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WAVES, SPECTRA, AND PENDULA: ACOUSTICS BY COMPUTER*

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1. Introduction

A required course in the major sequence in linguistics at the University of Wisconsin-Milwaukee is the Phonetics Practicum (550-370). This course has two components. One trains students to produce and transcribe speech sounds from the languages of the world. The second component of the course teaches students about the auditory, articulatory, and acoustic bases of speech. This latter goal necessarily involves exposing students to certain basic principles of a more physical-mathematical nature than the typical liberal arts major is accustomed to dealing with. For example, students are exposed to basic concepts of acoustics like frequency, amplitude, resonance, harmonics plus the basics of speech synthesis, source-filter theory, etc. Needless to say, these are difficult concepts to grasp for a student whose mathematics and physics background is limited.[1]

Consider, for example, the notion of a complex wave. A basic acoustic fact is that all complex (speech) sounds or waveforms can be decomposed into component simple sine waves and that simple waveforms can be combined to form more complex waveforms. Thus in understanding the acoustic properties of a complex sound, such as that of the vowel [a], it is incumbent on the phonetics student to understand that the waveform is a consequence of summing component simple waves to produce [a].

In lecturing on this material, pictures, diagrams, and handouts are useful. For example, the following figure (Figure 1) shows how frequency and amplitude of component waves affects the frequency, amplitude, and shape of the resulting complex waveform (Ladefoged 1962:35).

There are two shortcomings with presenting complex waves in this fashion. First, handouts are fixed images that cannot be conveniently altered. Thus, if a student wants to know what would happen if, for example, another component wave with a frequency of 230 cps were added to the complex wave in (1), another diagram would have to be constructed ad hoc to show the results. A better alternative would be some sort of interactive system where students could alter components and see the effect on the complex wave immediately.

A second problem with this teaching methodology is that it does not take advantage of the acoustic aspect of acoustic theory. To help students understand the acoustic consequences of a particular waveform, it would obviously be very useful for them to hear it. This has not been possible in phonetics courses at UWM.

These problems are relevant to almost all aspects of the acoustics component of the phonetics course. Acoustic principles are more easily demonstrated interactively and are more easily demonstrated when the relevant distinctions can be heard.

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[1] This same point is made by Port (1981:35)

