Hayward Tuning Vine

Documentation for v1.5.0

Introduction

The *Hayward Tuning Vine* is a colour-coded model of harmonic space in Just Intonation, invented in 2012 by the microtonal tuba player and composer Robin Hayward. This software will allow you to explore that harmonic space in real-time, using your computer's sound card to produce audio.

Versions of the software exist for all major desktop systems: OSX, Windows and Linux (via Wine). This manual is meant to cover all those platforms, and teach you how to install the software (System Requirements & Installation) and become familiar with the user interface (1. Learning the Interface).

Finally, the manual will guide you through the software in a series of steps that gradually become more complex (2. How the Hayward Tuning Vine works). Once you have completed these chapters, you should have a thorough understanding of the *Hayward Tuning Vine* and be able to use it as an interface for exploring Just Intonation.

System Requirements

Supported operating systems:

- Windows 7, Windows 8, Windows 10
- Mac OSX 10.10 (Yosemite) to 11 (Big Sur)

The *Hayward Tuning Vine* is also known to work on the Linux platform through Wine (using the default Win compatibility settings).

Installation

Step-by-step installation instructions for each supported platform

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Mac

To install

1. Start by downloading the Mac OSX installer from www.tuningvine.com
2. Make sure you uninstall any previous version of the software.
3. Locate the downloaded file (a disk image, or “dmg” file) on your hard drive, and double-click it to mount the disk image.
4. The disk image will display it’s contents. Drag the application (33.app) into your Applications folder to install it.
5. Click on the Hayward Tuning Vine application to launch it.
6. A popup menu may appear informing you that the app is downloaded from the Internet, and asking if you are sure you want to open it. Click on ‘Open’ to proceed. (You may need to visit ‘Security and Privacy’ under ‘System Preferences’ in order to open the software).

To uninstall

Drag the Hayward Tuning Vine application from the Applications folder into the Trash.

Windows

To install

1. Start by downloading the Windows installer from www.tuningvine.com
2. Make sure you uninstall any previous version of the software.
3. Locate the downloaded file (file name ends with “Setup.exe”) on your hard drive, and double-click it to launch the installer.
4. Windows might tell you that the software is downloaded from the internet, or from an unknown publisher. If you are OK with this, tell Windows to run the installer.
5. The installer is launched, and will take you through the installation process. You can specify the location where the software is installed, and whether to create a desktop icon etc.

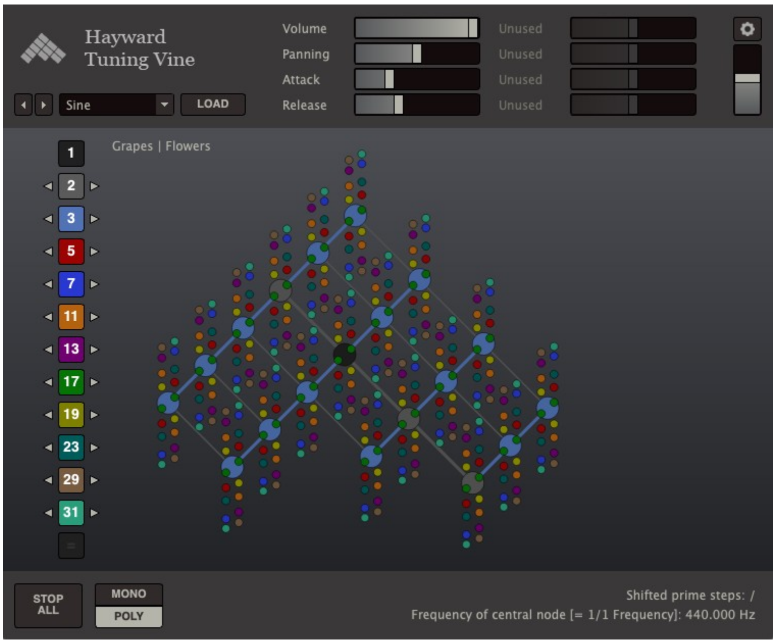
To uninstall

1. From the start menu, go to the folder named “Hayward Tuning Vine” and select “Uninstall Hayward Tuning Vine”.
2. Alternatively, from the program files folder, go to the folder named “Hayward Tuning Vine” and launch the executable file whose name starts with “unins” (e.g. “unins000.exe”).

1. Learning the Interface

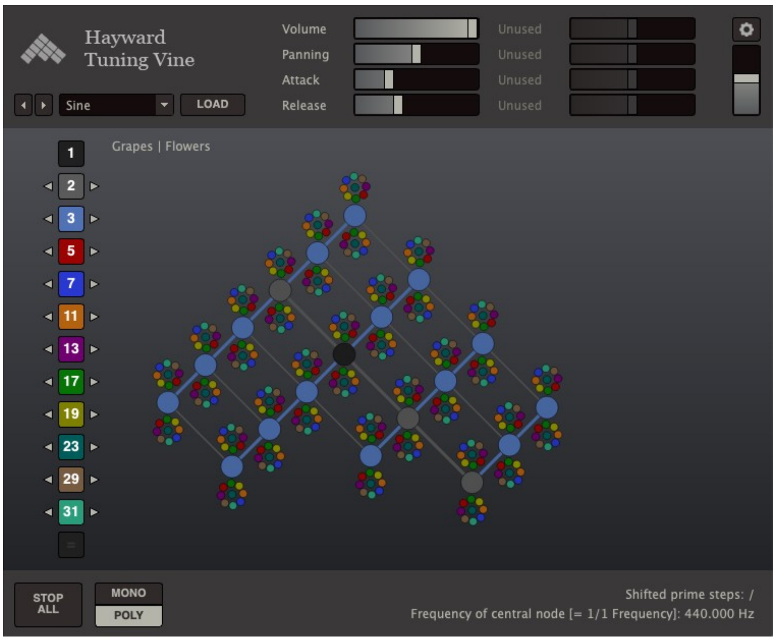
The Hayward Tuning Vine: Flowers / Grapes view

When you first open the Hayward Tuning Vine, this image appears on your computer screen:



Each of the coloured nodes represents a unique pitch. By clicking your mouse on them, you can build chords of up to a 128 pitches.[1] Use the 'STOP ALL' button in the lower left hand corner of the screen to turn off any currently sounding pitches.

Next, click on 'Flowers' above and to the left of the tuning vine lattice. The screen now looks like this:



1 In case you can't hear any sound, click on the 'Options' icon above the volume slider at the upper right corner of the screen. Make sure the correct audio interface is selected, and that the volume slider is not turned all the way down.

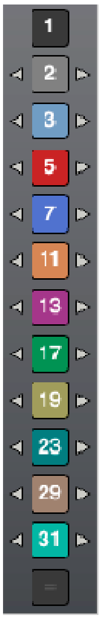
Although they look different, the two views contains exactly the same information. In 'Flowers', it is immediately clear which smaller nodes are associated with which larger nodes, so it is the better choice for becoming familiar with the *Hayward Tuning Vine*.

In 'Grapes', each node is positioned according to the height of the pitch it refers to - the higher the pitch, the higher the vertical position on the screen. It therefore gives a more accurate reflection of the melodic pitch relationships.

You can compare the two directly by selecting some of the smaller nodes and toggling between 'Grapes' and 'Flowers' view.

Now toggle to 'Flowers' view and click on 'STOP ALL' at the lower left of the screen before moving onto the next section.

Number boxes and shift arrows



Each of the coloured number boxes running down the left of the screen corresponds to the coloured nodes within the tuning vine lattice. Try clicking on the turquoise number box numbered '23'. You'll notice that this deactivates all the turquoise nodes. To reactivate them, simply click on the turquoise number box again.

All of the colours in the *Hayward Tuning Vine* may be toggled on and off except black, grey and light blue, which stay permanently on.

With the exception of the black number box marked '1', all of the number boxes also have arrows placed to the left and right of them. These are 'shift'[2] arrows, which enable you to shift the tuning vine in the direction of any of the numbers. We'll come to the higher numbers in the section 'How the Hayward Tuning Vine works'. For now you can start by clicking on the central black node, and then on the arrows to the left and right of the grey number box marked '2', and the light blue number box marked '3'. Notice how this changes the position of the sounding pitch within the tuning vine lattice.[3] Meanwhile the central node turns pale, providing a clear visual reminder that shift arrows are currently activated.

Now reset all the shift arrows by clicking on the '=' sign beneath the number boxes. Notice how the sounding node returns to its central position, which turns black again to signal that the shifts are no longer active. Before moving onto the next section, turn off the sounding pitch by clicking again on the black node or on 'STOP ALL' at the lower left of the screen.

MONO / POLY modes

The 'MONO / POLY' toggle is located next to 'STOP ALL'. 'POLY' mode is ideal for building up chords, as each note remains sustained until it is turned off. 'MONO' mode is better for playing melodies, as each note stops when the next note starts. It's possible to toggle between the two modes while the notes are sounding. So for example, you can build up a chord in 'POLY' mode, and then switch to 'MONO' mode to solo over it.

2 In earlier manuals these were referred to as 'transposing' arrows. This terminology proved confusing, as it is not the actual pitches that are transposed, but rather their position within the lattice. 'Shift' reflects these changing positions, without implying that the sound itself is transposed by clicking on the arrows.

3 For all arrows, shifting may be continued as long as the central black node stays within the audible range of 20 – 20000 Hz. Outside this range the arrow disappears from the screen, to indicate that further shifting in this direction is no longer possible.

Before moving onto the next section, make sure the *Hayward Tuning Vine* is set to 'POLY' mode.

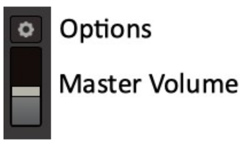
Patch selection and parameters

The patch selection buttons are located at the upper left of the screen. Here you can select what sort of sound that will be played when you click on the coloured nodes, either by selecting directly from the drop-down menu, or by toggling through the arrows to the left it. The *Hayward Tuning Vine* comes with the standard wave shapes of Sine, Square, Triangle, and Sawtooth. You can also synthesise your own sounds using the free software Pure Data, and enter them into the application using the 'LOAD' button (see the section Creating your own voice patch).

To the right of the 'LOAD' button are the parameter settings. Here you can adjust the volume, panning, attack and release times the sine waves, along with a lowpass filter when using more complex waveforms. Note that the inbuilt parameter settings always affect the pitches you're about to play, rather than those that are already sounding.

Options and Master Volume

At the top right hand corner of the screen are situated the 'Options' icon and the 'Master Volume' slider.



Before each session with the *Hayward Tuning Vine*, play the maximum number of pitches you anticipate simultaneously using. If the resulting chord causes the sound to distort, lower the 'Maser Volume' level until the distortion disappears. The session will then be free from distortion.

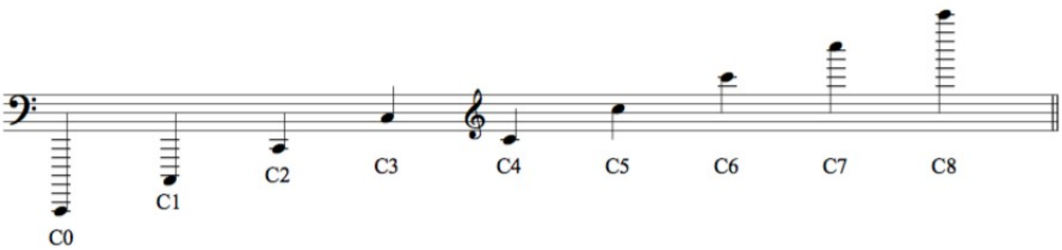
Above the 'Master Volume' slider is the 'Options' icon. Clicking on it opens the dialogue box for selecting your 'Audio Device', the 'Calibration' and the '1/1 Note' (pronounced '1 to 1 Note'). As on standard tuners, 'Calibration' is the reference frequency on which the tuning is based. By convention this is always set to 'A4', the pitch a major sixth above 'middle C' on a piano keyboard. When the software is first installed this pitch is tuned to 440 Hz, but you can change it to any number between 349 and 499 Hz.[4]

'1/1 Note' then sets the pitch of the central black node in the tuning vine lattice. By default it is also set to 'A4', but you're free to set it to any other pitch in the chromatic scale via the toggle-down menu to the right of '1/1 Note'. You may for example choose to set it to 'F4', a major third below the 'A4' of the calibration frequency, to 'C4', the 'middle C' on a piano keyboard, or to 'C3', an octave below 'middle C'.

Scientific Pitch Notation (SPN)

The number occurring after each note name in the toggle-down menu refers to its octave position. The very lowest 'C' on the piano is written as 'C1', and the chromatic scale immediately above it as 'D♭1', 'D1', 'E♭1' etc. up to 'B1'. The second lowest 'C' is then notated as 'C2' and the chromatic scale above it as 'D♭2', 'D2', etc. up to 'B2'. The principle is repeated over the seven-octave range of the piano. (The three lowest pitches of the piano are referred to as 'A0', 'B♭0', and 'B0').

This system of notating octaves is known as 'scientific pitch notation' or SPN, and it is summarised in the following chart:



The ‘1/1 Note’ toggle-down menu also allows you to select between enharmonically equivalent pitches, for example between ‘B♭’ and ‘A♯’. All other pitches in the tuning vine are then spelled in relation to the chosen ‘1/1 Note’ spelling.

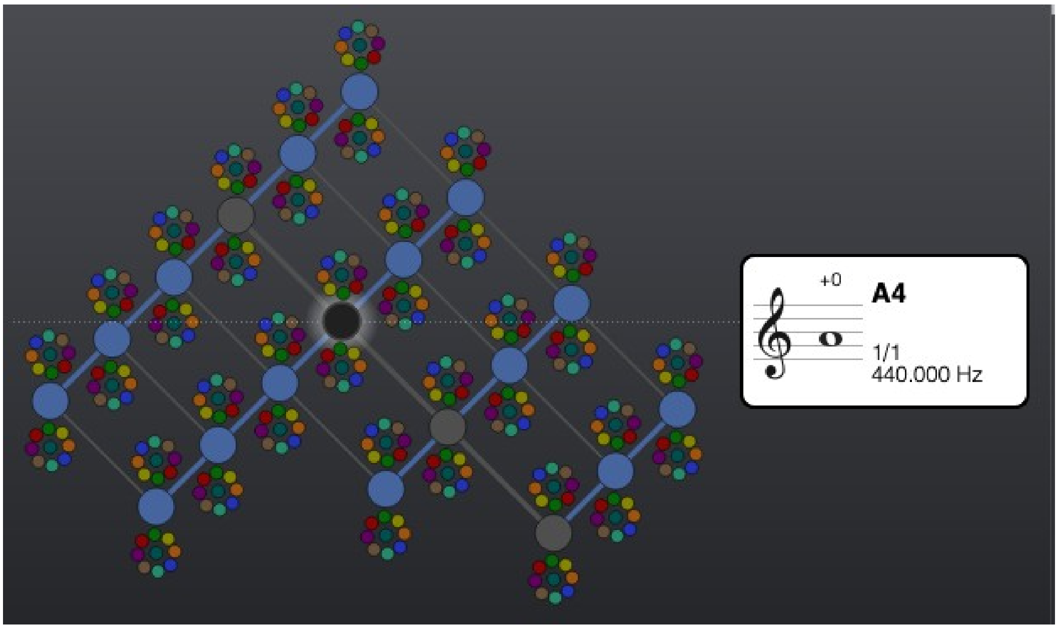
Before moving onto the next section, make sure that ‘Calibration A4’ is set to ‘440’, and ‘1/1 Note’ to ‘A4’.

2. How the Hayward Tuning Vine works

In this chapter, we will take a closer look at what the differently coloured nodes refer to, and how they relate to the system of tuning known as Just Intonation. As you work your way through the chapter, be sure to spend some time exploring and experimenting to get a feel for how the software works.

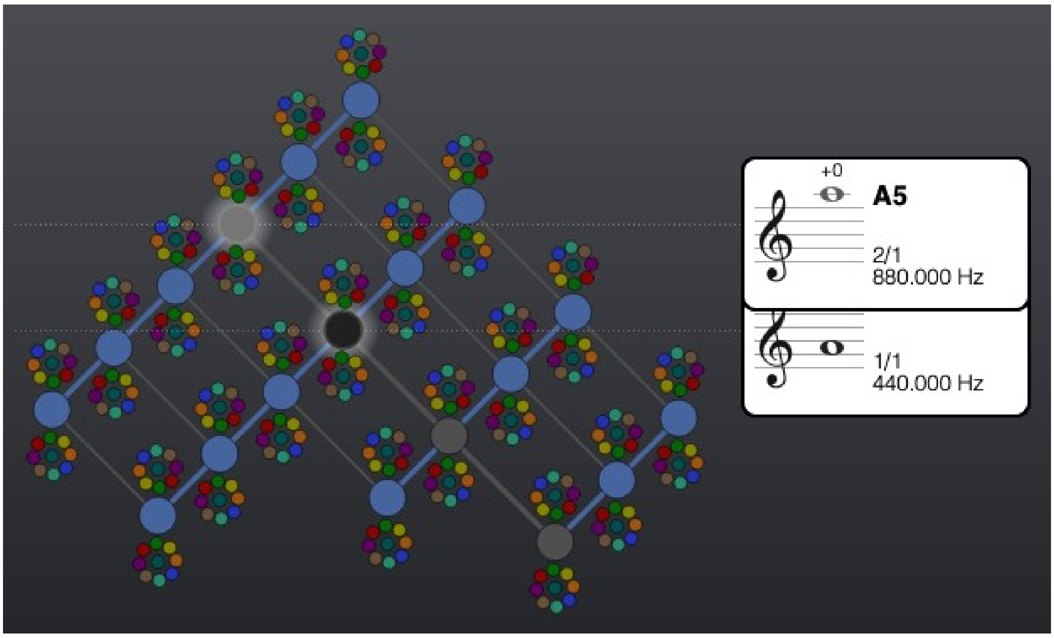
Prime number two: the octave

Start by clicking on the black node in the middle of the tuning vine. Along with sounding a musical tone, the node lights up and a notation card appears on the right of the screen:



This card shows the musical notation of the sounding pitch, plus some additional information. The staff notation reveals the pitch to be the ‘A’ above the ‘middle C’ on a piano keyboard. In SPN (scientific pitch notation) this pitch is referred to as ‘A4’, as indicated in bold type above and to the right of the staff. Below and to the right of the staff is ‘440.000 Hz’, showing that this ‘A4’ is tuned to 440 Hz. Directly above this is the ratio ‘1/1’ (pronounced ‘1 to 1’). In the system of tuning known as Just Intonation, this ratio always refers to the pitch from which all other pitches are derived, which is why it is placed at the centre of the tuning vine.

Now click on the grey node above and to the left of the central black node, connected to it by a grey strut:



Notated on the card attached to this grey node is the 'A' an octave and a major sixth above 'middle C', exactly an octave higher than the pitch sounded by the black node. Because it is an octave higher, it is now referred to as 'A5'[5] rather than 'A4', and its frequency has been doubled from 440 to 880 Hz. This is reflected in the ratio indication of '2/1' (pronounced '2 to 1') - the ratio is twice that of the central black node. If you look carefully at the notehead in the card, you'll notice that it is also coloured grey, matching the colour of the node it's connected to.

