Hayward Tuning Vine

Documentation for v1.0, rev.2

Introduction

The Hayward Tuning Vine is a colour-coded model of harmonic space in Just Intonation, invented in 2012 by the 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 this 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 get familiar with the user interface (Learning the Interface).

Finally, the manual will guide you through the Hayward Tuning Vine in a series of steps that gradually become more complex (How the Hayward Tuning Vine works). Once you have completed these chapters, you should have a thorough understanding of the harmonic theory behind the Hayward Tuning Vine (and thus, also how Just Intonation works).

System Requirements

Supported operating systems:

- Windows XP, Windows Vista, Windows 7, Windows 8
- Mac OSX 10.6 (Snow Leopard), 10.7 (Lion), 10.8 (Mountain Lion), 10.9 (Mavericks)

Also, The Hayward Tuning Vine is known to work on the Linux platform through Wine (using the default Win-XP compatibility settings). A separate version for Linux is in development.

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 (Hayward Tuning Vine.app) into your Applications folder to install it.
5. Click on the Hayward Tuning Vine application to launch it

To un-install

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

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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.

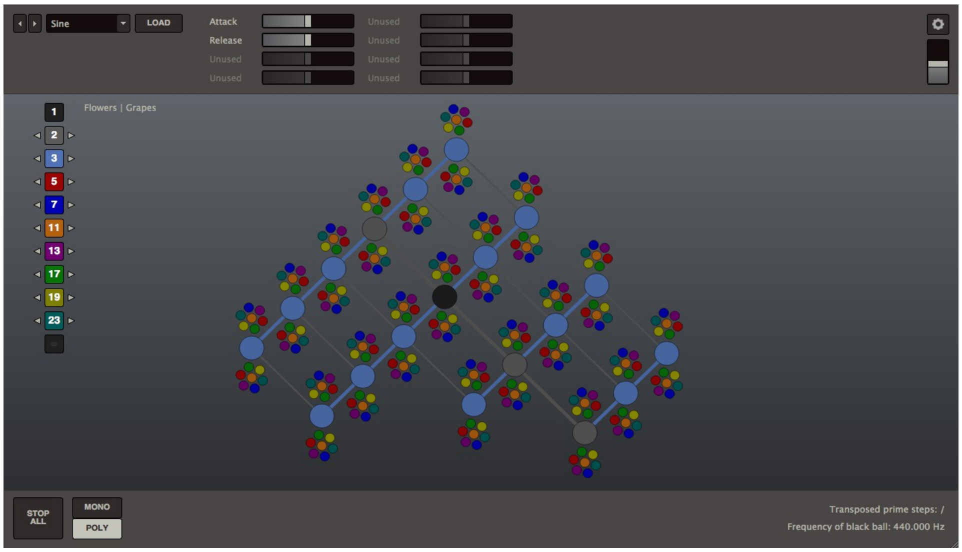
To un-install

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

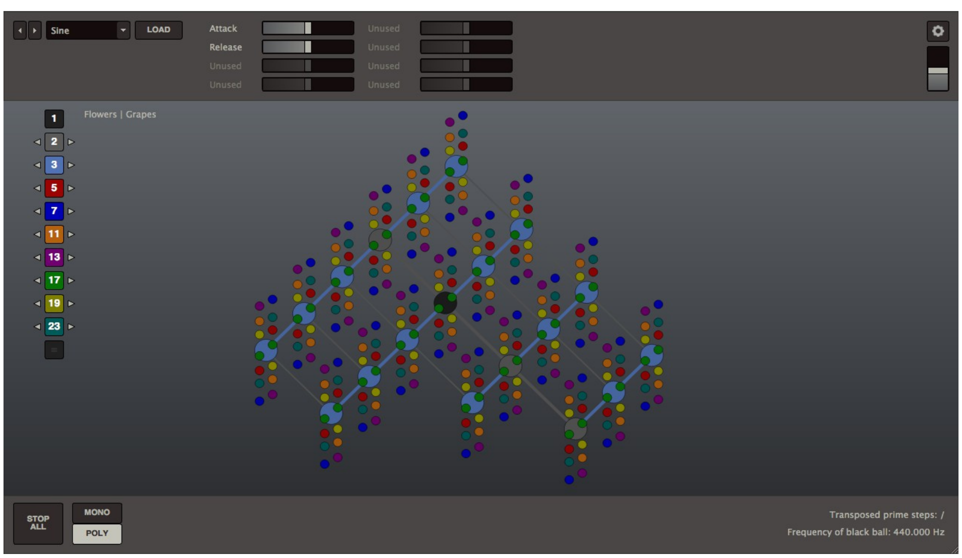
The Hayward Tuning Vine: Flowers / Grapes view

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



Each of the coloured balls 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 stop any currently sounding pitches.

Next, click on 'Grapes' at the top left hand corner of the screen. The screen now looks like this:



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

Although they look quite different, the 'Grapes' view contains exactly the same information as the 'Flowers' view. In 'Flowers', it is immediately clear which smaller balls are associated with which larger balls, so it is the better choice for getting familiar with the Hayward Tuning Vine. In 'Grapes', each ball is positioned according to the height of the pitch it refers to - the higher the pitch, the higher the vertical position within the Vine. It therefore gives a more accurate reflection of the melodic pitch relationships. You can compare the two views directly by selecting some of the smaller balls and then toggling between 'Grapes' and 'Flowers'.

Now toggle back to 'Flowers' view and click on 'STOP ALL' before moving onto the next section.

Number boxes and transposing arrows

Each of the coloured number boxes running down the left hand side of the screen corresponds to the coloured balls within the Hayward Tuning Vine. Try clicking your mouse on the turquoise number box numbered '23'. You'll notice that this deactivates all the turquoise balls. To reactivate them, simply click on the turquoise box again.

All of the colours in the Hayward Tuning Vine may be deactivated except black, grey and light blue.

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 'transposing' arrows, which enable you to transpose the 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', but for now you can start by clicking on the central black ball, and then on the arrows to the left and right of the grey number box marked '2'. Notice how this changes the range of the pitches contained within the Vine[2].

Now reset all the transposition buttons by clicking on the '=' sign beneath the number boxes, and then click on 'STOP ALL' in order to turn off all the pitches before moving onto the next section.

[2] For both the octave and other transposition arrows, transpositions may be continued as long as the central black ball stays within the audible range of 20 - 20 000 Hz. After this the arrow disappears from the screen, to indicate that further transpositions are no longer possible.

MONO / POLY modes

The 'MONO' and 'POLY' mode buttons are located next to the 'STOP ALL' button at the lower left hand corner of the screen. POLY mode is ideal for building up chords, as each note remains sustained until it is turned off. MONO mode is better suited 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.

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 the top left hand corner of the screen. Here you can select what sort of sound will be played when you click on the coloured balls, either by selecting 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 load them into the application using the 'LOAD' button.

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 with the synthesizer patches that come with the software, the 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 button and Master Volume slider. Before each session with the Hayward Tuning Vine, play the maximum number of pitches you anticipate simultaneously occurring during the session. If the resulting chord causes the sound to distort, lower the slider level until the distortion disappears. You will now be free to start the session free from distortion.

Above the volume slider is the Options button, which opens the dialogue box for selecting your Audio Device, the Calibration and the 1/1 Frequency (pronounced '1 to 1 frequency'). As on standard tuners, 'Calibration' refers to the reference pitch on which the tuning system 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. '1/1 Frequency' sets the frequency of the central black ball in the Hayward Tuning Vine.

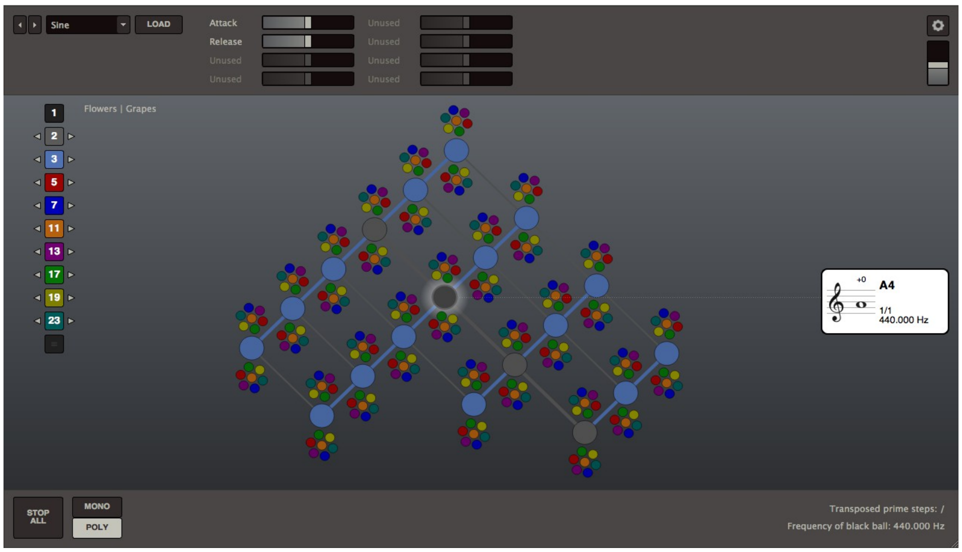
During the initial stages of using the Hayward Tuning Vine, the 1/1 frequency of the central black ball should be set to the same frequency as the Calibration. Once you become familiar with how it works you may however wish to set it to a different frequency, for example to an 'F4', a major third below the A4 of the calibration frequency, or to 'C4', the middle C on the piano keyboard. For detailed information of how to set this, see 'Guide to setting the 1/1 frequency' at the end of the next section.

