Hearing the Shape of a Drum

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One wants to know the extent to which the spectrum of the Laplacian controls the geometry of the manifold. M. Kac originally put the question; it has been restated subsequently by M. Protter: "Suppose a drum is being played in one room and a person with perfect pitch hears but cannot see the drum. Is it possible for her to deduce the precise shape of the drum just from hearing the fundamental tone and all the overtones?" [1]

Let $D$ be a second order operator with scalar leading symbol; as $t \to 0$, $\text{Tr}(e^{-tD}) = \sum a_j(D)t^{n-j-\frac{m+2}{2}}$. The heat equation asymptotics $a_j(D)$ are computed for $n \leq 6$ in terms of geometrical data. [The SC® indicates that this paper has been cited in over 155 publications, making it the most-cited paper for this journal.]

vanish if $n$ is odd for $\partial M = \emptyset$; the invariants $a_0, a_3$, and $a_4$ are fairly easy to compute by hand. I used extensive computer calculations to compute $a_9$. Recently, $a_9$ has been computed by I. G. Avramidi and independently by P. Amsterndamski, A. Berkin, and D. O'Connor; it has formidable combinatorial complexity. This gives complete information concerning $a_j$ for $n \leq 8$; there is partial information available for all $n$ (see reference 4 for details). If $\partial M = \emptyset$, the situation is somewhat more complicated; recent work with Tom Branson computes $a_j$ for $n \leq 4$.

The formulas become exponentially more complicated as $n$ increases; for example, the formula for $a_9$ has 46 terms if $\partial M = \emptyset$, while the formula for $a_9$ if $\partial M = \emptyset$ has over 50 terms. There are by now many different algorithms for computing the heat equation asymptotics; there always seems to be an irreducible combinatorial complexity.

After doing the calculation of $a_9$, I found a paper by T. Sakai that did the scalar case using different methods. This enabled me to check directly 17 of the coefficients. I recall the feeling of anxiety as I spent one entire afternoon comparing the two answers; this was a nontrivial calculation as we had different bases for the space of invariants. I made the final calculation to determine the two answers agreed! I looked out of my office in Princeton and just gazed at the view for a long time in great relief.

The paper on spectral geometry contains a sign error on page 609; Theorem 2.1 should read $D = D_{\mathcal{V}}$ (not $D_{\mathcal{V}} + \mathcal{E}$). The error doesn't propagate and is isolated. Judging by the number of citations, the paper has been useful to lots of people. That is a very satisfactory pay off for the very lengthy complicated calculations involved. I am currently embarked on studying first order operators and operators with nonscalar leading symbol, which I hope will prove equally useful.}


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