Now try clicking on the other grey nodes. Listen to the resulting tones and observe the information in the cards. (Remember that the ratios are always pronounced 'higher number to lower number', so for example the ratio '1/2' is not pronounced has 'half' but as 'one to two').

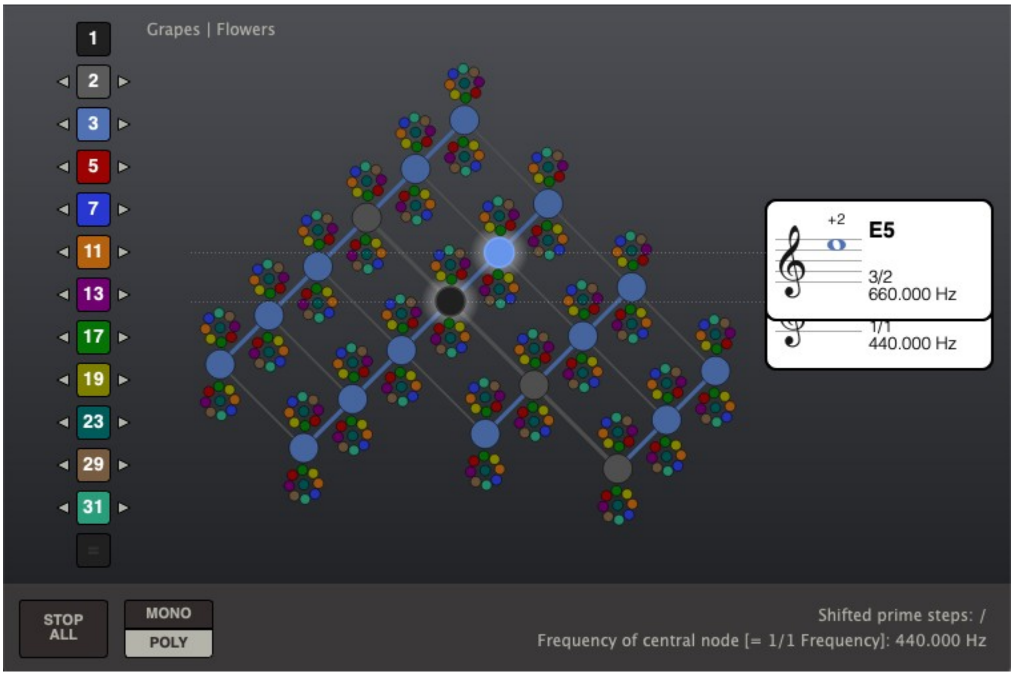
As you've probably worked out, the grey nodes always indicate octave relationships in relation to the central black node. From an acoustic standpoint, octave relationships are based on multiplying or dividing a frequency by two. This is the reason the grey number box in the list of transpose buttons on the left of the screen contains the digit '2'. The shift arrow to the left of it divides the central '1/1' frequency by two, and the arrow to the right of it always multiplies the frequency by two. You can verify this by clicking through the octave shifts and observing the information at the bottom right hand corner of the screen, as in the following example in which the tuning vine has been transposed down two octaves:

Before moving onto the next section, click on the '=' sign beneath the number boxes to reset the shift arrows, and then on 'STOP ALL' to turn off any notes that are still sounding.

5 See Scientific Pitch Notation (SPN)

Prime number three: the perfect fifth

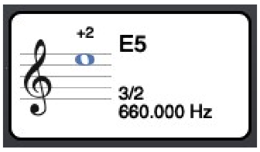
Now click on the black node again, and then on the light blue node to the above right of it, connected to it by a light blue strut. Along with hearing a musical interval, you should see this image on your computer screen:



This interval is a 'perfect fifth', as may be confirmed by examining the notation contained in the cards to the right of the screen. Because this interval is smaller than an octave, the cards now overlap, but you can choose which card is foremost by hovering the mouse either over the highlighted nodes or over the cards themselves. So for example if you want the 'A4' to be foremost, hover your mouse over the central black node or the corresponding card; to revert to to 'E5' being foremost, hover over the light blue node or the card that is attached to it.

Let's take a closer look at the information contained within the card attached to the light blue node. It is now labelled as 'E5' rather than 'E4', signalling that it belongs to a higher octave than the 'A4' it forms the perfect fifth with.[6] Whenever you play a note on the *Hayward Tuning Vine*, this scientific pitch notation allows you to immediately locate which octave it is in, as well as become familiar with how this correlates with the traditional staff notation.

Also appearing on the card attached to the light blue node is the ratio '3/2' (pronounced '3 to 2'). This indicates the relationship between its frequency and that of the central black node. The frequency of the black node is 440 Hz, and multiplying this by '3/2' results in 660 Hz, as is also indicated on the card:



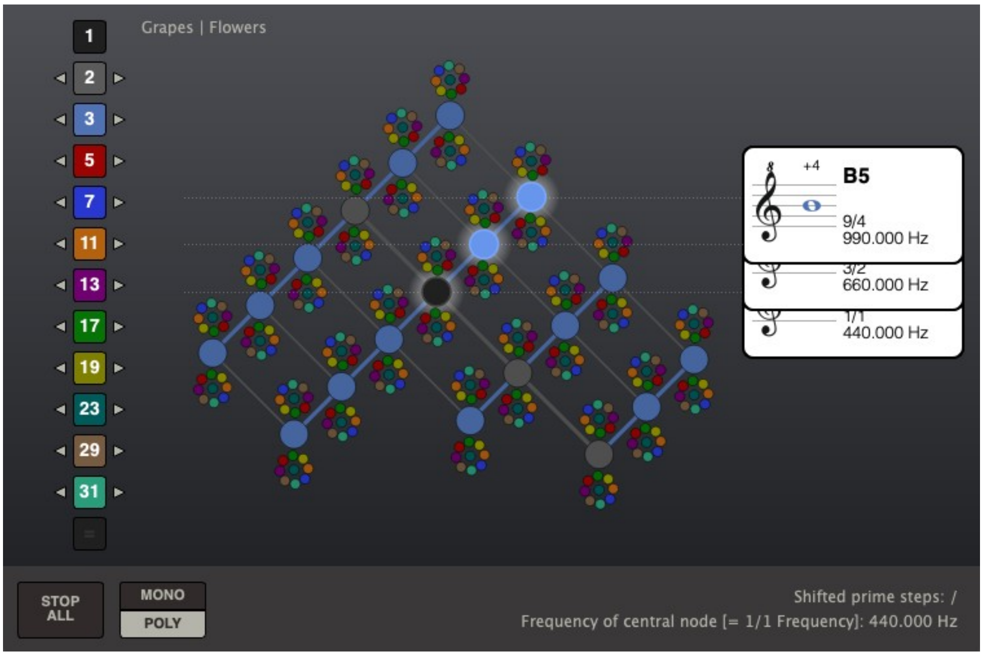
The final piece of information shown on this card is the '+2' that appears directly above the notehead. This is an indication of the pitch's 'cents deviation'. A cent is an extremely small musical interval, just 1/100th of

6 See Scientific Pitch Notation (SPN)

the tempered semitone occurring between the black and white keys on a piano. Just as there are 100 cents in a dollar, so there are 100 cents in a tempered semitone.[7]

The semitones generally found on a piano keyboard are ‘tempered’ because they are not based on whole number ratios. Whereas the ‘E5’ shown in the card above arises from multiplying the black node’s ‘1/1’ by the ratio ‘3/2’, the tempered perfect fifth between ‘A4’ and ‘E5’ on a piano keyboard can’t be described by such a simple ratio, or indeed by any whole number ratio, because it has been made very slightly smaller in order to fit into the tuning system known as ‘equal temperament’. The ‘rational interval’ of ‘3/2’ has been ‘tempered’ in order to fit into this system.

The cents indication above the notehead in the notation card shows the extent to which the pitch, based on a ‘rational’ whole number interval, deviates from the tempered ‘irrational’ interval typically found on a piano keyboard. As you can see from the cents indication, this deviation is very small in the case of a perfect fifth; two cents is only 1/50th of a tempered semitone. But as perfect fifths are stacked on top of each other, the difference starts to accumulate. Try clicking on the light blue node two steps to the above right of the central black node:



First notice how the ratio contained within the corresponding card is now ‘9/4’. This is because it is now two light blue struts away from the central black node, and each of these steps represents a ratio of ‘3/2’. The ratio associated with the ‘B5’ is therefore ‘3/2 x 3/2’, which equals ‘9/4’.

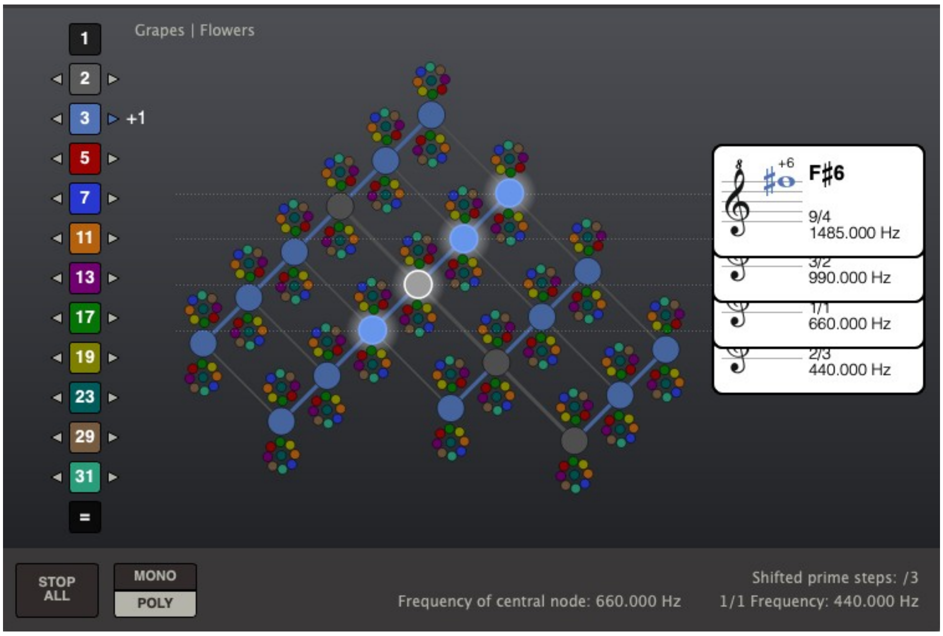
This principle of multiplying ratios applies to all the pitches in the *Hayward Tuning Vine*. However complex a ratio appears, it may always be traced from the central node by multiplying the ratios associated with the consecutive steps together, and traced back to the central node by dividing these ratios by each other.

Returning to the cents deviation, the card attached to the ‘B5’ shows that it has now increased to ‘+4’ cents, which is two cents higher than was the case for the ‘E4’. In order to find out how this process continues

7 In the *Hayward Tuning Vine* all cents indications are rounded to the nearest cent. It is actually impossible to notate cents deviations completely accurately, as this would require an infinite number of digits after the decimal point, the cent being an irrational number. For purposes of practical music making it is generally sufficient to notate to the nearest cent, although intervals may be tuned by ear much more accurately than this by using the sounding nodes of the tuning vine as an aural reference.

when moving up another perfect 5th to ‘F♯6’, it is first necessary to bring the ‘F♯6’ within visible range by clicking on the ‘shift’ arrow to the right of the light blue number box:

The central node turns pale to signal that a shift has been activated. The entire tuning vine has in fact been shifted up a perfect 5th, thus bringing the ‘F♯6’ into visible range. Clicking on it reveals the following information:



As shown on its notation card, the cents deviation for ‘F♯6’ is now ‘+6’. In fact, every time you move a perfect fifth upwards on the tuning vine, two cents are added to the resulting pitch.

Notice how this contrasts with the ratios. Whereas a given cents value is always added or taken away for each step within the tuning vine, consecutive ratios are always multiplied or divided.[8] This applies not just to those intervals based on prime number three, but to all the intervals within the tuning vine.

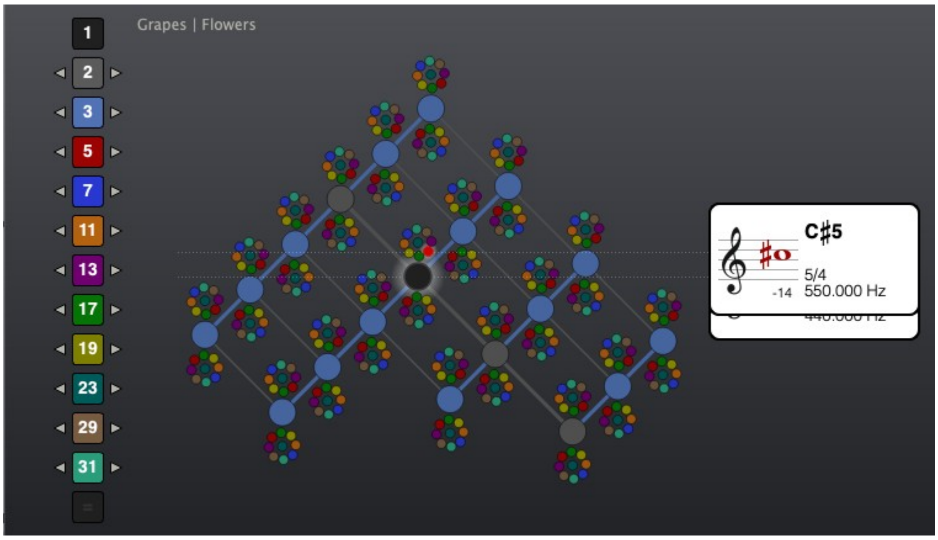
Now click either on the shift arrow left of light blue number box, or on the ‘=’ sign below the number boxes, to undo the right shift. Notice how the central node turns back from pale to black, signifying that the shift has been deactivated. Then click on all the visible highlighted nodes, to turn them off. ‘F♯6’ is still sounding, even though it can no longer be seen, as it now lies outside the range of the currently visible tuning vine.

Before moving onto the next section, click on ‘STOP ALL’ to turn the ‘F♯6’ off.

8 The reason for this is that the cent is a logarithmic value, representing the 1200th root of two – the number which when multiplied by itself 1200 equals two. It is not necessary to fully understand logarithmic values to use the tuning vine, as the mathematics is carried out in the background.

Prime number five: the major third

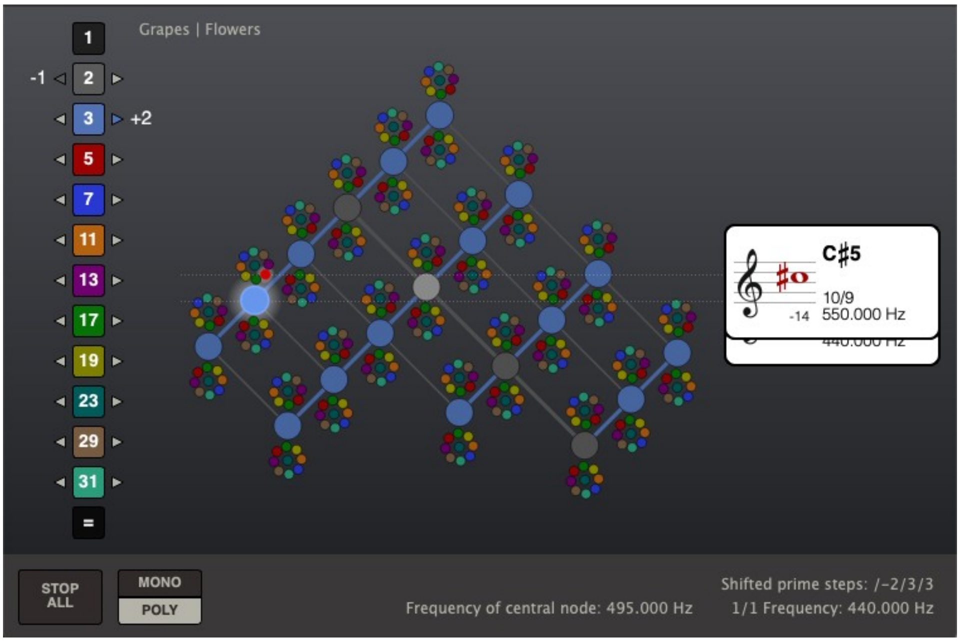
Start by clicking on the black node together with the small red node above and slightly to the right of it:



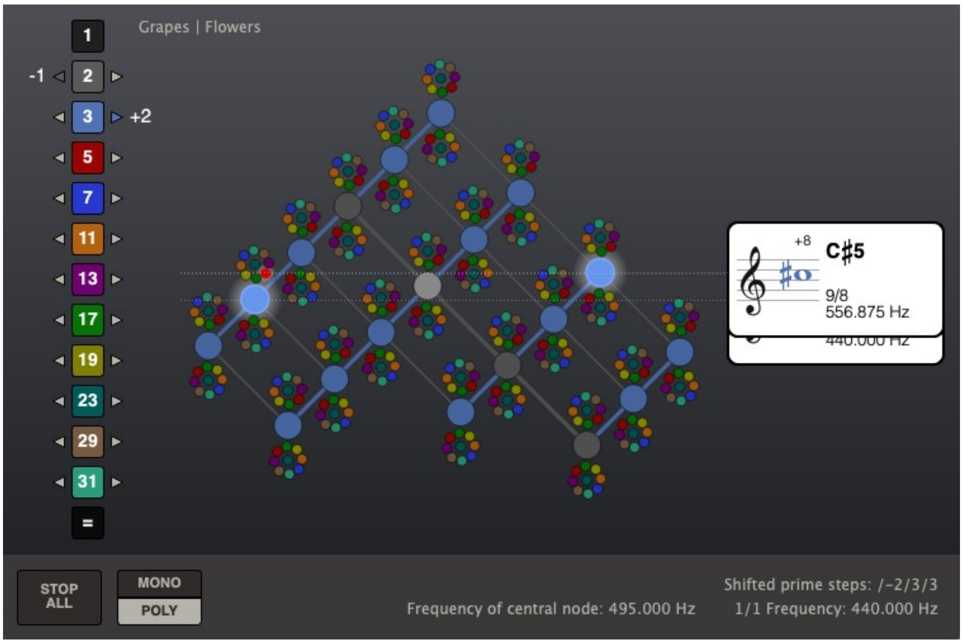
The ratio shown in the card is '5/4'. This means that the 440 Hz of the central black node has been multiplied by '5/4', resulting in 550 Hz. This interval is known as Just major third. The cents deviation of '-14' reveals it to be significantly smaller than the tempered major third typically found on a piano keyboard.

All of the intervals contained within the *Hayward Tuning Vine* are 'Just' intervals, because they are based on whole number ratios. 'Just Intonation' is the name given to the system of tuning based on whole number ratios between frequencies.

The *Hayward Tuning Vine* actually contains more than one Just major third. In order to compare the one based on the ratio '5/4' with one based on prime number three, click the shift arrow to the left of the grey number box once, and the shift arrow to the right of the light blue number box twice. The tuning vine has now been shifted down one octave and up two perfect fifths, moving the highlighted nodes representing 'A4' and 'C♯5' to the left of the lattice:



Now follow the dotted horizontal line passing through to the highlighted red node until it crosses the large light blue node at the right of the lattice. Then click on this light blue node and listen to the results:



The beating is caused by the two 'C♯'s corresponding to the red and the light blue nodes lying so close to each other. You can see exactly *how* close by holding your mouse over each node and comparing the Hertz values and cents deviations in their respective notation cards. The light blue node has a frequency of '556.875 Hz' and a cents deviation of '+8'; the red node is slightly lower, with a frequency of 550 Hz and a cents deviation of '-14'.

