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Cyclic Homology of Triangular Matrix Algebras

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where R and T are unital k-algebras, k any commutatitive ring with unity, M a unitary R-T bimodule, with multiplication in the triangular matrix algebra to the left being matrix multiplication. The computation is interesting because algebraic K-theory satisfies an analogous equation. The method of computation is to use relative homological algebra and define new cyclic homology groups for subalgebras containing unity: one reduces the problem to relative cyclic chains where the canonical idempotents in the triangular algebra are free to move across the tensors. This method also gives a greatly simplified presentation of Morita invariance of cyclic homology and a special case of the Kunneth formula. We end with a survey of other applications of relative cyclic homology - to group rings and the Bass conjecture, to cyclic homology of quiver algebras, to norm continuous cyclic cohomology of nest algebras, and to algebraic K-theory.

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1 Introduction

The purpose of this paper is to give an account of the methods and proof of a property of cyclic homology shared by algebraic K-theory [1,7,20,26]:

Theorem 1.1 $HC_n\begin{pmatrix} R & M \\ 0 & T \end{pmatrix} = HC_n(R) \oplus HC_n(T) \quad (n = 0, 1, 2, \ldots)$ [1]

R and T are unital k-algebras where k is an arbitrary unital commutative ring, M is a unitary R-T bimodule, and the left-hand side is given matrix addition and multiplication.

The method of proof, oddly enough, is to *generalize* cyclic homology of a k-algebra A, $HC_*(A)$, to noncommutative or non-central scalars in a subalgebra S of A, which contains the unity element 1_A. We get homology groups $HC_n(A, S)$ which we call relative cyclic homology groups because they are related by the

[1] announced in [14] and independently in [31].

Connes long exact sequence to the relative Hochschild homology groups of [13, Relative homological algebra]. Where $S = k1_A$ we recover ordinary cyclic homology $HC_n(A)$. For any unital subalgebra there is a natural homomorphism $\phi : HC_n(A) \to HC_n(A, S)$. If S is a separable k-algebra, then ϕ is an isomorphism. Then choosing the right scalars, we give direct proofs at the level of cyclic module for theorem **1.1** and Morita invariance of cyclic homology, which we revisit in section 6.

Cyclic homology of algebras is a noncommutative generalization of de Rham cohomology of manifolds [5,23] that is related to K-theory via a generalized Chern character [18]. Many similiarities of cyclic theory with algebraic K-theory were known by 1983: e.g., Morita invariance of both theories, the Loday-Quillen-Tsygan theorem which provides an additive version of the Milnor-Moore-Quillen theorem in rational algebraic K-theory [23], and relations with algebraic K-theory of spaces [21, Cyclic homology,a survey] and rational algebraic K-theory relativized by a nilpotent ideal [11, Goodwillie's theorem]. It became urgent and interesting to re-compute, and in many cases extend, the well-known computations of K-theory for the new cyclic homology functor. Thus, cyclic homology of many rings of functions, filtered algebras, group algebras, and self-adjoint operator algebras were computed: the last two computations led, respectively, to much progress on the Bass conjecture in group theory [8], and the settling via H-unitality of the Karoubi conjecture stating the equality of topological and algebraic K-theories of stable C^*-algebras [30]. The methods of computation that evolved from the most basic one of the Connes long exact sequence and projective resolution of homological algebra include: mixed complexes and strongly homotopy linear maps [19], homotopy-theoretic computations with fibrations associated to a cyclic set [3], an assortment of spectral sequences [2,5,31,27], and H-unitality of C^*-algebras [31].

In particular, theorem 1.1 and its analogue in algebraic K-theory together indicate some extension of Goodwillie's theorem to rings not containing the rationals [22, for a conjecture in birelative K-theory]. This paper is organized as follows. Two preliminary sections cover the theory of cyclic modules in the relative case, and then separable k-algebras from the homological viewpoint of [12, Hochschild]. In section 4 we prove our main theorem, which is already known and applied in Hochschild cohomology with general coefficients [9], though we give a new simplicial proof for the cyclic theory. In section 5 we prove theorem **1.1** . In section 6 we give a new, simplified proof of Morita invariance of cyclic homology [29] and a special case of the Künneth theorem [19]. [2] We conclude with section 7 in which is discussed a key role played by relative cyclic homology in getting further results on the Bass conjecture [28, J. Schafer], continuous cyclic cohomology of non-self adjoint operator algebras, and other computations that use a relative homological approach.

[2] we thank Loday for pointing out this approach

2 The Cyclic Module Z(A,S)

Fix the notation $k1_A \subseteq S \subseteq A$ of section 1. Let A^e denote $A \otimes_k A^{op}$, the device that turns bimodules into one-sided modules.

Define a cyclic k-module Z(A,S), i.e., a simplicial object in **k-Mod** with actions from all finite cyclic groups, [6,10] by

$$Z_n(A,S) = \underbrace{A \otimes_S \cdots \otimes_S A}_{n+1} \otimes_{S^e} S.$$

Note that $Z_0(A,S) = A/[A,S]$, and elements of $Z_n(A,S)$ can be written as linear combinations of $a_0 \otimes_S \cdots \otimes a_n$ with the extra condition

$$sa_0 \otimes_S \cdots \otimes a_n = a_0 \otimes_S \cdots \otimes a_n s \quad \forall s \in S$$

The n+1 face maps $d_i : Z_n(A,S) \longrightarrow Z_{n-1}(A,S)$ are defined by

$$d_i(a_0 \otimes_S \cdots \otimes a_n) = a_0 \otimes_S \cdots \otimes a_i a_{i+1} \otimes \cdots \otimes a_n \quad (i = 0, 1, ..., n-1)$$

$$d_n(a_0 \otimes_S \cdots \otimes a_n) = a_n a_0 \otimes \cdots \otimes a_{n-1}.$$

The action of the cyclic group Z/n+1 on $Z_{n+1}(A,S)$ is given by

$$t_{n+1}(a_0 \otimes_S \cdots \otimes a_n) = a_n \otimes_S a_0 \otimes \cdots \otimes a_{n-1}.$$

The face and cyclic action maps are well-defined with respect to non-central scalars in S thanks to the extra circularity relation.

