Information Impedance Matching*

Peter Martin

Martin and Riener Technical Services
and
Oregon State University**

In electrical (power) and electronics (signal) engineering, there is a principle called "impedance matching": to achieve the most effective transfer of energy from one part of a circuit to another part, match the parts, with certain characteristics, in a complementary way. The impedances should be complex conjugates at the operating frequency (resistances should be equal and the capacitive reactance of one should equal the inductive reactance of the other). For example, to produce as much light as possible with a certain battery and an incandescent bulb use a bulb not of extremely high resistance nor of extremely low resistance, but of resistance equal to the battery's (internal) resistance. Match the filament impedance to the battery impedance.

Similarly, in the communication of information the best representation of the information occurs when the data are displayed at the resolution indicated by the source: one pixel to one pixel. Thus, in loose analogy to the principle of electrical impedance matching, the principle of information impedance matching suggests itself, to describe the optimal matching of an information source and an information receiver. This analogy seems appropriate because the fields of information theory and signal processing implicitly recognize the equivalence of energy and information when speaking of "energy compaction" in transform coding for purposes of compression and similar ideas (Goyal, 2001).

Geographic data, as spatial or temporal distributions of values, can be regarded as cases of "signals", carriers of information to be detected by those who use maps or other displays of geographic information. Thus, the application of ideas from signal processing and information and communication theory is justified, and may provide practical insight for spatial data communication in geographic information science.

The material that follows offers some reflections on geographic information impedance matching derived from the electrical/electronics analogy noted above. To apply impedance matching ideas to the communication of geographic information, one might first inquire as to the likely location and quantity of information that can be carried by a geographic data set, in a given representation, such as an image or an electronic file. Representations are not absolute. They should not be confused with that which they represent contrary to Wittgenstein's (1922) claim that a symbol must have something in common with that which it represents. Representations might closely resemble reality; they are, however, mere models or symbols—not reality.

The squared norm of a signal, as the sum of the squares of all its component values, is a measure of its deviation from the origin of function space, and is called its energy. "Energy compaction" refers to use of a transform to arrive at a coordinate system in which the location of the signal in function space can be approximated by a few orthogonal components in the new coordinate system. Then the projection of the signal onto those components' axes contains most of the signal's energy. It can be argued that this coordinate system allows a more “natural” representation of the signal, at least for the purposes of information transmission and storage. The sum of mutually-exclusive projection energies should equal the full-dimension energy.

Energy is always defined in relation to a frame of reference, such as a coordinate system, and the same is true of information. Information is the figure perceived against the ground, even if the location of meaning can be argued (Hofstadter, 1989). The ground reference is the context of the signal, and if the source and receiver agree on this common ground, then just the figure can be transmitted, for that is the carrier of information. In this case, source and receiver are well matched. If this is not the case, the ratio of information flow to data flow becomes small. Awareness of these ideas might prevent errors in geographic information science.

Cartographers are clearly concerned with the effective transfer of spatial information, which depends on attention to information impedance matching in data collection, data conversion, and data representation. The risks of neglecting information impedance matching are information loss, pseudo-information generation, and loss of efficiency

One might naturally compare and contrast these ideas with Tobler’s 1963 view of cartograms, matching the area of a state with its population. Newman, in physics, has recently revisited Tobler’s earlier work in light of new technology and other recent developments (Johnson, 2004). A more thorough analysis of the connections between Tobler’s subsequent work and the ideas presented here is underway.

The cartogram analogy, and the interesting connection between it and models of diffusion to a sort of isopycnal state, appears, however, not to dovetail with the notion of information impedance matching: the key question of information transformation is absent. The motivation for the cartogram is to convey information. In the case of impedance matching, the ingenuity is the invention of a representation, not the matching of one representation to another. Indeed, the cartographer (information source) finds a way to convey information (relative populations of states) to an information receiver (who looks at the cartogram), but the information was not ***first*** in a format that had to be matched to the receiver's preferred format. If "information impedance matching" is considered as any case of formatting information for best communication, then the cartogram analogy appears too broad to be pointed.

In data collection, one rule is not to record more apparent significant digits of a numerical measurement than are justified by the precision of the instrument (or by other practical or theoretical considerations of maximum possible precision). Ignorance of this rule results in an information impedance mismatch insofar as much of the flow of numbers conveyed is overburden, not representing information.

In data conversion, any sort of re-sampling or re-projection of data likely constitutes an information impedance mismatch. Re-projection generally entails interpolation of a regular grid, where original data are discarded and new data are created. It is inevitable that information will be lost and pseudo information created in this process; the severity of the mismatch is of the most interest. Different spatial patterns will be affected in different ways by such mismatches. For example, even if a grid of data is simply “reprojected” to a grid of coarser resolution, it may in some cases be preferable simply to subsample; in other cases it may be preferable to use a convolution filter, to minimize discontinuities or to maintain subband definition for purposes of scale analysis. In the familiar case of image size reduction, subsampling might preserve “sharpness” of certain features, while resampling with a convolution filter may better display continuity of areas and of edges not aligned with the grid axes.

A form of pseudo-information that might arise in resampling is aliasing. Kimerling [3] reported on the Moire-like patterns apparent in data quality maps of resampled equal-angle grids. Information impedance mismatching can produce similar patterns (or similarly-caused patterns) in the presentation of the *data itself*, which should be of considerable concern to those who prepare and analyze spatial information.