The speed of the beating is the result of the difference between the two Hertz values. As '556.875 – 550 = 6.875 Hz', this means there are almost seven beats per second, which you can verify by counting the beats and observing the seconds passing on a stopwatch.

Whatever shift arrows are activated, the ratios in the notation cards are always displayed in relation to the *shifted* '1/1' frequency of the central node. This node turns pale to remind you that it now represents the shifted and not the original 1/1 frequency, which is always represented by a black central node. This is why the ratio in the card corresponding to the light blue node representing 'C♯5' is 9/8, as the pitch of the central node has been shifted to 'B4', as you can verify by clicking on it. 'C♯5' is a Just major second above 'B4', and this particular Just major second is represented by the ratio '9/8'.[9]

The relationship between 'A4' and the 'C♯5' represented by the light blue node is '9/8 x 9/8', resulting in '81/64'. Starting from the 'A4', the first '9/8' leads to the 'B4' represented by the central pale node, and the next '9/8' leads from the central pale node to the light blue node representing 'C♯5'. In order to keep track of the original '1/1' frequency – the frequency of the central black node when no shift arrows are activated – its Hertz value appears in the bottom left hand corner of the screen, along with the a record of the shifts and the frequency of the current (shifted) central node:

9 Don't worry if you don't fully understand at this stage precisely why this Just major second is represented by 9/8, rather than a different ratio. For a more detailed explanation of ratios see The harmonic series and subharmonic series below.

The difference between the major third tuned as ‘5/4’ and tuned as ‘81/64’ is known as a ‘comma’, and it is only one example of many commas that occur between the various prime numbers in Just Intonation. Rather than seeing the commas as a problem, they may also be featured when making music in Just Intonation, and the various speeds of beatings they result in offers one possible way of connecting tuning with rhythm.

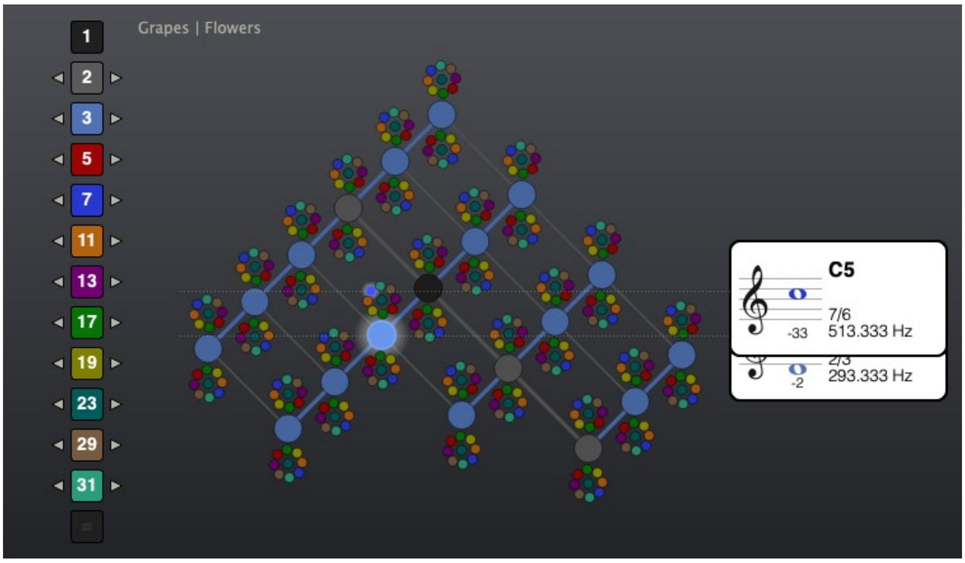
Intervals based on prime number three are often referred to as ‘Pythagorean’ intervals, and those based on prime number five as ‘Ptolemaic’ intervals.[10] The major third tuned ‘81/64’ is therefore known as a ‘Pythagorean major third’ (as ‘3^4 = 81’), and the major third tuned ‘5/4’ as a ‘Ptolemaic major third’. In the Medieval period of music history Pythagorean tuning was dominant. In the Renaissance Ptolemaic tuning was (re)introduced for tuning major and minor thirds and sixths.

Before moving onto the next section, click on the ‘=’ sign below the number boxes to reset the shift arrows, and on ‘STOP ALL’ to turn all currently sounding pitches off.

Prime number seven: ‘blues’ intervals

The harmonic theory of Western classical music since the Renaissance has generally been restricted to ‘five-limit’ musical intervals, which means that it is based on intervals based exclusively on the prime numbers two, three, and five covered in the previous sections. Whilst the tempered intervals found on the piano keyboard represent deviations from these intervals, the family of intervals opened up by prime number seven deviates sufficiently far from equal temperament that it has generally been excluded from Western music theory. ‘Seven-limit’ intervals do however frequently occur in Blues music, as well as non-western traditions such as Maqam. Going further back into the history of western music, intervals based on prime numbers higher than five were also integral to the music theory of Ancient Greece.

In order to start exploring ‘septimal’ intervals, first click on the light blue node one strut below and to the left of the central black 1/1 node, and then the smaller dark blue node above it:

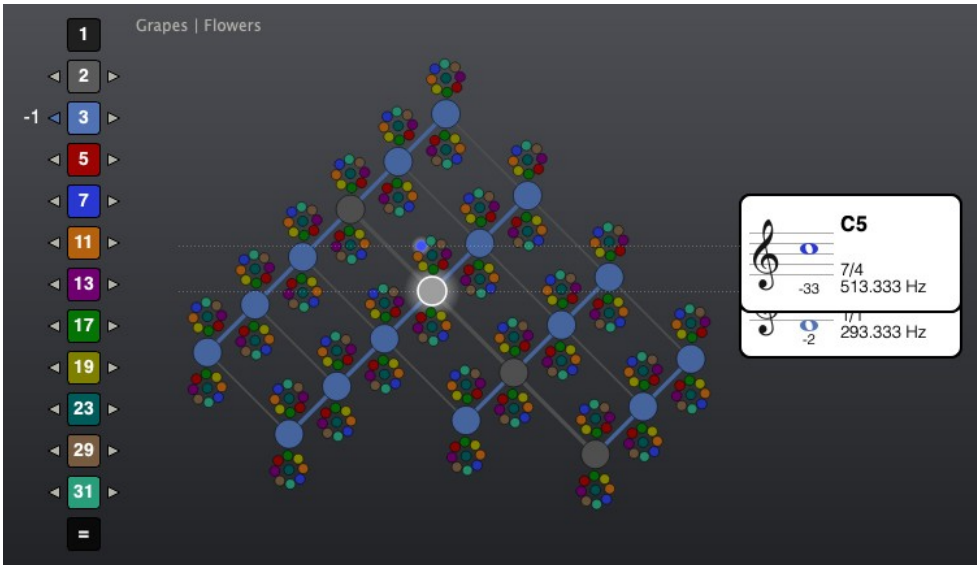


10 These terms derive from the Ancient Greek mathematician and philosopher Pythagoras (c. 570 – c. 495 BC) and mathematician, astronomer, geographer and music theorist Claudius Ptolemy (c. 100 – c. 170 AD).

This interval is known as a ‘septimal minor seventh’. Because neither of the two highlighted pitches is the central black node, the interval’s ratio is not directly indicated in the tuning vine. It may however be deduced from the two ratios contained within the notation cards.

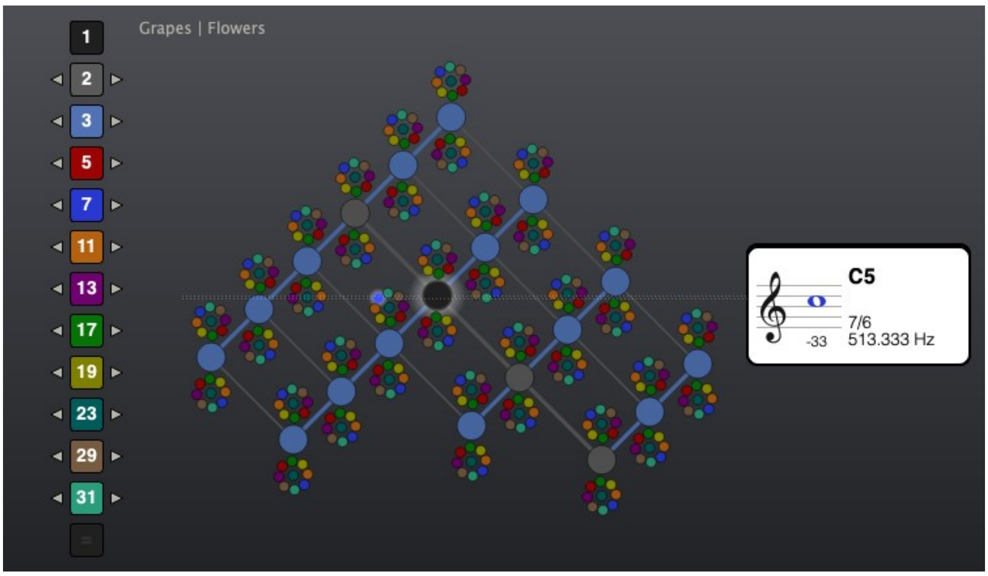
As the ‘D4’ corresponds to the ratio ‘2/3’, multiplying it by ‘3/2’ arrives back at central ‘1/1’ frequency (as ‘2/3 x 3/2 = 1/1’). Multiplying ‘3/2’ by ‘7/6’, the ratio of the highlighted dark blue node in relation to the central black node, then gives ‘21/12’. Dividing both numerator and denominator by three results in ‘7/4’, which is the ratio of the septimal minor seventh.

A quicker way of calculating the ratio of an interval that does not directly include the central node, is to shift it to a position that does include it. If you shift the tuning vine down a perfect fifth by clicking on the arrow to the left of the pale blue number box, the septimal minor seventh is now displayed directly in relation to central node, which has turned pale to indicate that a shift has taken place. The ratio may now be read directly from the card corresponding to the highlighted dark blue node:



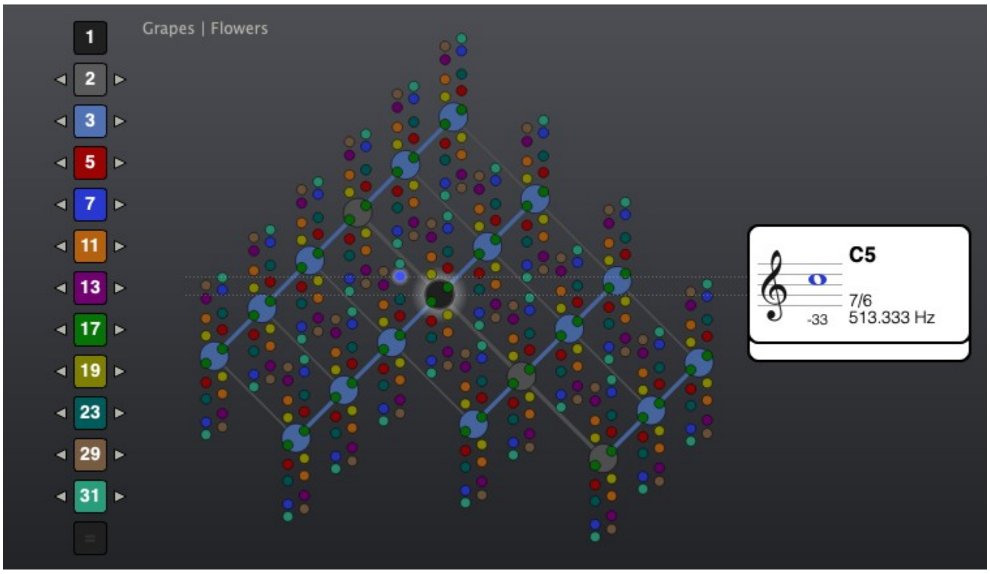
Now click on the ‘=’ sign below the number boxes, or on the shift arrow to the right of the light blue number box, to reset the shift.

In order to hear a septimally lowered minor third, click next on the central black node, and then on the highlighted large light blue node in order to turn it off. Then move the mouse over the highlighted dark blue node to bring its card to the front of the screen:



As indicated in the card, with '-33' cents deviation the septimally lowered minor third is almost exactly a third of a semitone lower than the tempered minor third typically found on a piano keyboard. This is the flattened minor third often associated with Blues music.

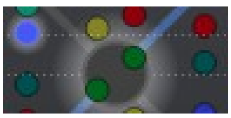
Yet on the 'Flowers' view, the dark blue node currently appears slightly *lower* than the black node, even though it signifies a Blues minor third *above* it. Try switching to 'Grapes' view, and observe how the dark blue node is now positioned significantly higher than the black node, reflecting the actual melodic positions of the respective pitches:



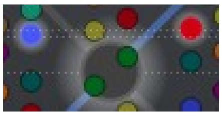
'Flowers' view is good for grasping the harmonic relationships within tuning vine, as it is immediately clear that the highlighted dark blue node is connected harmonically to the larger light blue node below it. Once these harmonic relationships have become clear, 'Grapes' view then shows how these harmonic relationships interact with the melodic relationships. The horizontal dashed line that extends to the left and right of each highlighted node enables you to see immediately which other nodes are melodically close to it, even when they may be harmonically quite distant from it.

Once you become more experienced at using the interface you'll probably only use 'Grapes' view, as the immediate connection between harmonic and melodic relationships it allows is what makes the tuning vine so intuitive to use. For learning purposes it's useful to alternate between both views, in order to be sure how the melodic steps are rooted in the harmonic relationships.

Using 'Grapes' view it's now possible to compare the septimal minor third to a Ptolemaic minor third, tuned '6/5', and a Pythagorean minor third, tuned '32/27'. If you follow the dotted line that attaches the highlighted dark blue node to its card on the right, you'll see that it passes over the lower part of a red node above and to the right of the black node:



By clicking on this node, you can hear the beating caused by the comma difference between these two intervals:



Try hovering your mouse alternately over the highlighted dark blue and red nodes, and compare the information in the respective notation cards regarding their ratios, Hertz numbers and cents deviations.

To compare the septimal and Ptolemaic minor thirds directly, first click on both the dark blue and red nodes to turn them off. Then toggle to ‘MONO’ mode in the lower left corner of the screen, and click again on the dark blue and smaller nodes to alternate between them. Nodes sounded while ‘MONO’ mode is selected automatically turn off when a new node is sounded, making it possible to hear the intervals in succession rather than simultaneously. Now toggle back to ‘POLY’ and leave only the black node sounding.

Accessing the Pythagorean minor third ‘32/27’ is a little more involved, but it is well worth the effort as it’s a great way of getting to understand the interface in more depth. Breaking a ratio into its ‘prime factors’[11] can seem a little daunting at first to the less mathematically minded, but understanding how these individual ratios map onto the tuning vine will stand you in good stead for finding any whole number ratio, no matter how complex, providing that it does not include prime numbers higher than 31.[12]

In order to locate the Pythagorean minor third, first reduce ‘32/27’ to its prime factors. As

32 = (2 x 2 x 2 x 2 x 2)

and

27 = (3 x 3 x 3)

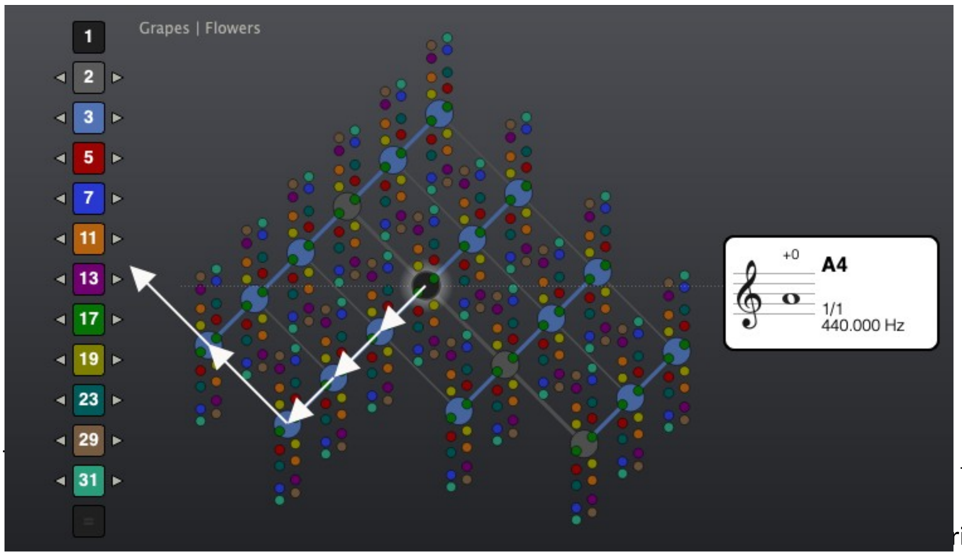
‘32/27’ may be rewritten as

(2 x 2 x 2 x 2 x 2) / (3 x 3 x 3)

Next, break this complex ratio into the five simple ratios

‘2/3 x 2/3 x 2/3 x 2/1 x 2/1’

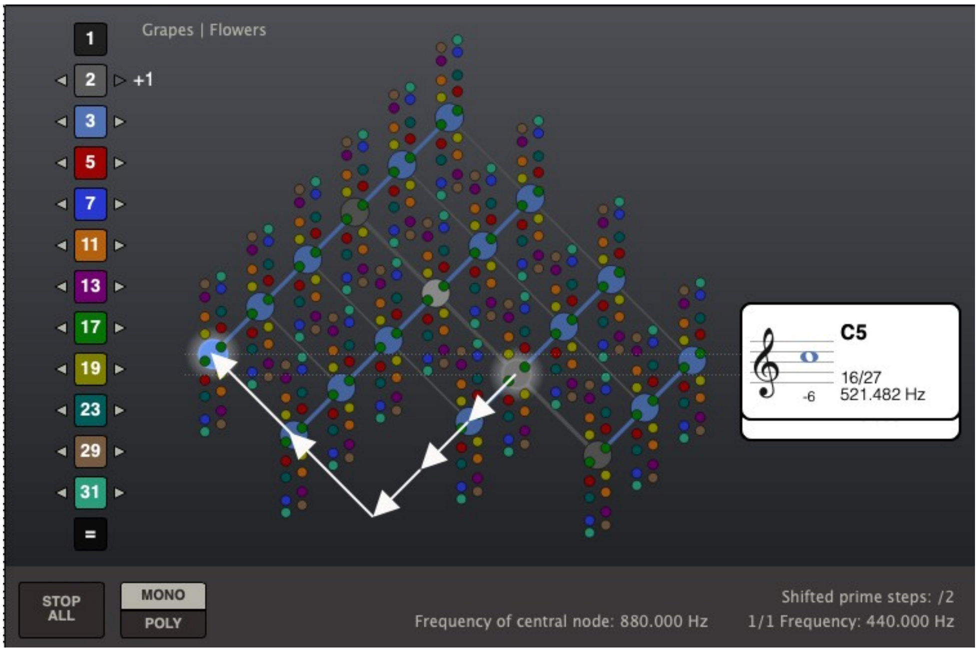
Now, starting from the central black 1/1 node, consider how each of these ratios represents a step within the tuning vine. As ‘2/3’ indicates a step down a perfect 5th, and ‘2/1’ a step up an octave, the five ratios translate into a movement down three light blue struts and up two light grey struts from the black node:



the prime factors of ten are

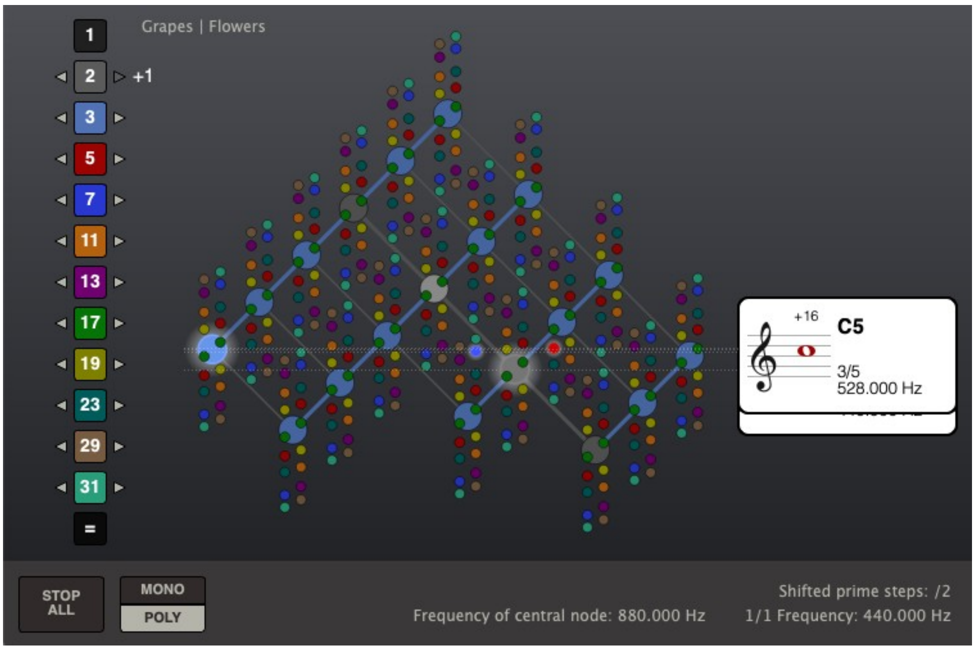
rime numbers higher than this may not be displayed on it. Prime numbers higher than this are not included as they are very hard to distinguish by ear, and are generally therefore of less musical use.