Degeneracy maps can also be defined:

$$s_i(a_0 \otimes_S \cdots \otimes a_n) = a_0 \otimes_S \cdots \otimes a_i \otimes 1 \otimes a_{i+1} \otimes \cdots \otimes a_n \quad (i = 0, 1, ...n).$$

Cyclic modules satisfy the usual simplicial relations [24] together with three additional relations involving t_{n+1} [10], the most obvious being $t_{n+1}^{n+1} = 1$.

Lemma 2.1 *Z(A,S) is a cyclic module.*

Proof. If S is the unit subalgebra $k1_A$ then Z(A,S) is the usual cyclic module ZA associated to an algebra [10]. There is a canonical surjection $\phi : ZA \longrightarrow Z(A,S)$ given by

$$a_0 \otimes_k \cdots \otimes a_n \longmapsto a_0 \otimes_S \cdots \otimes a_n,$$

which commutes with face, degeneracy, and cyclic action maps. Then Z(A,S) satisfies all the relations of ZA; in particular, it is a cyclic module.□

For the convenience of the reader we review the theory of cyclic modules [10] in order to show how relative cyclic and Hochschild homologies are defined and related by the Connes long exact sequence.

The first step is to form the Tsygan first quadrant bicomplex $C_{**}(A,S)$:

$$
\begin{array}{ccccccc}
\downarrow b & & \downarrow -b' & & \downarrow b & & \\
Z_{n+1}(A,S) & \xleftarrow{1-T} & Z_{n+1}(A,S) & \xleftarrow{N} & Z_{n+1}(A,S) & \xleftarrow{1-T} & \\
\downarrow b & & \downarrow -b' & & \downarrow b & & \\
Z_n(A,S) & \xleftarrow{1-T} & Z_n(A,S) & \xleftarrow{N} & Z_n(A,S) & \xleftarrow{1-T} & \\
\downarrow b & & \downarrow -b' & & \downarrow b & &
\end{array}
$$

where $b, b' : Z_n(A,S) \to Z_{n-1}(A,S)$ $(n \geq 1)$ are defined by

$$b = \sum_{i=0}^{n} (-1)^i d_i \qquad b' = \sum_{i=0}^{n-1} (-1)^i d_i = b - (-1)^n d_n$$

and $N, T : Z_n(A,S) \to Z_n(A,S)$ are defined by

$$T = (-1)^n t_{n+1} \qquad N = 1 + T + \cdots + T^n$$

The rows and columns are indeed chain complexes, and the squares commute [23]. The even columns are identically $(Z_n(A,S), b)$, which we call the relative Hochschild complex with groups $HH_n(A,S)$ $(= Tor_n^{(A^e, S\otimes A^{op})}(A,A)$, a functor of relative homological algebra [13]). The odd rows are identically $(Z_n(A,S), -b')$, an acyclic complex since $b's + sb' = 1$ where $s = (-1)^n s_n$.

Definition 2.1 Relative cyclic homology is defined as

$$HC_n(A,S) = H_n(Tot \quad C_{**}(A,S), d' + d''),$$

i.e., as the homology of the total complex with $d' + d''$ the sum of vertical and horizontal differentials.

Lemma 2.2 *If k is a field of characteristic zero, then*

$$HC_*(A,S) = H_*(Z_n(A,S)/im(1-T), b).$$

Proof. One checks that the rows of $C_{**}(A,S)$ are exact under the hypothesis on k. □

The Connes long exact sequence. It is easy to check that the cokernel sequence for the inclusion I of the first two columns of $C_{**}(A,S)$ yields a homology long exact sequence

$$\cdots \longrightarrow HC_{n-1}(A,S) \xrightarrow{B} HH_n(A,S) \xrightarrow{I} HC_n(A,S) \xrightarrow{\mathbf{S}} HC_{n-2}(A,S) \longrightarrow \cdots$$

where **S** is the homology map induced by projection (the coker of I) and B is the connecting homomorphism induced by (1-T)sN.

Remark 2.1 Fix the notation in lemma 2.1 for the surjection $\phi : ZA \longrightarrow Z(A,S)$. Certainly a morphism of cyclic modules induces a morphism of Tsygan bicomplexes, their total complexes, their Hochschild and cyclic homologies and the Connes long exact sequences. We emphasize here that ϕ very much depends on the presence of 1_A in S. We study the map ϕ because its image has the advantage of its reduced size due to more tensorial relations.

The next lemma is valid for the other variants of cyclic homology, HC^-* and HP_*. These variants come from an obvious extension to the second quadrant of the Tsygan bicomplex.

Lemma 2.3 *If $\psi : Z \longrightarrow W$ is a morphism of cyclic modules, then the induced map in Hochschild homology is an isomorphism iff the induced map in cyclic homology is an isomorphism.*

Proof. ($\Rightarrow$) The induced morphism on Connes long exact sequences is an isomorphism on every third arrow. But $HC_0 = HH_0$. [3] Then apply induction and the five lemma. ($\Leftarrow$) Apply only the five lemma. □

3 Separable k-Algebras

We recall here some facts and examples in this classical subject. Again, k is *any* commutative ground ring with unity. In this section we briefly use S in a different context from its role as subalgebra.

Definition 3.1 S is a separable k-algebra (or k-separable) iff there exists an element $e = \sum_{i=1}^{N} u_i \otimes v_i \in S^e$, called a separability idempotent, such that $\sum_{i=1}^{N} u_i v_i = 1$ and $se = es \; \forall s \in S$.

Example 3.2 $S = M_n(k)$, the full matrix algebra over k, is k-separable with $e = \sum_{i=1}^{n} E_{i1} \otimes_k E_{1i}$ where the E_{ij} are the matrix units.

Example 3.3 $S = C[G]$ where $o(G) < \infty$ is C-separable with

$$e = \frac{1}{o(G)} \sum_{g \in G} g \otimes_k g^{-1} \quad .$$

Example 3.4 $S = H$, the real quaternions, is a separable R-algebra with $e = \frac{1}{4}(1 \otimes 1 - i \otimes i - j \otimes j - k \otimes k)$.

Example 3.5 Any separable finite extension of a field k is a separable k-algebra, as is any finite dimensional semi-simple algebra over a perfect field k.

