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Spectral Landscapes: Visualizing Electromagnetic Interactions

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Electromagnetic fields are formed through complex interactions between outer space, the Sun, our Earth, its atmosphere, and the built environment. Our communications technology makes use of them to enable the transmission of information at local, global, and even extraterrestrial scales. Mastery of electromagnetic fields made the information age possible, and the constant acceleration of innovation in communication technology continues to profoundly influence contemporary culture. Because wireless communication takes advantage of ranges of the electromagnetic spectrum that we are unable to sense physically, it is necessary to translate these signals into a domain that human beings can more readily perceive in order to understand them.[1] Not only is it relevant to see the signals themselves (which is commonly done through instruments such as oscilloscopes or spectrum analyzers), it is also important to understand what kinds of information are being transmitted via these signals and the sociopolitical mechanisms that define and govern their use.

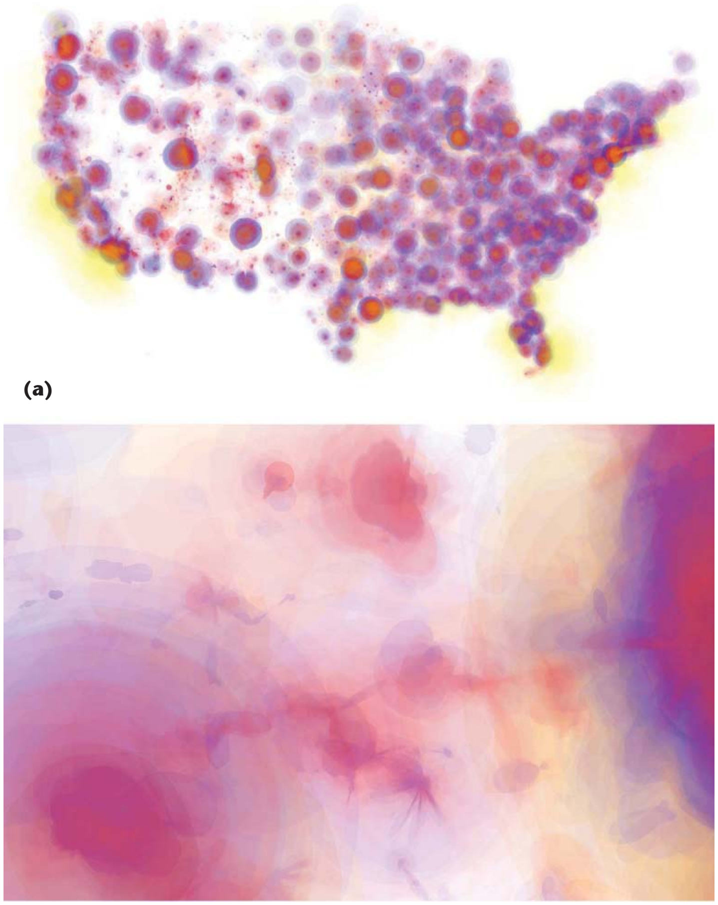
This article introduces a series of artworks that explore new creative opportunities made possible via low-cost sensors (which can be used to hone in on a small region of the spectrum within limited ranges) and state-of-the-art receivers (which are able to capture terabytes of spectrum data per second from great distances). Each of the projects described here—*Noospheric Atlas*, *Local Area Networks*, *Aerial Modulations*, *Traversing the Spectrum*, and *Radio Streams*—engages with the electromagnetic spectrum as a medium of creative expression that maps the invisible landscapes of what Anthony Dunne has termed "Hertzian space."[2]

While previous artworks explored visualizing electromagnetic signals, notably Timo Arnall's *Immaterials*[3] and Richard Vijgen's *The Architecture of Radio*,[4] the projects introduced here explore the intersections between information visualization and artistic representation. That is, these projects aim to accurately represent or rapidly respond to streams of data received from electromagnetic sensors while expanding the viewer's awareness of the activity and functionality of wireless communications. The projects were developed by an interdisciplinary team at the University of Illinois at Chicago that includes computer scientists and new media artists who collaborated both to create new projects and to extend previous research in creatively visualizing and interacting with complex data.[5–9]

Mapping the Spectrum

Although the electromagnetic spectrum is a continuum of energies that vibrate at different frequencies, we divide the spectrum into regions based on their physical properties as well as how they are used for practical purposes. Visible light is the region of the electromagnetic spectrum that we can see, and the radio spectrum is the region most appropriate for wireless communications. The Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) split the radio spectrum (3 kHz to 300 GHz) into regions that are allocated for different types of communication or services, such as FM and AM broadcasts, cordless phones, cell phones, pagers, Wi-Fi, automotive keyless entry systems, walkie-talkies, aeronautical navigation, and amateur radio.[10,11]