To bring the final node into visible range you need to shift up an octave by clicking on the arrow to the right of the grey number box. Then click on the large light blue node to the far left in order to hear the Pythagorean minor third ‘32/27’:



The ratio shown in the notation card is ‘16/27’ rather than ‘32/27’, because it is displayed in relation to the central pale node representing the shifted ‘1/1’. This has been transposed up an octave from ‘A440’ to ‘A880’, as you can verify by clicking on it and examining its notation card. Make sure to turn the pale node off again before continuing.

It is now possible to sound the septimal, Ptolemaic and Pythagorean minor thirds simultaneously:



By selecting ‘MONO’ mode and clicking successively on the highlighted light blue, dark blue and nodes, you can also alternate between them to compare the Pythagorean, Septimal and Ptolemaic minor thirds consecutively.

Prime numbers 11 and above: complex intervals

You are now in a position to explore the musical intervals based on prime numbers 11, 13, 17, 19, 23, 29 and 31. Each new prime number opens up a unique family of intervals, each with its own peculiar set of flavours. By clicking on the differently coloured nodes near the central black node and studying the notation cards, you can familiarise yourself with the various ratios, and find out to what extent the Just intervals deviate from the tempered intervals found on a piano keyboard.

As you will see, prime numbers 11, 13, 29 and 31 deviate from tempered tuning quite considerably, and may even sound quite ‘out of tune’ at first. But once you have grown accustomed to them, the vast harmonic universe implicit within Just Intonation may well make the equally tempered intervals of the piano keyboard seem ‘out of tune’ and harmonically restricted.

Based on the prime number relationships which underlie Just Intonation, the *Hayward Tuning Vine* provides an alternative interface to the piano keyboard, allowing an intuitive exploration of harmonic space without the need to limit the number of pitches to 12 per octave.

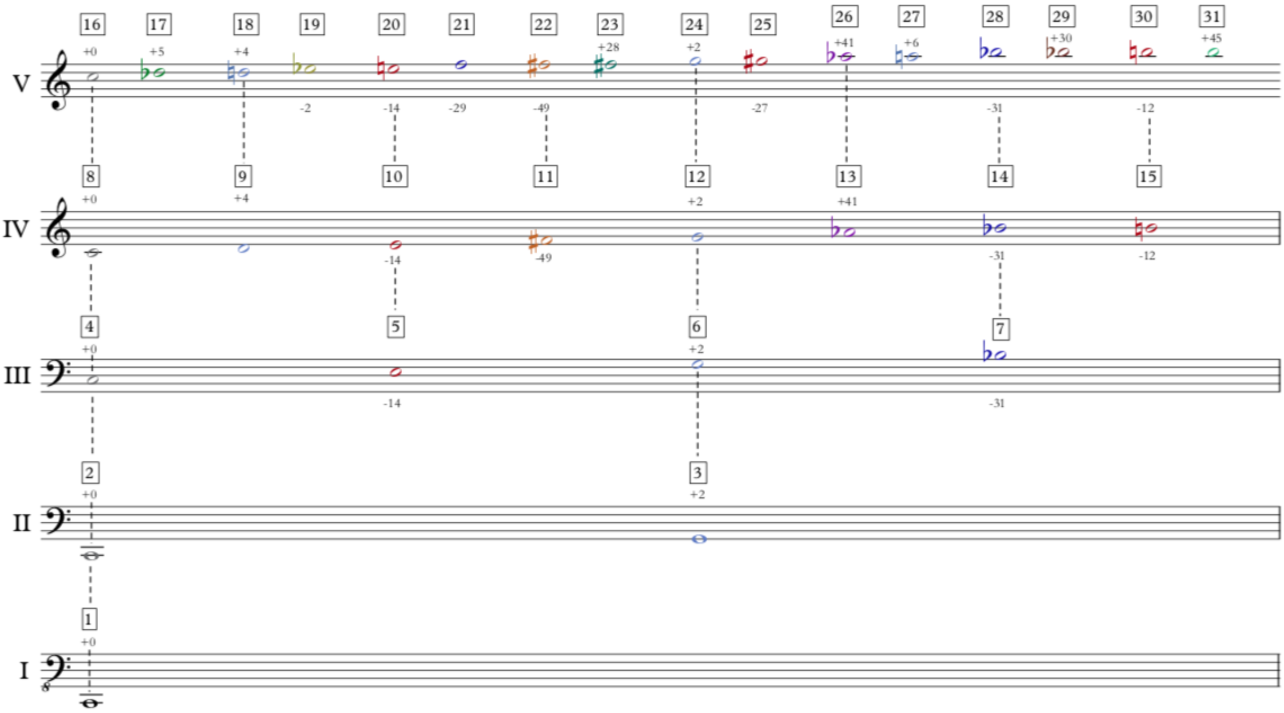
Before moving onto the next section, click on the ‘=’ sign below the number boxes to reset the shift arrows, and on ‘STOP ALL’ in order to turn all the sounding pitches off. ‘View’ should remain set to ‘Grapes’.

The harmonic series and subharmonic series

All of the intervals within Just Intonation may ultimately be derived from the harmonic and subharmonic series. Stated simply, the harmonic series is based on *multiplying* a given frequency by positive integers (1, 2, 3, 4, 5...), and the subharmonic series on *dividing* a given frequency by positive integers.

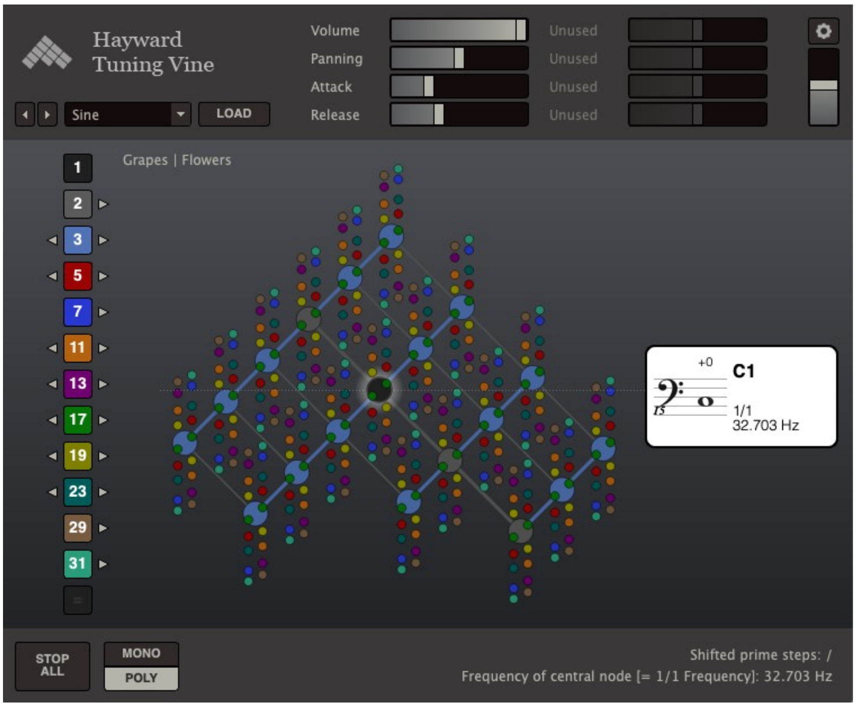
The harmonic series

If the first note in a harmonic series is defined as ‘C1’, the lowest ‘C’ on the piano, the first five octaves of the harmonic series may be written as:



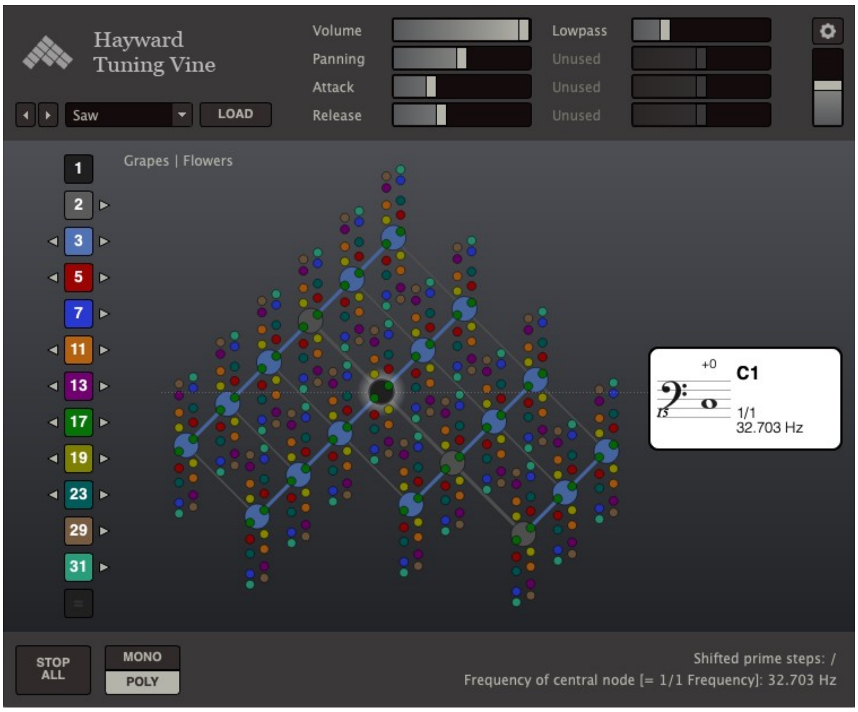
We are now going to map this harmonic series onto the *Hayward Tuning Vine*, in order to gain a deeper understanding of how it works.

First set the ‘Calibration’ in ‘Options’ to ‘C1’ and ‘1/1 Note’ to ‘440’. Then click on the central black node:



Although you can *see* that the central black node is now set to ‘C1’, it’s possible that you can’t currently hear it. This is because its frequency is 32.703 Hz, which is considerably lower than the computer speakers can play, and lower than many other speaker systems can play too, unless they include a subwoofer.

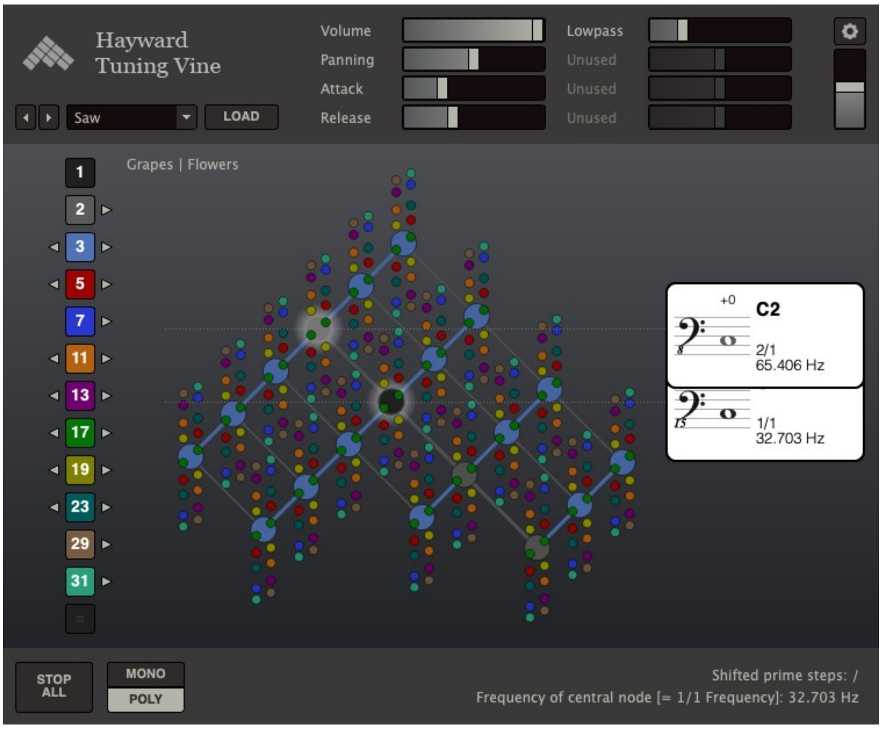
In case you can’t hear the ‘C1’, click again on the black node to turn it off. Now reset the waveform at the upper left of the screen to ‘Saw’, and click again on the black node. You should now be able to hear the note, although it may sound rather abrasive. To make it sound smoother, adjust ‘Lowpass’ at the top of the screen, and replay the black node:



‘Lowpass’ belongs to the parameter settings placed at the top of the screen. The settings already built into the software only affect the pitches that are about to be played, not the pitches that are already sounding (see Patch selection and parameters).[13]

In order to activate the second tone of the harmonic series, the ‘1/1’ must be multiplied by two. Following the convention of Just Intonation, the ‘1/1’ frequency would actually be multiplied by ‘2/1’ (pronounced ‘two to one’). Although this of course amounts to the same thing, it’s useful to follow this convention as it keeps things consistent when dealing with more complex ratios, and also serves as a reminder that the interval between the first and second tones in the harmonic series is in fact ‘2:1’, equivalent to an octave.[14]

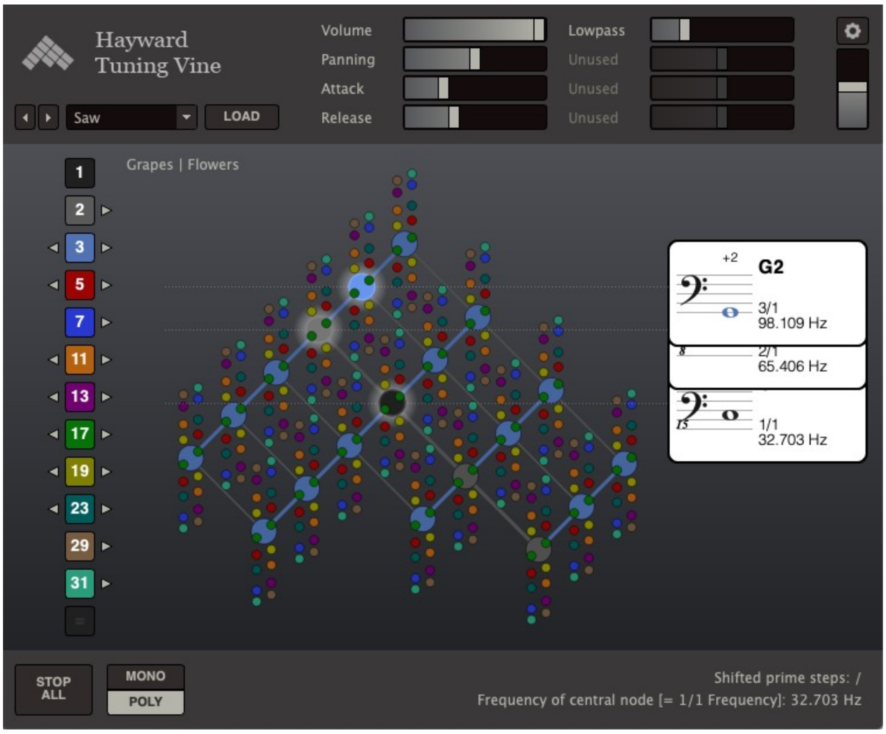
In order to perform this calculation on the tuning vine, first check you are in ‘POLY’ mode so that the ‘1/1’ keeps sounding when the ‘2/1’ is introduced. Then follow the grey strut corresponding to number box marked ‘2’ upwards and to the left of the central black 1/1 node, and click on the light grey node it leads to:



In order to play the third harmonic, follow the light blue strut corresponding to number box marked ‘3’ upwards and to the right from the highlighted grey node, and click on the light blue node at the end of it:

13 If you toggle back to the ‘Sine’ waveform, you’ll see that ‘Lowpass’ is now greyed out. This is because a sine wave consists only of a single frequency, without any upper partials, which means that its timbre cannot be altered. Because the other waveforms contain upper partials, they may be played even on speaker systems whose cutoff frequency is above the fundamental of the given pitch. This is why ‘C1’ may be heard through computer loudspeakers if the ‘Saw’ waveform is selected, but not when ‘Sine’ is selected.