2. How the Hayward Tuning Vine works

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

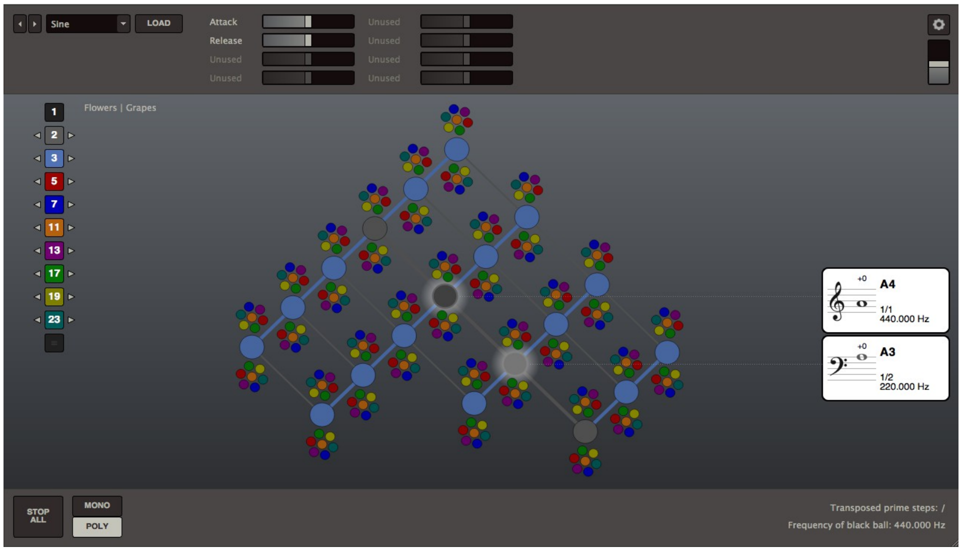
Prime number 2: the octave

Start by clicking on the black ball in the middle of the Vine. Along with sounding a musical tone, the ball lights up and a 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. This pitch is also referred to as ‘A4’, as indicated in bold type above and to the right of the staff. Below right of the staff is ‘440.000 Hz’, showing that this A4 is tuned to 440 Hz (‘Hz’ is short for ‘Hertz’ which means ‘number of vibrations per second’). 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 central pitch from which all other pitches are derived, which is why it is placed at the centre of the Vine.

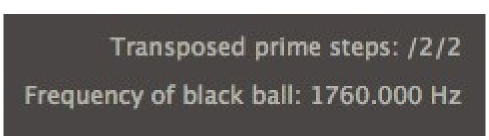
Now try clicking on the grey ball directly below and to the right of the central black ball:



Notated on the card attached to this grey ball is the ‘A’ a minor third below middle ‘C’, exactly an octave lower than the pitch sounded by the black ball. Because it is an octave lower, it is now referred to as ‘A3’ rather than ‘A4’, and its frequency has been halved from 440 to 220 Hz. This is reflected in the ratio indication of 1/2 (pronounced ‘1 to 2’) - the ratio is half that of the ratio of the central black pitch. If you look carefully at the note head in the card, you’ll notice that it is also coloured grey, matching the colour of the ball it’s connected to.

Now try clicking on the other grey balls. Listen to the resulting tones and observe the information in the cards.

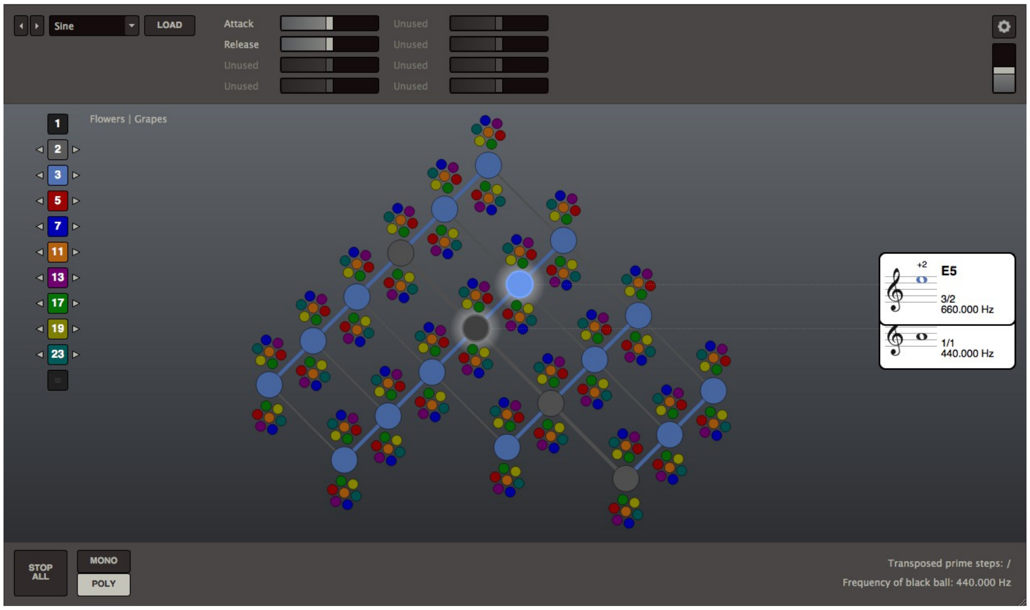
As you’ve probably worked out, the grey balls always indicate octave relationships in relation to the central black ball. From an acoustic standpoint, octave relationships are always based on multiplying or dividing a pitch by 2. This is the reason the grey button in the list of transpose buttons on the left of the screen contains the number 2. The transposition arrow to the left of it divides the central 1/1 frequency by 2, and the arrow to the right of it always multiplies the frequency by 2. You can verify this by clicking through the octave transpositions and observing the information at the bottom right hand corner of the screen, as in the following example in which the Vine has been transposed up two octaves:



Before moving onto the next section, click on the ‘=’ sign to reset the transpositions, and then on ‘STOP ALL’ to turn off any notes that are still sounding.

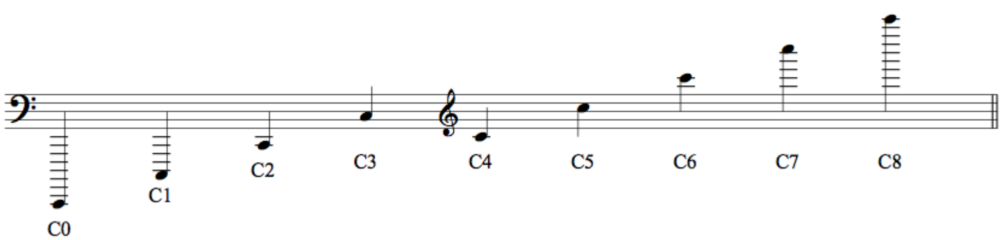
Prime number 3: the perfect fifth

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



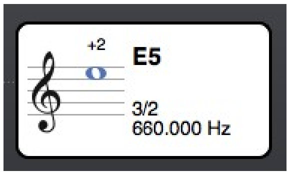
This is the interval known as a ‘perfect fifth’, as may be confirmed by examining the notation contained in the cards to the right of the screen. Because this interval is smaller than an octave, the cards now overlap, but you can choose which card is foremost by hovering the mouse over the highlighted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

Let’s take a closer look at the information contained within the card attached to the light blue ball. It is now labelled as ‘E5’ rather than ‘E4’, signalling that it belongs to a higher octave than the ‘A4’ below it. This system of numbering pitches to signify their octave position is known as ‘scientific pitch notation’ and is based on where the pitch lies within an ascending series of ‘C’s:



The ‘A’ sounded when the central black ball is played is named ‘A4’ because it lies within the octave starting from ‘C4’. The ‘E’ sounded when the light blue ball is played is named ‘A5’ because it lies within the octave starting from ‘C5’. Whenever you play a note on the Hayward Tuning Vine, the 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.

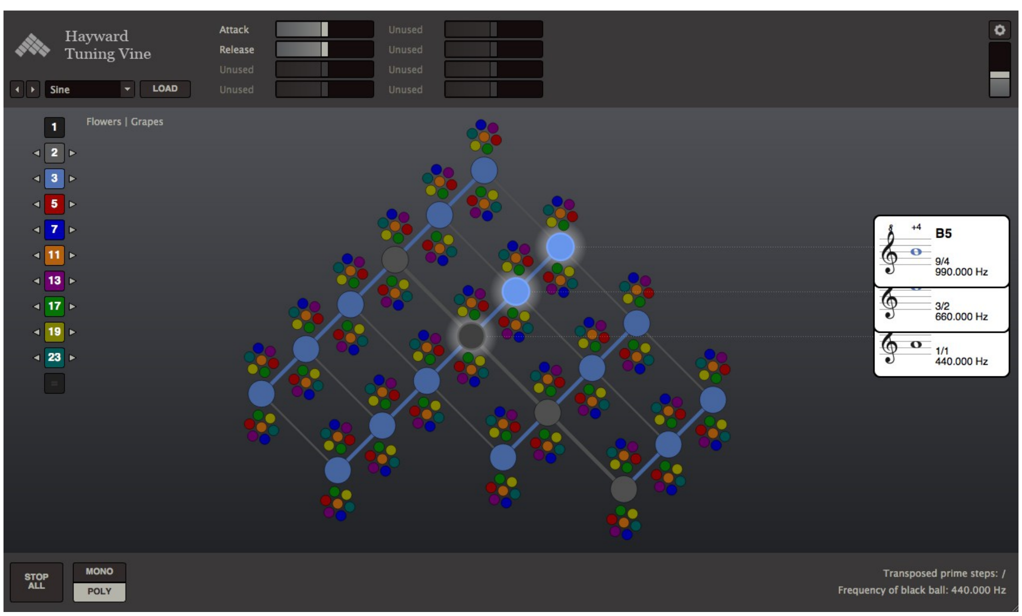
Also appearing on the card attached to the light blue ball is the ratio 3/2. This indicates the relationship between the frequency of the light blue ball and the frequency of the central black ball. The frequency of the central black ball is 440 Hz, and multiplying this by 3/2 results in 660 Hz. This is the frequency of the light blue ball, as is indicated on the card attached to it:



The final piece of information shown on this card is the '+2' that appears directly above the note head. This is an indication of the pitch's 'cents deviation'. A cent is an extremely small musical interval, just 1/100th of a tempered semitone on a piano keyboard. Just as there are 100 cents in a dollar, so there are 100 cents in a tempered semitone.

