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2. ACTION OF σ_{n+1} ON $\rho_k(\Sigma_k)$

In this section, we show how the n usual generators $(0, 1), \dots, (n-1, n)$ of the group σ_{n+1} act on the subset $\rho_k(\Sigma_k)$ of $(\mathbf{Z}/k\mathbf{Z})^{n-1}$.

LEMMA 2.1. *Let $(\alpha_1, \dots, \alpha_{n-1}) \in \rho_k(\Sigma_k)$. Then*

$$\begin{aligned} (0, 1) \cdot (\alpha_1, \alpha_2, \dots, \alpha_i, \dots, \alpha_{n-1}) &= ((1 - \alpha_1 - \alpha_2 - \dots - \alpha_{n-1}), \alpha_2, \dots, \alpha_i, \dots, \alpha_{n-1}) \\ (i, i+1) \cdot (\alpha_1, \dots, \alpha_i, \alpha_{i+1}, \dots, \alpha_{n-1}) &= (\alpha_1, \dots, \alpha_{i+1}, \alpha_i, \dots, \alpha_{n-1}), \quad 1 \leq i \leq n-2 \\ (n-1, n) \cdot (\alpha_1, \dots, \alpha_i, \dots, \alpha_{n-2}, \alpha_{n-1}) &= (-\alpha_1 \alpha_{n-1}^{-1}, \dots, -\alpha_i \alpha_{n-1}^{-1}, \dots, -\alpha_{n-2} \alpha_{n-1}^{-1}, \alpha_{n-1}^{-1}) \end{aligned}$$

In particular, if $(\alpha_1, \dots, \alpha_{n-1}) \in \rho_k(\Sigma_k)$, then α_{n-1} is invertible (mod k).

Proof. Let us show the first equality. Let $(\alpha_1, \dots, \alpha_{n-1}) \in \rho_k(\Sigma_k)$. Consider the numerated simplex S_v with vertices

$$(2.2) \quad v_0 = 0, v_i = e_i, 1 \leq i \leq n-1, v_n = ke_n + \sum_{i=1}^{n-1} a_i e_i$$

(a_i representant of the class α_i).

Let us identify \mathbf{R}^n with the points of the hyperplane H of \mathbf{R}^{n+1} defined by $x_{n+1} = 1$. By identifying the elements of \mathbf{R}^n with vector columns we see that

$$0 \mapsto \begin{pmatrix} 0 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ 1 \end{pmatrix}, \quad e_i \mapsto \begin{pmatrix} 0 \\ \cdot \\ 1 \\ \cdot \\ \cdot \\ 0 \\ 1 \end{pmatrix}$$

where 0 is the origin in \mathbf{R}^n and $\{e_1, \dots, e_n\}$ is the usual basis of \mathbf{R}^n and the 1 in the second matrix is where you think it should be, namely at the i -th row. There exists a natural injection of the group $\text{Aff}(\mathbf{Z}^n)$ in the subgroup of $GL_{n+1}(\mathbf{Z})$ which preserves H . It is easy to check that the following matrix $M \in GL_{n+1}(\mathbf{Z})$ exchanges v_0 and v_1 , preserves v_i for $2 \leq i < n$ and sends v_n to the element $ke_n + (1 - \sum_{i=1}^{n-1} a_i)e_1 + \sum_{i=2}^{n-1} a_i e_i$:

$$M = \begin{pmatrix} -1 & -1 & -1 & \dots & -1 & 0 & 1 \\ 0 & 1 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \dots & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \dots & 1 & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & 1 & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 1 \end{pmatrix}.$$

The calculations for the transposition $(i, i + 1)$ are immediate if $1 \leq i \leq n - 2$.

Finally, let us consider the last equality: We take again the simplex S_v with vertices as in (2.2). Since S_v is small-faced, there exists a simplex S'_μ , $(n - 1)$ integers b_1, \dots, b_{n-1} and an element $g \in \text{Aff}(\mathbf{Z}^n)$ such that the vertices of S'_μ are

$$v'_0 = 0, v'_i = e_i, 1 \leq i \leq n - 1, v'_n = ke_n + \sum_{i=1}^{n-1} b_i e_i$$

and such that $g(v_i) = v'_i$ for $0 \leq i \leq n - 2$, $g(v_{n-1}) = v'_n$ and $g(v_n) = v'_{n-1}$. Since $v_0 = v'_0 = 0$ we have $g(0) = 0$ and g is in fact in $GL_n(\mathbf{Z})$. The matrix of g with respect to the standard basis is

$$\begin{pmatrix} 1 & 0 & 0 & \dots & 0 & 0 & b_1 \\ 0 & 1 & 0 & \dots & 0 & 0 & b_2 \\ \cdot & \cdot & \cdot & \dots & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \dots & 1 & 0 & b_{n-2} \\ 0 & 0 & 0 & \dots & 0 & 1 & b_{n-1} \\ 0 & 0 & 0 & \dots & 0 & 0 & k \end{pmatrix} \begin{pmatrix} 1 & 0 & \dots & 0 & a_1 & 0 \\ 0 & 1 & \dots & 0 & a_2 & 0 \\ \cdot & \cdot & \dots & \cdot & \cdot & \cdot \\ 0 & 0 & \dots & 1 & a_{n-2} & 0 \\ 0 & 0 & \dots & 0 & a_{n-1} & 1 \\ 0 & 0 & \dots & 0 & k & 0 \end{pmatrix}^{-1}$$

this gives

$$\begin{pmatrix} 1 & 0 & 0 & \dots & 0 & 0 & b_1 \\ 0 & 1 & 0 & \dots & 0 & 0 & b_2 \\ \cdot & \cdot & \cdot & \dots & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \dots & 1 & 0 & b_{n-2} \\ 0 & 0 & 0 & \dots & 0 & 1 & b_{n-1} \\ 0 & 0 & 0 & \dots & 0 & 0 & k \end{pmatrix} \frac{1}{k} \begin{pmatrix} k & 0 & 0 & \dots & 0 & 0 & -a_1 \\ 0 & k & 0 & \dots & 0 & 0 & -a_2 \\ \cdot & \cdot & \cdot & \dots & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & \dots & k & 0 & -a_{n-2} \\ 0 & 0 & 0 & \dots & 0 & 0 & 1 \\ 0 & 0 & 0 & \dots & 0 & k & -a_{n-1} \end{pmatrix}.$$

But since $g \in GL_n(\mathbf{Z})$ this implies that

$$-a_i - b_i a_{n-1} \equiv 0 \pmod{k} \quad 1 \leq i \leq n - 2.$$

Let us now suppose that a_{n-1} is not invertible (mod k). Then there exists some prime p dividing both k and a_{n-1} . But then the prime p divides a_i too for every i . So p divides all coefficients of the vector $v_n - v_0$ which is an edge of S_v . But then S_v is not small-faced which contradicts the fact that $(\alpha_1, \dots, \alpha_{n-1}) \in \rho_k(\Sigma_k)$. So we have proved that a_{n-1} is invertible (mod k). And the b_i 's satisfy

$$b_i \equiv -a_i a_{n-1}^{-1} \pmod{k} \quad 1 \leq i \leq n - 2 \quad \text{and} \quad b_{n-1} \equiv a_{n-1}^{-1} \pmod{k}.$$

This proves the last equality. \square