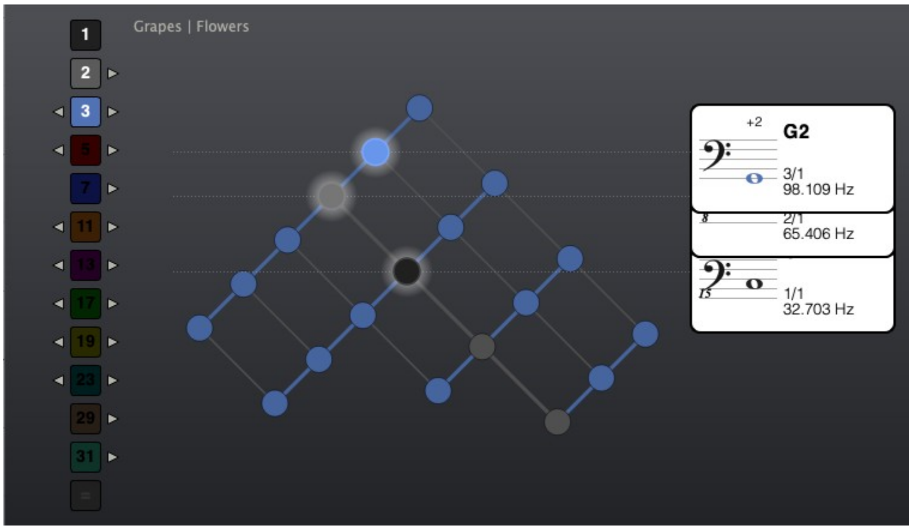
14 This manual follows the convention introduced by David B. Doty in ‘The Just Intonation Primer’ of using slash notation for pitch ratios and colon notation for interval ratios. So, the interval between ‘1/1’, the first pitch of the harmonic series, and ‘2/1’, the second pitch in the series, is ‘2:1’, equivalent to the musical interval of an octave. In all cases the ratios are pronounced ‘one to one’, ‘two to one’ etc.



Notice how this tone forms a '3:1' interval with the first tone and a '3:2' interval with the second tone in the harmonic series. This latter interval is a Just perfect fifth, as explained above in Prime number three: the perfect fifth. Wherever they are positioned within the tuning vine, the light blue struts always represent the Just perfect fifth '3:2', and the grey struts the octave '2:1'.

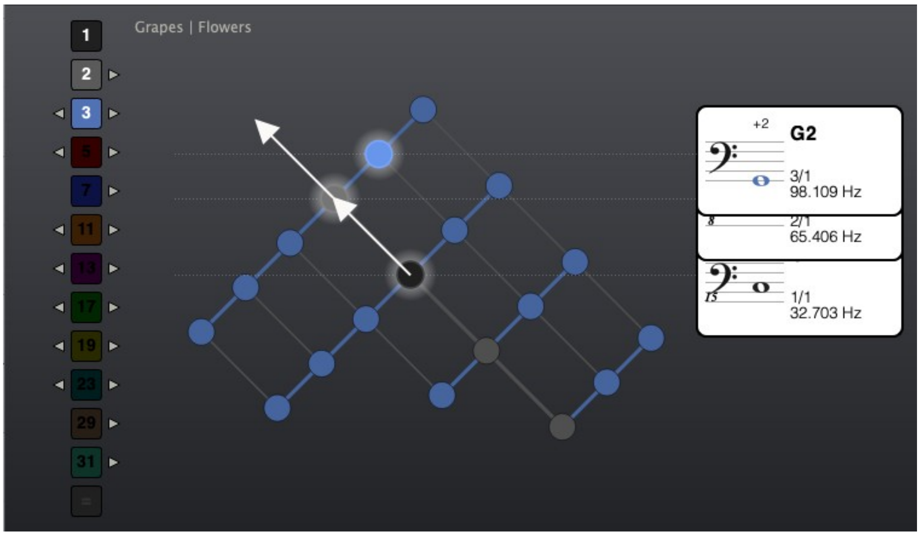
The first octave of the harmonic series contains only one tone, the fundamental '1/1'. The second octave contains two tones, the octave '2/1' and the octave-plus-fifth '3/1'. Compare how this information is displayed on the tuning vine with the lowest two staves of the five-octave harmonic series shown above at the beginning of this section on The harmonic series.

In geometrical terms, the '1/1' represented by the black node corresponds to zero dimensions in harmonic space – a single point. The '2/1' opens up the first dimension, extending along a single grey axis. The '3/1' then opens up the second dimension in harmonic space, extending along a single light blue axis. Parallel grey and light blue axes then form a grid within this two-dimensional space, thereby forming rectangles between grey and light blue axes. This may seen most clearly by toggling off all number boxes containing prime numbers higher than '3':

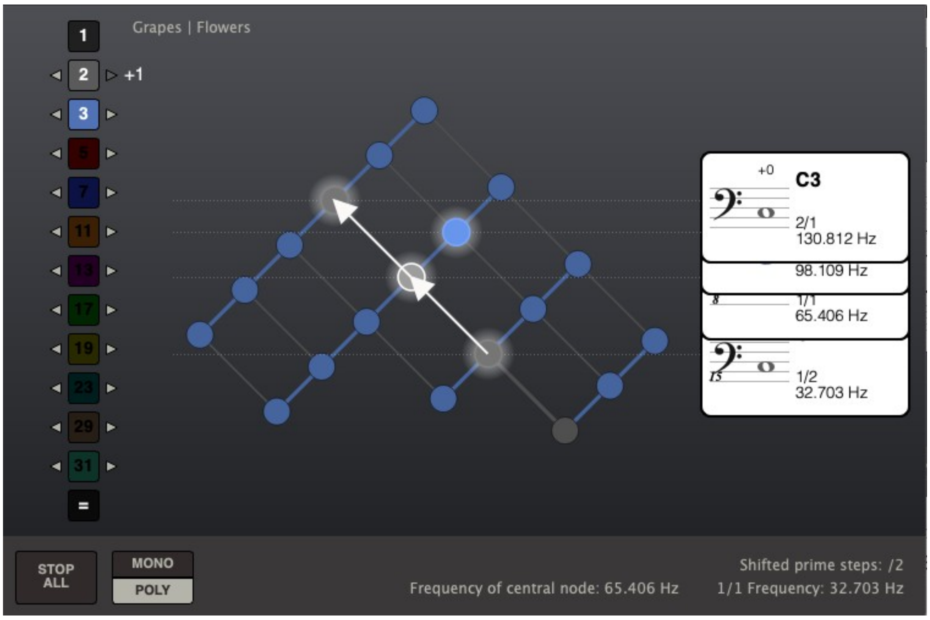


Focusing on the single rectangle formed above the black node, the third harmonic is reached by jumping from the ‘1/1’ at its lowest corner to the ‘3/1’ at its highest corner. The ‘3:1’ interval thus formed remains constant for all such rectangles within the tuning vine. Once you become familiar with them, the paths traced by the various musical intervals will start to become second-nature, allowing you to focus fully on the music.

The ratio corresponding to the fourth tone in the harmonic series is ‘4/1’. In order to find it on the tuning vine, first restate it in its prime factors, as ‘(2 x 2)/1’. Breaking this into two separate ratios gives ‘2/1 x 2/1’. As ‘2/1’ represents a step upwards along a single grey strut, ‘2/1’ x ‘2/1’ must represent two such upward steps. But as only one grey strut is visible above the black node, the sought after node currently lies outside the visible range:



In order to bring into range, shift the tuning vine up an octave by clicking on the arrow to the right of the grey number box. The fourth tone may now be sounded by clicking on the highest grey node, above the central node that has now turned pale due to the upward shift:

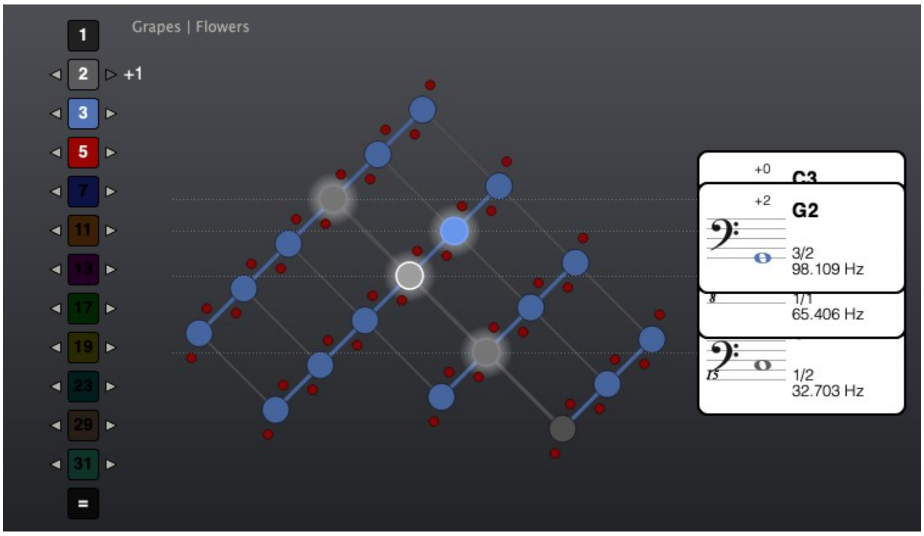


The fourth pitch within the harmonic series forms a ‘4:1’ (two octave) interval with the ‘1/1’, a ‘2:1’ (octave) interval with the second pitch ‘2/1’, and a ‘4:3’ (Just perfect fourth) interval with the ‘3/1’. Notice how the

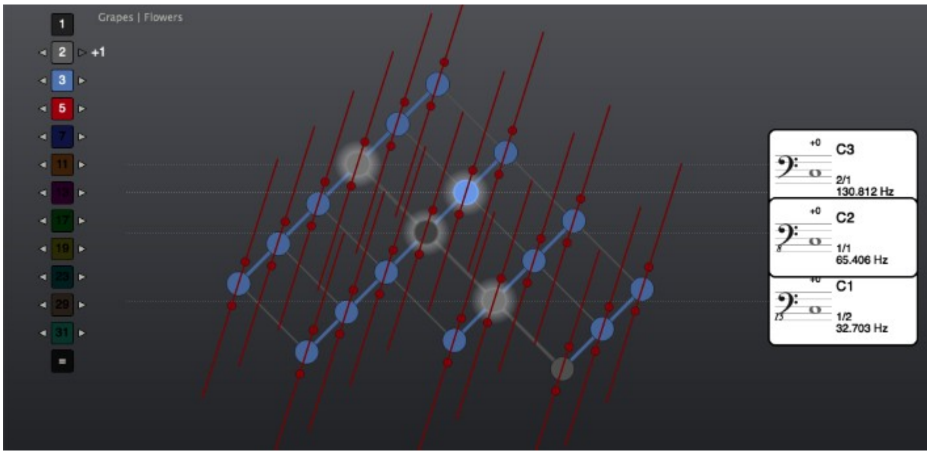
Just perfect fourth ‘4:3’ entails jumping from the rightmost to leftmost corner of the rectangle formed between the grey and light blue axes.

‘C1’, the original 1/1, has now been shifted down an octave, so that it corresponds to the grey node below the pale central node. The notation card for ‘C1’ therefore now displays the ratio ‘1/2’, as it is shown in relation to the shifted ‘1/1’. In order that you can keep track of them, the current central node frequency, shifted prime steps and original ‘1/1’ frequency are all displayed in lower right hand corner of the screen.

The fifth tone within the harmonic series is represented by the ratio ‘5/1’. As five is a new prime number, this means opening up a third dimension in harmonic space, which is accomplished by clicking the red number box containing ‘5’:



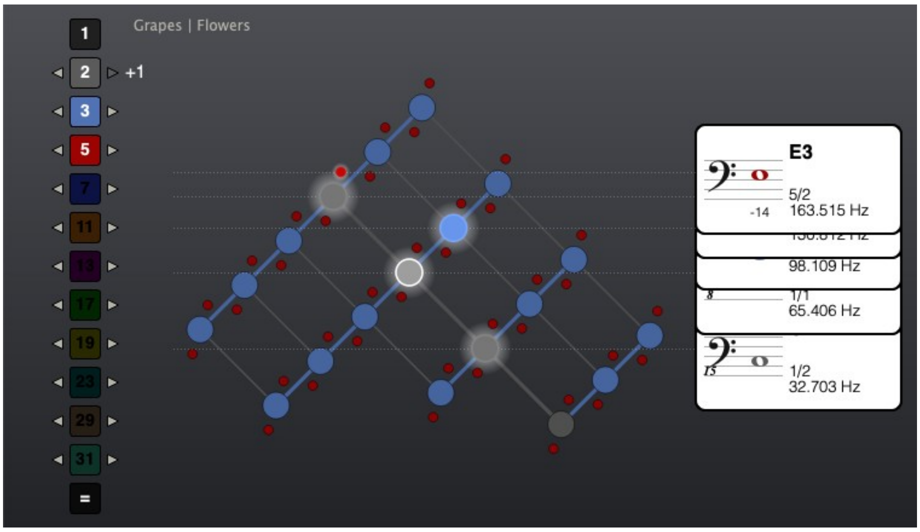
This third dimension is of course depicted in two dimensions on the computer screen. It may be visualised by imagining parallel red lines connecting each of the small red nodes via the larger node between them:



If it were practical to do so, these red struts would be included in the software, along with further small red nodes placed at regular intervals along them to represent the other pitches occurring in this dimension of harmonic space. Whilst this might remain feasible for prime number five, it becomes increasingly less so as higher prime numbers are introduced, as the interface would fast disintegrate into visual chaos.

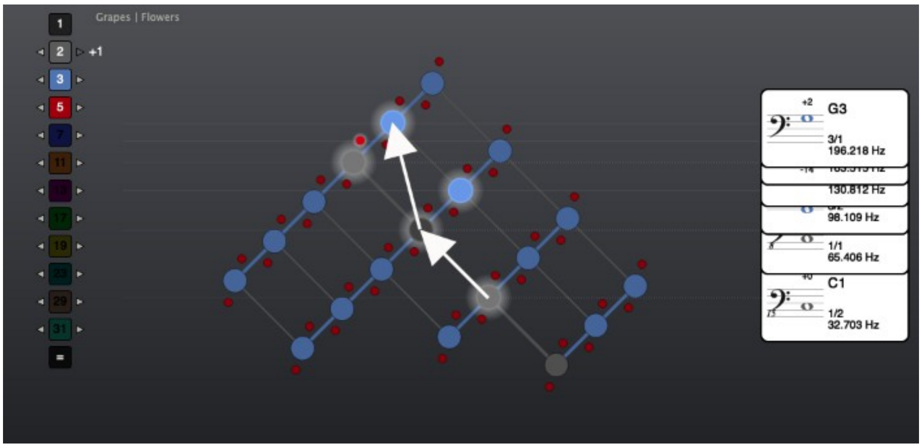
For this reason all prime numbers from five upwards are displayed as pairs of smaller nodes above and below each of the larger nodes forming the main two-dimensional grid. If is proves necessary to move further along any of the resulting axes than are thereby made visible, the shift arrows placed to the left and right of each number box make it possible to do so.

Now click on the red node placed above the fourth tone in the harmonic series:

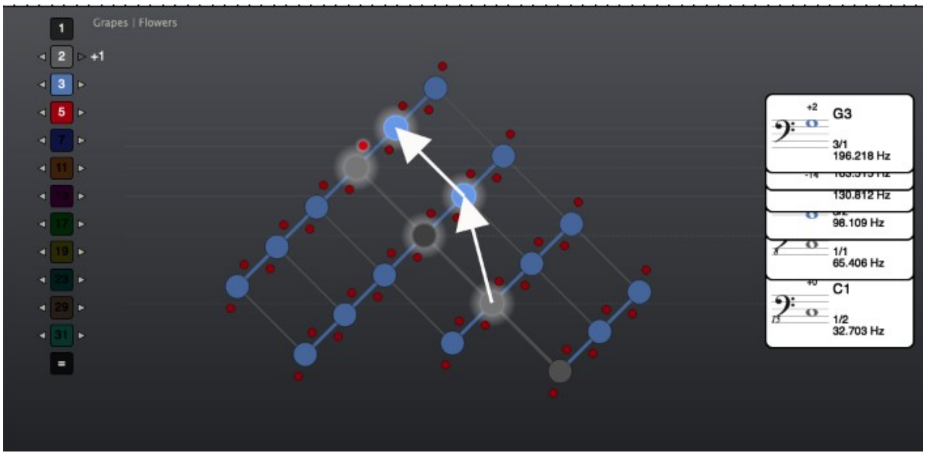


The fifth tone forms the intervals ‘5:1’ (two octaves and a Just major third) with the first tone, ‘5:2’ (one octave and a Just major third) with the second tone, ‘5:3’ (a Just major sixth) with the third tone, and ‘5:4’ (a Just major third) with the fourth tone of the harmonic series. Each of these intervals may be heard in isolation by toggling off the other tones within the series.

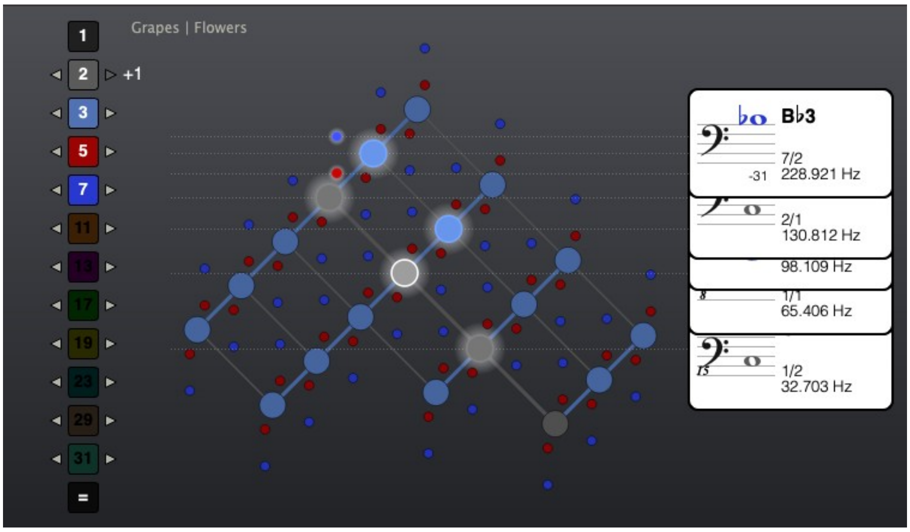
As ‘6/1 = (2 x 3)/1’, the sixth tone in the series does not introduce any new prime numbers, but is contained within the two-dimensional grid formed between the grey and light blue nodes. Breaking the ratio into two gives ‘2/1 x 3/1’, which provides the first of two routes by which the sixth pitch maybe be traced from the original ‘1/1’:



The second route is provided by reversing the order of the two ratios to ‘3/1 x 2/1’:

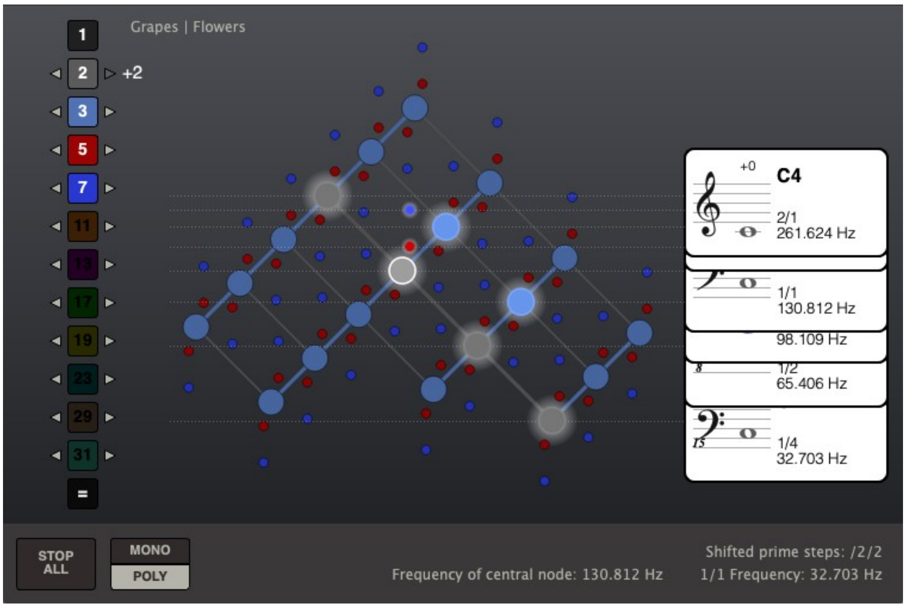


As seven is a prime number, the seventh tone in the harmonic series opens up a fourth dimension in harmonic space, activated by clicking on the dark blue number box marked ‘7’. Click on the dark blue node suspended above the fourth tone to sound the seventh tone in the harmonic series:



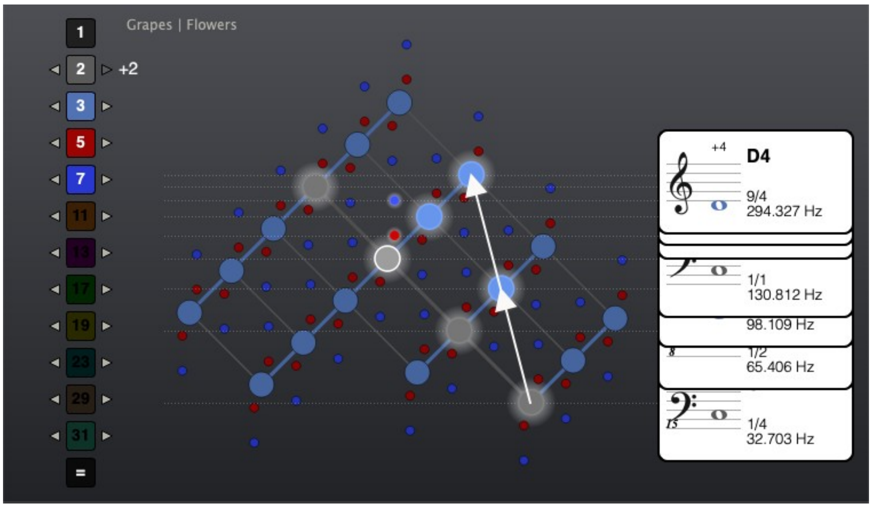
Before locating and playing the eighth pitch in the harmonic series, it’s worth comparing the first three octaves displayed on the tuning vine with the lower three staves shown at the start of this section on The harmonic series. The first octave contains one tone, the second octave two tones, and the third octave four tones. For each new octave the number of tones is doubled, and this remains the case for the higher octaves in the harmonic series.