Proposition 3.1 (Hochschild [12]) *S is a separable k-algebra iff Hochschild (co)homology with any coefficient bimodule vanishes in positive degrees. Every extension of a separable k-algebra by a bimodule is trivial, and Wedderburn's principal theorem follows from this.*

[3] $HC_0(A,S) = A/[A,A]$ = the cotrace group

Separable extensions of algebras. Consistent with the idea that separable k-algebras S satisfy a homology vanishing condition, one defines a separable extension of k-algebras $1_A \in S \subseteq A$ as precisely those satisfying $H_n(A, S; M) = 0$ $\forall M_{A^e}$ and $n > 0$. These relative homology groups with coefficients are obtained as the homology of the relative Hochschild complex with M replacing the first tensor factor A in the first column of $C_{**}(A, S)$. Three non-trivial examples are $(A \otimes_k S, A)$ where S is a separable k-algebra, $(k[G], k[H])$ where k is a field of characteristic p, H a sylow p-subgroup of a finite group G,and (M, N) where N is a type II_1 subfactor of M of finite Jones index[17]. This approach yields straightforward generalizations of the theorems below [16].

4 Main Theorem

Theorem 4.1 *The canonical map $\phi : HC_*(A) \to HC_*(A, S)$ is an isomorphism if S is k-separable.*

Proof . The method of proof will be to find a section ψ for the epimorphism of simplicial modules underlying ϕ such that $\psi \circ \phi$ is chain homotopic to the identity in the Hochschild complex. Then $\phi : HH_*(A) \to HH_*(A, S)$ is an isomorphism, and we finish the proof by invoking Lemma 2.3.

Let $e = \sum_{i=1}^n u_i \otimes_k v_i$ be a separability idempotent in S^e. Define the simplicial map $\psi : Z(A, S) \to ZA$ by

$$\psi(a_0 \otimes_S \cdots \otimes a_n) = \sum_{i_0, \ldots, i_n = 1}^{n} v_{i_n} a_0 u_{i_0} \otimes_k v_{i_0} a_1 u_{i_1} \otimes \cdots \otimes v_{i_{n-1}} a_n u_{i_n}.$$

ψ can be shown to be well-defined since $se = es$ $\forall s \in S$. Clearly ψ commutes with all face maps and $\phi \circ \psi = 1$ since $\sum u_i v_i = 1$.

A simplicial homotopy [24] between $\psi \circ \phi$ and 1 is given by n+1 maps

$$h_i : Z_n A \to Z_{n+1} A$$

$$h_i(a_0 \otimes_k \cdots \otimes a_n) = \sum_{j_0, \ldots, j_i = 1}^{n} a_0 u_{j_0} \otimes_k v_{j_0} a_1 u_{j_1} \otimes \cdots \otimes v_{j_{i-1}} a_i u_{j_i} \otimes v_{j_i} \otimes a_{i+1} \otimes \cdots \otimes a_n$$

Then $h'_n = \sum_{i=0}^n (-1)^n h_i$ satisfies $bh'_n + h'_{n-1} b = 1 - \psi \circ \phi$. □

An analogue of theorem **4.1** is valid for Hochschild cohomology with any coefficients (see [9] where this technique is used to prove that Hochschild cohomology $H^n(A, A)$ is simplicial cohomology of a finite simplicial complex if A is an associated poset algebra).

5 Triangular Algebras

Let R and T be unital k-algebras, and let M be a unitary R-T bimodule. Then

$$A = \begin{pmatrix} R & M \\ 0 & T \end{pmatrix}$$

is a k-algebra with 2 x 2 matrix multiplication and k-module structure. Many nonsingular rings are iterations of this basic construction [1] and their cyclic homology is computed from the following

Theorem 5.1 (= 1.1) $HC_n \begin{pmatrix} R & M \\ 0 & T \end{pmatrix} = HC_n(R) \oplus HC_n(T) \quad (n = 0, 1, 2, \ldots)$

Proof. Note the following idempotents:

$$e_1 = \begin{pmatrix} 1_R & 0 \\ 0 & 0 \end{pmatrix}, \qquad e_2 = \begin{pmatrix} 0 & 0 \\ 0 & 1_T \end{pmatrix}$$

Consider the subalgebra $S = ke_1 + ke_2$. S is k-separable since $e_1 \otimes_k e_1 + e_2 \otimes_k e_2$ is a separability idempotent in S^e.

We next show that $Z(A, S) \cong ZR \oplus ZT$ as cyclic modules (clearly an abelian category), whence $HC_*(A) \cong HC_*(R) \oplus HC_*(T)$ by theorem **4.1**. It follows readily from our proof that the split surjection $\begin{pmatrix} r & m \\ 0 & t \end{pmatrix} \mapsto \begin{pmatrix} r & 0 \\ 0 & t \end{pmatrix}$ induces an isomorphism in cyclic homology.

Let $a_i = \begin{pmatrix} r_i & m_i \\ 0 & t_i \end{pmatrix}, a_i' = \begin{pmatrix} r_i & 0 \\ 0 & t_i \end{pmatrix}, m_i' = \begin{pmatrix} 0 & m_i \\ 0 & 0 \end{pmatrix}, r_i' = \begin{pmatrix} r_i & 0 \\ 0 & 0 \end{pmatrix}$, and $t_i' = \begin{pmatrix} 0 & 0 \\ 0 & t_i \end{pmatrix}$ for i = 0,1,...,n. Define a morphism of cyclic modules $G : Z(A, S) \to ZR \oplus ZT$ by

$$G(a_0 \otimes_S \cdots \otimes a_n) = (r_0 \otimes_k \cdots \otimes r_n, t_0 \otimes_k \cdots \otimes t_n).$$

Now define a right inverse to G, $F : ZR \oplus ZT \to Z(A, S)$ by

$$F(r_0 \otimes_k \cdots \otimes r_n, t_0 \otimes_k \cdots \otimes t_n) = a_0' \otimes \cdots \otimes a_n'.$$

F is in fact also a left inverse of G by the following computation with S-relative chains:

If $a_i = m_i'$ for some $i = 0, 1, \ldots, n$ then $a_0 \otimes_S \cdots \otimes a_i \otimes \cdots \otimes a_n =$

$$a_0 \otimes \cdots \otimes e_1 m_i' e_2 \otimes \cdots \otimes a_n = a_0 \otimes \cdots \otimes e_1 m_i' \otimes e_2 a_{i+1} \otimes \cdots \otimes a_n =$$

$$a_0 \otimes \cdots \otimes e_1 m_i' \otimes t_{i+1}' e_2 \otimes \cdots \otimes a_n = \cdots =$$

$$e_2 a_0 \otimes \cdots \otimes e_1 m_i' \otimes t_{i+1}' \otimes \cdots \otimes t_n' = \cdots = t_0' \otimes \cdots \otimes e_2 e_1 m_i' \otimes t_{i+1}' \otimes \cdots \otimes t_n' = 0.$$