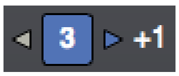
The semitones on a piano keyboard are called 'tempered' because they are not intervals based on 'whole-number ratios'. Whereas the 'E5' shown in the card above is based on multiplying central black ball by the ratio 3/2, the tempered perfect fifth between 'A4' and 'E5' on a piano keyboard can't be described by such a simple ratio, 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 note head in the card shows the extent to which the rational interval contained within the Tuning Vine deviates from the tempered interval 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 - 2 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 ball two steps to the above right of the central black ball:

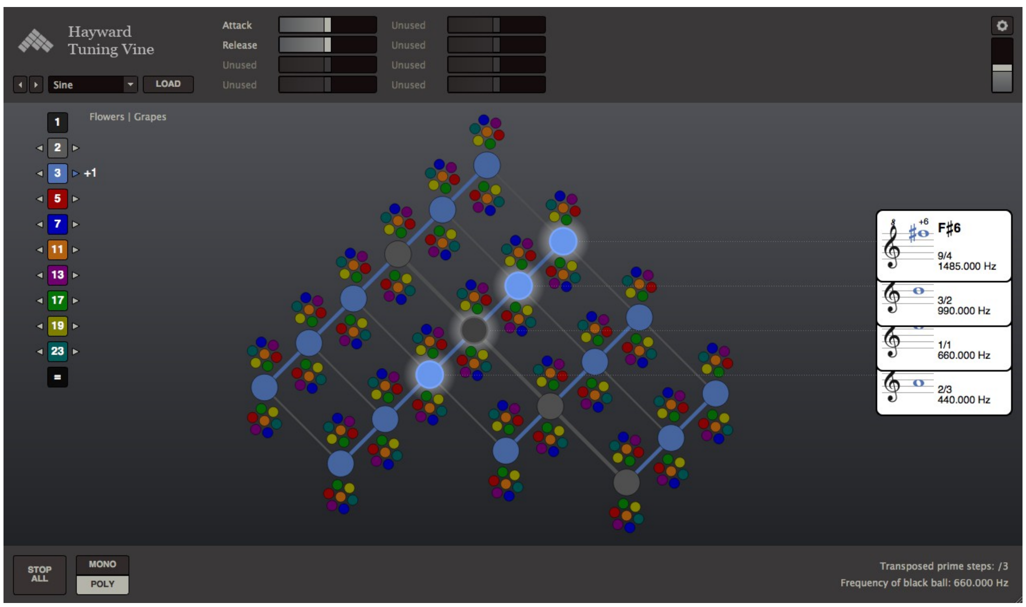


Note that the ratio contained within the card is now 9/4. This is because it is now two light blue struts away from the central black ball, and each of these steps represents a ratio of 3/2. The ratio associated with the 'B5' is therefore 3/2 multiplied by 3/2, which makes 9/4. This principle of multiplying ratios applies to all the pitches contained within the Hayward Tuning Vine. However complex a ratio appears, it may always be traced from the central black ball multiplying the ratios associated with the consecutive steps together.

Returning to the cents deviation, the card attached to the 'B5' shows that it has now increased to +4 cents, 2 cents higher than was the case for the 'E4'. In order to find out how this process will continue 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 transpose arrow key to the right of the light blue number box:



This will transpose the whole Vine up a perfect 5th, thus bringing the 'F♯6' into the visible range of the Vine. Clicking on the 'F♯6' reveals the following information:



As shown on its card, the cents deviation for 'F♯6' is now set at +6. In fact, every time you move a perfect fifth upwards on the Vine, two cents are added to the resulting pitch.

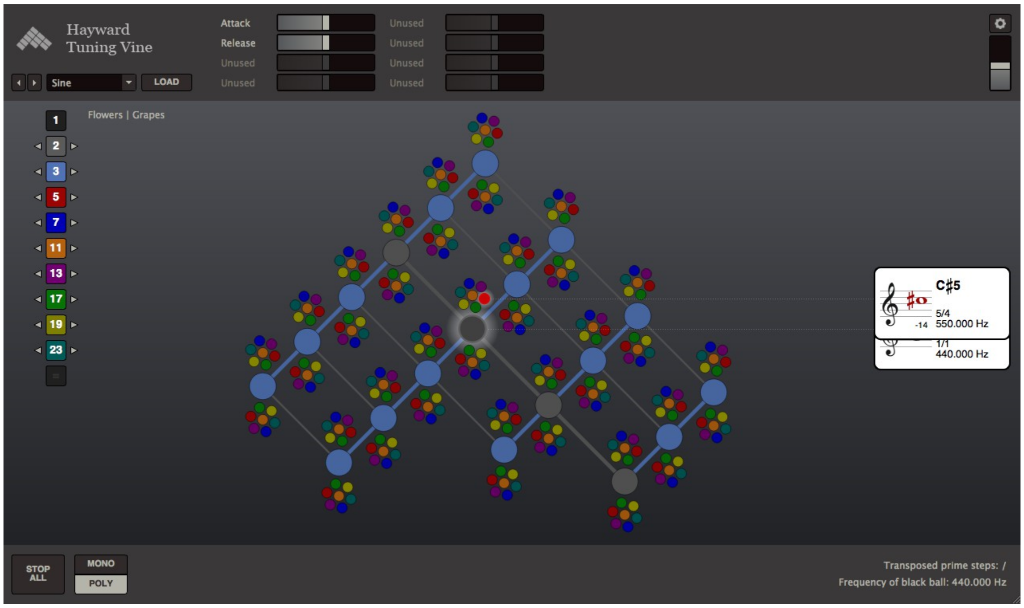
Note how this contrasts with the ratios. Whereas a fixed cents value is always added or taken away for each step along the Vine, consecutive ratios are always multiplied together. This applies not just to those intervals based on prime number 3, but to all the intervals contained within the Vine.

Now click on the '=' sign below the number boxes to undo the transposition. Notice how 'F♯6' is still sounding, even though it can no longer be seen, as it now lies outside the range of the visible Vine.

Before moving onto the next section, click on 'STOP ALL' in order to turn all the sounding pitches off.

Prime number 5: the major third

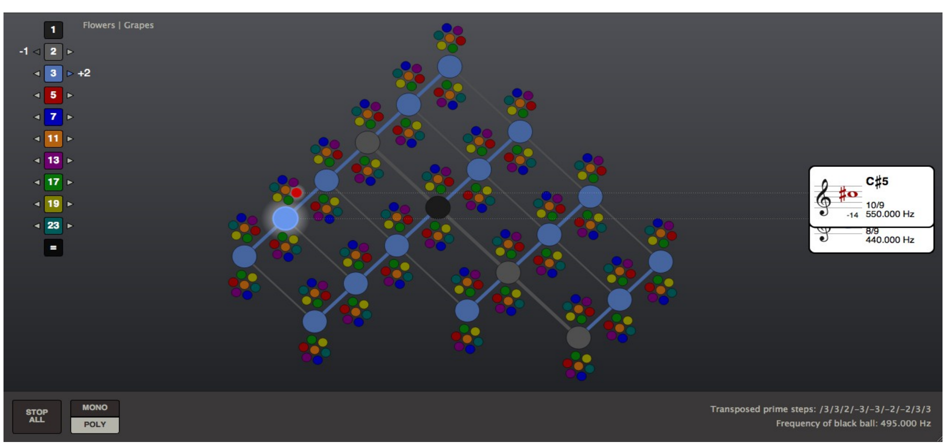
Begin by clicking on the central black ball together with the small red ball above and slightly to its right:



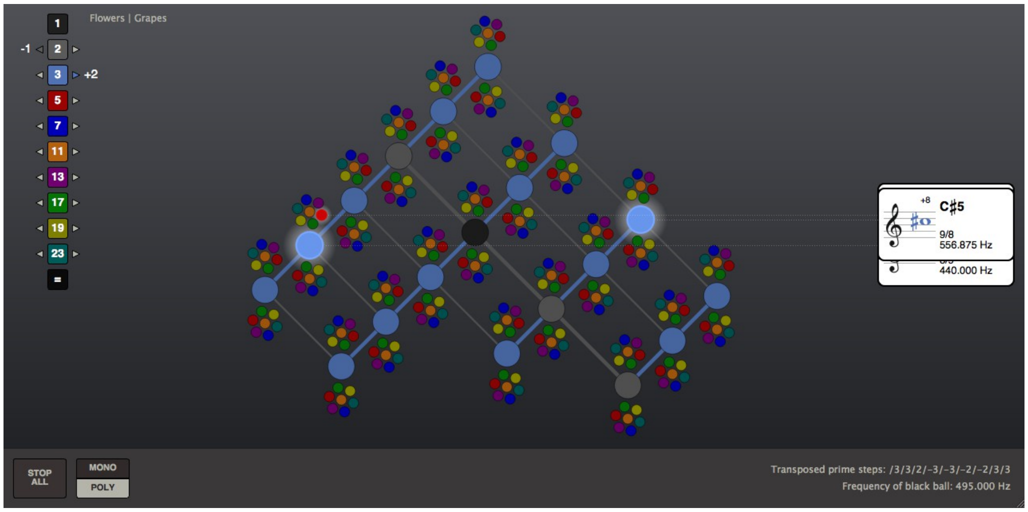
The ratio shown in the card is 5/4, which means that the 440 Hz of the central black ball has been multiplied by this ratio, giving 550 Hz. This interval is known as the Just major third. The cents deviation of -14 reveals it to be significantly smaller than the tempered major third found on a piano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

All of the intervals contained within the Hayward Tuning Vine are known as ‘Just’ intervals, because they are based on whole number ratio relationships. ‘Just Intonation’ is the name given to the system of tuning based on whole number ratios between frequencies.