The eighth pitch in the harmonic series is described by the ratio ‘8/1’. Written as prime factors this is ‘(2 x 2 x 2)/1’, which split into separate ratios becomes ‘2/1 x 2/1 x 2/1’. As this represents moving up three grey struts from ‘C1’, and there are only two such struts currently visible, it’s necessary to shift up another octave to bring the eighth tone into view:

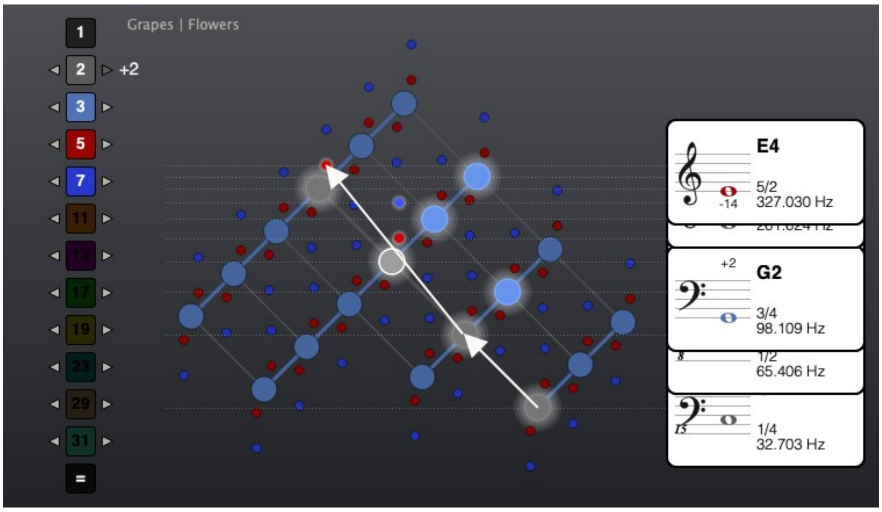


The ninth tone corresponds to the ratio ‘9/1’. Restated in prime factors this is ‘(3 x 3)/1’, which split into two ratios becomes ‘3/1 x 3/1’.

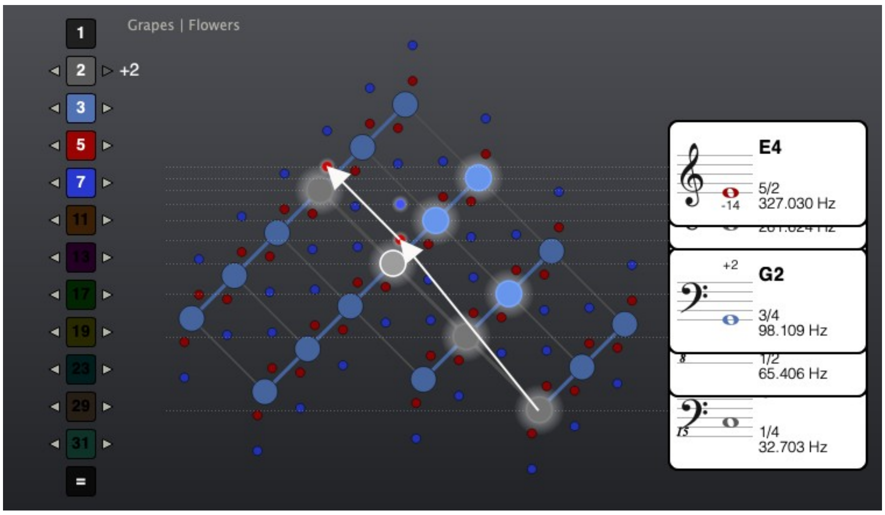
We noted above that ‘3/1’ implies jumping from the lowest to highest corner in the rectangle formed between the grey and light blue struts. Following this principle, the ninth tone may now be located as follows:



The 10th tone in the harmonic is formed by the ratio ‘10/1’. This may be restated as ‘(2 x 5)/1’. Split into two ratios this becomes ‘2/1 x 5/1’, which correspond to the following route within the tuning vine:



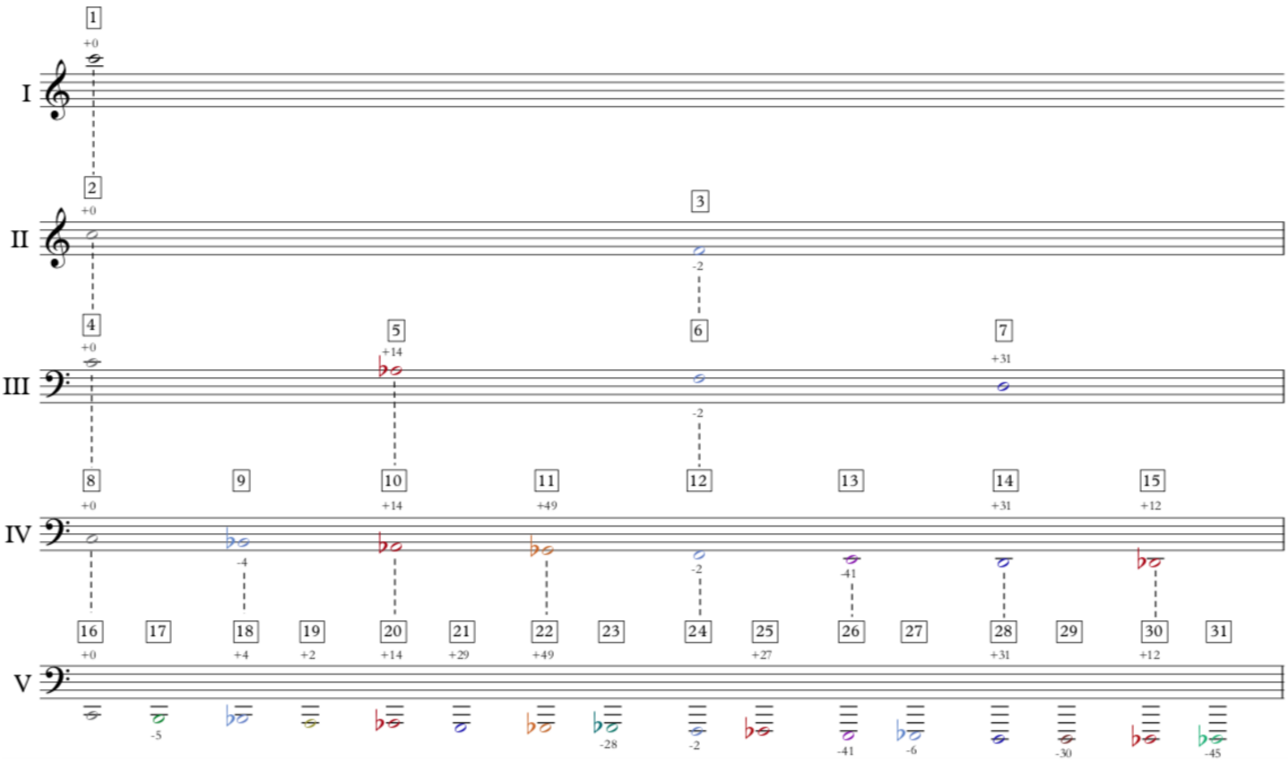
If the order of the ratios is reversed to ‘5/1 x 2/1’, the route changes to:



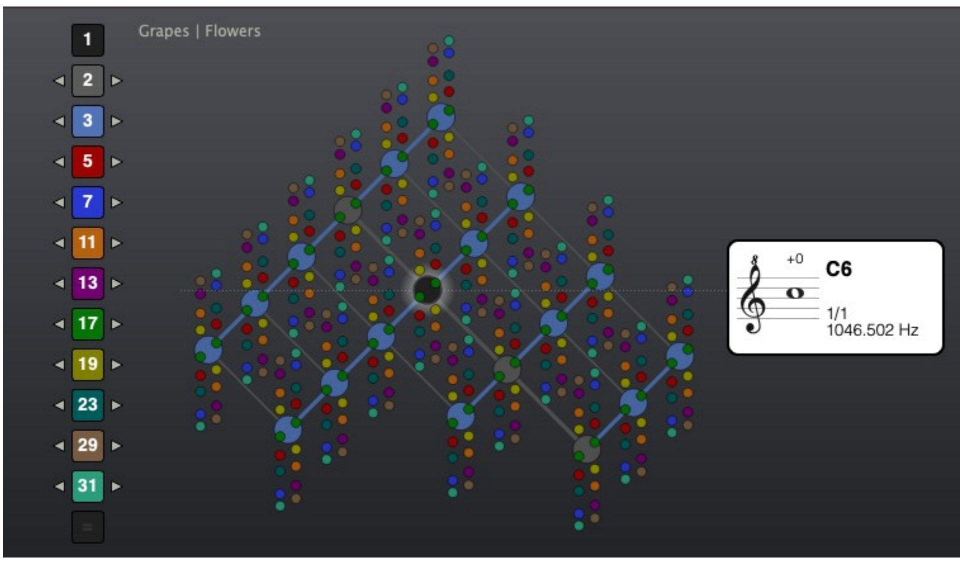
Now try continuing up the harmonic series until the 31st tone. You can use the depiction of the first five octaves at the start of this section on The harmonic series to check that you're selecting the right nodes. The most challenging tone to find is the 25th, as this requires shifting along the '5' axis. Once you've found 25, shift back along the '5' axis to bring the remaining tones into view. The 27th tone then also requires shifting the tuning vine, this time along the '3' axis.

The Subharmonic series

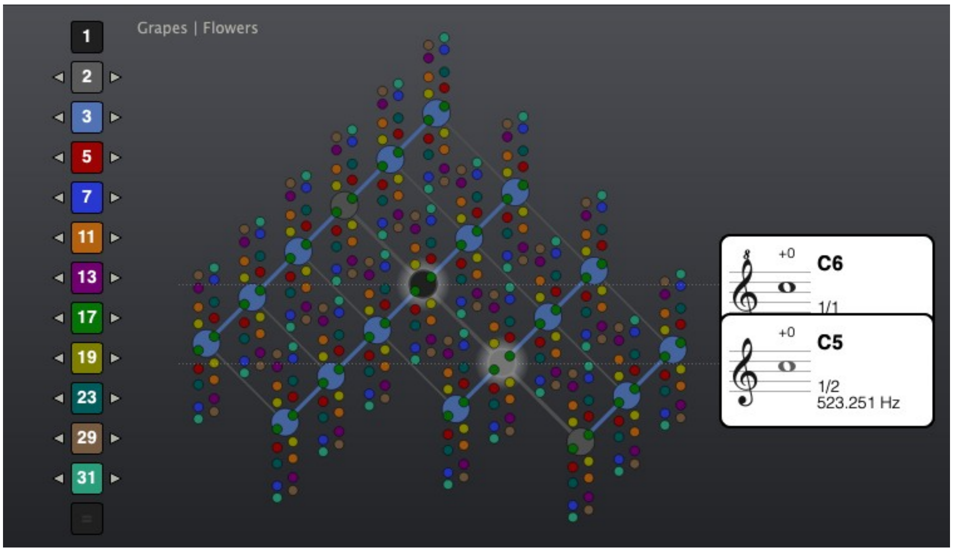
If the first note in a subharmonic series is defined as 'C6', the first five octaves may be written as:



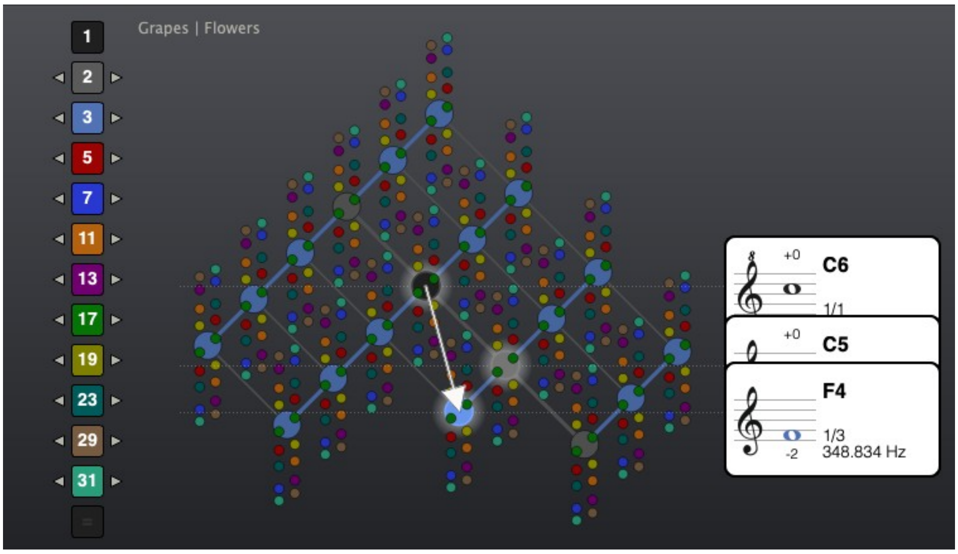
Precisely the same principles apply to mapping of the subharmonic series as apply to mapping the harmonic series onto the *Hayward Tuning Vine*. Start by setting '1/1 Note' to 'C6'. Then click on the central black node to sound the first tone of the subharmonic series:



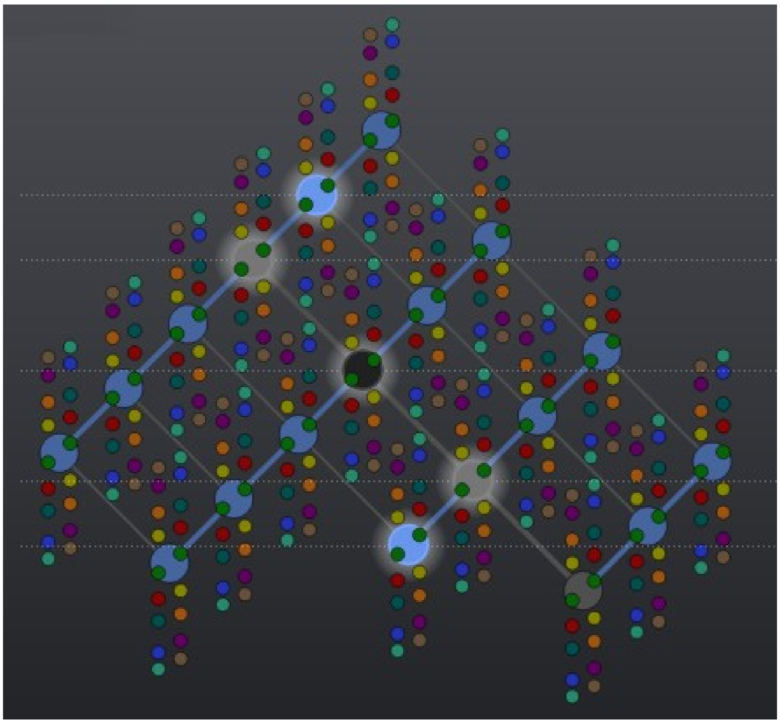
The second tone in the series is described by the ratio ‘1/2’. Just as ‘2/1’ implies moving up one grey strut within the harmonic series, so ‘1/2’ implies moving *down* one grey strut in the subharmonic series:



The third tone in the subharmonic subharmonic series corresponds to the ratio ‘1/3’. In the harmonic series ‘3/1’ implies jumping from the bottom to top corner within the rectangle above the ‘1/1’. ‘1/3’ in the subharmonic series therefore implies jumping from the top to bottom corner within the rectangle below the ‘1/1’:



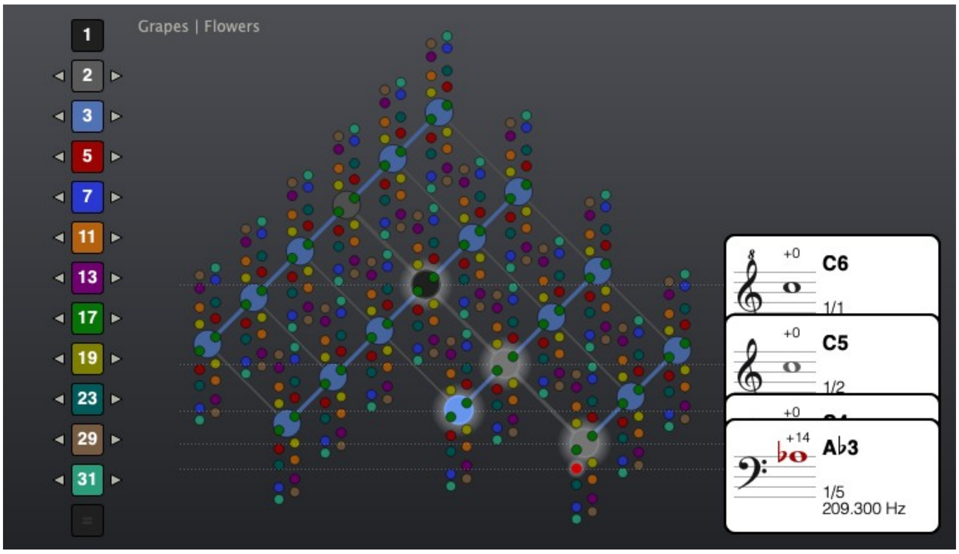
The ‘1/3’ forms the intervals ‘3:1’ with the ‘1/1’, and ‘3:2’ with the ‘1/2’. Notice how these intervals are identical with those formed between the third tone and first two tones of the harmonic series. Viewed together, it may immediately be seen how the second and third tones of the subharmonic series mirror those of the harmonic series through the pivot of the central ‘1/1’:



This mirrored geometry is maintained throughout the subharmonic series. It arises because the subharmonic series is based on *dividing* a given frequency by whole numbers, as opposed to the harmonic series *multiplying* a given frequency by whole numbers.