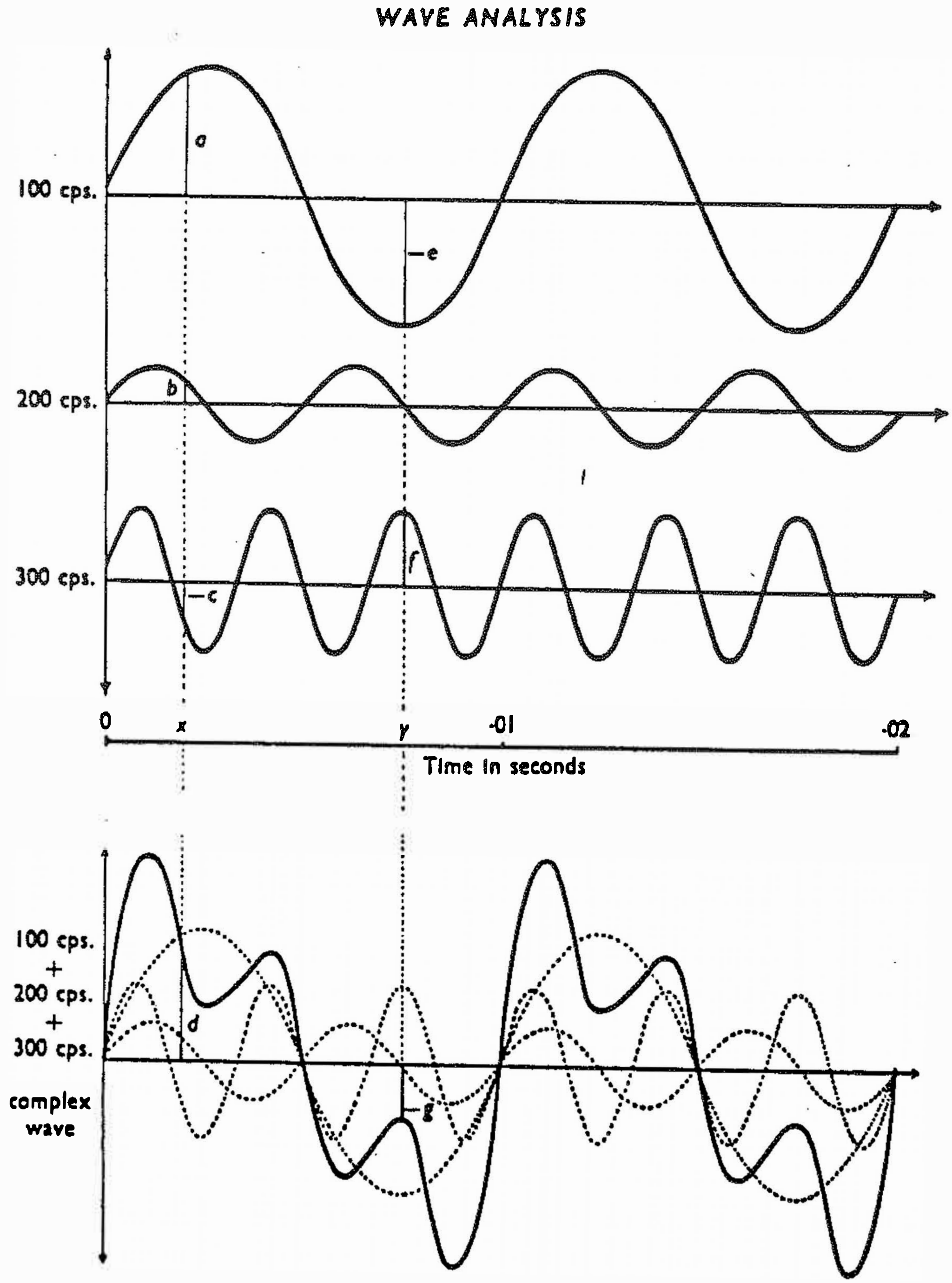

Figure 1

In this paper we describe a series of computer programs we have been developing for teaching some simple acoustic principles. These programs address both of the problems above. First, they allow students to manipulate acoustic primes (e.g. frequency and amplitude, or source and filter) to construct various objects (waveforms and spectra). Thus the student gets immediate visual feedback. The programs address the second problem above as well. The programs allow the student to hear the acoustic objects he has constructed.

2. Resources

We decided to develop these programs for the Macintosh microcomputer. Our reasoning was threefold. First, the Mac is an extremely easy machine for programming graphics and sound--the key ingredients for the programs. Second, Macs have become rather common in the linguistics community, particularly among phoneticians.[2] Our reasoning here was that the software would be most useful if it were as widely available as possible. Our third consideration was that the Mac is well-known as an easy-to-use machine. We did not want a complex operating system or user interface to prevent easy use by students.

The language we chose to develop the programs in is Pascal. The basic reasons for this are as follows. First, Pascal is a highly structured language which makes it fairly easy to use. Second, and most importantly, the basic documentation on the Mac is written for Pascal.

The compiler we chose was *Lightspeed Pascal*. It compiles very quickly, conforms well to the Mac interface, and allows one to run 'virtually interpreted' code for debugging.

3. Waves

The basic goal of 'Waves' program is to demonstrate how complex waves can be produced by summing simple waves. In this section we show how this program works.

The program allows the user to enter frequencies and amplitudes for up to four simple waves. These waves can be displayed as waveforms or as a sound spectrum and they can be played out through the sound generator. In figure 2 we show the screen that appears when the program is started up.