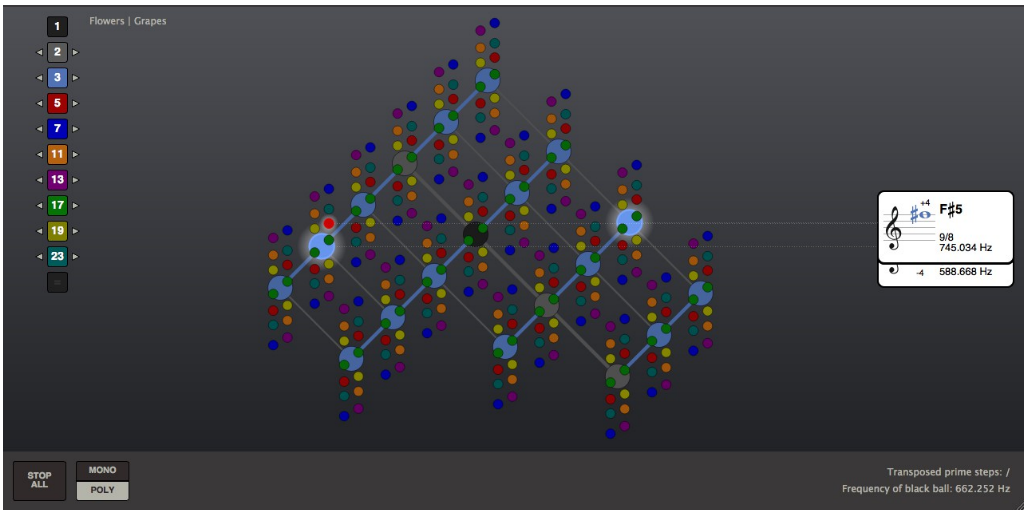
The Hayward Tuning Vine actually contains more than one Just major third. In order to compare the one based on the ratio 5/4 with one based on prime number 3, click the arrow to the left of the grey number box once, and the arrow to the right of the light blue number box twice. The Vine has now been transposed down one octave and up two perfect fifths, shifting the highlighted notes of the ‘A’and ‘C♯’ to the left of the screen:



Now follow the dotted line attached to the highlighted red ball until it crosses the large light blue ball at the right of the screen. Try clicking on this ball and listen to the results:



The resulting beating is due to the fact that the pitches of the red ball and the light blue ball lie so close to each other. You can see exactly how close by holding your mouse over each ball and comparing the Hertz numbers and cents deviations. The light blue ball has a frequency of 555.875 Hz and a cents deviation of +8; the red ball is slightly lower, with a frequency of 550 Hz and a cents deviation of -14. Yet on the current 'Flowers' view, the red ball appears slightly higher than the light blue ball. Try switching to the 'Grapes' view, and observe how the red ball is now positioned slightly lower than the light blue ball, reflecting the actual melodic positions of the respective pitches:



Whatever transpositions are activated, the ratios shown in the cards are always in relation to the current frequency of the central black ball. This is why the ratio in the card attached to the light blue ball representing 'C♯5' is 9/8, as the pitch of the central black ball has been shifted to 'B4'. The relationship between 'A4' and the 'C♯5' represented by the light blue ball is 9/8 multiplied by 9/8, which gives 81/64. Starting from the 'A4', the first 9/8 leads to the 'B4' represented by the central black ball, and the next 9/8 leads from the central black ball to the light blue ball representing 'C♯5'.

The difference between the major third tuned as 5/4 and tuned as 81/64 is known as a 'comma' difference, and it is just one example of many comma differences that occur between the different 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 a possible way of connecting tuning with rhythm.

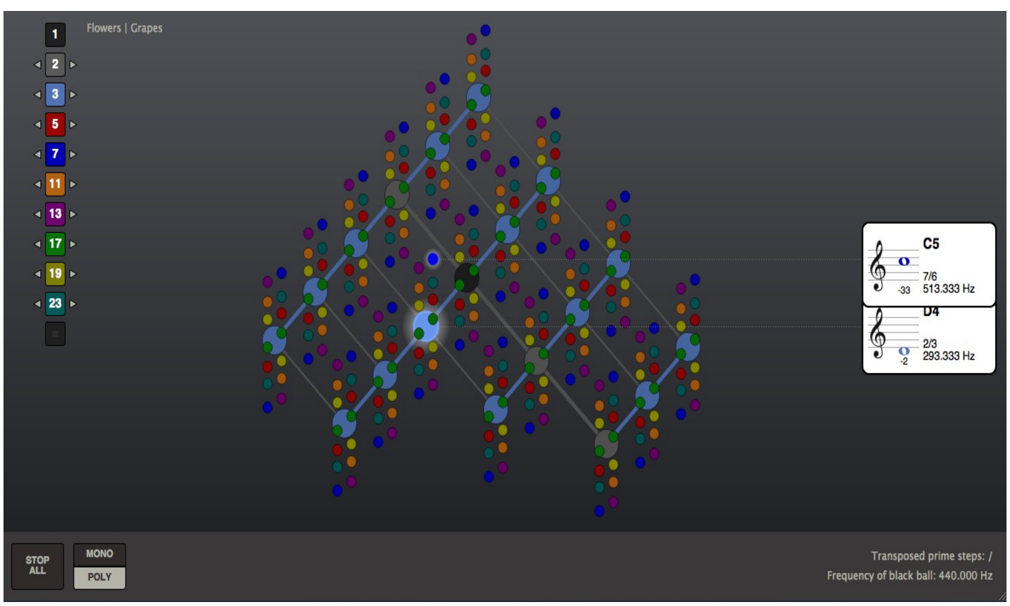
Intervals that are based on prime number 3 are often referred to as 'Pythagorean' intervals, and those based on prime number 5 are as 'Ptolemaic' intervals. Therefore, the major 3rd tuned 5/4 is known as a 'Ptolemaic major third', and the major third tuned 81/64 as a 'Pythagorean major third'.

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

Prime number 7: 'blues' intervals

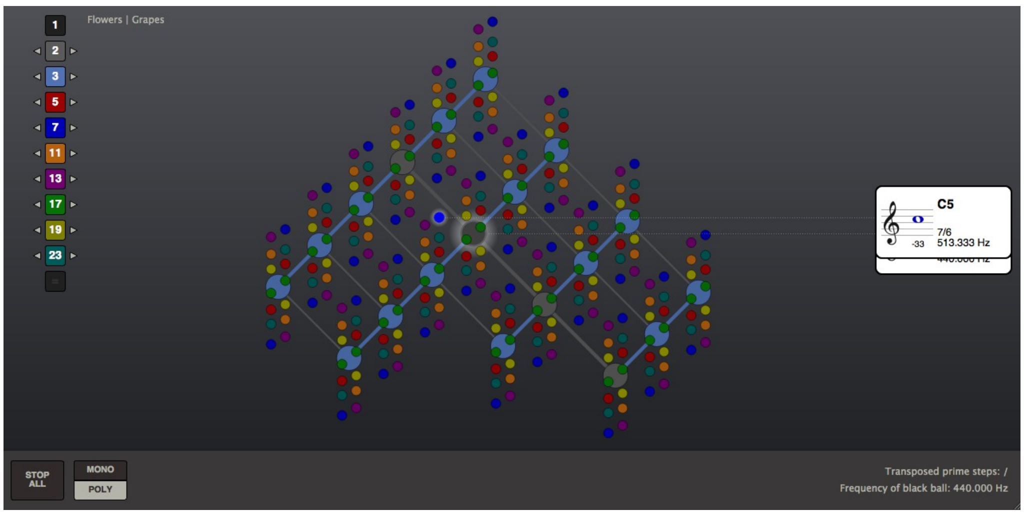
The conventional harmonic theory of western classical music is based on '5-limit' musical intervals, which means that it is based on intervals based exclusively on the prime numbers 2, 3, and 5 covered in the previous sections. Whilst the tempered intervals found on the piano keyboard represent deviations from these intervals, the family of intervals opened up by prime number 7 deviate sufficiently far from equal temperament that they have generally been excluded from classical western music theory. '7-limit' intervals do however frequently occur in blues music, as well as non-western traditions such as Indian Classical music. Intervals based on higher prime numbers than 5 are also integral to the music theory of Ancient Greece.