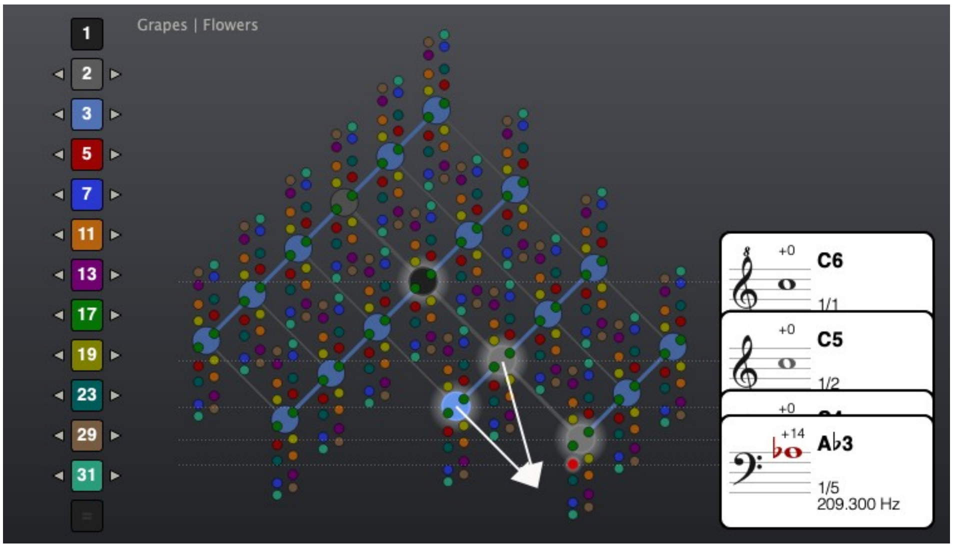
Both the harmonic and subharmonic series therefore contain one tone within their first octaves, and two tones within their second. The difference is that octaves ascend within the harmonic series and descend within the subharmonic series. Compare the mapping of the first three tones of the subharmonic series on the tuning vine with the depiction at the beginning of this section on The Subharmonic series.

The fourth and fifth tones within the subharmonic series are mapped onto the tuning vine as follows:

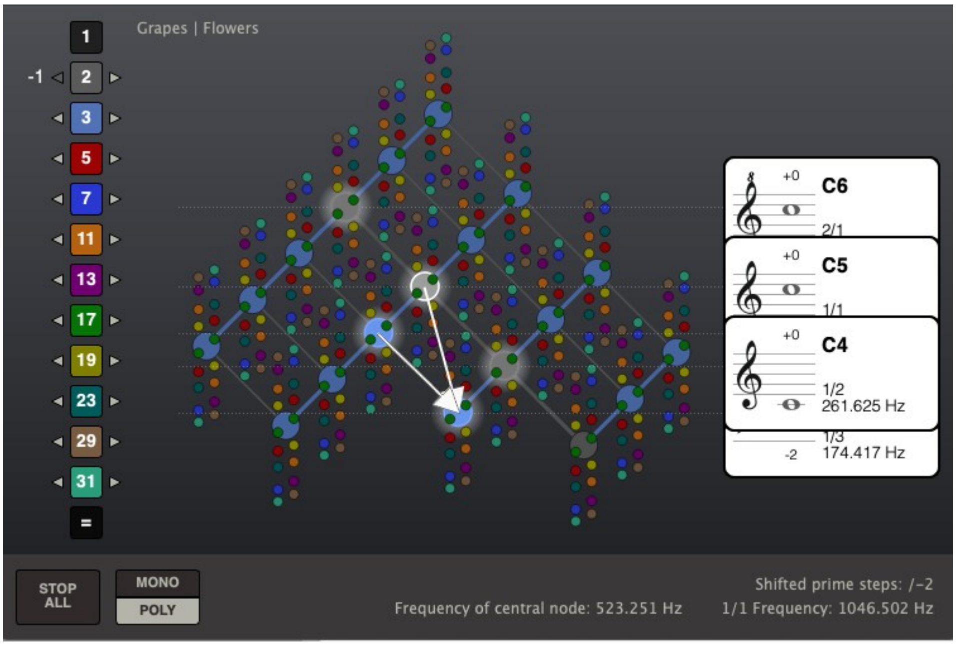


The mirrored geometry between the harmonic and subharmonic series is also revealed in the cents values shown above and below the noteheads within the notation cards. Whereas the third and fifth tones within the harmonic series are marked by cents deviations of '+2' and '-14', the third and fifth tones within the subharmonic series have cents deviations of '-2' and '+14'. This is because the intervals are now measured downwards rather than upwards from the '1/1' that marks the beginning of the series.

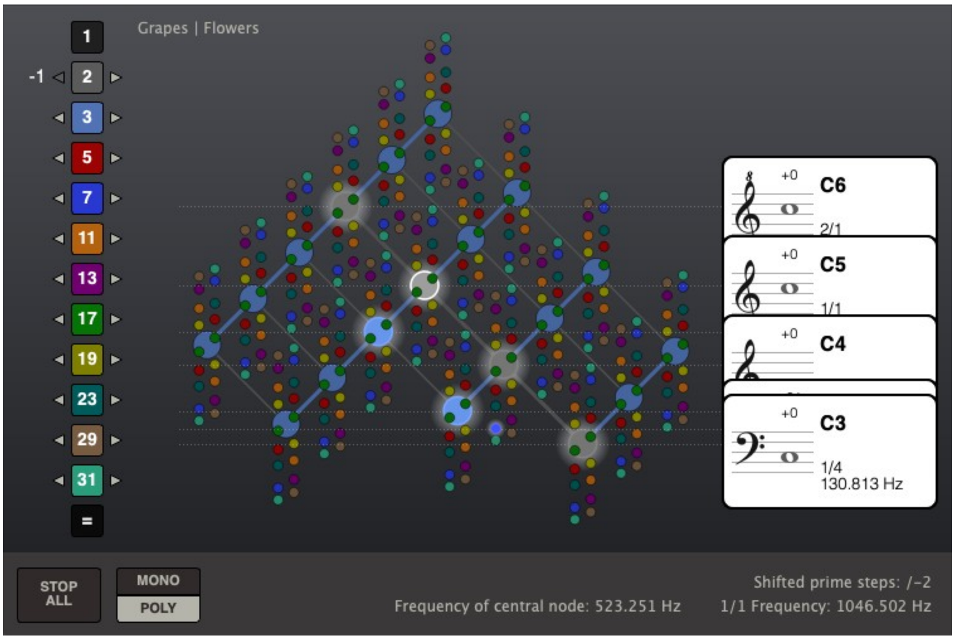
The sixth tone of the subharmonic series lies an octave and a fifth below the second tone, and an octave below the third tone:



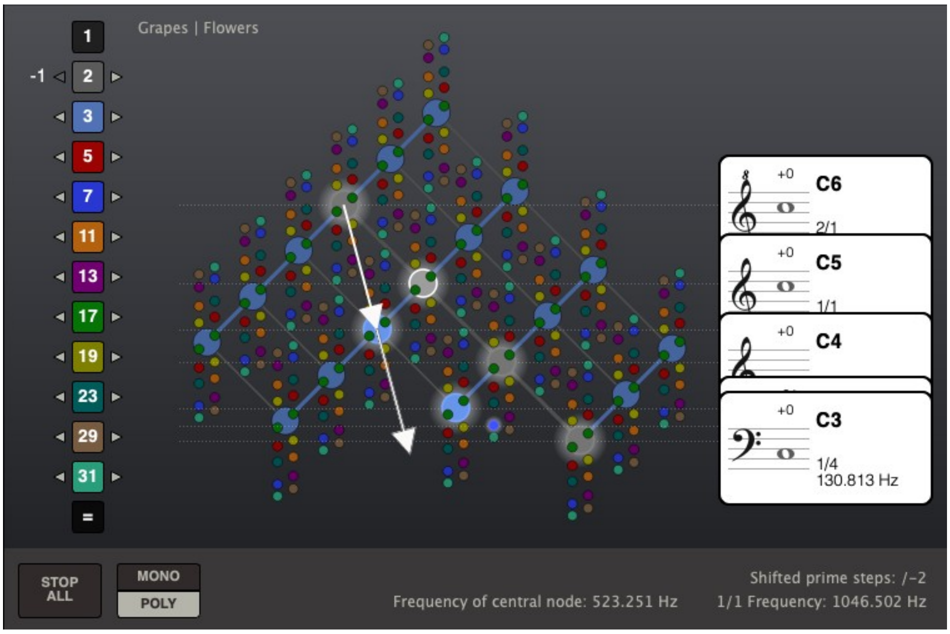
In order to bring it into view the tuning vine now needs to be transposed down and octave, by clicking on the shift arrow to the left of the grey number box:



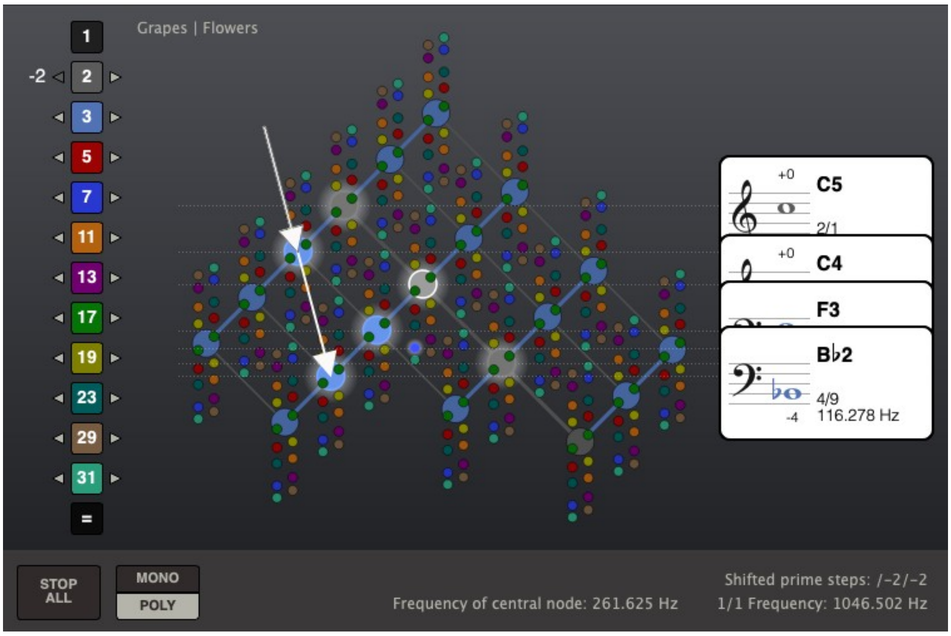
The octave shift has also brought the seventh and eighth tones into view:



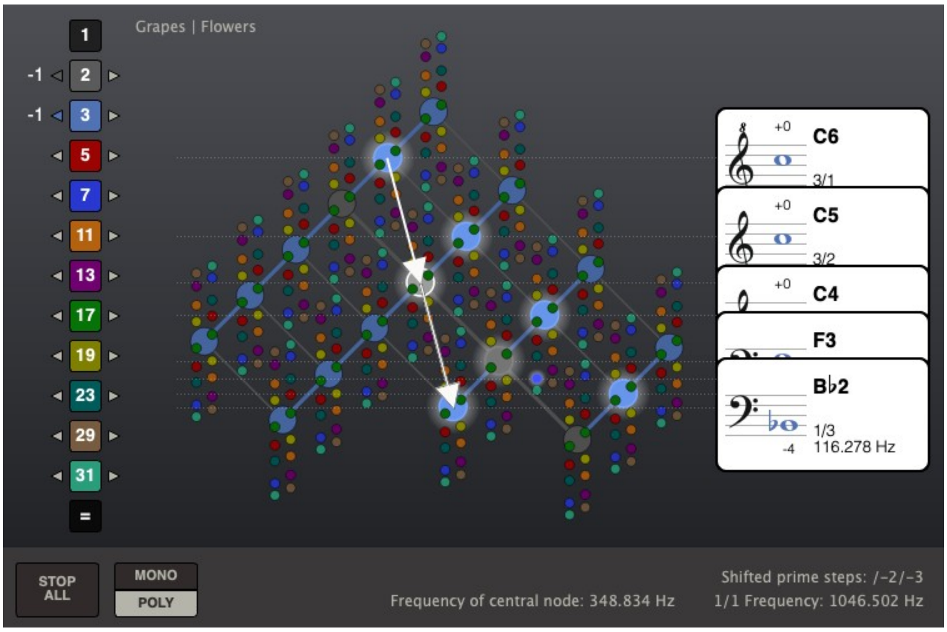
The ninth tone is described by the ratio ‘1/9’. Restated in its prime factors this is ‘1/(3 x 3)’, which split into two ratios gives ‘1/3 x 1/3’. As ‘1/3’ is mapped onto the tuning vine by jumping from the top to bottom corners within the rectangle below the (unshifted) ‘1/1’, ‘1/9’ therefore signifies two such jumps:



Playing it therefore requires another shift down, either along the grey octave axis:



…or along the light blue perfect fifth axis:



Shifting along the light blue axis has the advantage that all of the tones within the subharmonic series remain visible.

You are now in a position to map out the full subharmonic series down to the 31st tone. As you find and play the tones on the tuning vine you can use The Subharmonic series shown at the beginning of this section to check your results.

Harmonic and subharmonic series may be started from anywhere within the *Hayward Tuning Vine*, not just from the central black node. Any node may of course be shifted to the central position, where it will be displayed as a pale node.

Guide to colour-coding

The colour-coding of the prime numbers is based on psychological association rather than any strict system. Some knowledge of the associations may nevertheless help speed up the process of learning which colour is associated with which prime number.

The central ‘1/1’ node is coloured black when it is unshifted, and off-white when it is shifted, because it is the source of all the other intervals, and therefore the source of all the other colours. The octaves, based on prime number two, are coloured grey because they do not imply a categorical shift away from the central ‘1/1’ – the pitches maintain their basic identity when they are transposed into different octaves.

Prime number three, which opens up the family of intervals based on the perfect fifth, is coloured light blue as it provides the rational framework into which other intervals are fitted. The intervals based on prime number five are coloured red because they include the major and minor intervals often associated with emotion in music. The reason for the dark blue colouring of prime number seven has already been hinted at – the family of septimal intervals it opens up is often associated with Blues music.

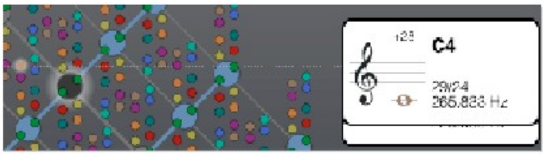
The interval ‘11/8’ lies almost exactly midway between a perfect and augmented fourth. It is a sharp, penetrating sound, suggestive of a hot, bright colour such as orange. Also the thirds and sixths based on prime number 11 are also almost exactly neutral, fitting to the secondary colour orange that lies midway between two primary colours on the colour wheel.

Lying nearly midway between a major and minor sixth, the harmonic neutrality of the ‘13/8’ interval makes it very unfamiliar to ears used to the diatonic tonal system. The colour violet, lying at the end of the visible light spectrum, therefore seems an appropriate choice for prime number 13.

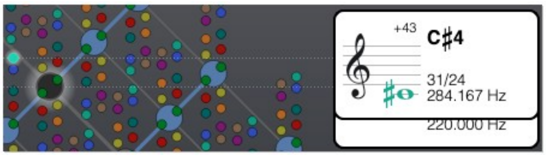
By contrast, the interval ‘17/16’ is only five cents larger than the tempered semitone found on a piano keyboard. It therefore invites an everyday colour such as green. It is also the first interval contained within the fifth octave of the harmonic series, offering associations with the green shoots of spring.

With only ‘-2' cents deviation, ‘19/16’ lies even closer to the minor third found on the piano. But as it is higher up within the fifth octave of the harmonic series than prime number 17, and is also a *minor* third, the autumnal colour of ochre seems well suited to it.

‘23/16’ corresponds to an augmented fourth plus 28 cents. Lying between the familiar and unfamiliar, the colour turquoise, based on a mixture between two colours used for lower primes, seems an appropriate choice for the set of intervals based on 23.



The prime number 29 opens up a third category of neutral intervals, following those based on 11 and 13. Mixing together the respective orange and violet colours of these two prime numbers results in brown. The interval ‘32:29’, corresponding to a tempered minor third plus 28 cents, can also be perceived as a ‘sweetened’ version of the smaller minor thirds, for which a chocolate colour seems particularly fitting.

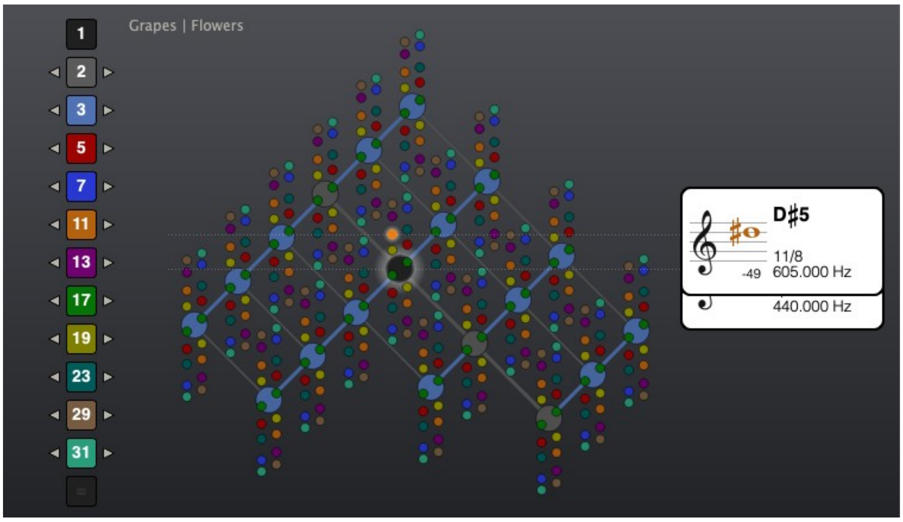


Representing a major seventh plus 45 cents, ‘31/16’ has similarly biting character as the family of intervals opened up by 11. In contrast to 11, however, the major thirds based on 31 are sharpened rather than made neutral, suggesting a refreshing mint flavour. Mint also seems an appropriate choice to follow the chocolate-flavoured 29.