In general, $a_0 \otimes_S \cdots \otimes a_n = (a_0' + m_0') \otimes_S \cdots \otimes (a_n' + m_n') = a_0' \otimes_S \cdots \otimes a_n'$. □

Remark 5.1 Let I = $\begin{pmatrix} 0 & M \\ 0 & 0 \end{pmatrix}$ denote the evident nilpotent ideal in A. Since the projection $A \to A/I$ induces isomorphism in both algebraic K-theory [20] and cyclic theory it follows that in the relative algebraic K-theory and cyclic theory of [11, Goodwillie] we have $K_n(A,I) = HC_{n-1}(A,I) = 0$ for $(n = 1,2,\ldots)$. This would provide evidence together with [22, Loday] for a weakening of the hypothesis in Goodwillie's theorem [11] that the ground ring contain the rationals. Of course, one can turn this around and give an easy proof from the known result in algebraic K-theory that $A \to A/I$ gives an isomorphism in cyclic homology if A contains a copy of the rationals in its center.

6 Morita Invariance Revisited

Theorem 6.1 *If S is a separable k-algebra and A is any unital k-algebra, then* $HC_*(A \otimes_k S) = HC_*(A) \otimes S/[S,S]$.

Proof . $1_A \otimes S$ is k-separable since it is a homomorphic image of S. It will suffice to show by **4.1** that $Z(A \otimes S, 1 \otimes S) \cong ZA \otimes S/[S,S]$ as cyclic modules (where the right side is tensor product of all modules and maps by constant module and identity).

Define $F : Z(A \otimes_k S, 1 \otimes S) \to ZA \otimes_k S/[S,S]$ by

$$F(a_0 \otimes_k s_0 \otimes_S \cdots \otimes a_n \otimes s_n) = a_0 \otimes_k \cdots \otimes a_n \otimes_k (s_0 \cdots s_n + [S,S]) \quad n = 0,1,2,\ldots)$$

a well-defined cyclic module morphism because we map into S modulo commutators.

Its inverse is given by

$$a_0 \otimes_k \cdots \otimes a_n \otimes_k (s + [S,S]) \mapsto a_0 \otimes_k s \otimes_S a_1 \otimes 1 \otimes \cdots \otimes a_n \otimes 1.$$

Corollary 6.1 *For any* $n \geq 1$, $HC_*(M_n(A)) = HC_*(A)$.

Proof . $S = M_n(k)$ is k-separable as noted in example **3.2** . □

Remark 6.1 Note that $F \circ \phi$ is the Dennis trace map. More generally, the Dennis trace map descends to an isomorphism of cyclic modules $Z(M_n(A), M_n(S)) \xrightarrow{\cong} Z(A,S)$ for any subalgebra S [16].

7 Discussion

With just slightly more effort the computations in sections 4-6 could be carried out only with relative Hochschild homology. However, J. Schafer has made a strong case in [28] for relative cyclic homology as a legitimate abstract entity. We recapitulate the main argument in this light.

Remark 7.1 Let R be any unital ring and P a finitely generated (f.g.) projective R-module. The Hattori-Stallings rank r_P of P is an element of the cotrace group $R/[R, R] = HC_0(R)$; e.g., if $P = eR^n$ for some idempotent n x n matrix e, then $r_P = trace(e) = \sum_{i=1}^{n} e_{ii} + [R, R]$.

Now fix $R = Q[G]$, any rational group algebra, and $S = Q[H]$, where H is any normal subgroup of G. It is easy to check that $HC_0(R)$ is a rational vector space with the conjugacy classes of G as basis. The Hattori-Stallings rank then has components in each conjugacy class denoted by $r_P(x)$ for a representative x.

Conjecture 7.1 (Bass, over Q) *For arbitrary G and P as above, $r_P(x) = 0$ if x has infinite order in G. (A group G satisfying this hypothesis on $r_P(x)$ we will say satisfies the Bass conjecture.)*

Remark 7.2 Burghelea computes in [3] $HC_*(R) = \bigoplus_{[x]} HC_*^{[x]}(G)$, a direct sum over all conjugacy classes where the summands are the group homology of certain subquotients of G. The Connes long exact sequence undergoes a similar direct sum decomposition. Schafer computes relative cyclic homology to have the similar form $HC_*(R, S) = \bigoplus_{[x]} HC_*^{[x]}(G/H)$, also indexed by the conjugacy classes of G, but now the summands are group homology of analogous subquotients of G/H. The map ϕ behaves naturally with respect to these decompositions (see diagram below).

Theorem 7.1 (Eckmann [8]) *G satisfies the Bass conjecture if G is both a group of finite rational homology dimension and is either (i) a nilpotent group, (ii) a torsion-free solvable group, (iii) or a group of rational cohomological dimension ≤ 2.* [4]

Remark 7.3 There are three conceptual steps to the proof. First, $[P] \mapsto r_P \in HC_0(R)$ defines a homomorphism $K_0(R) \mapsto HC_0(R)$, in fact the Chern character Ch_0 of Connes [5]. Second, Karoubi shows the existence of lifts to higher cyclic homology $HC_{2n}(R)$ via the "higher Chern characters" $\mathrm{Ch}_0^n : K_0(R) \to HC_{2n}(R)$ and the periodicity operator S (see the diagram below). Third, given G satisfying the hypothesis in theorem 7.1 one shows using group homology theory that $HC_{2n}^{[x]}(R) = 0$ for n large enough if x has infinite order in G. Then the left part of the commutative diagram below gives $r_P(x) = 0$. This argument, the computation for relative cyclic homology for group algebras, and the commutative diagram below lead to

Theorem 7.2 (Schafer [28]) *Let $x \in G$ with H a normal subgroup such that G/H satisfies the hypotheses of theorem 7.1. If Hx has infinite order in G/H, then $r_P(x) = 0$ for arbitrary f.g. projective G-module P. In particular, G satisfies the Bass conjecture if there exists a finite normal subgroup H for which G/H satisfies the hypothesis of theorem 7.1.*