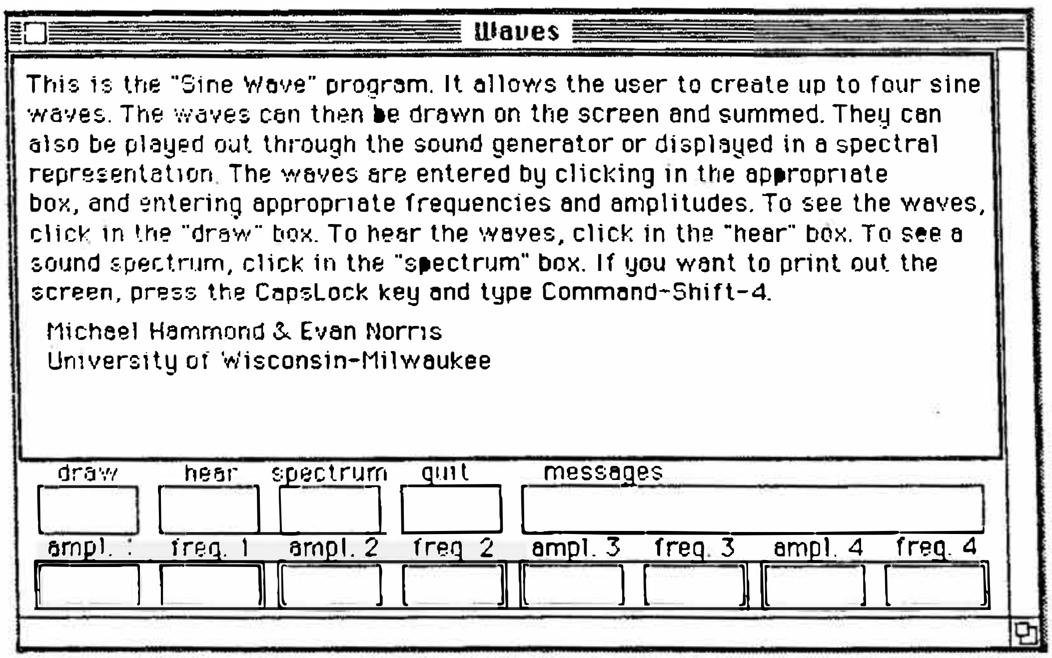

Figure 2

2 See, for example, Ladefoged (1985a,b) for evidence of this.

Frequencies and amplitudes are entered by clicking in the appropriate box with the mouse and then typing in an appropriate number. When one of the frequency or amplitude boxes is clicked in, the message box reminds the user of the appropriate range for that box.

Once amounts are entered, the user can then select one of the three buttons: 'draw', 'hear', or 'spectrum'. At this point, if one of the amounts is out of range, an appropriate message appears, e.g. 'Freq. 2 out of range'. If the amounts are in range, the different buttons trigger different functions. The 'spectrum' button will display a simple line spectrum for the frequencies and amplitudes entered. In figure 3 we show the spectral display.

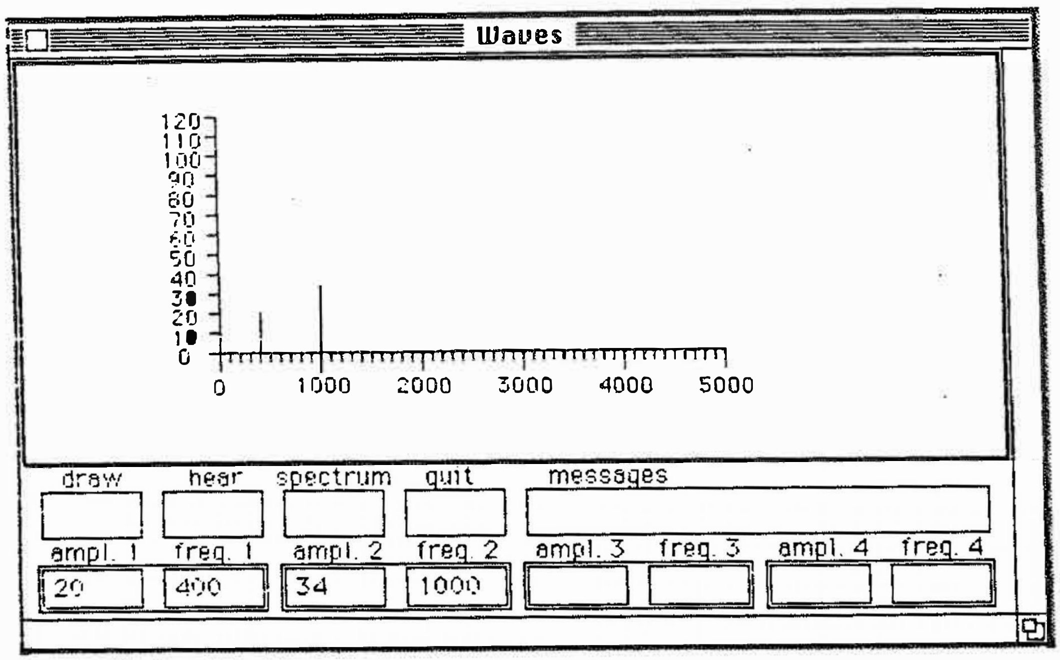

Figure 3

The 'draw' button draws out waveforms appropriate to the numbers entered. The waves are summed and the complex wave is also drawn, with a darker line. The program does not allow the user to manipulate phase to change wave shape. Even though phase has a significant effect on waves of this sort, it is generally irrelevant to speech acoustics and has therefore been excluded here. In Figure 4, we show the output of the 'draw' function for the same waves as in (3) above.

Last, the 'hear' function allows the user to play the wave created.

4. Spectra

This program allows the user to manipulate sound spectra and hear the output. The user enters formant peaks and a fundamental frequency, and the program calculates harmonics and can play out the result. In Figure 5, we show the screen that comes up when the program starts.