Brett Balogh's *Noospheric Atlas* is an artwork that visualizes the spatial organization of mass media broadcast areas in the United States.[5] The details of every licensed AM, FM, and TV station in the United States are located in the FCC's licensing



(a)

(b)

Figure 1. ***Noospheric Atlas*. This work represents the United States as it appears in Hertzian space, a nation of communications and signals. Here we see (a) the entirety of the United States and (b) a detail of the Rocky Mountains in Colorado.**

database, which also includes geospatial data indicating these stations' protected contours. *Noospheric Atlas* plots these overlapping contours as a map using different transparent colors to indicate the type of service (see Figure 1). The geographic density of stations results in maps with great variations in color and texture. Plotted without a base map of administrative boundaries, such as country or state lines, the resulting map represents the United States as it appears in Hertzian space, a nation of communications and signals.

As the radio and television did for previous generations, the Wi-Fi router brings the world of communications into the home. It enables Internet-connected devices within a household to maintain a constant presence in the ether and to exist in a state of continual communication. Similar to how the *Noospheric Atlas* depicts the geography of the United States through its broadcast communications, Balogh's *Local Area Networks* visualizes the home and the neighborhood through its Wi-Fi networks.[12] Balogh used a custom handheld, location-aware Wi-Fi scanner to map the Wi-Fi signals in Noble Square, a neighborhood in Chicago. He walked through the streets and alleyways of this neighborhood, logging each Wi-Fi access point by name (SSID), signal strength, and location. The structure of the shapes used to graphically represent these access points provides an alternative architectural organization different from the built environment. Walls and property lines do not contain the home, but rather the home expands and mingles with its neighbors (see Figure 2). The Hertzian footprint of the home extends outward from its physical boundaries; what one might consider private in the home is public in the ether.

Visualizing the Data Stream

The data for both the *Noospheric Atlas* and *Local Area Networks* projects was collected using low-cost sensors with limited range and bandwidth. However, professional equipment enables the capture of a much greater range of the spectrum at high-throughput rates. Keysight Technologies produces the N6841A RF sensor, used primarily for spectrum monitoring and interference detection.[13] The sensor can operate across a large part of the electromagnetic spectrum and has a measurement range of 20 MHz to 6 GHz with 20 MHz of simultaneous bandwidth. It is therefore possible to look at the entire FM broadcast band (88–108 MHz) in one sweep of the sensor. The sensor is capable of collecting both frequency and time data that can be transferred to dedicated visualization applications. A time-averaging filter adaptively determines the noise floor in a number of frequency bands of interest and identifies specific types of activity.

Through collaboration with Keysight Technologies, we used the N6841A RF sensor to develop new visualization projects. These projects were first showcased at Data Improvisations, the IEEE VIS Arts Program in Chicago, Illinois, in October 2015 (see Figure 3).[14] Each project involves interrogating the frequency bands of interest, monitoring the energies in these bands, and interpreting these energies in the form of discrete events. Additionally, the visualizations reveal the socially significant components of the Hertzian space.

Balogh's *Traversing the Spectrum* consists of different views of a 3D visualization that represents interesting features in real-time RF data. An initial view shows a number of frequency bands simultaneously. In this view, it is possible to get an overview of all RF activity, similar to a traditional spectrum waterfall display. A second view provides a 3D perspective that shows the frequency scale of center frequencies. Average activity graphs appear above the center frequencies, and vertical lines connecting the two appear whenever an event trigger occurs—a spike in energy in a particular frequency band. The third view lets the user scroll through the visualization for a detailed view of the activity in each frequency band. This visualization presents the vast range of frequencies and types of service as a traversable landscape. It makes use of features familiar to electrical engineers, such as a frequency scale, but casts the viewer as an inhabitant within a 3D world of radio signals, providing a spatial context for viewing radio spectrum activity. Figure 3 shows the *Traversing the Spectrum* visualization.

Paul Murray's *Radio Streams* is a real-time visualization of electromagnetic emissions from consumer electronics, including automobile key fobs, cell phones, and FM radio. An event-detection algorithm identifies meaningful signals and vividly triggers a notification of activity that splashes across the visualization. Users are invited to interact with *Radio Streams* using their personal communication devices in order to visually experience the hidden world of persistent, streaming radio activity. Figure 4 shows a screenshot of the *Radio Streams* visualization.