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



This interval is known as the 'septimal minor seventh'. Because neither of the two pitches is the central black ball, the interval's ratio is not directly indicated in the Hayward Tuning Vine. It may however easily be deduced from the two ratios contained within the cards. As the 'D4' is a perfect fifth (2/3) below the central black ball, multiplying it by 3/2 gives the central 1/1 frequency (2/3 x 3/2 = 1/1). Multiplying 3/2 by 7/6, the ratio of the highlighted dark blue ball in relation to the central black ball, then gives 21/12, which is equivalent to 7/4, and this 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 black ball, is to transpose it to a position that does include the central black ball. For example, if you transpose the 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 shown in relation to central black ball, and ratio may be read directly from the card attached to the highlighted dark blue ball: Now click on the '=' sign to reset the transpositions.

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

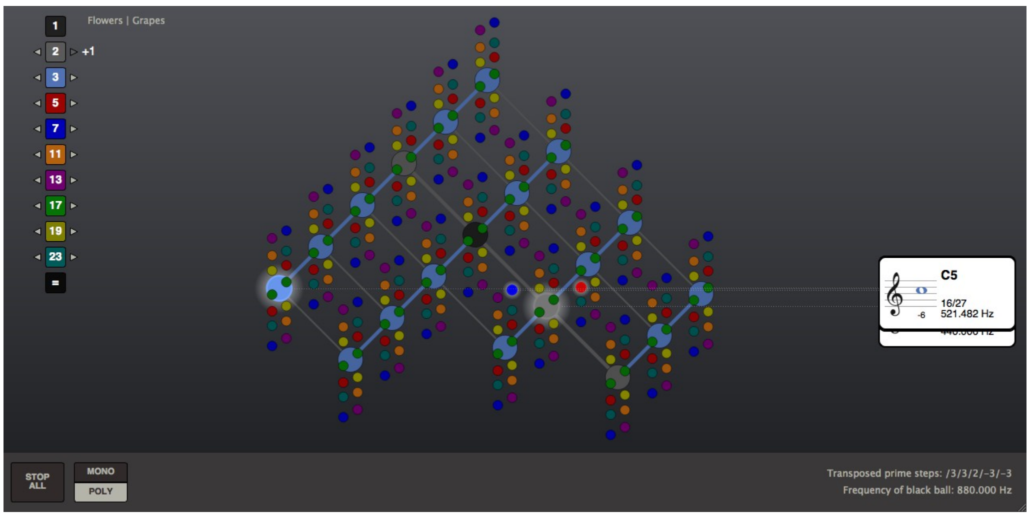


As indicated in the card, at -33 cents the septimally lowered minor third is almost exactly a third of a semitone lower than the tempered minor third typically found on a piano keyboard. This is the flattened minor third often associated with blues music.

On the Hayward Tuning Vine it is possible to directly compare this 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 ball to its card, you'll see that it passes over the lower part of a red ball above and to the right of the light blue ball:

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

In order to locate the Pythagorean minor third, ratio 32/27, on the Hayward Tuning Vine, first break this ratio down into its lowest prime numbers. As 32 = 2 x 2 x 2 x 2 x 2, and 27 = 3 x 3 x 3, 32/27 may therefore be rewritten as '2 x 2 x 2 x 2 x 2 / 3 x 3 x 3'. Next, break this 'prime factorial' ratio into its individual ratios: '2/3 x 2/3 x 2/3 x 2/1 x 2/1'. Now, starting from the central black 1/1 ball, consider how each of these ratios translates into a step along the Vine. As 2/3 indicates a movement down a perfect 5th, and 2/1 a movement up an octave, the five ratios translate into a movement down three light blue struts and up two light grey struts from the central black ball. As the final strut lies outside the visible range of the Vine, you need to transpose it up an octave by clicking on the arrow to the right of the grey number box. By clicking on the large light blue ball to the far left of the Vine, you can now hear all three minor thirds sounding simultaneously:



By switching to MONO mode, and clicking alternately on the highlighted red and highlighted light blue balls, you can alternate between them to compare them directly.

Note that the ratio indication on the card attached to the light blue ball is now 16/27, rather than 32/27. This is because the ratio is always given in relation to the central black ball, whose frequency has now been transposed up an octave.

Prime numbers 11 and higher: complex intervals

You are now in a position to explore the musical intervals based on prime numbers 11, 13, 17, 19 and 23. Every new prime number opens up a unique family of intervals, each with its own peculiar flavour. By clicking on the coloured balls in the immediate vicinity of the central black ball and studying the information that appears in the associated cards, you can familiarise yourself with the frequency 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 and 13 deviate from tempered tuning to quite a considerable extent, and may even sound quite 'out of tune' at first. But once the ear has grown accustomed to it, the vast harmonic universe contained within the system of Just Intonation may well make the tempered intervals of the piano keyboard appear to be 'out of tune' and harmonically limited.

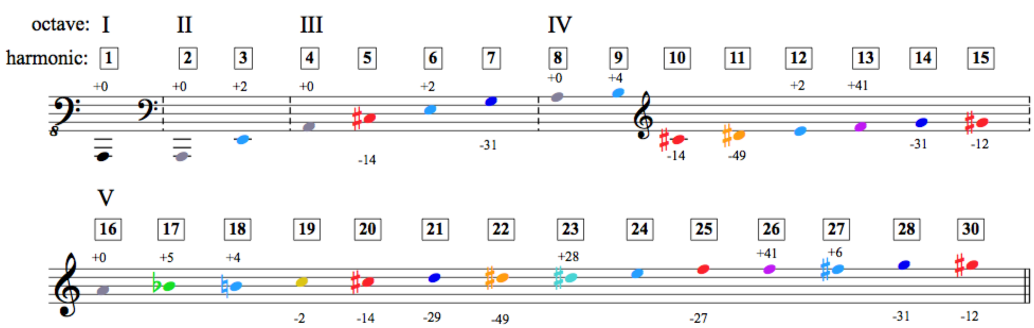
Based on the prime number relationships which underlie musical harmony, the Hayward Tuning Vine provides an alternative interface to the piano keyboard, allowing an intuitive exploration of harmonic space without the need to limit the number of pitches to only 12 steps per octave.

Before moving onto the next section, reset both the Calibration A4 and the 1/1 Frequency to A440, click on the '=' sign below the number boxes in order to reset the transpositions, and on 'STOP ALL' in order to turn all the sounding pitches off. 'View' should remain set to 'Grapes'.

Prime numbers, the harmonic series, and the subharmonic series

All of the intervals within the system of tuning known as 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 whole number integers, and the subharmonic series on *dividing* a given frequency by whole number integers.

If this frequency were to be defined as 'A0', the harmonic series for the first five octaves of the harmonic series would appear as[3]:

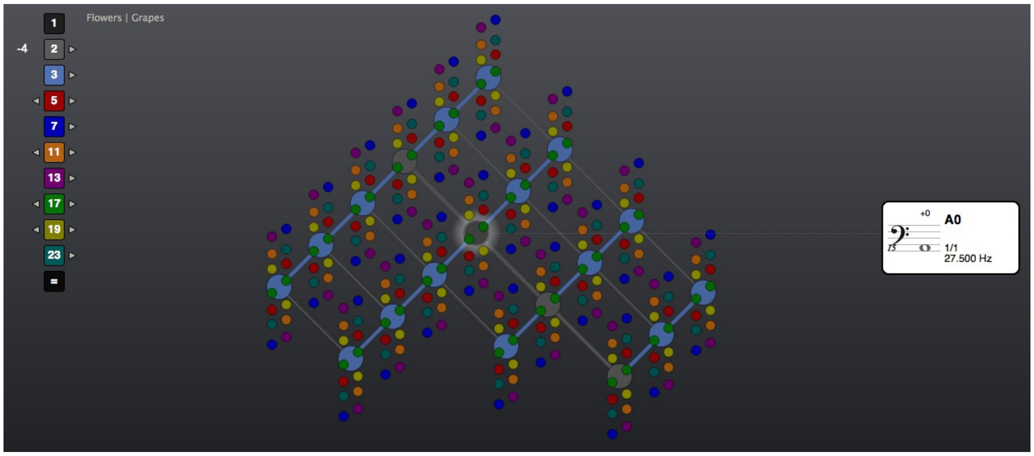


We are now going to map this harmonic series onto the Hayward Tuning Vine, in order to gain a deeper understanding of how it works.

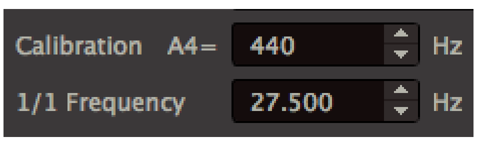
[3] Prime numbers 29 and 31 have been left out of the fifth octave, as they are not included in the current version of the Hayward Tuning Vine.

