SIGNAL AND NOISE: THE BASICS
STUDENT GUIDE

DESCRIPTION

Have you been in a noisy room trying to have a conversation with a friend? Have you watched a YouTube video of an old movie when the picture was fuzzy and grainy? These are examples of audio and video in a noisy environment.

Physicists have the same problem when they try to collect data in a "noisy" environment. With complicated equipment such as our cosmic ray detector, there are many sources of possible "noise" in the signal. In this activity, we learn what factors affect the noise level and how to recognize a signal in noisy data.

Work in groups of two or three. There will be many thought questions.

Record your own answers.
Discuss the questions with your group and record the group consensus.
Pay attention to the vocabulary words listed below.
Copy the list and when you find the definition; be sure to update your vocabulary page.

VOCABULARY

- Signal
- Noise
- Signal-to-noise ratio

This activity is divided into three sections. As you do each section, work with your partners to answer ***What Do You Think*?** Your teacher may ask your group to present your answers.

ANALYSIS PART 1: NOISE IN OUR DAILY LIVES

Section 1: Sound Waveforms

Listen to two short audio tracks. One track is a drummer and the other is a recording of a tribal bells ceremony.

Below is a depiction of the waveform for a regular drum beat (*link to drum file*) sample:

Figure 1. Typical drum waveform.
https://www.soundsnap.com/search/audio/checker+drum/score

and the other a tribal bells ceremony (*link to tribal bells ceremony*):

Figure 2: Tribal bell dance.
https://www.soundsnap.com/search/audio/BTF+06+Tribal_30_Bells-+Dance-+People-+Crowd-General-+Ambience_06/score

1. ***What Do You Think?***
   Suppose you are on vacation and observe a tribal bells ceremony. You notice it becomes difficult to tell what you are hearing because of the increasing noise from the crowd, so you try to get closer to the ceremony.
   - What do you hear? Does moving closer to the ceremony solve the problem?
   - Compare the wave form for the drum and the wave form of the tribal bells ceremony. Record the similarities and differences.
   - Suppose the drum track had a lot of noise in it; what would the picture of the waveform in Figure 1 look like?

Section 2: Video Noise
Consider the images shown below:

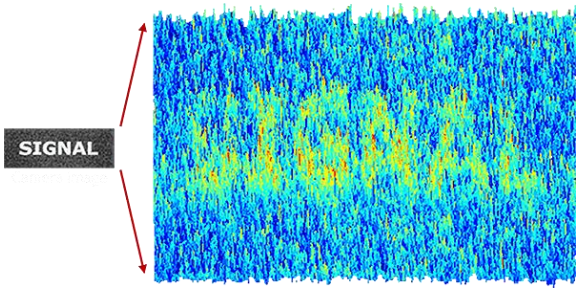

Figure 3.
http://cdn.cambridgeincolour.com/images/tutorials/noise_signal2_new.png

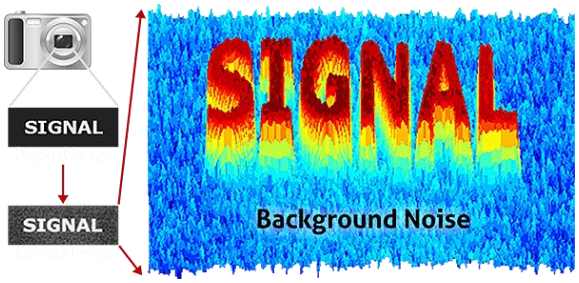

Figure 4.
http://cdn.cambridgeincolour.com/images/tutorials/noise_signal1_new.png

2. ***What Do You Think?***
   You are working the video board at the local recording studio. You notice that there are controls labeled contrast and gain. Contrast controls the difference between the brightest and the darkest the image can be. Gain controls the amplitude of the signal.
   - Describe how the contrast and gain knobs were adjusted to create the image in Figure 4 from the image in Figure 3.

PART 2: NOISE IN AN INSTRUMENT READOUT
Section 3: Cosmic Ray Detector Noise
Similar to sound waves created by hitting drums, the cosmic ray detector "hears" signals produced by muons that pass through one of the counters. When the muon passes through the counter, it produces a brief flash of light that is converted into an electronic "signal." The figure below shows what a typical muon signal looks like when plotting PMT voltage vs. time.

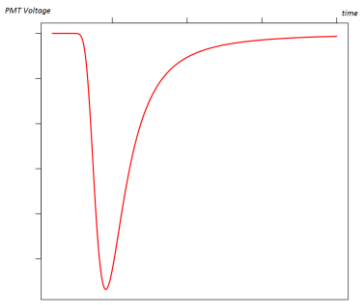

Figure 5. A typical muon signal.
https://upload.wikimedia.org/wikipedia/commons/thumb/2/2a/Landau_distribution.svg/1024px-Landau_distribution.svg.png

This plot shows a very smooth curve which is the ideal representation of ideal data. However, there are lots of other things happening in addition to the muon passing through, and all of these things can add noise to the data. This noise could come from a variety of sources and can have a variety of shapes. Below is an example of what a noisy readout looks like, next to a less-noisy readout where the signal is easier to see.

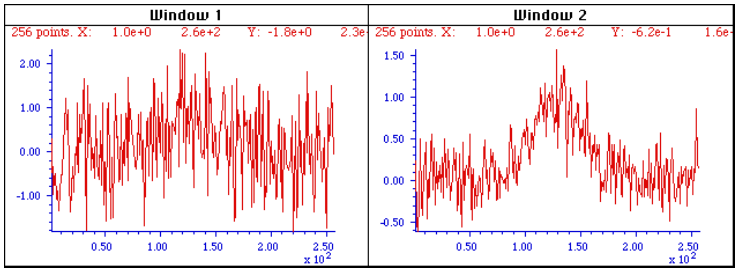

Figure 6: Noisy vs. less-noisy readout.
http://terpconnect.umd.edu/~toh/spectrum/Figure3.GIF

Physicists need to know how well to trust that a signal is present. One measure of this is the signal-to-noise ratio. If the readout is very noisy as in the left readout in Figure 6 above, the signal does not clearly rise out of the noise and the signal-to-noise ratio is small. When the signal clearly rises above the noise as in the right readout in Figure 6 above, the signal-to-noise ratio is larger. The bigger the signal-to noise-ratio, the more we can trust that a signal is present.

3. What Do You Think?

When looking at the readouts shown above, Student A said that both of the readouts have so much zigzagging that it is impossible to decide if there is a signal present. Student B said that the zigzags on the right were smaller and the peak was higher than the zigzags on either side, so the readout on the right must have a signal.

- Who is correct, Student A or Student B? Explain your reasoning.
- Describe the details that led you to the claim that a signal is present in a noisy readout.