

Introduction

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HIGHER EULER CHARACTERISTICS (I)

by Ross GEOGHEGAN¹⁾ and Andrew NICAS²⁾

To Peter Hilton on the occasion of his 70-th birthday.

ABSTRACT. The classical Euler characteristic $\chi \equiv \chi_0$ of a finite complex lies at the bottom of a sequence of homotopy invariants. The next invariant in this sequence χ_1 is introduced here and studied in some detail. The rest of the sequence, χ_n with $n \geq 2$, will be discussed in a sequel paper. Applications to geometric group theory are found by considering the behavior of χ_1 on an aspherical finite complex of fundamental group G . Just as the $\chi(G) \neq 0$ implies that the center of G is trivial (Gottlieb's Theorem), it is shown here that (under a weak additional hypothesis and using rational coefficients) $\chi_1(G) \neq 0$ implies that the center of G is infinite cyclic. We also find a generalization of Gottlieb's Theorem in which the Lefschetz number of an automorphism of G is related to the fixed subgroup of the automorphism.

INTRODUCTION

From our point of view, the classical Euler characteristic of a finite complex is “zero-th order”. In this paper we introduce a “first order” analog, a new invariant in topology and group theory. In a sequel paper and in [GNO] we extend these ideas to an “ n -th order” Euler characteristic for all positive n .

For a finite complex X , the new invariant $\chi_1(X; R)$, defined in §1, comes in different forms, depending on the coefficient ring R ; and a more sophisticated version $\tilde{\chi}_1(X; R)$ defined in §2, involves the universal cover of X . By contrast, the classical analogs of these are essentially the same, namely the integer $\chi(X)$. We should tell the reader from the start that all our first order invariants are trivial if X is simply connected.

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The paper begins with three rather different definitions of $\chi_1(X; R)$, a discussion of their equivalence, and some motivation for these definitions. Our point of view is geometric, but for readers more interested in homotopy theory we include (at the end of §1) a brief discussion of a fourth definition in terms of stable homotopy theory.

Next, we discuss the computation of $\chi_1(X; R)$ for 1-complexes, certain 2-complexes, 3-dimensional lens spaces, circle bundles and mapping tori.

In §5 and §7, we apply these ideas to group theory. Motivated by Gottlieb's theorem [Got] that if X is a finite aspherical complex with fundamental group G and if $\chi(G) \equiv \chi(X) \neq 0$ then the center of G is trivial, we find an analog (Theorem 5.4) which says, roughly, that if $\chi_1(G; \mathbf{Q}) \equiv \chi_1(X; \mathbf{Q}) \neq 0$ then the center of G is infinite cyclic. This leads us to surprising generalization of Gottlieb's theorem (Theorem 8.1). In this theorem, one is given an automorphism θ of G induced by a map $f: X \rightarrow X$. By the *Lefschetz number*, $L(\theta)$, of θ we mean the Lefschetz number of f . We prove (under a weak K -theoretic hypothesis on G) that if θ has order r in the group of outer automorphisms of G and if $\sum_{i=0}^{r-1} L(\theta^i) \neq 0$ then the intersection of the center of G and the fixed subgroup of θ is trivial. We do not know of a previous theorem which relates so directly the fixed subgroup of an automorphism to the classical fixed point theory of the associated map.

We also introduce a more refined invariant $\tilde{\chi}_1(X) \in H^1(\Gamma, HH_1(\mathbf{Z}G))$ where $HH_1(\mathbf{Z}G)$ is the first Hochschild homology group of $\mathbf{Z}G$ (see §1). This is an analog of what one obtains when one computes the classical Euler characteristic as a Hattori-Stallings trace in the universal cover of X . In the classical case one essentially recovers $\chi(X)$, but a significant distinction appears in the case of the "higher order" invariants. In a natural manner, $\tilde{\chi}_1(X)$ maps to $\chi_1(X)$ regarded as an element of $H^1(\Gamma, H_1(G))$. Applications of $\tilde{\chi}_1$ to characteristic classes and Seifert fiber spaces will be given in [GN₅].

The ideas presented here are an outgrowth of the one-parameter fixed point theory developed in [GN₁] and its application to dynamics in [GN₂]. A summary has appeared as [GN₃]. Most of this paper can be read independently of [GN₁] and [GN₂]. We make modest use of a few technical propositions from [GN₁] in §2 and §3; in §10 a difficult result from [GN₁] is invoked.

One of the definitions of $\chi_1(X; R)$ employs a formula introduced more than twenty years ago in [Kn]; we thank Boris Okun for drawing our attention to that paper.