Anıl Çamcı's *Aerial Modulations* provides panoramic video of four scenarios in which radio signals assume a pivotal role in mediating everyday life. Computers, cell phones, and other communication devices used in a variety of settings (a meeting room, an office, an art gallery, and a parking lot) are dynamically labeled with RF data using video motion tracking, as depicted in Figure 5. For example, in the meeting room scenario, we can observe the constant interruption of communication activities as text messages and emails are sent and received over the course of the meeting. In the parking lot scenario (see Figure 5b), we observe a dynamic tableau of everyday interactions with the electromagnetic spectrum, including the phone conversations of passersby, walkie-talkies communications between security guards, and drivers remotely locking and unlocking their vehicles with key fobs. Participants experience *Aerial Modulations* using an Oculus Rift VR headset or tablet device to navigate through each scenario.

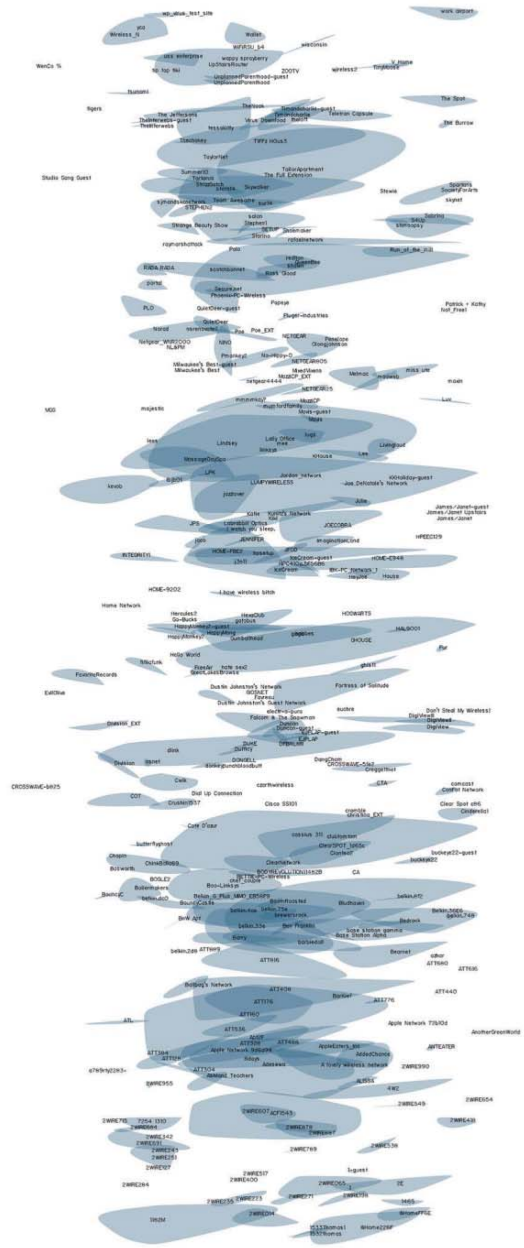


Figure 2. ***Local Area Networks*. This visualization provides an alternative architectural organization of a city neighborhood, making it easier to see how the communication footprint of each home extends outward from its physical boundaries.**

While existing techniques for visualizing the electromagnetic spectrum are, for the most part, aimed toward tasks relevant for experts in the telecommunications industry, such as planning wireless networks, determining the optimal placement of cell towers, and detecting and locating signal interference, the wealth of data provided by both low-cost and professional-grade sensors provides new opportunities. In the projects we present here, a main goal was to create novel ways to promote an awareness of the Hertzian landscape through visualizing electromagnetic events at particular frequencies. Although this landscape is normally invisible, it is nonetheless a significant natural resource that enables the myriad communication technologies that shape contemporary culture.

Each member of our team is motivated by an interest in using RF sensors to facilitate better understanding of the existing sociopolitical systems

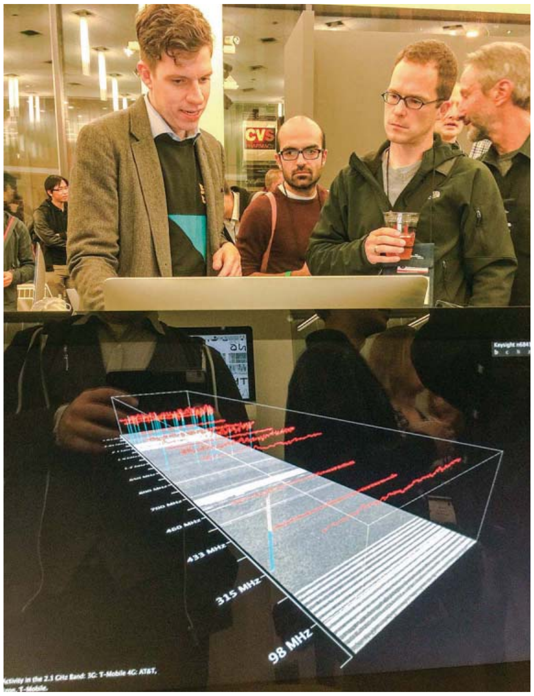


Figure 3. Data Improvisations, the IEEE VIS Arts Program exhibition. *Traversing the Spectrum*, *Radio Streams*, and *Aerial Modulations* were first presented at this exhibition in October 2015. *Traversing the Spectrum* can be seen on the screen in the bottom half of the image.

