

Turning noise into signal: a paradox?
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About a century ago, Poincaré wrote in an essay *Science and Method*: “If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment. But even if it were the case that the natural laws had no longer any secret for us, we could still only know the initial situation approximately. If that enabled us to predict the succeeding situation with the same approximation, that is all we require, and we should say that the phenomenon had been predicted, that it is governed by laws. But it is not always so; it may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible, and we have the fortuitous phenomenon.” Quite a visionary anticipation of chaos theory!

Since the last turn of the century, developments in seismology, ultrasonics and underwater acoustics have caused a 180 degrees turn in the way we think about diffuse wave fields and noise. Contrary to their definition, diffuse wave fields appeared not to be fully disorganized and without any information. It has been shown theoretically and experimentally that the heterogeneities and boundaries of the medium in which a diffuse wave field exists leave an imprint on the wave field which is characteristic for the medium, just as a fingerprint identifies its owner. What was even more surprising was the fact that the inherited information about the medium can be retrieved in a very simple manner, simply by cross-correlation, a very standard operation in signal processing. To be more specific, if one measures the noise of a diffuse wave field at two arbitrary points in space and computes the cross-correlation between these two noise registrations, one obtains the impulse response of the medium that would be measured if there were a source at one of the two points and a receiver at the other. In other words, by passively listening at noise and applying a very simple operation, one obtains the same information that would be obtained in a controlled experiment with manmade sources. It appeared that this is true no matter how complex the heterogeneities and boundaries of the medium. This very simple principle has far-reaching consequences. To mention a few examples: in the field of ultrasonics noise of thermal fluctuations in a specimen has been successfully turned into pulse-echo measurements of the specimen, in regional seismology recordings of ambient seismic noise have been used to reconstruct the crustal structure of southern California and other regions and in exploration seismology recordings of background noise in a desert area have been turned into seismic reflection measurements of the area.

The extraction of a deterministic system response from noise is amazing in itself. In the light of Poincaré’s observations it is even more amazing that this process is fairly robust. It works, without knowledge of the positions of the sources (the initial conditions) and the properties of the noise. In the presentation I will argue that the solution of this paradox lies in the fundamental difference between the multiple scattering behavior of particles and that of waves. I will illustrate the principle of ‘turning noise into signal’ at the hand of various ultrasonic and geophysical examples.