

Numbers to Neurons: Digital Synaesthesia

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Keywords: music, art, visualization, sonification, digital media

Abstract

The basis of digital technology is the abstraction of information to numbers. With computers we sample our experience, reduce it to discrete measurements and store the measurements as simple binary codes—numeric data. A digital artist can re-purpose that data in a variety of ways. Number becomes the medium. It can be manifested to our ears as musical pitch. It can be seen as color. The number 255 can represent a saturated red, heard as middle C, or both simultaneously! Thus any image can be heard, any sound can be seen. Here we find the true power of mathematical abstraction, and a way to integrate the visual arts and music.

Using digital technology to map (or re-map) mathematical descriptions or numerical models, we can bridge music and visual art. We can see Beethoven's *Ode to Joy*. We can hear Monet's *Water Lilies*. Once visual art and music are reduced to number they are the same. A digital synaesthesia occurs. With our ability to map numbers as we please mathematics becomes a metaphoric language from which we can create poetry.

Sound and Light

Sound begins as vibration in the air—fluctuating air pressure enters the ear canal and vibrates the eardrum where the signal is transferred to the cochlea of the inner ear. From there the signal is transduced into electro-chemical energy stored as spikes in the neural cells of the brain. Light too is vibration. Fluctuations of electro-magnetic energy are received on the retina of the eye, converted to a signal that moves down the optic nerve and is finally stored in the brain as electro-chemical spikes.

In the sensorium, in the cortex of the brain, sound and light both exist as electro-chemical spikes in the nerve cells or neurons. In the brain it is dark. In the brain it is silent. In the brain the qualia we call sound and light do not exist. There is just data stored in the form of electro-chemical spikes—data created through transduction of energy from “outside” of us, entering through our senses and mapped into a different kind of energy that is stored in our neural networks. What sound and light are as human experience is still a mystery, but we are starting to understand a bit of the mechanics of how we process and retain the phenomena [1].

All our experiences are nothing more than electro-chemical spikes in the neurons of our brains. We call it memory. Life is the collecting of this data, mapped from signals received by our senses, and the comparing of new data with those already stored in memory. We look for relationships, patterns and differences. From the comparisons we consider options, we make choices, and we act.

Sometimes, for some people, the sensory data in the brain (the electro-chemical spikes) get misrouted. As sound signals enter the sensorium they get routed to pathways typically used for light signals, or sometimes light data go the way of sound. In the process of sensing to sensation the signals get crossed. With these mis-routings one might taste a whisper, smell a tickle or hear a rainbow. If neural data takes a detour then experience, while synchronized with the external source event, is mapped and perceived atypically (but not necessarily uninterestingly). This perceptual detour is called synaesthesia. Most of us do not experience this at all. Some of us try to simulate it. We make art.

Digital Sound and Light

In a digital world all is number. Whether generated with a computer, scanned, or captured by a camera, digital images are stored as discrete measurements of light, represented as binary numbers. Sound too, whether recorded through a microphone or synthesized artificially with digital tools, is stored in a computer as binary numbers.

Similar to the brain, all sensory signals mapped into digital data in a computer are in the same format—this time binary code. How the data is contextualized (ie. which software is being used) determines whether it is sound or light (or something else). Digital data are often mapped to analog electrical voltages, returning it to a signal that we can perceive with our senses. If the voltage illuminates a phosphor on a monitor or sprays a dot of ink on paper we see it. If the voltage moves a speaker cone we hear it. Mapping numbers is a flexible activity.

Data Mapping

Making art with digital tools is all about data mapping. For example, numbers representing an image as additive color in RGB space might get mapped into a subtractive color space of CMYK. A simple mapping, this is often done to take an image we see on the screen and re-contextualize it for printing.

Mapping can follow many paths. For example, a simple (and familiar) mathematical process

$$z_{n+1} = z_n^r + \lambda$$

can be expressed computationally as a simple program as seen in Code Example 1.

```
z[REAL][0] = 0.0;
z[IMAG][0] = 0.0;
lambda[REAL] = x_loc;
lambda[IMAG] = y_loc;

for (i=1; i < MaxIterationCount; ++i) {
    z[REAL][i] = xSquared - ySquared + lambda[REAL];
    z[IMAG][i] = 2 * z[REAL][i-1] * z[IMAG][i-1] + lambda[IMAG];
    xSquared = z[REAL][i] * z[REAL][i];
    ySquared = z[IMAG][i] * z[IMAG][i];
    zMag = sqrt(xSquared + ySquared);

    if (zMag >= 2){
        colorPixel(i);
        break;
    }
}
```

Code Example 1: Excerpt of pseudo code to plot a Mandelbrot fractal image.