The Harmonic series

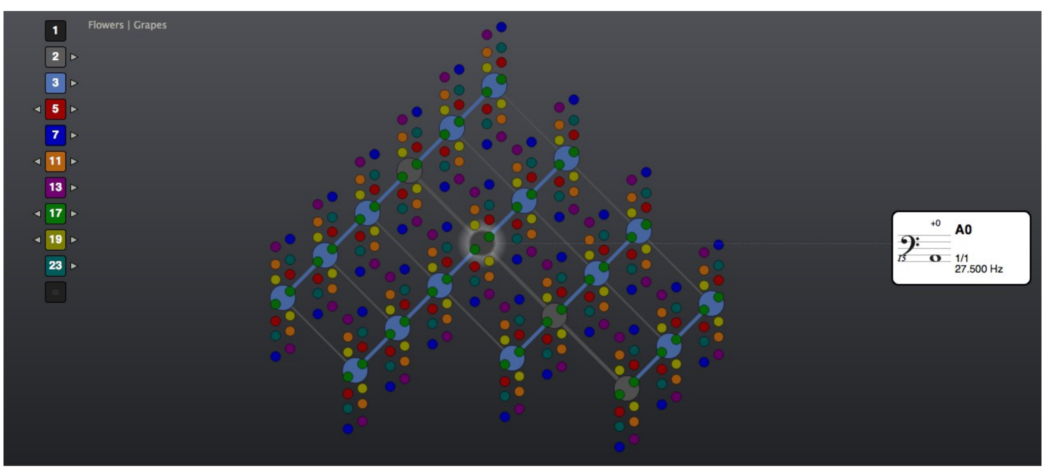
First click on the transposition arrow to the left of the grey number box four times, in order to transpose the Vine down four octaves. Now click on the central black ball:



As you can see, the central black ball is now set to A0, and has a frequency of 27.5 Hz[4]. Now go to Options and enter this number as the 1/1 Frequency:



Next, click on the '=' button under the number boxes in order to reset the transpositions, and on STOP ALL in order to turn off the previously sounding pitch. When you click on the central black ball, it is now set to 'A0', without the need for any transpositions:

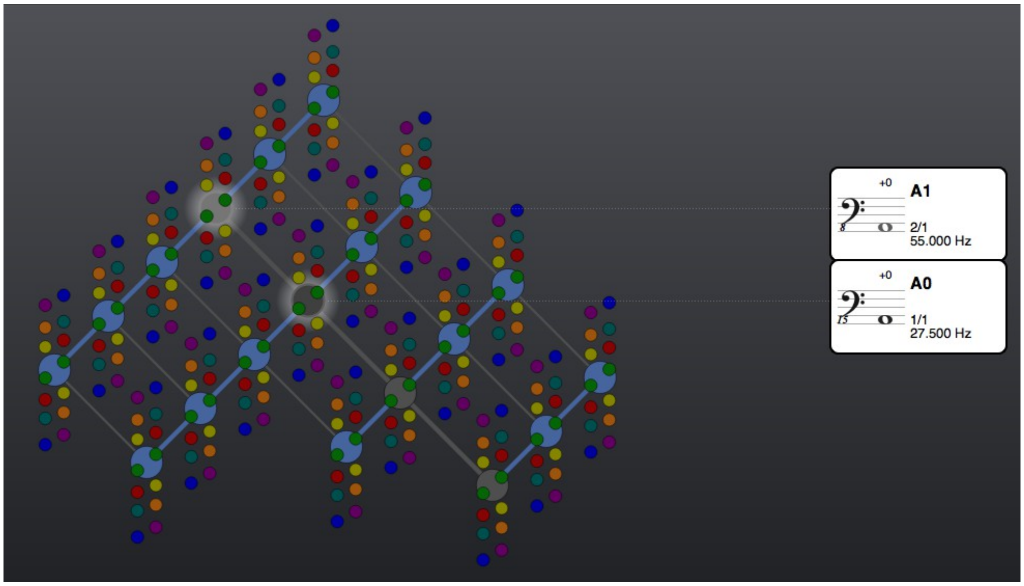


The central black ball has now been set to the first harmonic in the series starting on 'A0'.

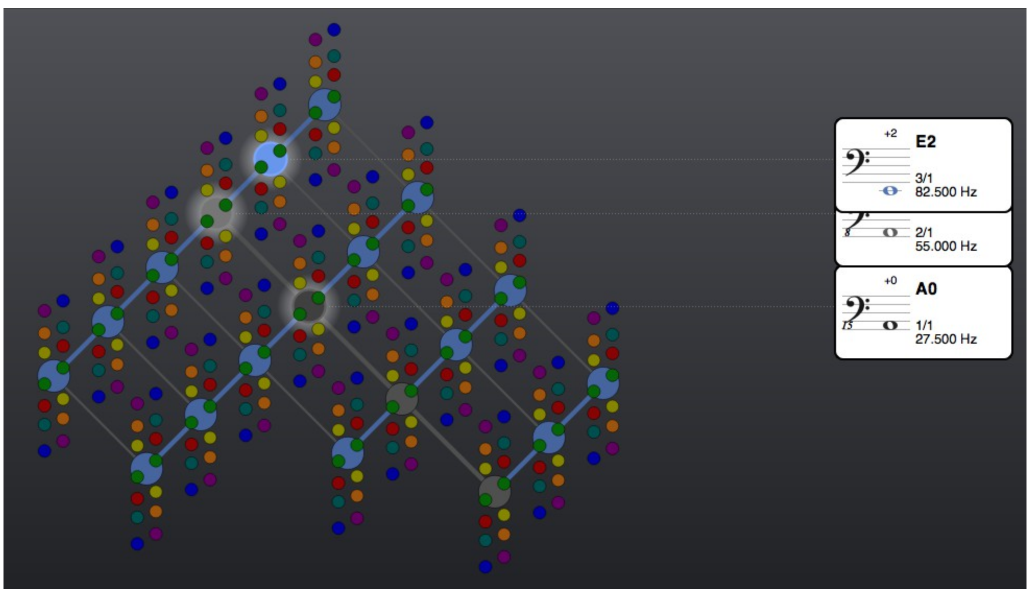
---

[4] Because of the low frequency, you might want to change to a different waveform than the default Sine, as this might not be audible on all speaker systems.

Continuing up the harmonic series, click on the grey ball above and to the left of the central black ball. Make sure you are in POLY mode so that the black ball keeps sounding when you click the grey ball:

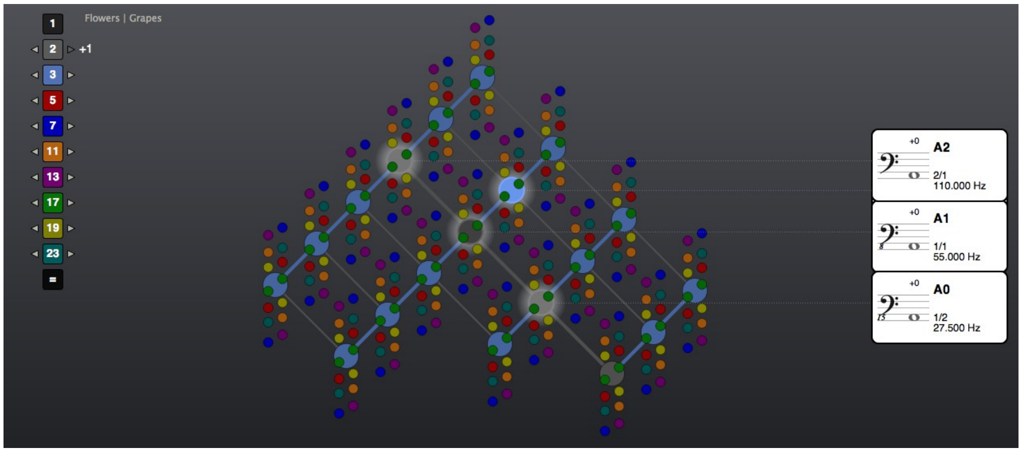


This grey ball signifies the second harmonic in the series. In order to play the third harmonic, click on the light blue ball to the above right of the highlighted grey ball:



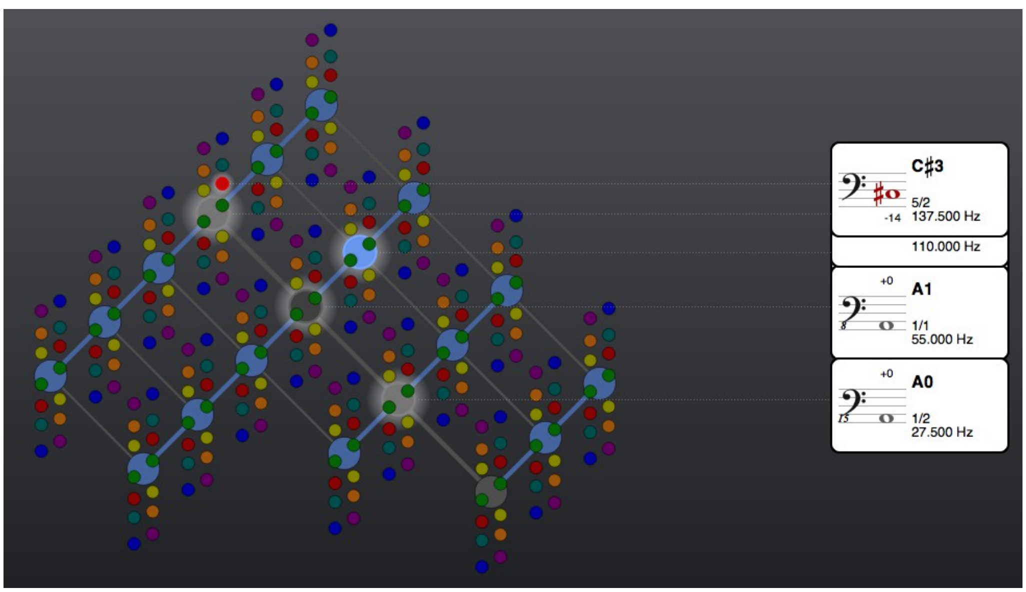
Notice how this pitch forms the ratio 3/1 with the *first* harmonic in the series, but that it forms the ratio 3/2 with the *second* harmonic in the series.