[4] Eckmann reproves a result by Bass for a fourth class of groups

$$\begin{array}{ccccc} & & HC_{2n}(R) & \xrightarrow{\phi} & HC_{2n}(R,S) \\ & \overset{Ch_0^n}{\nearrow} & \downarrow S^n & & \downarrow S^n \\ K_0(R) & \xrightarrow{Ch_0} & HC_0(R) & \xrightarrow{\cong} & HC_0(R,S) \end{array}$$

Remark 7.4 The calculation in section 5 is basic to any calculation for triangular algebras. But consider a fiber product of an upper and lower triangular algebra over the diagonal, $A = \begin{pmatrix} R & M \\ N & T \end{pmatrix}$ where R and T are unital k-algebras, M is an R-T bimodule, N a T-R bimodule, and $N \cdot M = 0 = M \cdot N$. The idempotent trick in section 5 is rendered useless in this situation. A step in the right direction is taken in [4] which computes cyclic homology of 2-nilpotent algebra A over a field. It is shown that if $A = S \oplus J$ where S is k-separable and J is an ideal, then $HC_n(A) = HC_n(S) \oplus HC_n^S(J)$, where the last summand is cyclic homology of the cyclic δ-module Z(J,S) (no degeneracy maps). If $J^2 = 0$, $HC_n^S(J)$ decomposes into a direct sum of group homologies. It turns out that $HC_n(A)$ depends on the number of proper oriented cycles of length dividing n+1 in the quiver graph representing A. For example, if $A = \begin{pmatrix} k & k \\ k & k \end{pmatrix}$ as a special case of the fiber product above, the underlying quiver is $\cdot \rightleftarrows \cdot$ and if k has characteristic 0 then

$$HC_n(A) = \begin{cases} k \oplus k & n \ even \\ k & n \ odd \end{cases}$$

Remark 7.5 The non-self adjoint operator algebras that provide an infinite dimensional generalization of the complex algebra of block-upper triangular matrices is the nest algebra N_F of bounded linear operators on a separable Hilbert space H that leave invariant a totally ordered set F of orthogonal projections including 0 and 1. The core C of N_F is the commutative C^*-algebra generated by the projections. C is *amenable* , and acts with respect to norm continuous Hochschild cohomology as the separable algebra $S = ke_1 + ke_2$ in section 5. If F is discrete, then a characterization of the Jacobson radical J of N_F by Ringrose gives a continuous version of $\begin{pmatrix} 0 & M \\ 0 & 0 \end{pmatrix} = \{a \in A : e_1ae_1 + e_2ae_2 = 0\}$ in section 5. A computation like 5.1 gives the following calculation in continuous cyclic cohomology

Theorem 7.3 ([15]) $H_\lambda^n(N_F) \cong H_\lambda^n(N_F/J)$

Remark 7.6 It seems quite probable that a result can be obtained like that for K_0 in terms only of the diagonal algebra [25]. In passing we note the easy theorem below, which gives hope to compute H_λ^n of any nest algebra from only its atomic part, as for K_0 in [25].

Theorem 7.4 *If F is a continuous nest, then* $H_\lambda^n(N_F) = 0 \quad (n \geq 0)$.

Proof . It is well-known that with this hypothesis on F, N_F is isomorphic to $N_F \otimes B(H)$ [25]. Now a theorem of Wodzicki [31, p. 49] states that $H^n_\lambda(A \otimes B(H)) = 0$ for any H-unital complex algebra A, which easily adapts to the continuous case. □

Remark 7.7 A K-theoretic version of relative cyclic homology $HC_n(A, S)$ exists [16]. The simplicial space underlying BGLA may be quotiented out by relations of the form

$$[\cdots \mid g_i h \mid g_{i+1} \mid \cdots] = [\cdots \mid g_i \mid h g_{i+1} \mid \cdots]$$

where the $g_i \in GLA$ and $h \in GLS$, to obtain a space spectra K(A,S) with $\pi_1 = GLA/normalclosure(GLS)$. Define relative K-groups $K_n(A, S) = \pi_n(K(A, S))$ $(n \geq 1)$. There exist Chern character homomorphisms c_n that make the square below commute (where ν is the natural map)

$$\begin{array}{ccc} K_n(A) & \xrightarrow{\nu} & K_n(A,S) \\ \downarrow Ch^0_n & & \downarrow c_n \\ HC_n(A) & \xrightarrow{\phi} & HC_n(A,S) \end{array}$$

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"A SIMPLE MODEL AF AC HOPPING CONDUCTIVITY".
Af: Jeppe C. Dyre.
Contributions to the Third International Conference on the Structure of Non - Crystalline Materials held in Grenoble July 1985.

106/85 "QUANTUM THEORY OF EXTENDED PARTICLES".
Af: Bent Sørensen.

107/85 "EN MYG GØR INGEN EPIDEMI".
- flodblindhed som eksempel på matematisk modellering af et epidemiologisk problem.
Projektrapport af: Per Hedegård Andersen, Lars Boye, CarstenHolst Jensen, Else Marie Pedersen og Erling Møller Pedersen.
Vejleder: Jesper Larsen.

108/85 "APPLICATIONS AND MODELLING IN THE MATEMATICS CURRICULUM" - state and trends -
Af: Mogens Niss.

109/85 "COX I STUDIETIDEN" - Cox's regressionsmodel anvendt på studenteroplysninger fra RUC.
Projektrapport af: Mikael Wennerberg Johansen, Poul Katler og Torben J. Andreasen.
Vejleder: Jørgen Larsen.

110/85 "PLANNING FOR SECURITY".
Af: Bent Sørensen

111/85 JORDEN RUNDT PÅ FLADE KORT".
Projektrapport af: Birgit Andresen, Beatriz Quinones og Jimmy Staal.
Vejleder: Mogens Niss.

112/85 "VIDENSKABELIGGØRELSE AF DANSK TEKNOLOGISK INNOVATION FREM TIL 1950 - BELYST VED EKSEMPLER".
Projektrapport af: Erik Odgaard Gade, Hans Hedal, Frank C. Ludvigsen, Annette Post Nielsen og Finn Physant.
Vejleder: Claus Bryld og Bent C. Jørgensen.

