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Artikel: ON THE GAUSS-BONNET FORMULA FOR LOCALLY SYMMETRIC SPACES OF NONCOMPACT TYPE

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standard geometric $q-1$ simplex ($q = \mathbb{Q}$-rank of $\mathbf{G}$). If $\Delta = \{\alpha_1, \dots, \alpha_q\}$ and $\Delta - \Theta = \{\alpha_{i_1}, \dots, \alpha_{i_s}\}$ with $1 \leq i_1 < \dots < i_s \leq q$, we define the boundary simplex $\triangle(\Theta)$ of $\triangle$ as $\triangle(\Theta) := [e_{i_1}, \dots, e_{i_s}]$. Let $\mathbf{P}$ be a *minimal* parabolic $\mathbb{Q}$-subgroup of $\mathbf{G}$ and let the set $\Gamma\backslash\mathbf{G}(\mathbb{Q})/\mathbf{P}(\mathbb{Q})$ be represented by $\{q_1, \dots q_m\}$ (see Proposition 2.1). We take m copies $\triangle^j = [e^j_1, \dots, e^j_q]$ of $\triangle$ with faces $\triangle^j(\Theta)$ corresponding to Θ. The corresponding homeomorphisms $\triangle \simeq \triangle^j$ are denoted by φ_j. The simplicial complex $\Gamma\backslash|\mathcal{T}|$, which provides a geometric realization of the quotient of the Tits building of $\mathbf{G}$ modulo Γ, is constructed from the simplices $\triangle^1, \dots, \triangle^m$ through the following *incidence relations*:

Two simplices $\triangle^j$ and $\triangle^l$ are pasted together along the faces $\triangle^j(\Theta)$ and $\triangle^l(\Theta)$ by the homeomorphism $\varphi_j \circ \varphi_l^{-1}|_{\triangle^l(\Theta)}$ if and only if

$$\Gamma q_j \mathbf{P}_\Theta(\mathbb{Q}) = \Gamma q_l \mathbf{P}_\Theta(\mathbb{Q}).$$

We remark that the points of $\Gamma\backslash|\mathcal{T}|$ are in one-to-one correspondence with equivalence classes of geodesic rays in the locally symmetric space $V = \Gamma\backslash X$ (see [Hat], [L1] and [JM]).

2.2. An exhaustion by polyhedra

We index the "edges" of the Weyl chamber $\overline{\mathfrak{a}^+}$ (or equivalently of $\overline{A^+}\cdot x_0$) by *simple* $\mathbb{Q}$-roots. More precisely, the edges of $\overline{A^+}\cdot x_0$ are given by geodesic rays $c_\alpha(t) = \exp(tH_\alpha)\cdot x_0$ where $H_\alpha \in \overline{\mathfrak{a}^+}$, $\|H_\alpha\| = 1$ and $\beta(H_\alpha) = 0$ for $\beta \neq \alpha$ $(\alpha, \beta \in \Delta)$. We further write $c_{k\alpha}$ for the edges $q_k a_0 c_\alpha$ of the chambers $q_k C$ in the fundamental set Ω (see Section 2.1 for the notation). If a geodesic ray c represents a point $z \in \partial_\infty X$ we write $z = c(\infty)$. The group G act naturally on $\partial_\infty X$ through $g\cdot c(\infty) = (g\cdot c)(\infty)$. For every $\alpha \in \Delta$ the isotropy group of $c_\alpha(\infty)$ under that action coincides with the (maximal) parabolic subgroups $P_{\Delta-\{\alpha\}}$ introduced above (see [L2] Lemma 1.2).

To a geodesic ray $c\colon [0,\infty) \longrightarrow X$ (parametrized by arc-length) which represents a point z in the ideal boundary $\partial_\infty X$ of X is associated a *Busemann function on* X *at* z given by

$$h_z\colon X \longrightarrow \mathbb{R} \quad ; \quad h_z(x) = \lim_{t\to\infty}\left[d\big(x, c(t)\big) - t\right].$$

The level sets of a Busemann function are *horospheres*, which foliate the symmetric space. We denote the Busemann functions which correspond to the rays $c_{k\alpha}$ by $h_{k\alpha}$. Note that $h_{k\alpha}\big(c_{k\alpha}(t)\big)$ tends to $-\infty$ if the arc-length t of the geodesic $c_{k\alpha}$ tends to $+\infty$.