Moving further up the harmonic series, in order to play the fourth harmonic you need to first transpose the Vine up an octave, and then click on the uppermost grey ball:



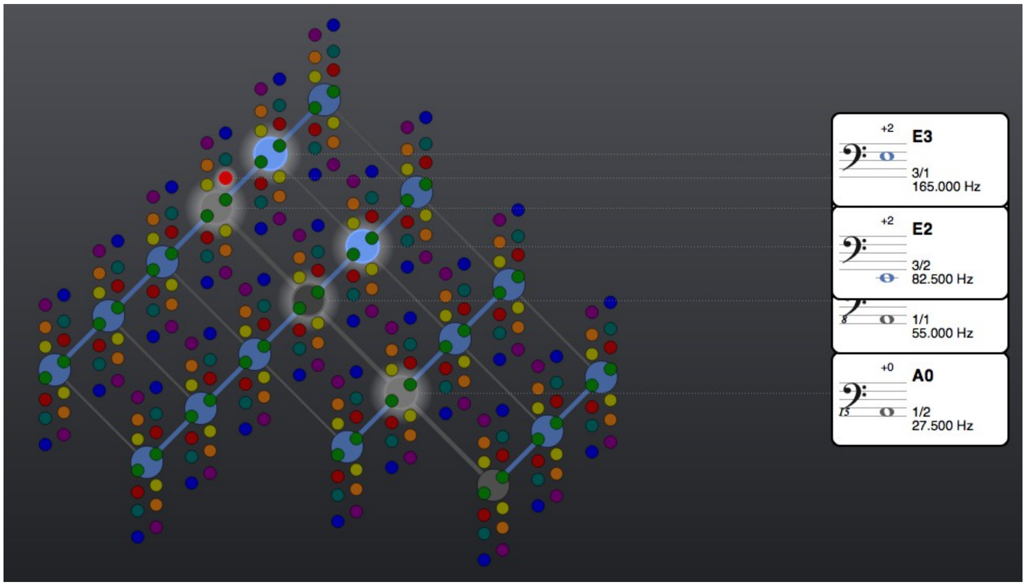
The fourth harmonic marks the beginning of the third octave within the harmonic series. It forms the ratio 4/1 with the first harmonic, 4/2 = 2/1 with the second harmonic, and 4/3 with the third harmonic (its card contains the ratio 2/1 because the Vine always indicates ratios in relation to the *current* pitch of the central black 1/1 ball, which by definition always remains set at 1/1).

To play the fifth harmonic, click on the red ball above the fourth harmonic:



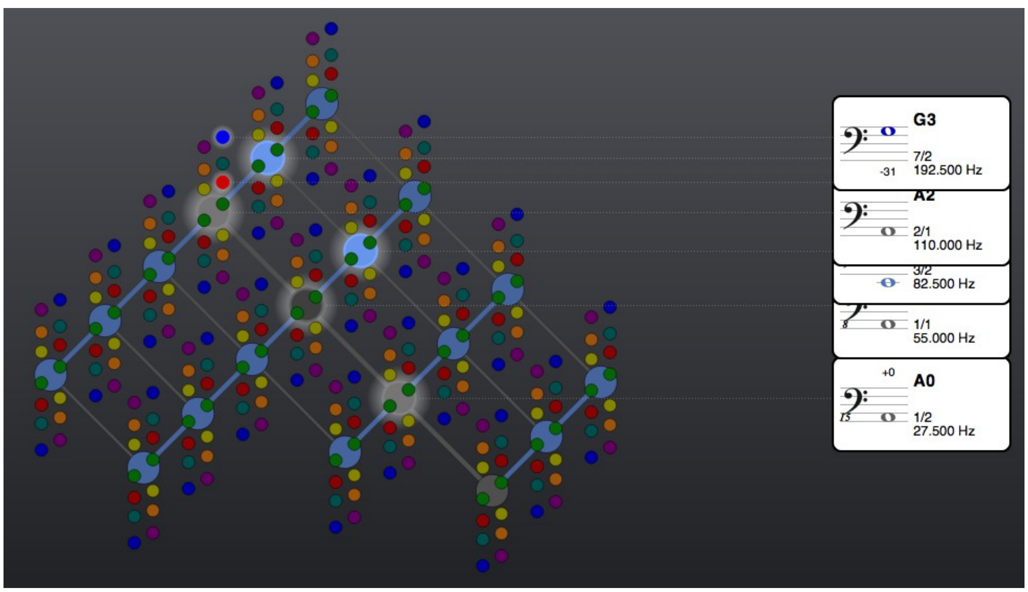
The fifth harmonic forms the ratio 5/1 with the first harmonic, 5/2 with the second harmonic, 5/3 with the third harmonic, and 5/4 with the fourth harmonic.

The sixth harmonic may now be sounded by clicking on the light blue ball above and to the right of the fourth harmonic, connected to it by a light blue strut:



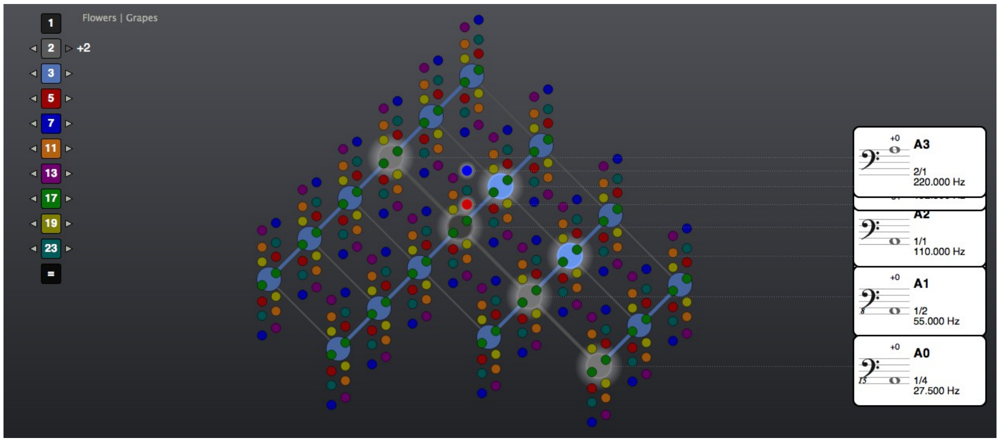
It forms the ratio 6/1 with the first harmonic, 6/2 = 3/1 with the second harmonic,
6/3 = 2/1 with the third harmonic, 6/4 = 3/2 with the fourth harmonic, and 6/5 with the fifth harmonic.

To sound the seventh harmonic, click on the dark blue ball above the light blue ball that signifies the fourth harmonic:

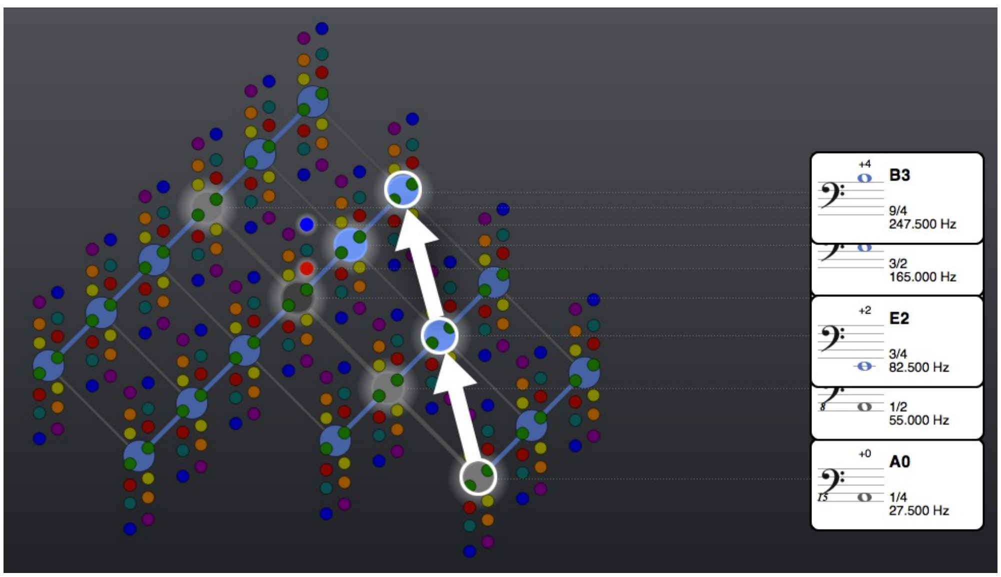


The seventh harmonic forms the ratio 7/1 with the first harmonic, 7/2 with the second harmonic,
7/3 with the third harmonic, 7/4 with the fourth harmonic, 7/5 with the fifth harmonic, and 7/6 (the 'blues minor third') with the sixth harmonic.

