Scattered Serendipities: How to Make Sense of Everything

Michael Vorländer

Random Walks from Astronomy to Acoustics

When I started writing this essay, I wondered how I could integrate the different interpretations of the term serendipity. Mostly, it is the observation of something you were not originally looking for that eventually leads to a new and surprising discovery. But it also refers to serendipitous moments in one's career that determine a pivot point in the decision tree of choosing A or B, with drastic consequences and repercussions in many ways.

We start in high school, where my main interest was math and physics. My most influential high-school teacher was a fascinating man with deep knowledge and an excellent teaching style that drew me even more into physics. By the way, there was also an influential music teacher at that school, and the serendipity was that she opened a door to a small room where musical instruments were kept, where I found my first drum kit!

The impetus to study physics in a five-year, single-track graduate program resulted from my passion for astronomy and particle physics. In my second year, in 1979, during a Sunday walk through a forest, I saw an elegant building labeled "Institute of Building Physics." What is that? My father, who was an architect, explained to me that it dealt with physics and engineering tasks in construction related to thermal and moisture insulation and acoustics. I applied at this institute as intern, was accepted, and assisted in various projects on sound insulation with porous absorbers and room acoustics. And it just so happened that I liked acoustics; it was something real and tangible. What about career opportunities in acoustics?

However, to complete my degree with a major in acoustics, I had to transfer to another university. The decision-making process was a confluence of two serendipitous moments that happened at the same time. First, my girlfriend Angelika (later my wife) moved to the city of Aachen to study. Second, RWTH Aachen University, Aachen, Germany, had a renowned acoustics institute headed by Heinrich Kuttruff. I knew of him from reading his book on room acoustics (Kuttruff, 1979) when I was still working as an intern. Now the decision was easy; moving to Aachen wasn't planned before but now it made a lot of sense.

Images and Scattering

My master's thesis under supervision of Heinrich Kuttruff in 1984 dealt with the spatial impression in concert halls. Mike Barron's "lateral energy fraction" is an objective quantity that correlates with the subjective impression of the apparent source width" (see Hochgraf, 2019, Table 1). One of the characteristics of a good concert hall is a sufficient amount of strong sidewall reflections as expressed in a high lateral fraction. Its application in the set of criteria in concert hall construction was not yet fully established in those days.

The task was to investigate the influence of the floor plan of the room on the lateral energy fraction. I implemented an image source model and examined room shapes. When the positions of the image sources were plotted for

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higher reflection orders, the result was a beautiful starry sky of image sources but with a drastically increasing number of reflection combinations, which led to needing astronomically large computer storage and computing times. It seemed like a good idea to get rid of the exponential increase in the construction of image sources; more on that serendipity later.

Another task was to investigate the influence of wall surface roughness on the angular distribution of reflected sound. Apart from some analytical solutions for surface scattering, measuring the reflected sound at a given sound incidence was the only possibility for any surface structures. Serendipitously, an ultrasonic source was available in the laboratory for scale-model experiments. Accordingly, flat plates with different arrangements of sticks and other small pieces on them were created and placed under an arrangement of sound source and microphone. The original aim was to measure the impulse response of the surface structure with various source-receiver arrangements so as to obtain information about the directional pattern of surface scattering. A digital oscilloscope was used to display an impulse response that was updated approximately every second. By looking at the impulse responses while moving the plate to make small adjustments, the now familiar random-incidence scattering coefficient emerged by serendipity.

The scattering coefficient is defined as the ratio between the diffusely scattered energy outside the specular ("incidence angle equals the reflection angle") direction and the total reflected energy. It was observed that the specular and the scattered sound components had very different characteristics. The specular sound changed very little due to the small movements of the plate, but the scattered component of the sound was subject to random amplitude and phase modulations (shown in **Figure 1**).

It was fun to move and rotate the plate and see this phenomenon in the impulse response. I then wondered if this could possibly be used to separate coherent and incoherent reflected sound. Yes, it was, and the end result years later was that a new method for measuring surface scattering was standardized in the International Organization for Standardization (ISO) 17497-1:2004 standard, which has big implications for geometrical-acoustic simulation techniques (ISO 17497-1:2004, 2004).

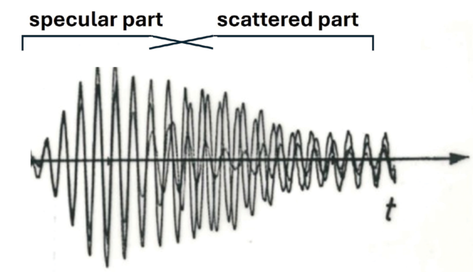

Figure 1. *Four bandpass-filtered reflections from a corrugated plate with a slightly shifted or rotated structure. The first part (specular component) stays coherent, whereas in the second part (scattered component), the four waveforms get out of phase during movement (Vorländer, unpublished figure).*

For the doctoral project, which began in 1985, Heinrich Kuttruff gave me absolute freedom to determine my own path. Inspired by his excellent teaching on the subject of room acoustics, I decided to study computer simulation of room acoustics. Ray tracing for use in room acoustics was known from programming on larger machines that filled entire rooms but doing this on a desktop PC with 640 kilobyte RAM was something else. It turns out that this worked well, and it was possible to simulate scattered and specular reflections and impulse responses at least with a temporal resolution of a few milliseconds. However, for auralization, which requires an impulse response with a sampling rate resolution (approximately 20 microseconds), working on a desktop PC was not feasible. Serendipitously, I discovered that the ray tracing algorithm could also be used to find image sources without the number of sources increasing exponentially and the calculation times being astronomically high, and this allowed me to use the PC. The key was the small algorithmic detail that the sequence of wall indices for each ray hitting one wall after the other contains exactly what is needed to find an audible image source. The temporal resolution can be as high as necessary. From then on, the path to auralization was paved.

