Chapter 2

Creative signals

Supplementary reading

Foley, J.D., A. van Dam and others *Introduction to Computer Graphics.* (Reading, Mass.; Wokingham: Addison Wesley, 1997) [ISBN 0201609215].

Oppenheim, A.V. and A.S. Willsky with S. Hamid Nawab *Signals and Systems.* (Upper Saddle River, N.J.; London: Prentice Hall, 1997) [ISBN 0138147574]. Introductory parts of Chapters 1 and 2.

2.1 Introduction

This subject takes signals as the fundamental mechanism for the creation of art, and we look first at the basic sources of signals – with a focus on sound and images. We look primarily at signals in the form of waves and patterns. Once we have understood the fundamentals of waves, and the mathematical ways that are used to describe them, we will look at ways to manipulate them and ways to analyse different waveforms, thereby creating new waves and hence new signals.

What is a signal? It can be viewed from many perspectives, including being:

- a medium or entity through which communication happens
- a physical or biological stimulus
- a (mathematical) function
- a cultural entity
- a subtle message
- a wave, or waveform, that is emitted.

2.2 Waves

Both light (which is what enables us to see) and sound (which is what enables us to hear) are periodic waveforms. Light also has a particle representation, which carries information too, but we focus on the wave aspect of light in this subject.

We will see in later chapters that any periodic waveform can ultimately be represented by a combination of sine waves,[1] so it is important that you understand what a sine wave is, what properties it has, and how it is described mathematically. We'll also see, in volume 2 of this guide, details of the way that these two kinds of waveforms interact with our ears and our eyes.

[1] This discovery is due to Joseph Fourier, a French mathematician of the 18th century.

Figure 2.1 shows a sinusoidal waveform; all sinusoids have a similar shape, and the values of frequency, wavelength, amplitude and phase may change. There are two interactive tutorials to be found, at `http://hermes.eee.nott.ac.uk/teaching/cal/h61sig/sig0001.html` and `http://www.music.sc.edu/fs/bain/atmi02/wt/sine/index.html`, which will help you understand some of the properties of sinusoids. The latter also has a facility that allows you to hear what a sinusoidal waveform sounds like.

Sinusoids can be represented mathematically in the form of a function; most commonly the function describes amplitude with respect to angle, and it is this that is related to the periodicity. The period is the length (usually of time) of one cycle; in terms of the signals we are looking at, this might be the cycling through all the angles of one full rotation of a circle. The angle may vary from $0°$ to $360°$, or 0 radians to 2π radians. Commonly, the frequency of a sinusoidal waveform is taken to be the number of oscillations or cycles per second.

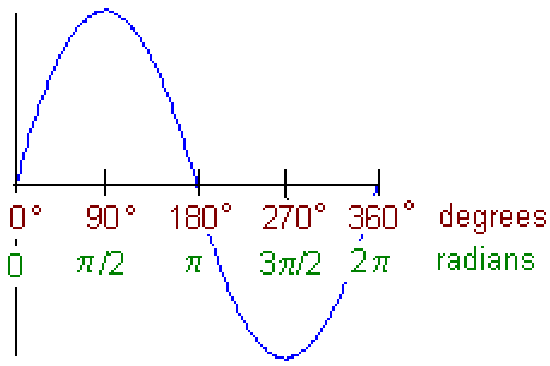

Figure 2.1: Sine wave showing degrees and radians.

Learning activity

What is a *radian*? What is the relationship between radians and degrees?

Construct a diagram that shows the equivalence between radians and degrees. Use *Processing* to turn your diagram into something visually interesting.

2.3 Signal processing

Signal processing involves the manipulation of signals, and usually takes signals to be in the form of waves. In the rest of this subject guide, we will look in much more detail at the various parts of this signalling arrangement. Although signal processing applies to analogue as well as to digital signals, we focus in this subject on the digital. Signal processing can be used as the basis of a wide range of applications, from scientific and engineering through to sound and visual art.

2.3.1 RADAR

RADAR was one of the earliest applications of signal processing theory. RADAR stands for radio detection and ranging – radio waves were used to detect both the presence of and distance away from an object. The radio waves are signals that are sent out in a particular direction. They have properties, including the fact that if they encounter an object they will change their shape and the direction in which they are moving. Also, they take a certain amount of time to travel through the air. So, many things can be measured and many things can be calculated. It was this understanding that led to the ability to use signal processing for detecting the presence of objects, without being able to actually 'see' them.

Here is one example of how it works, in a very simplified fashion: electromagnetic radiation is sent out. This radiation is modelled by waves, so we can think of the radiation as being waves. The waves encounter objects in their path, and some of the radiation bounces back. The RADAR system detects this radiation that has been bounced back. Because waves travel at a known speed through air, it is possible to tell how far away from the RADAR system the object that caused the bouncing is. Many other measurements can be made to determine factors other than the presence of an object, and its distance from the emitter. However, the earliest RADAR systems were developed for just this purpose: being able to silently detect the presence of enemy planes in the air.

2.3.2 Audio signals

An early use of audio signal processing was in radio, which was in the analogue domain for a long time. The development of digital radio is relatively recent.