113/85 "DESUSPENSION OF SPLITTING ELLIPTIC SYMBOLS 11".
Af: Bernhelm Booss og Krzysztof Wojciechowski.

114/85 "ANVENDELSE AF GRAFISKE METODER TIL ANALYSE AF KONTIGENSTABELLER".
Projektrapport af: Lone Biilmann, Ole R. Jensen og Arne-Lise von Moos.
Vejleder: Jørgen Larsen.

115/85 "MATEMATIKKENS UDVIKLING OP TIL RENESSANCEN".
Af: Mogens Niss.

116/85 "A PHENOMENOLOGICAL MODEL FOR THE MEYER-NELDEL RULE".
Af: Jeppe C. Dyre.

117/85 "KRAFT & FJERNVARMEOPTIMERING"
Af: Jacob Mørch Pedersen.
Vejleder: Bent Sørensen

118/85 "TILFÆLDIGHEDEN OG NØDVENDIGHEDEN IFØLGE PEIRCE OG FYSIKKEN".
Af: Peder Voetmann Christiansen

119/86 "DET ER GANSKE VIST - - EUKLIDS FEMTE POSTULAT KUNNE NOK SKABE RØRE I ANDEDAMMEN".
Af: Iben Maj Christiansen
Vejleder: Mogens Niss.

120/86 "ET ANTAL STATISTISKE STANDARDMODELLER".
Af: Jørgen Larsen

121/86 "SIMULATION I KONTINUERT TID".
Af: Peder Voetmann Christiansen.

122/86 "ON THE MECHANISM OF GLASS IONIC CONDUCTIVITY".
Af: Jeppe C. Dyre.

123/86 "GYMNASIEFYSIKKEN OG DEN STORE VERDEN".
Fysiklærerforeningen, IMFUFA, RUC.

124/86 "OPGAVESAMLING I MATEMATIK".
Samtlige opgaver stillet i tiden 1974-jan. 1986.

125/86 "UVBY,β - systemet - en effektiv fotometrisk spektralklassifikation af B-,A- og F-stjerner".
Projektrapport af: Birger Lundgren.

126/86 "OM UDVIKLINGEN AF DEN SPECIELLE RELATIVITETSTEORI".
Projektrapport af: Lise Odgaard & Linda Szkotak Jensen
Vejledere: Karin Beyer & Stig Andur Pedersen.

127/86 "GALOIS' BIDRAG TIL UDVIKLINGEN AF DEN ABSTRAKTE ALGEBRA".
Projektrapport af: Pernille Sand, Heine Larsen & Lars Frandsen.
Vejleder: Mogens Niss.

128/86 "SMÅKRYB" - om ikke-standard analyse.
Projektrapport af: Niels Jørgensen & Mikael Klintorp.
Vejleder: Jeppe Dyre.

129/86 "PHYSICS IN SOCIETY"
Lecture Notes 1983 (1986)
Af: Bent Sørensen

130/86 "Studies in Wind Power"
Af: Bent Sørensen

131/86 "FYSIK OG SAMFUND" - Et integreret fysik/historieprojekt om naturanskuelsens historiske udvikling og dens samfundsmæssige betingethed.
Projektrapport af: Jakob Heckscher, Søren Brønd, Andy Wierød.
Vejledere: Jens Høyrup, Jørgen Vogelius, Jens Højgaard Jensen.

132/86 "FYSIK OG DANNELSE"
Projektrapport af: Søren Brønd, Andy Wierød.
Vejledere: Karin Beyer, Jørgen Vogelius.

133/86 "CHERNOBYL ACCIDENT: ASSESSING THE DATA.
ENERGY SERIES NO. 15.
AF: Bent Sørensen.

134/87 "THE D.C. AND THE A.C. ELECTRICAL TRANSPORT IN AsSeTe SYSTEM"
Authors: M.B.El-Den, N.B.Olsen, Ib Høst Pedersen, Petr Viščor

135/87 "INTUITIONISTISK MATEMATIKS METODER OG ERKENDELSESTEORETISKE FORUDSÆTNINGER"
MASTEMATIKSPECIALE: Claus Larsen
Vejledere: Anton Jensen og Stig Andur Pedersen

136/87 "Mystisk og naturlig filosofi: En skitse af kristendommens første og andet møde med græsk filosofi"
Projektrapport af Frank Colding Ludvigsen
Vejledere: Historie: Ib Thiersen
Fysik: Jens Højgaard Jensen

137/87 "HOPMODELLER FOR ELEKTRISK LEDNING I UORDNEDE FASTE STOFFER" - Resume af licentiatafhandling
Af: Jeppe Dyre
Vejledere: Niels Boye Olsen og Peder Voetmann Christiansen.

138/87 "JOSEPHSON EFFECT AND CIRCLE MAP."

Paper presented at The International Workshop on Teaching Nonlinear Phenomena at Universities and Schools, "Chaos in Education". Balaton, Hungary, 26 April-2 May 1987.

By: Peder Voetmann Christiansen

139/87 "Machbarkeit nichtbeherrschbarer Technik durch Fortschritte in der Erkennbarkeit der Natur"

Af: Bernhelm Booss-Bavnbek
Martin Bohle-Carbonell

140/87 "ON THE TOPOLOGY OF SPACES OF HOLOMORPHIC MAPS"

By: Jens Gravesen

141/87 "RADIOMETERS UDVIKLING AF BLODGASAPPARATUR - ET TEKNOLOGIHISTORISK PROJEKT"

Projektrapport af Finn C. Physant

Vejleder: Ib Thiersen

142/87 "The Calderón Projektor for Operators With Splitting Elliptic Symbols"

by: Bernhelm Booss-Bavnbek og
Krzysztof P. Wojciechowski

143/87 "Kursusmateriale til Matematik på NAT-BAS"

af: Mogens Brun Heefelt

144/87 "Context and Non-Locality - A Peircean Approach

Paper presented at the Symposium on the Foundations of Modern Physics The Copenhagen Interpretation 60 Years after the Como Lecture. Joensuu, Finland, 6 - 8 august 1987.

By: Peder Voetmann Christiansen

145/87 "AIMS AND SCOPE OF APPLICATIONS AND MODELLING IN MATHEMATICS CURRICULA"

Manuscript of a plenary lecture delivered at ICMTA 3, Kassel, FRG 8.-11.9.1987

By: Mogens Niss

146/87 "BESTEMMELSE AF BULKRESISTIVITETEN I SILICIUM"

- en ny frekvensbaseret målemetode.