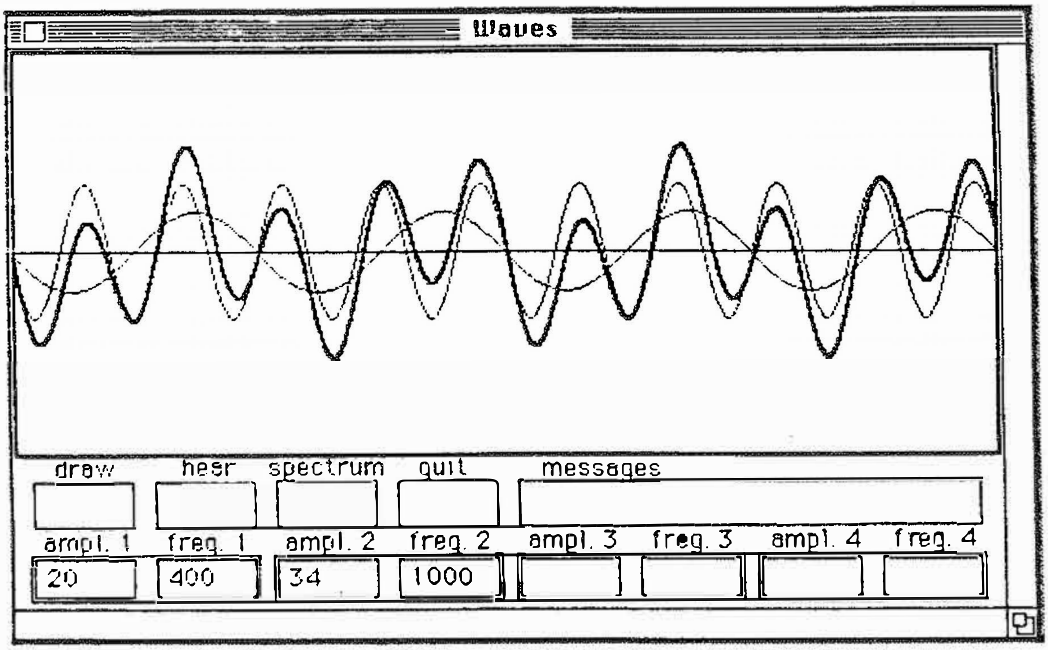

Figure 4

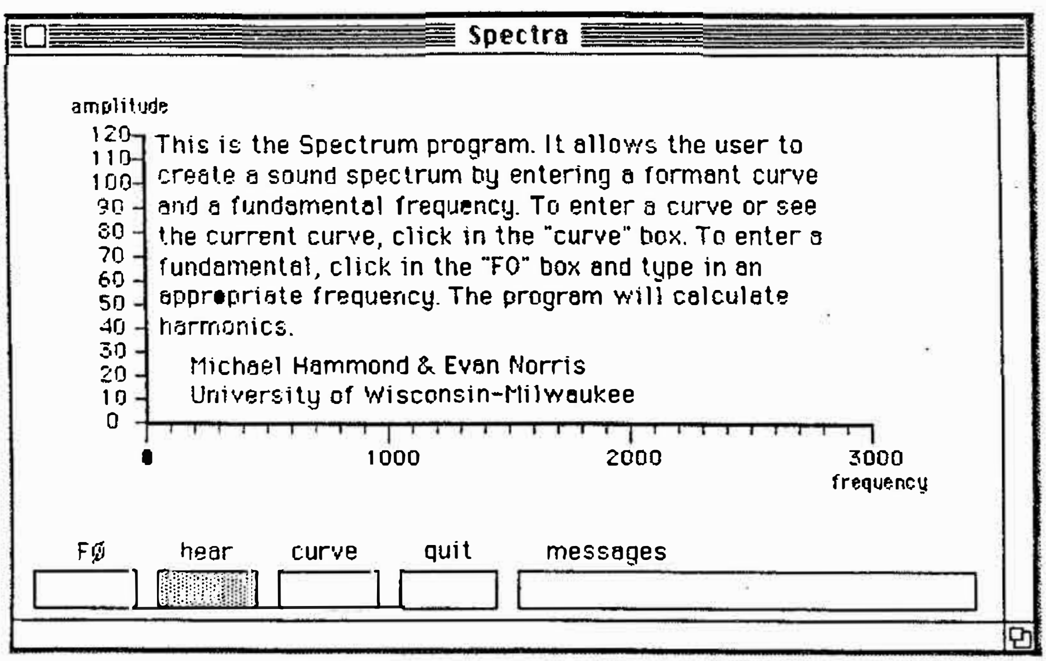

Figure 5

To enter a fundamental frequency, the user clicks in the 'FØ' box and types in an appropriate amount. As with the 'Waves' program, the user is reminded of the range by the message box. Once an appropriate FØ has been entered, the program calculates all harmonics up to 3000 Hz. In Figure 6, we show the result of entering 234 Hz in the 'FØ' box.