Learning activity

How does analogue radio work? What do the terms AM, FM, SW and LW mean, and what do they refer to in terms of the radio signal?

How does digital radio differ from analogue radio?

Speech and sound signal processing has been of interest in the digital world since the 1960s. An example of an audio signal is shown in Figure 2.2; sound signals can be visualised in a number of ways, which include the use of colour and light intensity, and the more traditional use of waveforms as indicated in the bottom section of the figure.

Audio signal processing covers music, speech, and other sound, and areas of interest include digital processing, manipulation of music and audio recordings, speech recognition, and speech generation. More recently, signal processing has been applied to the recognition and identification of music.

Learning activity

Find out what you can about Hermann von Helmholz. In particular, find out what his contributions have been to audio processing. What is a Helmholz resonator?

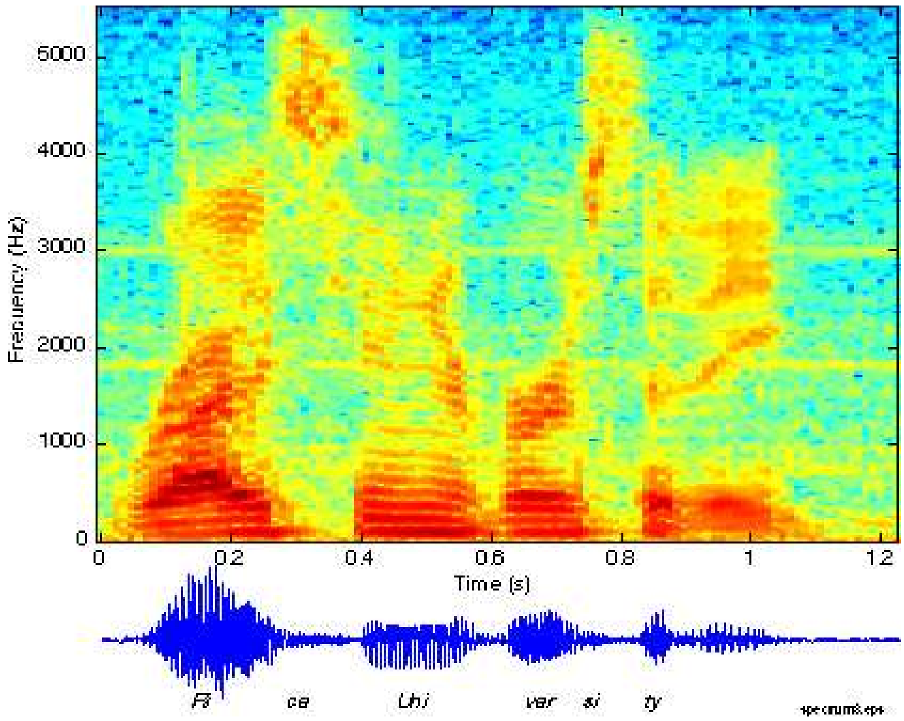

Figure 2.2: Speech signals.

2.3.3 Image signals

One form of image processing is the application of signal processing to images, and it can be considered especially within digital image processing. Simply taking a colour image and turning it into a black and white image is a type of signal processing. In this case, the signals for the image are the colour and light signals at each pixel, and the processing involves processing each of these to produce the desired output. There is a wide range of operations that can be applied to image signals to produce desired outputs and effects, from resizing to blurring. You saw some of these in *Processing* in Level 1. The focus in Level 2 is on signals and what can be done to them.

2.3.4 Visual art and music

Evolutionary and generative art can be viewed as an application of signal processing. In the Level 1 subject guide, you saw examples of image transformations using things like rotation and scaling, as well as texture mapping. Signal processing techniques can be applied to create interesting and novel images, and images that move and grow, as in the work of Karl Sims, who was an early exponent in this field.

William Latham is an artist who used digital techniques to model evolutionary processes, thereby creating distinctive artworks, as well as biologically relevant images, as demonstrated in Figure 2.3.

Figure 2.3: Image from William Latham's *Mutator*.

Figure 2.4 shows a screen of a digital music interface. Processing music as a digital signal allows us to analyse music from a different perspective, that examines the much smaller elements that then contribute to the overall whole. In Volume 2 of this guide, you'll see systems (soundspotter and videospotter), which apply a signal processing approach to the retrieval of specific information from a large bank of data.

As well as analysing music, the application of signal processing allows the creation and generation of novel music, such as in the work of John Cage.

Learning activity

Find more examples of musicians and artists who make use of signal processing explicitly in their work. Describe how they do this, and what is unique and interesting about it.

2.4 Signal definition

Signals are functions of independent variables that carry information.

For example:

- electrical signals – voltages and currents in a circuit
- acoustic signals – audio or speech signals (analogue or digital)
- video signals – intensity variations in an image (e.g. a CAT scan)
- biological signals – sequence of bases in a gene.