This program returns a grid of numbers. We map those numbers to luminosity and the process is visualized. See Figure 1. We could also map the numbers to audio frequency and hear it [2]. We could do both simultaneously!

Consider a music melody. A melody is nothing more than a temporal sequence of vibrations in the audio spectrum. Musical intervals are defined as ratios of frequencies so a melody is comprised of simple ratios unfolding in time—we hear number.



Figure 1: A visualization of a basic fractal.



Figure 2: Basic melody from Beethoven's *Ode to Joy*.

```

calc_tune(){
  int xcnt, ycnt;
  float radx, rady;

  for (xcnt = 0; xcnt < XDIM; ++xcnt) {
    radx = TWO_PI*((xcnt*1.0)/(XDIM*1.0));
    curr_x = (1.0)*cos(radx*(1.25)+(1.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.25)+(2.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.33333)+(3.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.5)+(4.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.5)+(5.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.33333)+(6.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.25)+(7.0/64.0)*TWO_PI) +
              (1.0)*cos(radx*(1.125)+(8.0/64.0)*TWO_PI) +
              :
              :
              etc...
  }
}

```

Code Example 2: Pseudo code excerpt (the first two bars) of *Ode to Joy*.

A melody such as that in Figure 2 can be expressed mathematically. From this expression a melody can also coded as a computer program. See Code Example 2. Melodic information of pitch (as a ratio from a tonic note), duration and temporal placement can be mapped to frequency, amplitude and phase of a sine function. And like the fractal example, the program can return a grid of numbers that can mapped to color. We can see the tune. (See Figure 3.)

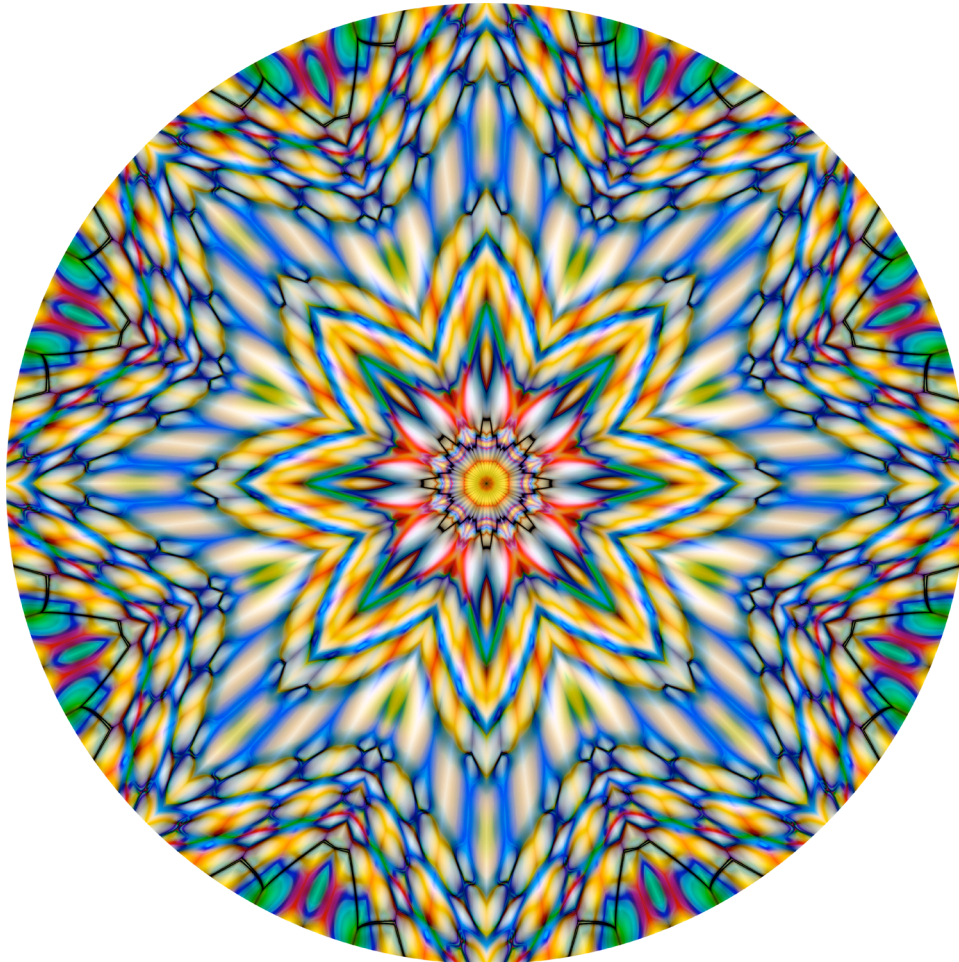


Figure 3: A visualization (a mapping) of Beethoven's *Ode to Joy*.