Figure 1 is a pair of images of the 256^2 discrete cosine transform (DCT) matrix. The image on the right was resized twice, which is expected to produce subsampling discontinuities. Displayed properly, the images would reveal hyperbolic bands bending toward the upper left corner, and a fainter hyperbolic cross at 2/3 across and 2/3 down from upper left. Any other variations seen are aliasing artifacts that result from information impedance mismatching. When viewing this document on a computer screen, try changing the magnification; the patterns should change.

These DCT matrix representations have undergone several conversions, including the conversion of 32-bit floating point numbers to 8-bit integers as well as conversions involving resizing, transformation raster to vector data and vector to raster data. These conversions were executed as pictures of the matrix, rather than as pictures of conversions of representations of the matrix.

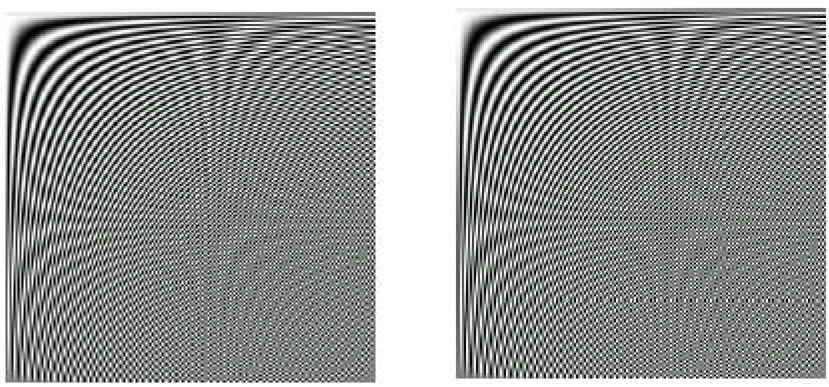

Figure 1. 256^2 DCT matrix. Reduced and enlarged image on right.

Because of the profusion of electronically-manipulated spatial data and the demands to reformat data sets for compatibility, it is incumbent upon those who work in geographic information science to be consciously aware of the distinction between the signal and its representation, and to minimize conversion and representation mismatches.

Loss of efficiency in information transmission matters because when efficiency drops, so does communication —consider for example a cluttered map, or a web page that is slow to load. Any representation of information is a sort of symbol. The key to avoiding information impedance mismatch is to have a sense of what the essential information components of a set of data are, and to employ representations that encode information in similar terms.

All representations are models, or symbols. The customary way to represent certain geographic data may not be the most “natural” choice. For example, graphs comprising lines and plots are not efficiently represented by the JPEG (Joint Photogaphic Experts Group) image format, whose components are smooth waves; such information would be represented more efficiently in vector format, such as EPS (Encapsulated PostScript), or if they must be in raster format for compatibility, then GIF (Graphics Interchange Format), PNG (Portable Network Graphics) or compressed TIFF (Tagged Image File Format) might be a better choice—the ratio of display quality to file size would be much higher.

Information impedance matching applies to non-spatial data as well. Common examples of information impedance mismatches that result in loss of efficiency are the conversion of documents from one format to another, and the conversion of text to image. In the parlance of signal analysis, the latter is a projection from one signal space to a much higher dimension signal space. Conversely, when numerical data (such as images) are encoded as ASCII (American Standard Code for Information Interchange) characters, as they are for email, a double conversion has taken place, with resulting loss of efficiency. A case in point is the passage of information electronically over the Internet, as in the case of a map server or other geographic data server. The price paid for a poor choice of data format is slow transfer of data. Data are not necessarily information, and it is only information that really needs to be served.

Information impedance matching can be summarized as facilitating information flow by making appropriate joints and transmission lines between information source and information receiver, employing transformation where appropriate, but avoiding it otherwise. Modular thinking cannot be discarded, but geographic information science practitioners must take the responsibility to understand the so-called “transparent” processes, such as data conversion or reformatting, that affect their geographic information and its effective communication.

Afterword.

In thinking about the diffusion models, it is useful to recall that Fourier analysis originated in the study of heat flow, which is also essentially diffusion toward constant density. In a world of specialization, models of interdisciplinary intellectual stimulation are important to identify.

References

V. Goyal. Theoretical foundations of transform coding. *IEEE Signal Processing Magazine*, 18(5):9–21, 2001.

D. Hofstadter. The location of meaning. In *Godel, Escher, Bach: an Eternal Golden Braid*, chapter 6, pages 158–180. Basic Books, New York, 1979.

R. C. Johnson, Chip diffusion modeling yields better maps. EE-Times, May 27, 2004 (1:00 PM EDT)

A. J. Kimerling. Predicting data loss and duplication when resampling from equal-angle grids. *Cartography and Geographic Information Science*, 29(2):111–126, 2002.

W. Tobler. Geographical area and map projections. *The Geographical Review*, III 1: 59-78, 1963.

L. Wittgenstein. *Tractatus Logico-Philosophicus*. Harcourt, Brace & Company, New York, 1922.

*Commentary is offered on the cross-discipline adaptation of the concept of impedance matching. These ideas arose from research on the theoretical foundations of interpolation of spatial data, using concepts and methods from information theory and signal processing.

**The author is a graduate student at Oregon State University;
mailto:martinp@science.oregonstate.edu