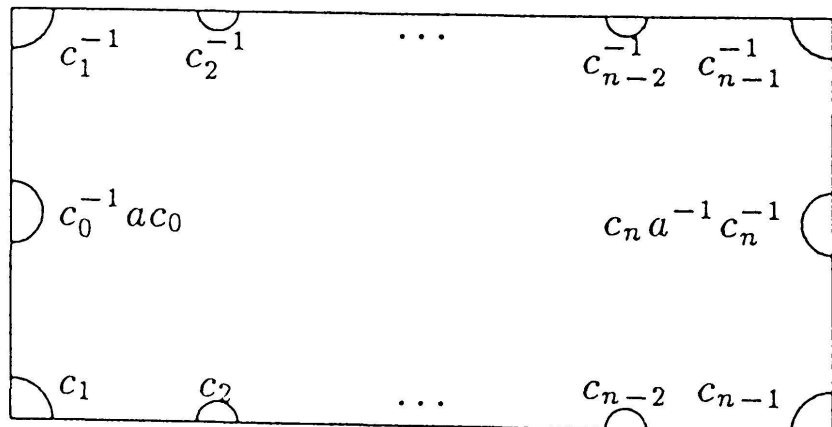


FIGURE 8
The 2-cell labelled by $w(a)$

Now consider the traffic flow defined as follows. The car associated to a 2-cell starts out from the base point $*$ and proceeds in an anticlockwise manner so that it takes a unit amount of time to reach the next corner. It is clear that any crash must take place at a 0-cell. By the crash theorem there are at least two total crashes so we can assume it takes place at a 0-cell where the angle labels multiply to 1. There are two cases to consider.

If the crash occurs at time $0 \pmod n$ then the clockwise labelling around this 0-cell is $c_\alpha^{-1}a_1c_\alpha, c_\alpha^{-1}a_2c_\alpha, \dots, c_\alpha^{-1}a_kc_\alpha$ where $a_1a_2 \cdots a_k = 1$ and $\alpha = 0$ or $\alpha = n$. A simple calculation shows that the anticlockwise product of the remaining angles of these k 2-cells is 1. So we may simplify the situation by collapsing these k 2-cells to a point.

If the crash occurs at a time $\neq 0 \pmod n$ then the clockwise labelling around this 0-cell is $c_i^k = 1$ for some $0 < i < n$ and some $k > 1$ contradicting the torsion free hypothesis. \square

Let H, H' be groups and let $\phi: H \rightarrow H'$ be an isomorphism. We shall use the notation h^ϕ to denote the image of $h \in H$ under ϕ . Similarly we shall write $a^b := b^{-1}ab$ for conjugation.

THEOREM 6.2 (Application to HNN extensions). *Let H and H' be two isomorphic subgroups of the group A under the isomorphism $h \rightarrow h^\phi, h \in H$. Let B be a group and let $w \in A * B - A$ have torsion free factors. Then the natural map*

$$A \rightarrow \langle A, B \mid w^{-1}hw = h^\phi, h \in H \rangle$$

is injective.

Proof. Consider the following groups

$$A' = \langle A, t \mid t^{-1}ht = h^\phi, h \in H \rangle,$$

$$A'' = \langle A, t, B \mid t^{-1}ht = h^\phi, [a, t^{-1}w] = 1, [t, w] = 1, h \in H, a \in A \rangle$$

$$= \langle A', B \mid [a, t^{-1}w] = 1, [t, w] = 1, a \in A \rangle,$$

$$A''' = \langle A, B \mid w^{-1}hw = h^\phi, h \in H \rangle.$$

We can construct the following commuting diagram,

$$\begin{array}{ccccc} & & & & A''' \\ & & & \delta & \\ & & & \nearrow & \downarrow \gamma \\ & & & & A'' \\ A & \xrightarrow{\alpha} & A' & \xrightarrow{\beta} & A'' \end{array}$$

where the maps α, β, γ and δ are induced by inclusion. In order for γ to be a well defined homomorphism it is necessary to check that the relation $w^{-1}hw = h^\phi, h \in H$ is a consequence of the relations $t^{-1}ht = h^\phi, [a, t^{-1}w] = 1, [t, w] = 1, h \in H, a \in A$. But this follows because $w^{-1}hw = w^{-1}tt^{-1}htt^{-1}w = w^{-1}th^\phi t^{-1}w = h^\phi$. Now α is injective because A' is an HNN extension of A (see [DD, p. 33] or [Se, p. 9]) and β is injective because of theorem 6.1. So δ is injective and this proves the theorem. \square

THEOREM 6.3. *Let*

$$(*) \quad u_i(t) = 1, i \in I$$

*be a set of equations over the group A where the exponent sum of t in each $u_i(t)$ is zero. Suppose $w = w(t) \in A * \langle t \rangle - A$ and the factors of w are all torsion free. Then the set of equations*

$$(**) \quad u_i(w(t)) = 1, i \in I$$

has a solution over A if and only if the set () has a solution over A .*

Proof. Let $w(t) = at$ where $a \in A$ has infinite order. Then a solution x for $u_i(w(t)) = 1$ defines a solution at for (*).

Conversely suppose $x \in A'$ is a solution of the set of equations $\{u_i(t) = 1 \mid i \in I\}$. Let G be the subgroup of A' generated by

$$\{x^{-n}ax^n \mid a \in A, n \in \mathbf{Z}\}.$$

Then A is a subgroup of G and G is a subgroup of

$$H = \langle G, t \mid w^{-1}gw = g^\phi, g \in G \rangle$$

where $g^\phi = x^{-1}gx$ by theorem 6.2. Because of the exponent sum condition $u_i(w) = 1, i \in I$. \square

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