You'll see more on signals in the context of sound and image analysis, and sound and image creation, in the rest of this subject. However, it is important to appreciate that there is theory about signals that cuts across a number of different subject areas, and

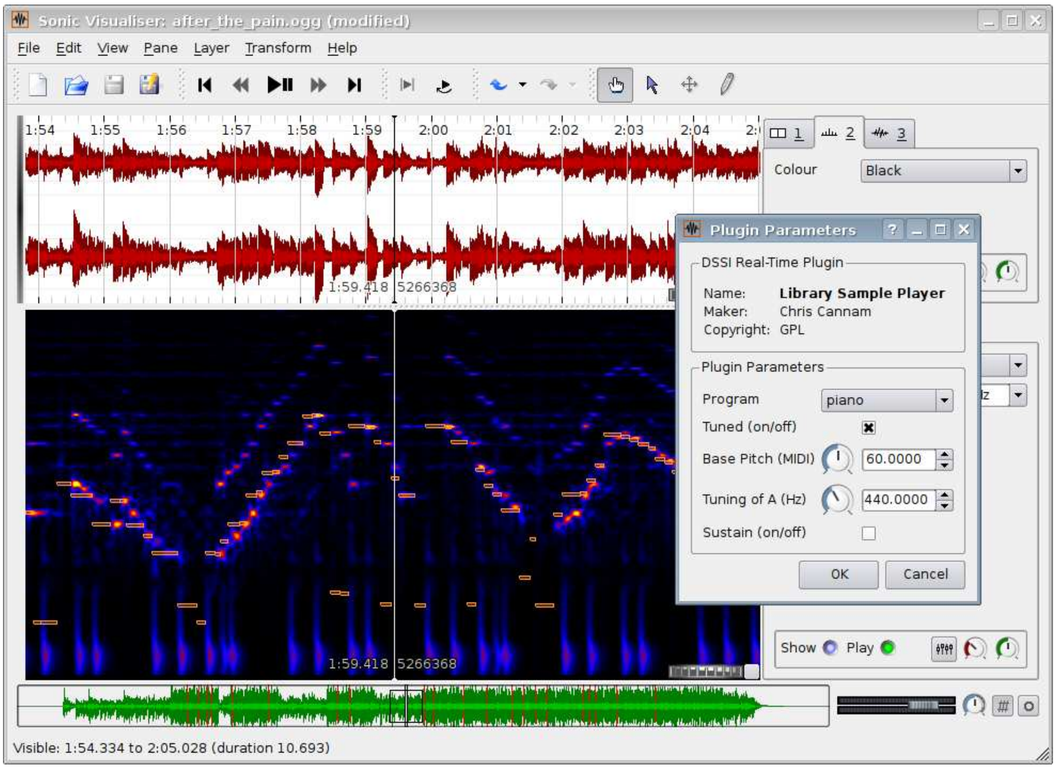

Figure 2.4: Output screen from an audio application.

much progress in research and discovery has been made through utilising those connections.

Learning activity

Write a short comparison that discusses the similarities and differences between the signal types listed above (electrical, acoustic, etc.).

Identify any other kinds of signals if you can, and include these in your comparison.

2.4.1 Independent variables in signals and systems

The independent variables in a signal or a system are those variables that can be manipulated directly, having an effect on the other variables in the system.

Signals (and the variables in them) can be continuous, such as the trajectory of a space shuttle, or mass density in a cross-section of a brain. They can be discrete, as in a DNA base sequence or in digital image pixels.

Variables, signals and systems can be 1-D, 2-D, . . . , N-D. An important 1-D independent variable, that you will see a lot of in the rest of this guide, is time.

We distinguish between:

- Continuous-Time (CT) signals: $x(t), t \rightarrow$continuous values
- Discrete-Time (DT) signals: $x[n], n \rightarrow$integer values only.

Discretisation involves taking a continuous time signal and turning it into a discrete time signal.

Learning activity

How would you go about discretising a continuous signal? What is quantisation? How would you go about quantising a signal?

Learning activity

For the signals in Section 2.4 above, which are the independent variables?

What is a dependent variable? Give some examples of dependent variables in relation to the first part of this learning activity.

2.5 Summary and learning outcomes

In this chapter we saw that sound and image, among many other things, can be viewed as signals. This is the approach taken in the rest of the volume, and this chapter has formed an introduction to the approach. In subsequent chapters, you will learn in more detail about different aspects of signals and signal processing, and how to apply these.

With a knowledge of the contents of this chapter and its directed reading and activities, you should be able to:

- discuss different types of signals
- describe the importance of waves in signal processing
- distinguish between discrete and continuous signals
- convert between angles in degrees and radians; and discuss how sine and cosine waves can be represented over time
- give examples of the application of signal processing in the making of artworks.

2.6 Exercises

1. For each of the different views of signals listed at the very start of this chapter, give a short paragraph explaining what is meant by that entity being a signal. Include examples in your response.
2. Cosine waves and sine waves are both examples of sinusoidal waveforms. What is the relationship between sine and cosine waves?

3. What is the independent variable in a sinusoidal waveform?
4. What do the functions $cos(x)$ and $sin(x)$ do? What is x in these functions?
5. What is the relationship between frequency and periodicity?
6. Find at least three different examples of displaying of audio signals. Describe how each of them works, and compare them in terms of their effectiveness and the advantages and disadvantages of the approach taken.