Enharmonic notation and double accidentals

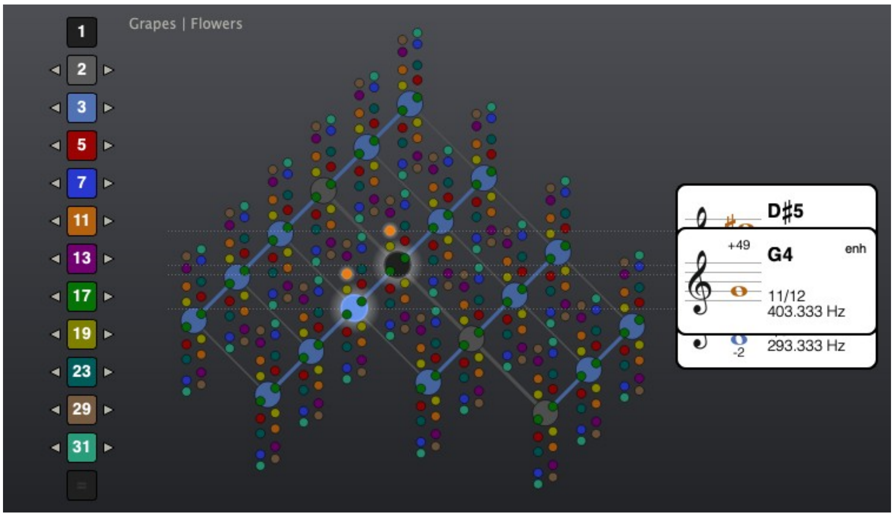
If you look closely at the spelling of the accidentals of the various microtones within the *Hayward Tuning Vine* - for example, whether a pitch is notated as a 'B♭' or an 'A♯' - you'll notice that the same interval is sometimes spelled differently according to where it occurs within the lattice.

An example of this is provided by prime number 11, colour-coded orange within the tuning vine. First reset '1/1 Note' to 'A4' in 'Options'. Now click on the central black 1/1 node, and then on the smaller orange node above it:



The interval formed between '11/8' and '1/1' is '11:8', lying almost exactly between an augmented and a perfect fourth. Because it is actually one cent closer to the augmented fourth, the noteheads are written as 'A' and 'D♯'.

Now click on the light blue node below the central black node, and then on the orange node above it:

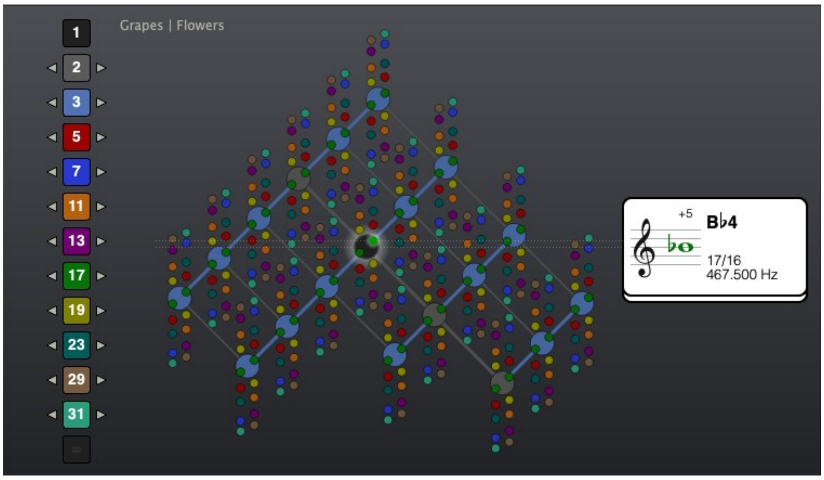


Although the interval between these two pitches remains '11:8', the noteheads are written as 'D' and 'G', which is a perfect rather than an augmented fourth. The reason for this different spelling is that the 'D' now has a cents deviation of '-2'. The orange notehead, if it were to be notated as a 'G♯', would therefore have a cents deviation of '-51'. This would exceed the limit of cents deviations allowed within the *Hayward Tuning Vine*, which follows the same convention as most electronic tuners, indicating cents deviations within a range of ‘-50’ to ‘+50’ cents. Cents deviations that exceed these limits are ‘flipped over’ to the neighbouring semitone, which is why in the current example the strictly harmonically correct spelling of ‘G♯ -51 cents’ is renotated as ‘G +49 cents’.[15]

Such respelling is known in music theory as an ‘enharmonic equivalent’, and this is the reason that the abbreviation ‘enh’ appears in the upper right hand corner of the ‘G4’ notation card. The implications of enharmonic spelling may be seen most clearly in the current example if you hover your mouse over each of the two highlighted orange nodes, in order to compare their notation cards. The interval between the ‘G4 +49 cents’ and the ‘D♯ -49 cents’ is a Just perfect fifth, even though the noteheads give the first impression of an augmented fifth. The ‘enh’ acts as a flag in such cases, warning you to examine the cents indications carefully, rather than relying solely on the harmonic implications of the noteheads, as may be done between pitches without any ‘enh’ indication.

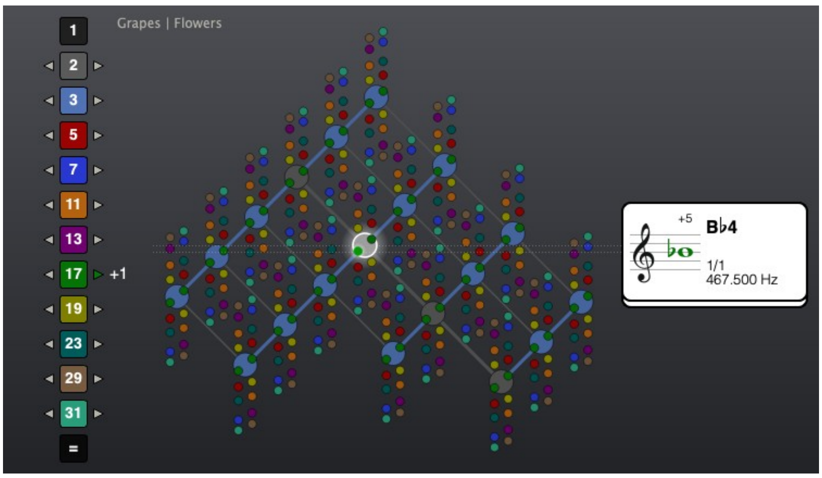
Along with the flipping over of cents indications when they exceed their limit, there is a second reason why enharmonic notation is sometimes used within the software. This has to do with double sharps and double flats, and may be demonstrated most clearly by examining prime number 17, colour-coded green.

First click on STOP ALL in order to turn off the currently sounding tones. Then click on the central black node, along with the green node positioned within its upper right border:



The interval between these two pitches is a minor second, and the cents deviation of ‘+5’ reveals it to be only five cents larger than the tempered minor second found on a piano keyboard.

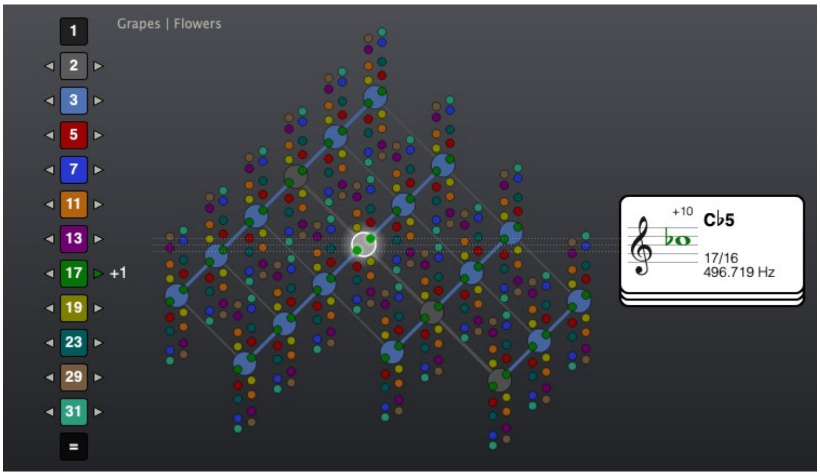
Next, click on the shift arrow to the right of the green number box containing ‘17’. The position of the sounding pitches has now been shifted to:



of ‘-50’ are automatically flipped to ‘+50’.

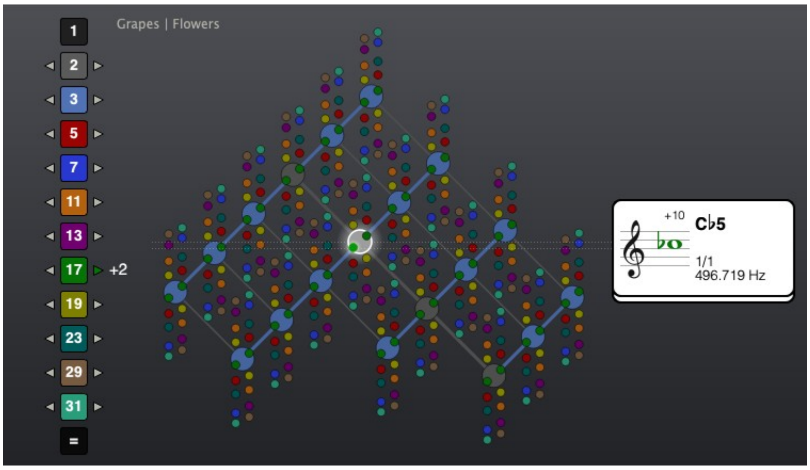
The ‘A’ now corresponds to the lower green node, and the ‘B♭’ with the pale node itself.

Now, click on the green node within the upper right border of the central pale node:

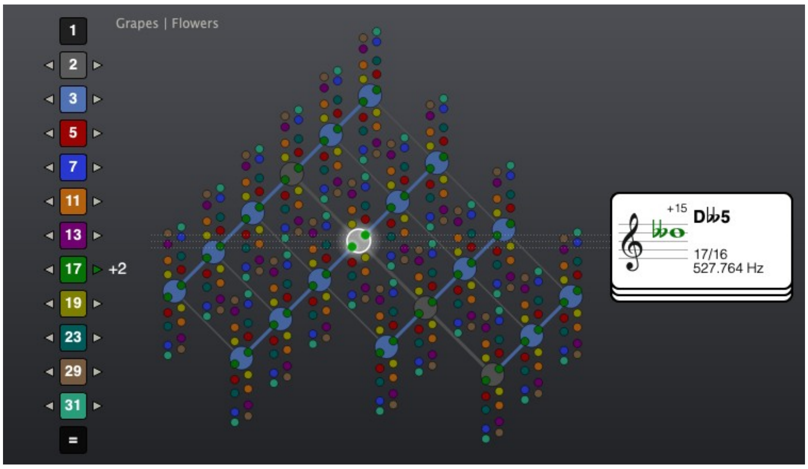


This pitch is notated as ‘C♭’ rather than as ‘B’, because it is a minor second higher than the ‘B♭’ now associated with the central pale node. Notating the upper green node as ‘B’ would imply the relationship of an augmented unison with the ‘B♭’ of the central pale node, which would be harmonically misleading.

Now click once more on the shift arrow to the right of the green number box. The position of the sounding pitches has again shifted in the direction of the lower green node, so that the ‘A’ is no longer visible, and the lower green and central pale nodes are now associated with ‘B♭’ and ‘C♭’ respectively:

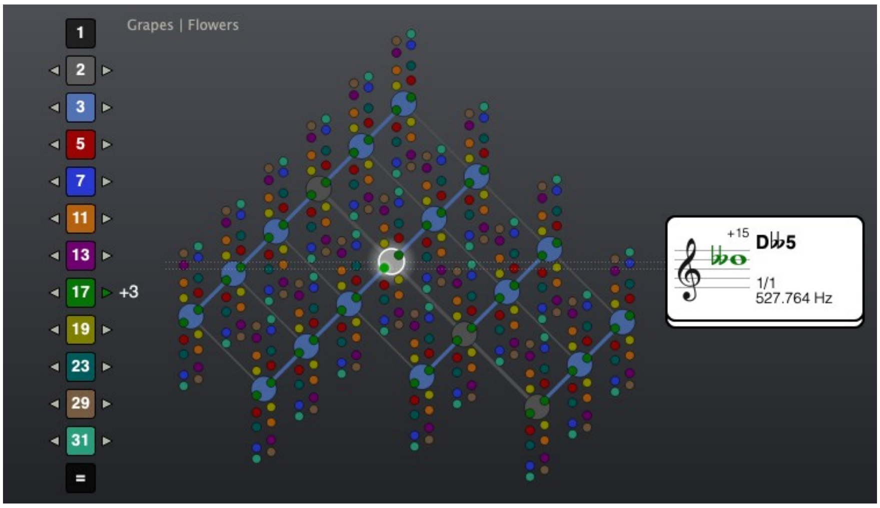


Now click again on the green node at the upper right hand border of the central pale node:

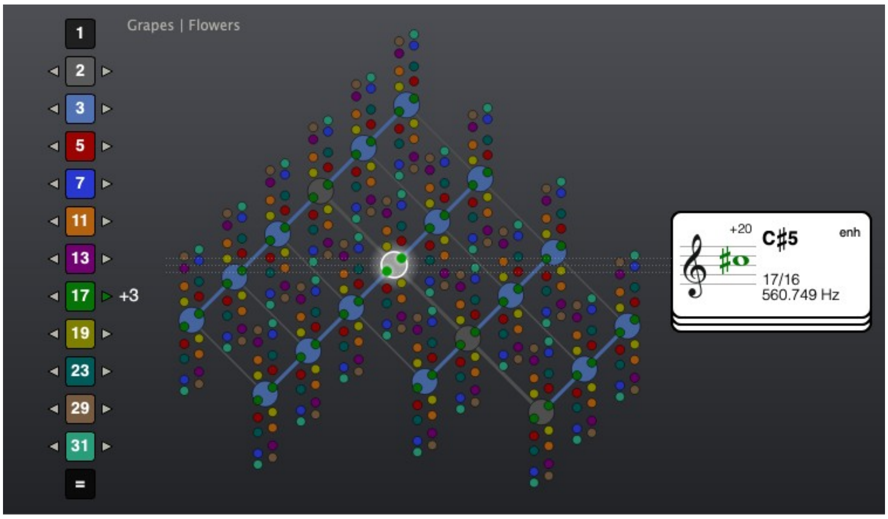


This pitch is notated as ‘D♭♭’ rather than as ‘C’, because it is a minor second higher than the ‘C♭’ now corresponding to the central pale node. Notating the upper green node as ‘C’ would imply the relationship of an augmented unison with the ‘C♭’ of the central pale node, which would again be harmonically misleading.

Now click once more on the shift arrow to the right of the green number box. The position of the sounding pitches shifts again in the direction of the lower green node, meaning that both the ‘A’, the unshifted pitch of the central black node, and the ‘B♭’, the unshifted pitch of the upper green node, are no longer visible. The lower green and central pale nodes now correspond to ‘C♭’ and ‘D♭♭’ respectively:



Click once more on the green node within the upper right hand border of the central pale node:



According to the logic of the previous two shifts, this pitch should be notated as ‘E♭♭♭’, to indicate the harmonic relationship of a minor second above the ‘D♭♭’, currently associated with the central pale node. But in the interest of striking the right balance between what is theoretically correct and what is practically useful, a limit has been set in the *Hayward Tuning Vine* that re-notates any pitch requiring more than two accidentals (i.e. two double sharps or two double flats) to its enharmonic equivalent. This is the reason that the ‘enh’ abbreviation once more appears in the upper right hand corner of the card attached to the ‘C♯’.

3. Custom voice patches

The *Hayward Tuning Vine* has patches for the basic waveforms Sine, Triangle, Square and Triangle. With sufficient knowledge, you can modify or create new synthesized voices for the software too. The software's audio is generated by *libPD*, and the patch editor may be downloaded for free at http://puredata.info/.[16]

Creating your own voice patch

The easiest way to create a custom voice patch is to base it on one of the existing patches. The patches for the four waveforms that come with the software are fundamentally similar.

Look in the application program folder[17] for the subfolder called 'patches'. Duplicate of one of the patches I it contains and restart the tuning vine. The new patch should now appear together with the built-in ones.

There are additional patches located in the subfolder 'shell'. These are lower-level patches designed to handle the communication between the 128 voices and the application itself. They are largely undocumented, and it is not recommended to modify these patches (at least, take a backup first!).

How voice patches are structured

If you open one of the voice patches using Pure Data, you will see that the patch itself contains inline documentation. This should help in understanding how each patch is working on a detailed level, but it's still a good idea to read this documentation to get an idea of the basic structure of a voice patch.

First of all, a voice patch is a single .pd patch which, when the application is started, will be instantiated 128 times. Each patch is an identical copy, and will work the same way, but it will generate its own audio signal, all of which are combined at the output stage. This means that you can have up to 128 unique voices playing in the *Hayward Tuning Vine* at any time.

Any voice patch will have a number of parameters that arrive via 'inlets'. The number of inlets is fixed and needs to be defined in order for a patch to work. The inlets themselves are divided into two categories: internal commands (called 'parameters'), and freely definable, optional commands (called 'macros').

`Parameters: Internal commands (required)`

Voice ID	this is an internal ID that identifies the voice among the 128 possible voices that can play at any given time.
Trigger	This value is either 1 or 0 - 1 when voice is playing, 0 when not
Frequency	A value specifying the current frequency in Hertz (between 20 and 20000)
Volume	A value specifying the current volume level (between 0 and 1)

16 When downloading Pure Data, be sure to choose the 'vanilla' distribution. The reason is that lipPD will not support compiled externals, such as those that are part of PD-extended. By running the vanilla version, there is less risk of using unsupported features for your project.

17 On Mac: right-click on the *Hayward Tuning Vine* application and select 'Show Package Contents', then proceed to the subfolder 'Contents'. On Windows: navigate to the *Hayward Tuning Vine* folder in 'Program Files'.

Macros: User-specified commands (optional)

Each voice-patch can define between 1 and 8 'macros' that you can control via the *Hayward Tuning Vine* UI (the sliders located at the top of the screen). It is completely open-ended how you use these parameters.

A macro is always defined as having a value between 0 and 1 (0 = slider to full left, 1 = slider to full right). If you want to make use of a different range, you will have to implement your own range. Fortunately, it is relatively simple to scale a value between 0 and 1 (for example, to make it go from 1 to 16 you would multiply by 15 and then add 1).

In the case of the built-in patches, all macros defined therein have generally been designed to work asynchronously. This means that you can adjust the value of each macro, but the value will only be applied in the very moment before the voice is being triggered. In other words, you can set the panning of a voice before it starts to play, but you cannot modify the panning of an already playing voice.

It is important to understand that applying changes in this manner is by design, and not a technical limitation as such. If you choose to create your own patches, you are of course completely free to choose how you want parameter changes to be applied.

The resulting sound from the voice is output via audio 'outlets', and then combined in the master patch (run through a compressor at the final output stage). If you experience that the audio is being distorted and/or compressed, it's a good idea to lower the master volume (see Options and Master Volume).

Links and resources

Poster presentation for NIME 2015

The Hayward Tuning Vine: An Interface for Just Intonation

David B. Doty: The Just Intonation Primer

Acknowledgements

Software development: Bjørn Næsby Nielsen, Erik Jälevik (v1.0.8), Philipp Moser (Version 1.5)

The *Hayward Tuning Vine* uses the following components from the open-source projects: QT, libPD (Pure Data), PortAudio