Binaural Technology, Microphones, and Reverberation Chambers

The next serendipitous event in my career was my graduation to Doctor in Natural Sciences (Dr. rer. nat.) in 1989 and my move from the university to the Physikalisch-

Technische Bundesanstalt (PTB) in Braunschweig, the German National Metrology Institute, which is equivalent to the National Institute of Standards and Technology (NIST) in the United States. The move started with a phone call between Jürgen Meyer and Heinrich Kuttruff. Jürgen Meyer is a recognized expert in musical acoustics and room acoustics, but he also headed a larger department at PTB that included four laboratories.

They were actually looking for a postdoctoral researcher in the laboratory for audiology and microphone calibration. Dummy heads, ear simulators, headphone technology, primary microphone calibration, these were fields in which I had almost no experience. Nevertheless, Heinrich recommended me, and Jürgen invited me for a job interview. When I was offered the job as a research officer at the PTB, I had to think about my next career step. However, because there were excellent conditions in this laboratory and interesting projects, the decision was quickly made. We moved to Braunschweig, now with a family of five. It is not serendipity but rather divine providence that my son's names (Paul, Tobias, and Benjamin) bear the initials P, T, and B. Whether you believe in divine providence or not, it all seems to make a lot of sense! Just a little joke on the side: as a scientist, I shouldn't follow superstitions. But I've heard that it works even if you don't believe in it.

After two years of work on dummy heads and hearing thresholds, a new challenge arose when I became head of the laboratory for room and building acoustics in 1991. The serendipity here was that the experience with upcoming digital measurement technology, in particular with maximum-length sequence correlation methods, unexpectedly paved the way for the idea of showing myself in competitions in academic nomination processes. A combination of room acoustics, primary microphone calibration, and digital measurement technology was the core of my second doctoral thesis, the so-called habilitation. The habilitation is still an important academic procedure in some European countries and particularly in the natural sciences and humanities. It is an expression of the desire to pursue an academic career. One needs a university that supports the individual process. The habilitation involves a defense in which research and teaching skills must be demonstrated. During my employment at the PTB and supported by Jürgen Meyer, I was given the freedom to use my research for my habilitation. It was awarded by the Technical University of Dresden, Dresden, Germany, in 1996.

There were other surprises at the PTB. For example, during a sound power calibration procedure, it was found that the diffuse field equation between the source power and the average room sound pressure could be improved even after so many years of established room acoustics theory. In particular, an equation from Sabine's and Eyring's reverberation theory in room acoustics could be generalized to include not only wall absorption but also air attenuation.

The result of the work at the PTB was also a strong involvement in the international community, with many inspiring contacts with colleagues and friends that have remained to this day, another serendipity!

Back to Academic Roots: Scattering, Images, and All That Virtual Reality

Serendipity also means accepting the challenge when it presents itself on stage. The appointment in 1996 to a professorship at the RWTH as successor to my esteemed teacher Heinrich Kuttruff was certainly the best of all serendipitous moments. As far as my delving into acoustics as a whole is concerned, it came about in the fortunate constellation of events arising from all of my earlier serendipitous experiences where it felt like all previous events were coming together to form a somewhat logical construct. The swing back from the tasks related more to applied acoustics in a national metrology institute to the roots in fundamental science offered a great variety of research opportunities that are seemingly chaotic and unconnected, activities that included things such as room acoustics theory and simulation, digital measurement technology, electroacoustics, perception, and hearing research.

However, during my 28 years at the university, all these seemingly chaotic specializations in acoustics have become more and more condensed into a wonderful new field within acoustics, auralization. Sound sources (power spectrum, directivity), propagation (waves, rays), materials (absorption, scattering), and three-dimensional (3D) sound reproduction can be created for complex environments, allowing us to create virtual acoustic environments, often referred to as virtual auditory displays, in a computer (Vorländer, 2020). The serendipity is that this combination of principles and techniques could never be planned in advance. A certain breadth within all technical areas of acoustics is required, less deep specialization and more generalization. In retrospect, this happened through a chain of serendipities indeed.

Conclusion: What If This and That Had Not Happened?

Without an internship at a consulting firm, I probably wouldn't have studied acoustics. Without my wife, I would not have moved to Aachen to study with Heinrich Kuttruff. Without the freedom that Heinrich Kuttruff gave me, I would not have found my way into computer simulation. Without the ultrasound equipment at the institute at the time, I would not have seen the modulation phenomenon in surface-scattering impulse responses. Without the freedom that Jürgen Meyer gave me, I would not have been able to gain experience with acoustics in reverberation chambers, sound source characterization, and microphone calibration. Without my doctoral students and all the institute staff at RWTH Aachen University, I would not have been able to achieve anything. Without being part of a global network of wonderful people in the acoustics community, it wouldn't have been as much fun!

Whatever the alternatives might have been, I think it's good that things turned out this way.

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