Fysikspeciale af Jan Vedde

Vejledere: Niels Boye Olsen & Petr Viščor

147/87 "Rapport om BIS på NAT-BAS"

redigeret af: Mogens Brun Heefelt

148/87 "Naturvidenskabsundervisning med Samfundsperspektiv"

af: Peter Colding-Jørgensen DLH
Albert Chr. Paulsen

149/87 "In-Situ Measurements of the density of amorphous germanium prepared in ultra high vacuum"

by: Petr Viščor

150/87 "Structure and the Existence of the first sharp diffraction peak in amorphous germanium prepared in UHV and measured in-situ"

by: Petr Viščor

151/87 "DYNAMISK PROGRAMMERING"

Matematikprojekt af:
Birgit Andresen, Keld Nielsen og Jimmy Staal

Vejleder: Mogens Niss

152/87 "PSEUDO-DIFFERENTIAL PROJECTIONS AND THE TOPOLOGY OF CERTAIN SPACES OF ELLIPTIC BOUNDARY VALUE PROBLEMS"

by: Bernhelm Booss-Bavnbek
Krzysztof P. Wojciechowski

153/88 "HALVLEDERTEKNOLOGIENS UDVIKLING MELLEM MILITÆRE OG CIVILE KRÆFTER"

Et eksempel på humanistisk teknologihistorie
Historiespeciale

Af: Hans Hedal

Vejleder: Ib Thiersen

154/88 "MASTER EQUATION APPROACH TO VISCOUS LIQUIDS AND THE GLASS TRANSITION"

By: Jeppe Dyre

155/88 "A NOTE ON THE ACTION OF THE POISSON SOLUTION OPERATOR TO THE DIRICHLET PROBLEM FOR A FORMALLY SELFADJOINT DIFFERENTIAL OPERATOR"

by: Michael Pedersen

156/88 "THE RANDOM FREE ENERGY BARRIER MODEL FOR AC CONDUCTION IN DISORDERED SOLIDS"

by: Jeppe C. Dyre

157/88 " STABILIZATION OF PARTIAL DIFFERENTIAL EQUATIONS BY FINITE DIMENSIONAL BOUNDARY FEEDBACK CONTROL: A pseudo-differential approach."

by: Michael Pedersen

158/88 "UNIFIED FORMALISM FOR EXCESS CURRENT NOISE IN RANDOM WALK MODELS"

by: Jeppe Dyre

159/88 "STUDIES IN SOLAR ENERGY"

by: Bent Sørensen

160/88 "LOOP GROUPS AND INSTANTONS IN DIMENSION TWO"

by: Jens Gravesen

161/88 "PSEUDO-DIFFERENTIAL PERTURBATIONS AND STABILIZATION OF DISTRIBUTED PARAMETER SYSTEMS:

Dirichlet feedback control problems"

by: Michael Pedersen

162/88 "PIGER & FYSIK - OG MEGET MERE"

AF: Karin Beyer, Sussanne Blegaa, Birthe Olsen, Jette Reich , Mette Vedelsby

163/88 "EN MATEMATISK MODEL TIL BESTEMMELSE AF PERMEABILITETEN FOR BLOD-NETHINDE-BARRIEREN"

Af: Finn Langberg, Michael Jarden, Lars Frellesen

Vejleder: Jesper Larsen

164/88 "Vurdering af matematisk teknologi
Technology Assessment
Technikfolgenabschätzung"

Af: Bernhelm Booss-Bavnbek, Glen Pate med
Martin Bohle-Carbonell og Jens Højgaard Jensen

165/88 "COMPLEX STRUCTURES IN THE NASH-MOSER CATEGORY"

by: Jens Gravesen

166/88 "Grundbegreber i Sandsynligheds-regningen"

Af: Jørgen Larsen

167a/88 "BASISSTATISTIK 1. Diskrete modeller"

Af: Jørgen Larsen

167b/88 "BASISSTATISTIK 2. Kontinuerte modeller"

Af: Jørgen Larsen

168/88 "OVERFLADEN AF PLANETEN MARS"
Laboratorie-simulering og MARS-analoger undersøgt ved Mössbauerspektroskopi.

Fysikspeciale af:

Birger Lundgren

Vejleder: Jens Martin Knudsen
Fys.Lab./HCØ

169/88 "CHARLES S. PEIRCE: MURSTEN OG MØRTEL TIL EN METAFYSIK."

Fem artikler fra tidsskriftet "The Monist" 1891-93.

Introduktion og oversættelse:

Peder Voetmann Christøansen

170/88 "OPGAVESAMLING I MATEMATIK"

Samtlige opgaver stillet i tiden 1974 - juni 1988

171/88 "The Dirac Equation with Light-Cone Data"

af: Johnny Tom Ottesen

172/88 "FYSIK OG VIRKELIGHED"

Kvantemekanikkens grundlagsproblem i gymnasiet.

Fysikprojekt af:

Erik Lund og Kurt Jensen

Vejledere: Albert Chr. Paulsen og
Peder Voetmann Christiansen

173/89 "NUMERISKE ALGORITMER"

af: Mogens Brun Heefelt

174/89 " GRAFISK FREMSTILLING AF FRAKTALER OG KAOS"

af: Peder Voetmann Christiansen

175/89 " AN ELEMENTARY ANALYSIS OF THE TIME DEPENDENT SPECTRUM OF THE NON-STATONARY SOLUTION TO THE OPERATOR RICCATI EQUATION

af: Michael Pedersen

176/89 " A MAXIUM ENTROPY ANSATZ FOR NONLINEAR RESPONSE THEORY"

af : Jeppe Dyre

177/89 "HVAD SKAL ADAM STÅ MODEL TIL"

af: Morten Andersen, Ulla Engström, Thomas Gravesen, Nanna Lund, Pia Madsen, Dina Rawat, Peter Torstensen