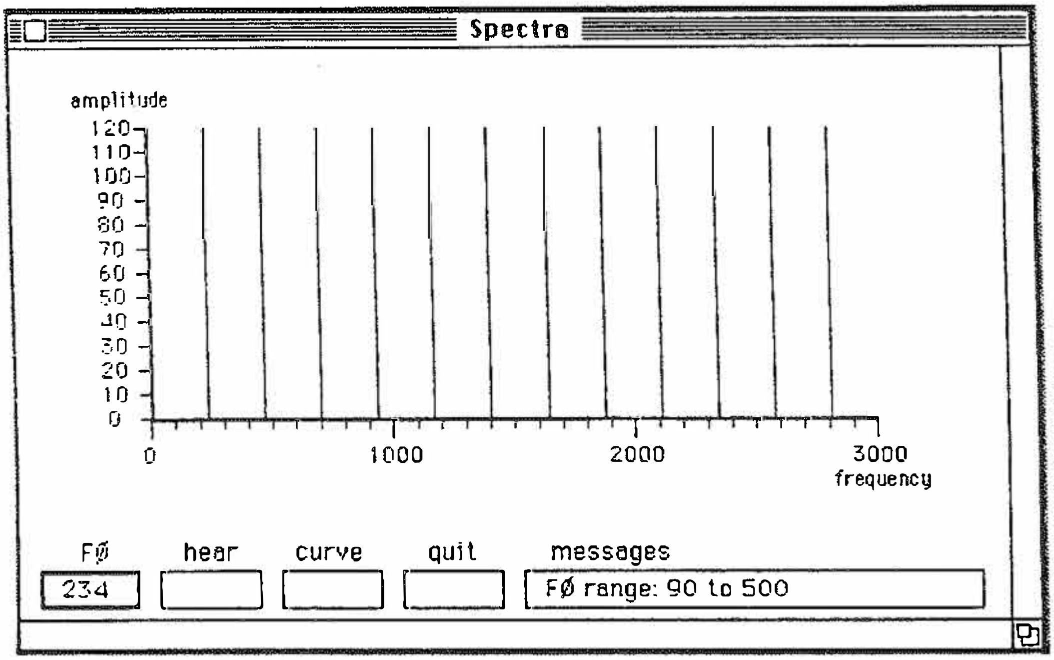

Figure 6

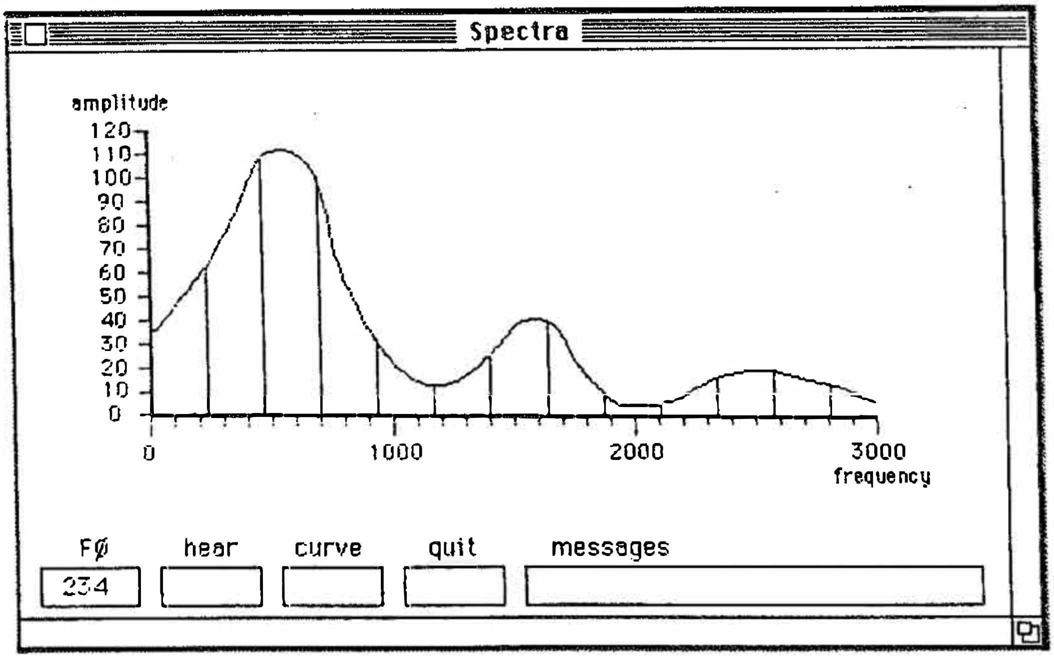

Figure 7

To enter a formant envelope, the user clicks in the 'curve' box. The program then redraws the current envelope (if there is one). If the user wants to enter a new curve, he can now click in the spectrum frame. A curve is drawn by then pulling the mouse from left to right. If a fundamental frequency has been already entered, the harmonics are automatically drawn under the envelope. In Figure 7, we show a curve that has been entered with the 234 Hz fundamental from (6).