that generate and legislate the flow of electronic communication. Balogh explains, "Mapping is inherently a political act; maps give us the ability to plan and the power to influence. Making interactive maps of radio spectrum enables the public to see who owns the medium and its geographic extent." Moreover, the distinction between private and public is becoming ever-more blurred as our communication devices leak increasing amounts data. Balogh's projects invite us to think about "the consequences of the convenience of ubiquitous communication." Similarly, Çamcı explains that his creative research projects bring awareness to "unintentional interactions" and investigate "the undercurrent of machine dialogue that surrounds social interactions and that reveals the invisible components of our connectedness."

Furthermore, these artistic explorations could lead to pragmatic outcomes.[15,16] We plan to continue our collaboration with researchers at Keysight

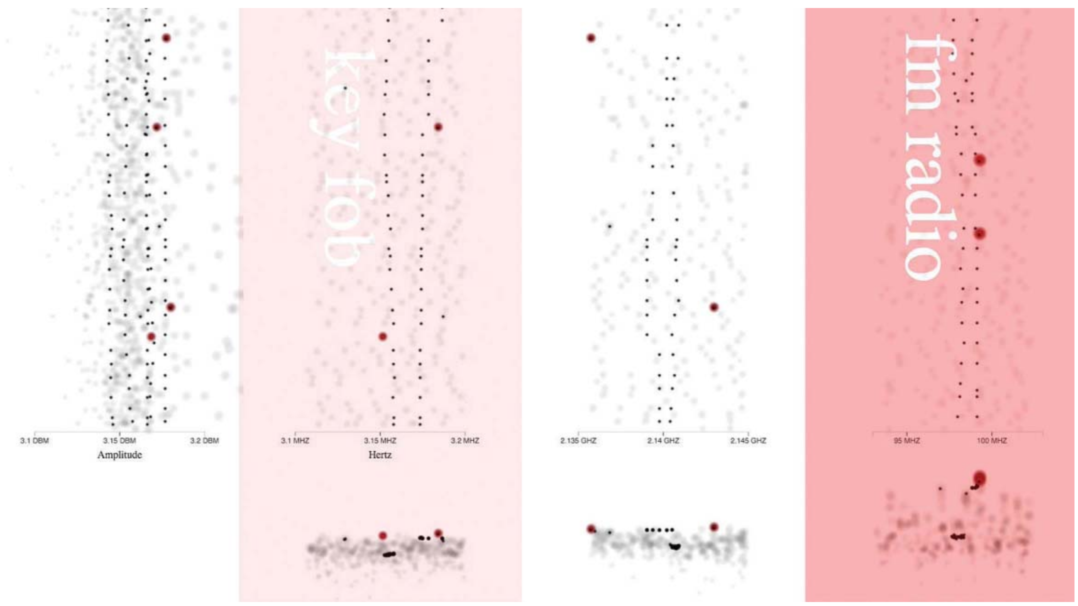


Figure 4. *Radio Streams*. The audience can use their cell phones and key fobs to explore electromagnetic signal data and to visually experience the hidden world of radio activity.

(a) **(b)**

Figure 5. *Aerial Modulations*. Participants can navigate through a range of scenarios in which radio signals assume a pivotal role in mediating everyday life. Here, we see (a) a scene from an art gallery and (b) another from a parking lot.

Technologies to introduce novel interactive visualization techniques in order to better view and manage the growing amount of communications data transmitted via radio spectrum. For example, Murray describes a future project using the N6841A RF sensor: "Transporting the sensor throughout the city allows us to record detailed data related to the geography and behavior of urban communications and to tell stories using the patterns we find." He is developing VR tools to create collaborative immersive user experiences that make it easier to navigate electromagnetic spectrum data. Balogh is also investigating how to represent electromagnetic phenomena using sound in order to uncover spatiotemporal patterns within spectrum data. Balogh says, "I do not feel it, nor do I see it, yet it is somehow everywhere and nowhere at the same time. I find it difficult to not be captivated by the intangibleness of radio."

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