Vejleder: Mogens Brun Heefelt

178/89 "BIOSYNTESEN AF PENICILLIN - en matematisk model"

af: Ulla Eghave Rasmussen, Hans Oxvang Mortensen, Michael Jarden

vejleder i matematik: Jesper Larsen
biologi: Erling Lauridsen

179a/89 "LÆRERVEJLEDNING M.M. til et eksperimentelt forløb om kaos"

af: Andy Wierød, Søren Brønd og Jimmy Staal

Vejledere: Peder Voetmann Christiansen
Karin Beyer

179b/89 "ELEVHÆFTE: Noter til et eksperimentelt kursus om kaos"

af: Andy Wierød, Søren Brønd og Jimmy Staal

Vejledere: Peder Voetmann Christiansen
Karin Beyer

180/89 "KAOS I FYSISKE SYSTEMER eksemplificeret ved torsions- og dobbeltpendul".

af: Andy Wierød, Søren Brønd og Jimmy Staal
Vejleder: Peder Voetmann Christiansen

181/89 "A ZERO-PARAMETER CONSTITUTIVE RELATION FOR PURE SHEAR VISCOELASTICITY"

by: Jeppe Dyre

183/89 "MATEMATICAL PROBLEM SOLVING, MODELLING. APPLICATIONS AND LINKS TO OTHER SUBJECTS - State. trends and issues in mathematics instruction

by: WERNER BLUM, Kassel (FRG) og
MOGENS NISS, Roskilde (Denmark)

184/89 "En metode til bestemmelse af den frekvensafhængige varmefylde af en underafkølet væske ved glasovergangen"

af: Tage Emil Christensen

185/90 "EN NÆSTEN PERIODISK HISTORIE"

Et matematisk projekt

af: Steen Grode og Thomas Jessen

Vejleder: Jacob Jacobsen

186/90 "RITUAL OG RATIONALITET i videnskabers udvikling"

redigeret af Arne Jakobsen og Stig Andur Pedersen

187/90 "RSA - et kryptografisk system"

af: Annemette Sofie Olufsen, Lars Frellesen
og Ole Møller Nielsen

Vejledere: Michael Pedersen og Finn Munk

188/90 "FERMICONDENSATION - AN ALMOST IDEAL GLASS TRANSITION"

by: Jeppe Dyre

189/90 "DATAMATER I MATEMATIKUNDERVISNINGEN PÅ GYMNASIET OG HØJERE LÆREANSTALTER

af: Finn Langberg

190/90 "FIVE REQUIREMENTS FOR AN APPROXIMATE NONLINEAR RESPONSE THEORY"

by: Jeppe Dyre

191/90 "MOORE COHOMOLOGY, PRINCIPAL BUNDLES AND ACTIONS OF GROUPS ON C*-ALGEBRAS"

by: Iain Raeburn and Dana P. Williams

192/90 "Age-dependent host mortality in the dynamics of endemic infectious diseases and SIR-models of the epidemiology and natural selection of co-circulating influenza virus with partial cross-immunity"

by: Viggo Andreasen

193/90 "Causal and Diagnostic Reasoning"

by: Stig Andur Pedersen

194a/90 "DETERMINISTISK KAOS"
Projektrapport af : Frank Olsen

194b/90 "DETERMINISTISK KAOS"
Kørselsrapport

Projektrapport af: Frank Olsen

195/90 "STADIER PÅ PARADIGMETS VEJ"
Et projekt om den videnskabelige udvikling der førte til dannelse af kvantemekanikken.

Projektrapport for 1. modul på fysikuddannelsen, skrevet af:

Anja Boisen, Thomas Hougård, Anders Gorm Larsen, Nicolai Ryge.

Vejleder: Peder Voetmann Christiansen

196/90 "ER KAOS NØDVENDIGT?"

- en projektrapport om kaos' paradigmatiske status i fysikken.

af: Johannes K. Nielsen, Jimmy Staal og Peter Bøggild

Vejleder: Peder Voetmann Christiansen

197/90 "Kontrafaktiske konditionaler i HOL

af: Jesper Voetmann, Hans Oxvang Mortensen og Aleksander Høst-Madsen

Vejleder: Stig Andur Pedersen

198/90 "Metal-Isolator-Metal systemer"

Speciale

af: Frank Olsen

199/90 "SPREDT FÆGTNING" Artikelsamling

af: Jens Højgaard Jensen

200/90 "LINEÆR ALGEBRA OG ANALYSE"

Noter til den naturvidenskabelige basisuddannelse.

af: Mogens Niss

201/90 "Undersøgelse af atomare korrelationer i amorfe stoffer ved røntgendiffraktion"

af: Karen Birkelund og Klaus Dahl Jensen

Vejledere: Petr Viščor, Ole Bakander

202/90 "TEGN OG KVANTER"
Foredrag og artikler, 1971-90.

af: Peder Voetmann Christiansen

203/90 "OPGAVESAMLING I MATEMATIK" 1974-1990

afløser tekst 170/88

204/91 "ERKENDELSE OG KVANTEMEKANIK"

et Breddemodul Fysik Projekt

af: Thomas Jessen

Vejleder: Petr Viščor

205/91 "PEIRCE'S LOGIC OF VAGUENESS"

by: Claudine Engel-Tiercelin
Department of Philosophy
Université de Paris-1
(Panthéon-Sorbonne)

206a+b/91 "GERMANIUMBEAMANALYSE SAMT A - GE TYNDFILMS ELEKTRISKE EGENSKABER"

Eksperimentelt Fysikspeciale

af: Jeanne Linda Mortensen

og Annette Post Nielsen

Vejleder: Petr Viščor

207/91 "SOME REMARKS ON AC CONDUCTION IN DISORDERED SOLIDS"

by: Jeppe C. Dyre

208/91 "LANGEVIN MODELS FOR SHEAR STRESS FLUCTUATIONS IN FLOWS OF VISCO-ELASTIC LIQUIDS"

by: Jeppe C. Dyre

209/91 "LORENZ GUIDE" Kompendium til den danske fysiker Ludvig Lorenz, 1829-91.

af: Helge Kragh

210/91 "Global Dimension, Tower of Algebras, and Jones Index of Split Seperable Subalgebras with Unitality Condition.

by: Lars Kadison

211/91 *"I SANDHEDENS TJENESTE"*

- historien bag teorien for de komplekse tal.

af: Lise Arleth, Charlotte Gjerrild, Jane Hansen, Linda Kyndlev, Anne Charlotte Nilsson, Kamma Tulinius.

Vejledere: Jesper Larsen og Bernhelm Booss-Bavnbek

212/91 *"Cyclic Homology of Triangular Matrix Algebras"*

by: Lars Kadison