An interesting feature of the program is that if the fundamental is entered or changed after the curve has been entered, then when the harmonics are (re)calculated, they are drawn under the envelope, but the curve is not redrawn. (The current curve can be redrawn by clicking again in the 'curve' box.) This allows the student to observe how the amplitude of the harmonics of a high frequency fundamental give relatively little information about the frequency of formant peaks. In Figure 8, we show the same curve as in (7) above, but where the curve has not been redrawn (yet) after the fundamental was entered.

As before, the output can be heard by clicking in the 'hear' box.

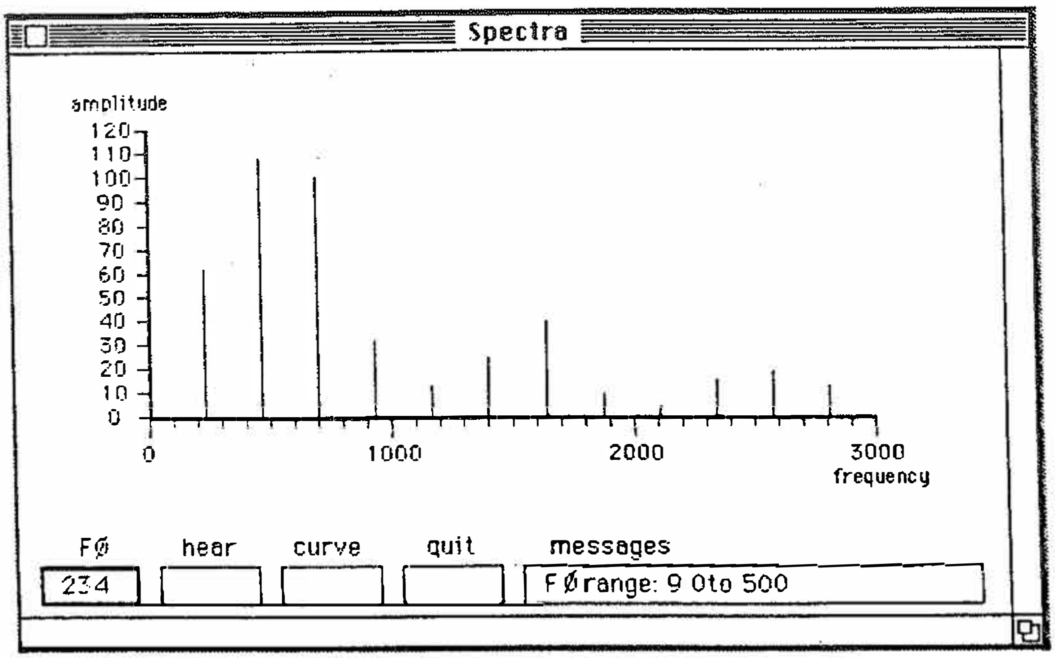

Figure 8

5. <u>Pendula</u>

The Pendulum Program demonstrates the relationship between periodic motion and sine waves through the use of animation graphics. When the program is invoked, a pendulum and various control buttons are drawn in the program window (Figure 9).

As the program runs, the pendulum swings back and forth and the tip of the pendulum traces a line in a rectangular area of the screen below the pendulum. (Figure 10) The contents of this area are continuously scrolled from top to bottom, creating the illusion of a waveform moving along a horizontal plane from the pendulum tip towards the viewer.

