4. On K-homology

Objekttyp: **Chapter**

Zeitschrift: **L'Enseignement Mathématique**

Band (Jahr): **49 (2003)**

Heft 1-2: **L'ENSEIGNEMENT MATHÉMATIQUE**

PDF erstellt am: **25.05.2024**

For R a fixed set of representatives for G/H, the map

$$\begin{aligned} \varphi_R \colon \operatorname{Ind}_H^G(S_{\widetilde{D}}) &\to S_{\bar{D}} \\ f &\mapsto \{f(r)\}_{r \in R} \end{aligned}$$

is well-defined by H-equivariance of the elements of $S_{\widetilde{D}}$ and one checks that it defines a G-equivariant isometric bijection. Similarly for the adjoint operators.

The following example is a particular case of the previous lemma.

EXAMPLE 3.2. Let us look at the case $\widetilde{M} = M \times G$. A section $\widetilde{s} \in C_c^\infty(\widetilde{M}, \pi^*E)$ is an element $\widetilde{s} = \{s_g\}_{g \in G}$ where $s_g \in C^\infty(M, E)$ and $s_g = 0$ for all but finitely many g's. Note that $L^2(\widetilde{M}, \pi^*E)$ can be identified with $\ell^2(G) \otimes L^2(M, E)$. Now

$$\widetilde{D}\widetilde{s} = \{Ds_g\}_{g \in G} \in C_c^\infty(\widetilde{M}, \pi^*F)$$

and hence $S_{\widetilde{D}}$ may be identified with $\ell^2(G) \otimes S_D \cong \ell^2(G)^d$, where $d = \dim_{\mathbb{C}}(S_D)$. In this identification the projection P onto $S_{\widetilde{D}}$ becomes the identity in $M_d(\mathcal{N}(G))$ and thus

$$\dim_G(S_{\widetilde{D}}) = \sum_{i=1}^{d} \langle e, e \rangle = d = \dim_{\mathbb{C}}(S_D)\,.$$

A similar argument for D^* shows that in this case not only does the L^2-Index of $\widetilde{D}$ coincide with the Index of D, but also the individual terms of the difference correspond to each other. This is not the case in general, see Example 2.2.

4. ON K-HOMOLOGY

Many ideas of this section go back to the seminal article by Baum and Connes [3], which has been circulating for many years and has only recently been published.

An elliptic pseudo-differential operator D on the closed manifold M can also be used to define an element $[D] \in K_0(M)$, the K-homology of M, and according to Baum and Douglas [4], all elements of $K_0(M)$ are of the form $[D]$. The index defined in Section 2 extends to a well-defined homomorphism (cf. [4])

$$\mathrm{Index}\colon K_0(M) \to \mathbf{Z}\,,$$

such that $\mathrm{Index}([D]) = \mathrm{Index}(D)$. On the other hand, the projection $\mathrm{pr}\colon M \to \{pt\}$ induces, after identifying $K_0(\{pt\})$ with $\mathbf{Z}$, a homomorphism

$$(*) \qquad \mathrm{pr}_*\colon K_0(M) \to \mathbf{Z},$$

which, as explained in [4], satisfies

$$\mathrm{pr}_*([D]) = \mathrm{Index}([D])\,.$$

More generally (cf. [4]), for a not necessarily finite CW-complex X, every $x \in K_0(X)$ is of the form $f_*[D]$ for some $f\colon M \to X$, and $K_0(X)$ is obtained as a colimit over $K_0(M_\alpha)$, where the M_α form a directed system consisting of closed Riemannian manifolds (these homology groups $K_0(X)$ are naturally isomorphic to the ones defined using the Bott spectrum; sometimes, they are referred to as K-homology groups with *compact supports*). The index map from above extends to a homomorphism

$$\mathrm{Index}\colon K_0(X) \to \mathbf{Z}\,,$$

such that $\mathrm{Index}(x) = \mathrm{Index}([D])$ if $x = f_*[D]$, with $f\colon M \to X$.

We now consider the case of $X = BG$, the classifying space of the discrete group G, and obtain thus for any $f\colon M \to BG$ a commutative diagram

$$\begin{tikzcd} K_0(M) \arrow[r, "\mathrm{Index}"] \arrow[d, "f_*"'] & \mathbf{Z} \arrow[d, equal] \\ K_0(BG) \arrow[r, "\mathrm{Index}"] & \mathbf{Z}. \end{tikzcd}$$

Note that $(*)$ from above implies the following naturality property for the index homomorphism.

LEMMA 4.1. *For any homomorphism $\varphi\colon H \to G$ one has a commutative diagram*

$$\begin{tikzcd} K_0(BH) \arrow[r, "\mathrm{Index}"] \arrow[d, "(B\varphi)_*"'] & \mathbf{Z} \arrow[d, equal] \\ K_0(BG) \arrow[r, "\mathrm{Index}"] & \mathbf{Z}. \end{tikzcd} \qquad \square$$

We now turn to the L^2-index of Section 2. It extends to a homomorphism

$$\mathrm{Index}_G \colon K_0(BG) \to \mathbf{R}$$

as follows. Each $x \in K_0(BG)$ is of the form $f_*(y)$ for some $y = [D] \in K_0(M)$, $f \colon M \to BG$, M a closed smooth manifold and D an elliptic operator on M. Let $\widetilde{D}$ be the lifted operator to $\widetilde{M}$, the G-covering space induced by $f \colon M \to BG$. Then put

$$\mathrm{Index}_G(x) := \mathrm{Index}_G(\widetilde{D}) .$$

One checks that $\mathrm{Index}_G(x)$ is indeed well-defined, either by direct computation, or by identifying it with $\tau(x)$, where τ denotes the composite of the assembly map $K_0(BG) \to K_0(C_r^*G)$ with the natural trace $K_0(C_r^*G) \to \mathbf{R}$ (for this latter point of view, see Higson-Roe [10]; for a discussion of the assembly map see e.g. Kasparov [12], or Valette [14]). The following naturality property of this index map is a consequence of Lemma 3.1.

LEMMA 4.2. *For $H < G$ the following diagram commutes:*

$$\begin{array}{ccc} K_0(BH) & \xrightarrow{\mathrm{Index}_H} & \mathbf{R} \\ \downarrow & & \| \\ K_0(BG) & \xrightarrow{\mathrm{Index}_G} & \mathbf{R}. \end{array} \qquad \square$$

Atiyah's L^2-Index Theorem 2.1 for a given G can now be expressed as the statement (as already observed in [10])

$$\mathrm{Index}_G = \mathrm{Index} \colon K_0(BG) \to \mathbf{R} .$$

5. ALGEBRAIC PROOF OF ATIYAH'S L^2-INDEX THEOREM

Recall that a group A is said to be *acyclic* if $H_*(BA, \mathbf{Z}) = 0$ for $* > 0$. For G a countable group, there exists an embedding $G \to A_G$ into a countable acyclic group A_G. There are many constructions of such a group A_G available in the literature, see for instance Kan-Thurston [11, Proposition 3.5], Berrick-Varadarajan [5] or Berrick-Chatterji-Mislin [6]; these different constructions are to be compared in Berrick's forthcoming work [7]. It follows that the suspension ΣBA_G is contractible, and therefore the inclusion $\{e\} \to A_G$