The Sonogram

With Fourier analysis we can create a mapping of sound that can be visualized. This technique distills a complex sound wave into a set of sine waves of varying frequencies, phases and amplitudes. When added together these component sine waves are equivalent to the original complex wave. This transform is used in many applications where sound analysis is desired. This analysis is useful in a variety of areas—speech research, the study of bird song, music analysis and synthesis [3]. As all sound (especially periodic sound) can be reduced to its sinusoidal components we can construct a visual mapping of the components and see how they change in frequency and amplitude over time. We call this visual mapping of a sound a sonogram. Figure 4 shows a sonogram of the spoken word “snowboard”. Frequency is mapped to the y-axis, time on the x-axis and amplitude is mapped to luminosity.

It is possible to invert a Fourier analysis. From a description of the sinusoidal components of a sound, we can reconstitute the sound and hear it. In computer music, sound is often created computationally by combining sine components. It is called additive synthesis [4].

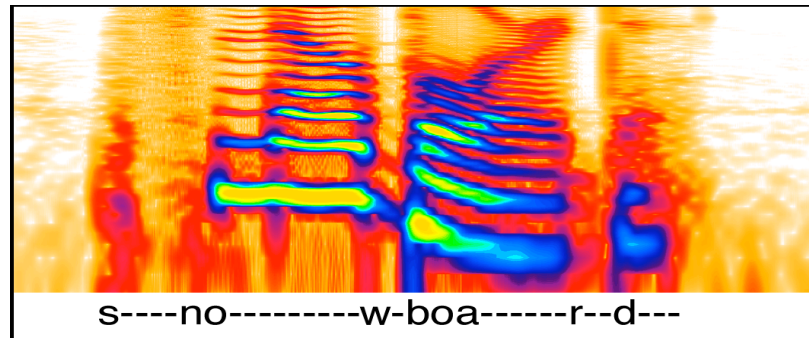


Figure 4: A sonogram of the spoken work “snowboard.” Vowels are seen as equidistant horizontal bands (harmonics), the noise of the consonant ‘s’ is seen as a wash of energy over the audio spectrum as are the short percussive ‘b’ and ‘d’.

Through an inverse Fourier transform (from sine wave components to a sound wave) it is possible to map a sonogram back into sound. Thinking more abstractly (and poetically), we can consider any image a sonogram, apply an inverse Fourier transform to the image and hear it. A sonogram visualizes sound. Through an inverse Fourier transform we sonify images. Digital technologies make both easy to do.

Digital Synaesthesia

With the power of data mapping, and the reduction of all data to number, all data can be contextualized as light or sound. All sounds can be seen. All images can be heard. In a digital world synaesthesia is easy.

All experience can be reduced to data mapping and information design. More poetically I like to think of these as metaphor and metonymy. Data mapping is like metaphor, the creation of relationships, the movement of pattern among and across things. Something is mapped to another. A relationship, an equivalence, an association is established and perhaps perceived. Through recognition of relationships we understand a little more about things, we are more able to note what unites, recognize commonalities and to also celebrate difference. We understand more of each as there are aspects of one in the other.

The ultimate language of metaphor is mathematics. Through mathematics these relationships are understood, patterns (often surprising patterns) are discovered and qualities are abstracted to their essences. It is a digital poetry that transcends language, but is no less potent and provocative. We abstract to number we seek relationship and with digital tools we cross the sensory divide—we hear the colors, we listen with our eyes.

References

- [1] Jeff Hawkins with Sandra Blakeslee, *On Intelligence*, (2004), Time Books: New York.
- [2] Brian Evans, “Hearing the Mandelbrot Set,” *The Csound Book*, ed. R. Boulanger, (2000), MIT Press: Cambridge.
- [3] Robert Cogan, *New Images of Musical Sound*, (1984), Harvard University Press: Cambridge.
- [4] Curtis Roads, *The Computer Music Tutorial*, (1996), MIT Press: Cambridge.

This research is supported with funds from a Research Advisory Committee Grant, University of Alabama.