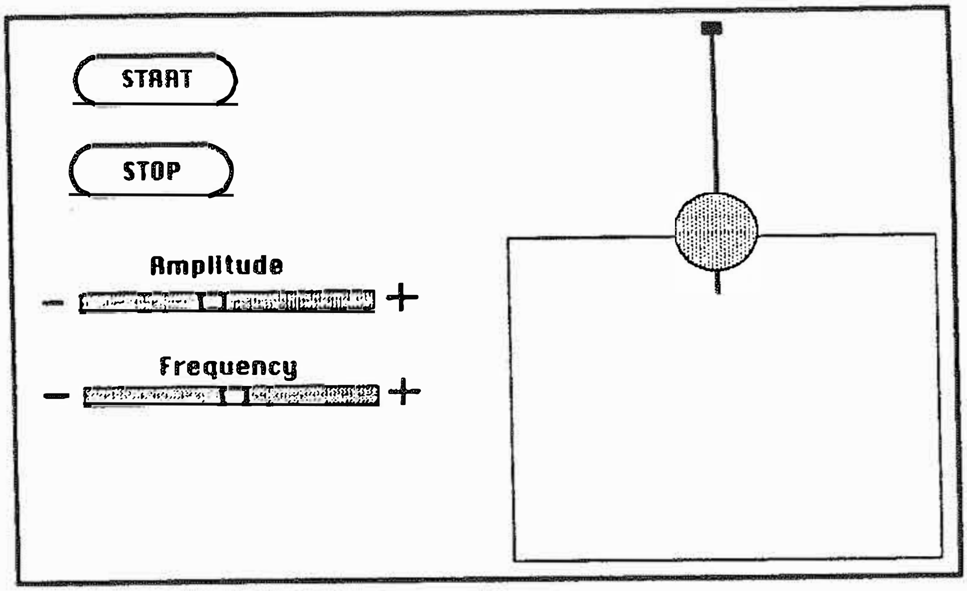

Figure 9

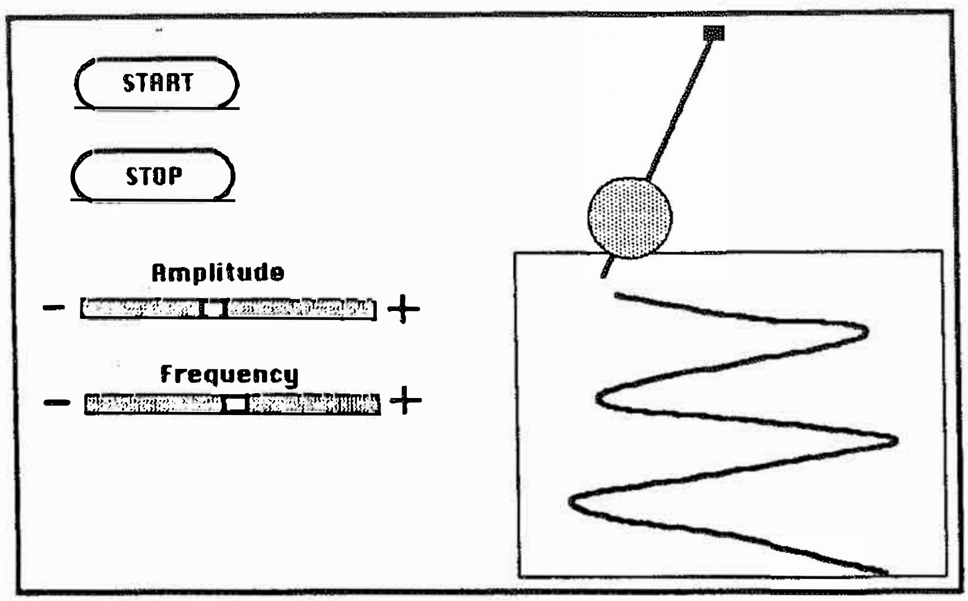

Figure 10

The two slide bar controls in the program window allow the user to control the frequency and the amplitude of the pendulum's swing within program-defined limits. The amplitude can be set to any whole degree value between 15 and 45 degrees of arc from the vertical. The initial value is 20 degrees of arc. Of course, as the user increases or decreases the amplitude of the pendulum's swing, the waveform generated by the pendulum becomes appropriately wider or narrower.

The user is also able to use the graphic slide controls to vary the frequency (or rate) of the pendulum's swing. When the control is activated by the user, the pendulum's motion becomes faster or slower and the waveform is appropriately modified. In the interests of verisimilitude, the pendulum bob is drawn correspondingly higher or lower on the pendulum whenever the frequency is changed.

Since this program treats the frequency and amplitude as independent parameters, the modification of one has no effect on the other. By allowing users to control amplitude and frequency, the program is able to clearly demonstrate how these factors interact in the generation of waveforms.

6. Particle Motion and Pressure Waves

Sound waves can be conceived of either as the movement of particles or changes in pressure. This program demonstrates the relationship between these two ways of looking at waves. When the program begins, the user is presented with a program window containing a line of particles, a flat pressure wave, and three control buttons. (Figure 11)

