The Open University

The sound of silence
Waves and harmonics

Janice Acquah
Back in the video band for unit 9, I learnt something about the maths of rhythm and the beat in music with this band, Betty's kitchen. Well today I'm hoping to find out why each musical instrument has its own characteristic sound. What exactly is going on that distinguishes a guitar from a fiddle.
I'm presuming it has something to do with this jazzy little display here, that lights up as the music plays, and claims to be telling me something to do with the frequencies. Well to be honest I've always wondered what exactly a display like this is telling me, I guess it has something to do with how loud the notes are and, which ones are low and high. But I'm hoping that Alan Graham who I teamed up with last time, is going to make it all crystal clear. Right I'm just going to give Alan a call on the mobile phone. Hello Alan it's Janice.

Alan Graham
Hello Janice.

Janice
Hi. I want to come round and talk to you about music again.

Alan Graham
That's fine, we've got a gig tonight, but maybe you could join us at the rehearsal this afternoon.

Janice
Great. Alright, I'll see you later then.

Alan Graham
Yeah see you bye.

Alan Graham
Can you just stop, I think you're a whee bit too loud Sheila, I'm just going to take you down a touch.

Sheila
I played it all wrong anyway.
LAUGH

Alan Graham
Okay let's try it from the beginning of part 2.

Everyone
Two three four.

Alan Graham
Hello Janice.

Janice
Hi there. How are you all. Good to see you.

Alan Graham
Anyway we're just about to have a break so, shall we just stop for a while.

Sheila
Yes.

Janice
Great. That sounded great Alan. Well I've come for my music lesson and to hear the performance later. But can I start with basics. When you're all playing the same not on your instruments, each note sounds different, why is that?

Alan Graham
Well to understand that, I think you need to know how a note is made up. Let's take a very simple example of a tuning fork. When a tuning fork is struck it gives a pure simple not, a single frequency, and let's look at the trace that it produces.

Alan Graham
Because it's such a pure not, it gives a When a tuning fork is tapped, the prongs or tines have been designed to oscillate at a particular rate.

Alan Graham
Look at the behaviour of just one of the prongs. It starts at rest with zero displacement from the horizontal. Plotting the displacement against time, gives you a regular sign curve. One peak and one trough together, represent a single cycle of the sign curve. A fork that's tuned to middle C, will produce a cycle two hundred and fifty six times a second. This frequency is often described as two hundred and fifty six hertz. So you've got this graph by plotting amplitude, that's the vertical displacement from the horizontal, against time.

Janice
So does it matter how hard you hit the tuning fork?

Alan Graham
Well, you might be tempted to think that if you strike it harder, the tines or the prongs vibrate more quickly, well that can't be true. This is a tuning fork in C, it will always strike C however hard you hit it. But if you strike it harder, and let's see what happens.

Alan Graham
and that's what it looks like when I hit it hard. You can see the amplitude has increased.

Janice
So the peaks and the troughs are more extreme aren't they?

Alan Graham
That's right. So strike it harder and it gets louder, but the pitch doesn't change.

Janice
So the amplitude tells you how loud the note is.

Alan Graham
That's right yeah.

Alan Graham
Tap the fork harder, and the prong is displaced by a greater amount.
You don't get a greater number of oscillations per second, what you do get, are oscillations of a greater amplitude than before. Each of these sign curves, has the same frequency, that's one cycle every two hundred and fifty sixth of a second, it's only their amplitudes that differ.
Janice So Alan if you change the note you play, how does that affect the trace you get?

Alan Graham
Well, you've seen the trace for the note C, now this blue tuning for is tuned to A, that's the A below C so it's a lower note, and if I hit that one.

Alan Graham
and just have a look at the trace. This lower trace is the one for A. and the waves are more widely spaced out here, than they were with the higher note. The reason being that, with A, the frequencies are less, so that they're more widely spaced, but there's not real difference in the amplitudes because I struck them both quite gently.

Janice
So in fact the compactness of the waves, tells us, whether the note is higher or lower in pitch.

Alan Graham
That's right yeah.

Alan Graham
This fork is tuned to the note A below middle C. As such, it's been designed to oscillate at a frequency of two hundred and twenty hertz. This new note in blue, vibrates more slowly, so its peaks and troughs are slightly more spread out, with one oscillation every two hundred and twentieth of a second.

Janice
But Alan, here you're talking about pure notes, what do these traces look like for real instruments. **Janice** But Alan, here you're talking about pure notes, what do these traces look like for real instruments.

Alan Graham
Well let's hear a real instrument. Moira if you could play us two notes. First of all play us a soft A.

Alan Graham
and that's the trace. Now, a loud A.

Janice
Well they're a lot messier aren't they.

Alan Graham
They are a lot messier but, there are some common themes. First of all, there's a regular repeating pattern, but secondly, the soft note had a much smaller amplitude than the loud note.

Janice
So what's all this messiness about?

Alan Graham
Well, on a real instrument when you play a note, it's not just the note that you play, that sets off a lot of other notes called harmonics. So what you're hearing is a fundamental note that you have played, combined with the various harmonics that have been set off.

Janice
and how can you tell what these different frequencies are?

Alan Graham
Well, it turns out that the frequencies of the harmonics are, exact multiples of the frequency of the fundamental note.

Alan Graham
Well, it turns out that the frequencies of the harmonics are, exact multiples of the frequency of the fundamental note. Here's a demonstration. It's like a big version of a fiddle string. There's a motor at one end which jigs up and down to set the string vibrating. At a certain frequency, the string forms a steady wave, this occurs at the fundamental or first harmonic

frequency of the string. Doubling the frequency of the motor, gives you the second harmonic. At three times the fundamental frequency, you get the third harmonic, and so on.

Janice
So, I can see there are different harmonics, but how do you know, how much of each harmonic there'll be for a particular instrument?

Alan Graham
Well it's pretty hard to separate them out from the sort of graph we've been looking at, it's very messy, but there's another way of representing that information. You can separate out each of the harmonics, and represent each one individually on a different type of graph called, a frequency spectrum, but with a frequency spectrum, instead of having amplitude against time, you have amplitude against frequency
Here's the wave form graph for the pure note C, at two hundred and fifty six hertz, with amplitude plotted against time. You can represent the amplitude of this note in a different way, on what's called a frequency spectrum graph, by plotting amplitude against frequency. A frequency of two hundred and fifty six hertz, can be represented as a point on the horizontal axis. The height of this spike on the graph, then represents the amplitude of the note of that frequency. Now here's the wave form graph for the note A.
It shows two differences from the previous note. The pitch of this note, is lower than the last one.
So the frequency of two hundred and twenty hertz, is at a point on the horizontal axis, that's slightly closer to the origin. This new note also happens to be quieter than the previous note, and so in this case, the amplitude, at two hundred and twenty hertz, appears as a shorter spike on the graph, than the spike at two hundred and fifty six hertz. So this is the wave form of fiddle, and this is the corresponding frequency spectrum. and you can see, this is the spike corresponding to the fundamental note, and all of these, are the various harmonics.

Janice and you can tell how much of each you need, INAUDIBLE the amplitude there.

Alan Graham
That's exactly right yes. and you could do that for any instrument. But this is the characteristic shape of the fiddle. If you like this is like a fingerprint of what a violin sounds like.

Janice
So, I've always wanted to play the saxophone, and I see you've got one there. So breaking it down like that, I could go away, and make my own saxophone sounds.

Alan Graham
Yes, why don't I play you a note, take it away, and that's the fingerprint of your own saxophone.