In contrast to an exact fundamental domain there are not only points on the boundary of a fundamental set Ω but possibly also interior points which are identified under the action of Γ. However, there is only a finite set of isometries $\gamma \in \Gamma$ with $\gamma\Omega \cap \Omega \neq \varnothing$. Furthermore it suffices to look at the (finite) set $\mathcal{D}$ of those γ for which this intersection is not relatively compact in X (all other intersections are contained in some compact subset of Ω). It turns out that every $\gamma \in \mathcal{D}$ has the crucial property that there are indices i, j such that $q_j^{-1}\gamma q_i$ is parabolic i.e. fixes at least one point in the ideal boundary $\partial_\infty X$ (see [L2] Proposition 2.2). Then for every $\gamma \in \mathcal{D}$ there are indices i, j, α such the family of horospheres of the form $h_{i\alpha}^{-1}(s), s \in \mathbb{R}$, is mapped isometrically to the family $h_{j\alpha}^{-1}(s), s \in \mathbb{R}$ (see [L2] Lemma 3.2). These identifications correspond to the incidence relations described above in the construction of the simplicial complex $\Gamma\backslash|\mathcal{T}|$. (To see this one has to use the fact that the Siegel set at infinity $\partial_\infty(q_j\mathcal{S})$ is canonically isomorphic to $\triangle^j = [e_1^j, \dots, e_q^j]$.) The main technical step is then to renormalize the Busemann functions as $\tilde{h}_{i\alpha} = h_{i\alpha} - s_{ij}$ (for certain constants s_{ij}) in such a way that each $\gamma \in \mathcal{D}$ maps a horosphere of some given level, say $\{\tilde{h}_{i\alpha} = s\}$, to another one, $\{\tilde{h}_{j\alpha} = s\}$, of the *same* level s (see [L2] Lemma 3.4). This fact finally allows us to truncate the constituents $q_i\mathcal{S}$ of the fundamental set Ω by removing the open horoballs $\mathcal{B}_{i\alpha}(s) := \{\tilde{h}_{i\alpha} < -\tau_\alpha s\}$ (for certain constants τ_α and for $s > 0$ sufficiently large). The above construction guarantees that the truncated fundamental set $\Omega(s) := \bigcup_{i=1}^m q_i\mathcal{S}(s)$ of Ω is relatively compact in X and invariant under the (restricted) action of Γ. Moreover for s sufficiently large the Γ-invariant "core" $X(s) := \Gamma \cdot \Omega(s)$ can be written as the complement in X of a union of (countably many) open horoballs: $X(s) = X - \Gamma \cdot \bigcup_{i=1}^m \bigcup_{\alpha \in \Delta} \mathcal{B}_{i\alpha}(s)$ (see [L3] Theorem 3.6). These horoballs are disjoint if and only if Γ is an arithmetic subgroup of a $\mathbb{Q}$-rank 1 group. The projection $\pi : X \longrightarrow V$ maps $X(s)$ to a compact submanifold with corners $V(s)$ of V whose fundamental group is isomorphic to Γ. The "centers" of the projected horoballs in $\partial_\infty V$ are in bijection with the vertices of $\Gamma\backslash|\mathcal{T}|$. The exhaustion function h is eventually defined in such a way that its level sets coincide with the boundaries $\partial V(s)$. We summarize the result in the following proposition (see [L2] Theorem 4.2).

PROPOSITION 2.2. *Let X be a Riemannian symmetric space of noncompact type and $\mathbb{R}$-rank ≥ 2 and let Γ be an irreducible, torsion-free, non-uniform lattice in the group of isometries of X. On the locally symmetric space $V = \Gamma\backslash X$ there exists a piecewise real analytic exhaustion function $h : V \longrightarrow [0, \infty)$ such that, for each $s \geq 0$, the sublevel set $V(s) := \{h \leq s\}$ is a Riemannian polyhedron in V. Moreover the level sets $\{h = s\} = \partial V(s)$ consist of projections of pieces of horospheres in X.*

Each polyhedron $V(s)$ is homotopically equivalent to V. More precisely we have

PROPOSITION 2.3. *For every sufficiently large s the locally symmetric space V is homeomorphic to the interior of the polyhedron $V(s)$ in V, and $V(s)$ is a strong deformation retract of V.*

For the proof see [L3], Theorems 5.2 and 5.5.

3. ESTIMATES FOR THE BOUNDARY SUBPOLYHEDRA

We wish to apply Proposition 1.1 to the polyhedra $V(s)$ in the above exhaustion and then take the limit for $s \to \infty$. To that end we need estimates for the second fundamental forms and the volumes of the (lower dimensional) boundary polyhedra.

For each Siegel set $\mathcal{S}_i := q_i \mathcal{S}$ which is part of the fundamental set Ω we have its truncated part

$$\mathcal{S}_i(s) := \mathcal{S}_i - \bigcup_{\alpha \in \Delta} \left(\mathcal{B}_{i\alpha}(s) \cap \mathcal{S}_i\right) .$$

The top dimensional boundary faces of $\mathcal{S}_i(s)$ in $\mathcal{S}_i$ (resp. of $\Omega(s)$ in Ω) are subsets of horospheres:

$$\mathcal{H}_{i\alpha}(s) := \{\tau_\alpha^{-1} \tilde{h}_{i\alpha} = -s\} \cap \mathcal{S}_i(s) \ , \qquad \alpha \in \Delta \ .$$

The "horospherical" pieces $\mathcal{H}_{i\alpha}(s)$ together with their Γ-translates form the boundary of the manifold with corners $X(s)$ in X. For any nonempty subset Θ of Δ we set

$$\mathcal{H}_{i\Theta}(s) := \bigcap_{\alpha \in \Theta} \mathcal{H}_{i\alpha}(s) \subset \mathcal{S}_i(s) .$$

The various boundary subpolyhedra of $V(s)$ are then unions of projections of the pieces $\mathcal{H}_{i\Theta}(s)$ under the canonical projection $\pi : X \to V$. More precisely, as explained in Section 2, for any subset $\Theta \subset \Delta$, we have the equivalence relation on the set $I = \{1, \dots , m\}$

$$j \sim_\Theta l \quad \text{if and only if} \quad \Gamma q_j P_\Theta = \Gamma q_l P_\Theta$$

(the q_i are as in Proposition 2.1). This relation $\sim_\Theta$ induces a partition, $I(\Theta)$, of the set I whose components will be denoted by E. Let $n = \dim X = \dim V$, let k be the cardinality of Θ and let $E \in I(\Theta)$. Then $V_E^{n-k}(s) := \pi\left(\bigcup_{i \in E} \mathcal{H}_{i\Theta}(s)\right)$ is a $(n-k)$-dimensional boundary polyhedron of $V(s)$; and moreover, any boundary polyhedron arises in this way (see [L3] §4).