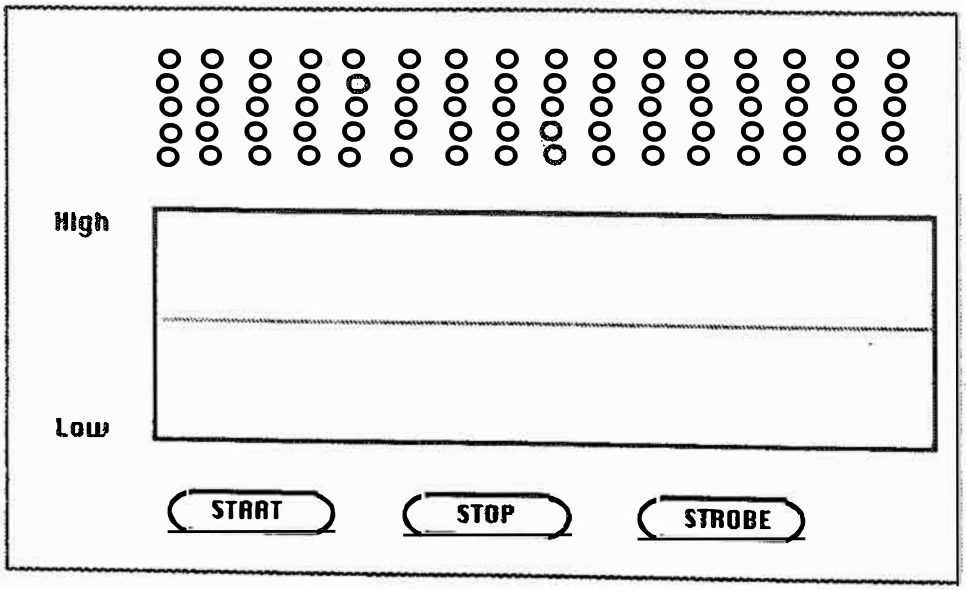

Figure 11

Clicking on the START button activates the animation. (Figure 12) The leftmost particle moves rightward and bumps into its neighbor. The collision causes the second particle to move rightward while the first particle moves back toward its original position. The second particle collides with the third, which collides with the fourth, and so on.

The parallel representation of the wave as changes in pressure takes place in the lower part of the screen. A line drawn across the screen below the particles represents relative pressure. As adjacent particles move relative to one another, the pressure wave registers the relative pressure between them. Since the pressure wave is generated by the serial movement of adjacent individual particles, it has the same form as the wave describing the motion of any of the individual particles.

The screen in which this activity occurs relies on interaction with the user. When the program begins, the images on the screen are motionless until the user clicks on the GO button. The leftmost particle begins moving toward the second and the pressure wave beneath the first and second particles shows an increase in pressure. The motion of the particles and the variation in the pressure wave move steadily across the screen. Clicking on the STOP button will freeze the images at any point.

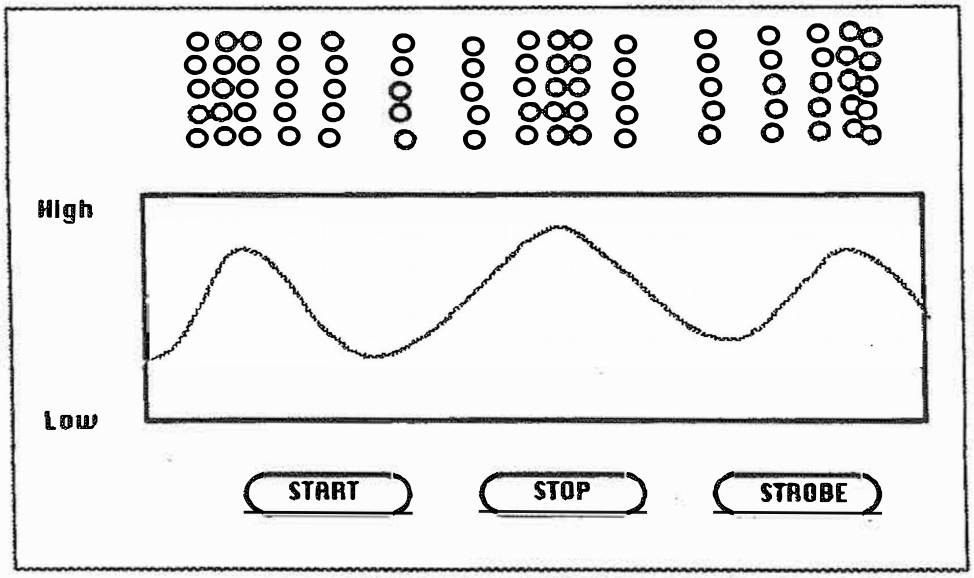

Figure 12

In the same way as a photographer uses a strobe light to record the movement of an object in a series of still photographs, the user can click on the STROBE button to freeze the motion of the images. Subsequent clicks on the button will advance the images one step further in their cycle of movement and again freeze the motion. This option allows the user to step through the progression of events very slowly and to observe the relation between the various elements in a way that can be very difficult when the images are in continual motion.

7. Appendix

Both source code and compiled versions of the first two programs are available through electronic mail: hammond @ rvax. cclt. arizona. edu or evan. norris @ mail. admin. wisc. edu. (Compiled programs can be downloaded with BinHex.)

The programs and source code are also available through normal mail: (enclose a 3.5-inch disk).

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References

Ladefoged, Peter. 1962. *Elements of Acoustic Phonetics*. Chicago: University of Chicago Press.

_____. 1985a. Macintosh usage for linguists. *UCLA Working Papers in Phonetics* , 60. 84-6.

_____. 1985b. Macintosh models and plots for phoneticians. *UCLA Working Papers in Phonetics,* 61. 65-71.

Port, Robert F. 1981. An acoustic curriculum for a phonetics course. *Innovations in Linguistics Education,* 2.1, 35-56