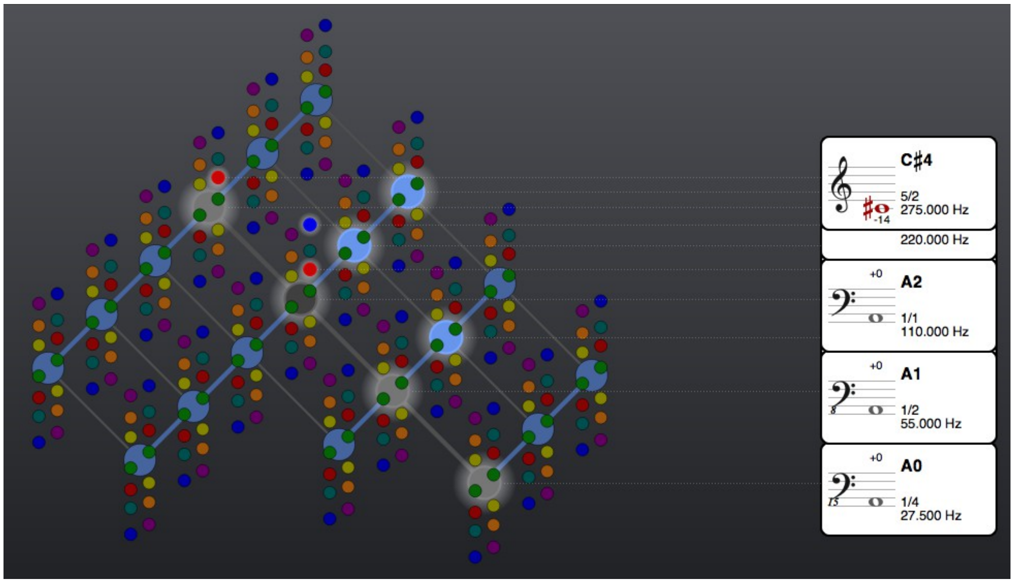
In order to play the eighth harmonic, you need to transpose the Vine up another octave, in order to bring another light grey ball in view. Clicking on it then sounds the eighth harmonic:



You can trace the route from the first to the ninth harmonic via two steps of the interval 3/1:

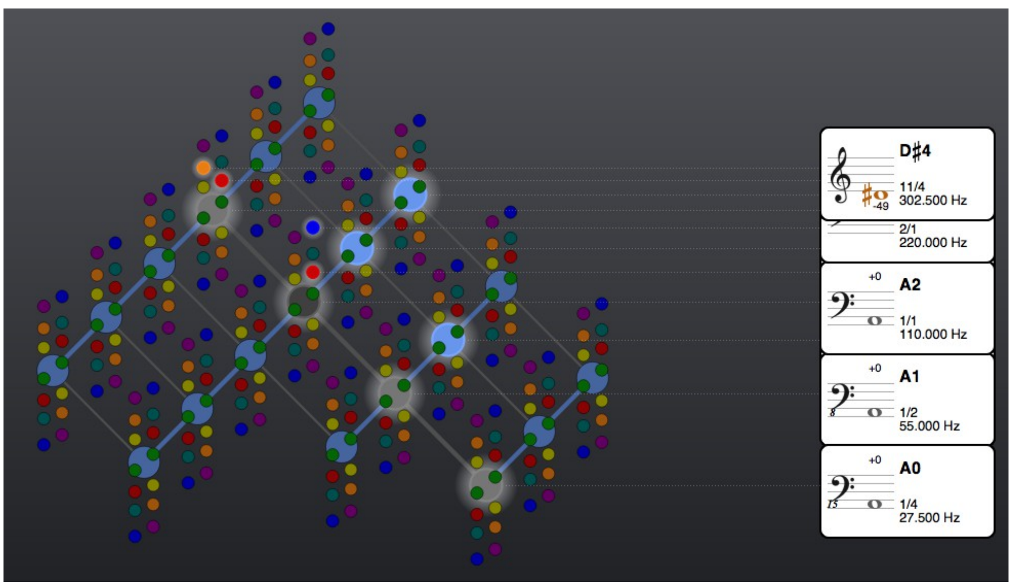


The 10th harmonic is activated by the red ball above the eighth harmonic:



The ratio it forms with the eighth harmonic is 10/8, the equivalent of 5/4, as can be seen in the positions of the two highlighted red balls, the 5/4 directly above the black ball, and the 10/8 directly above the uppermost grey ball.

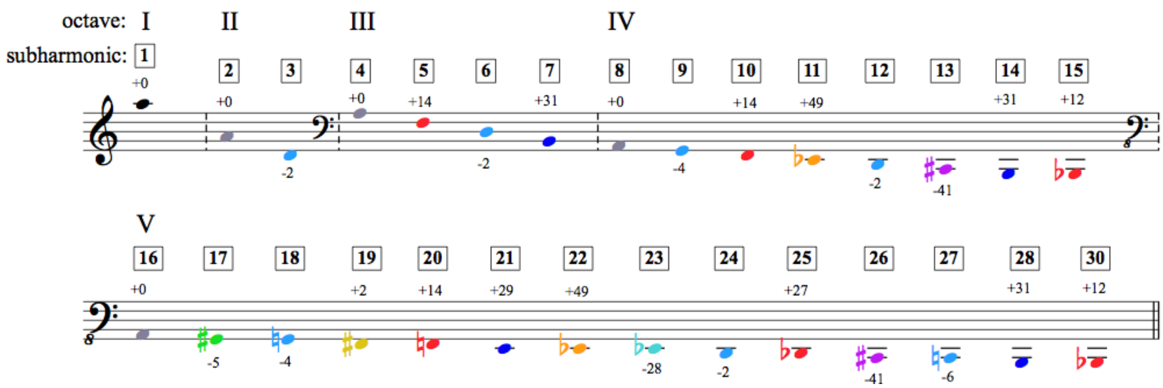
The 11th harmonic may be sounded by clicking on the light orange ball above the eighth harmonic:



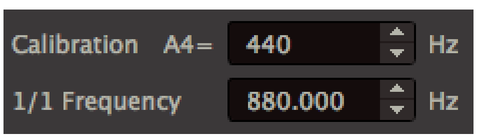
Try continuing up the harmonic series, noting in particular where the prime numbers lie, and familiarising yourself with their positions within the harmonic series.

The Subharmonic series

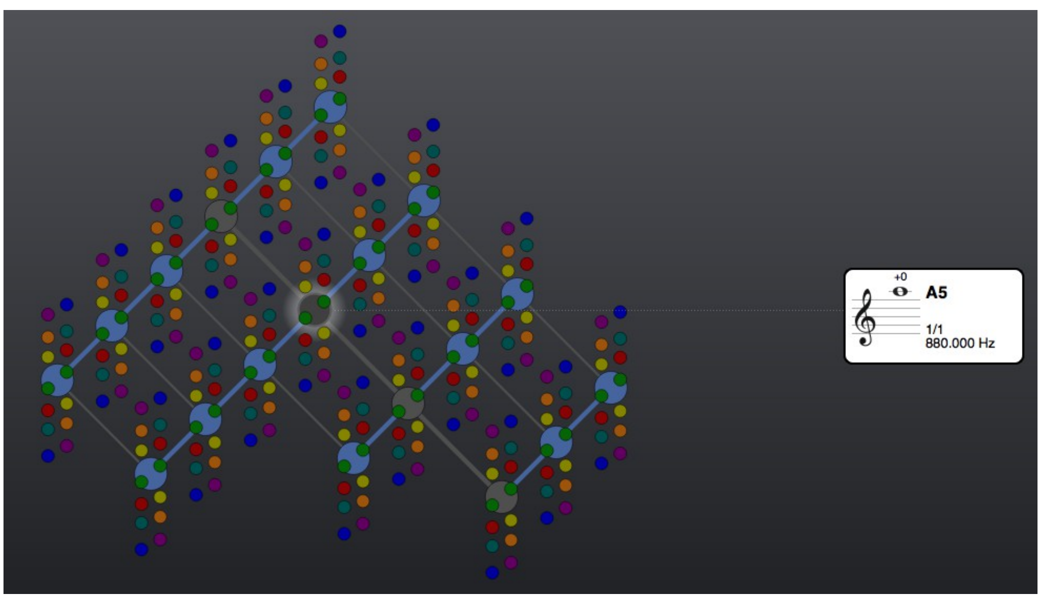
Precisely the same principles apply to the mapping of the subharmonic series as apply to mapping the harmonic series onto the Hayward Tuning Vine. Based on dividing frequencies, it makes sense to start the subharmonic series from a high frequency, in order to leave room for the lower subharmonics. In the following subharmonic series, this frequency has been set at A5:



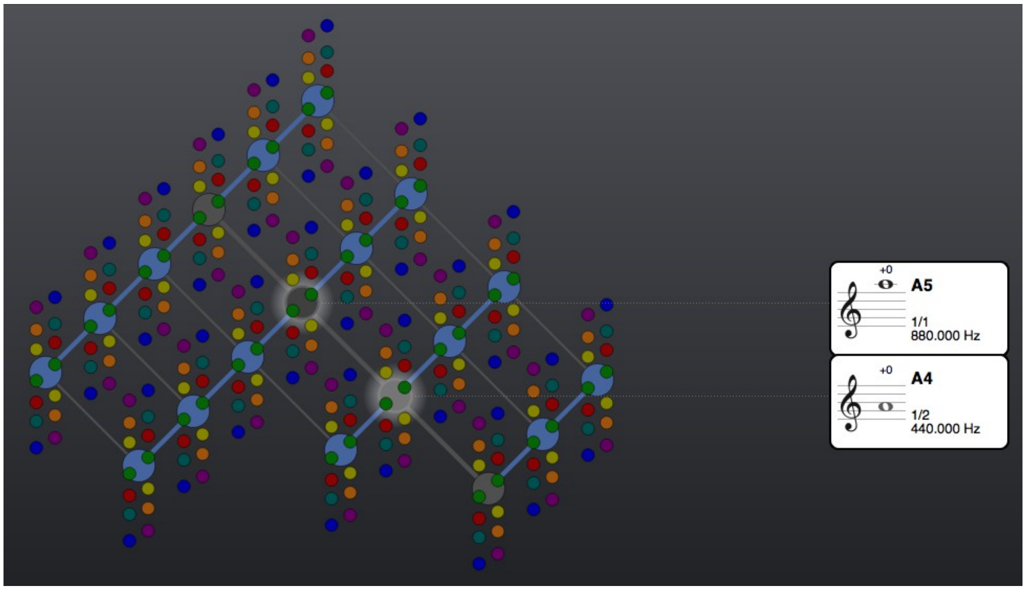
In order to explore how this maps onto the Hayward Tuning Vine, first set the Calibration A4 frequency of the Vine to 440 Hz, and then the 1/1 Frequency to 880 Hz:



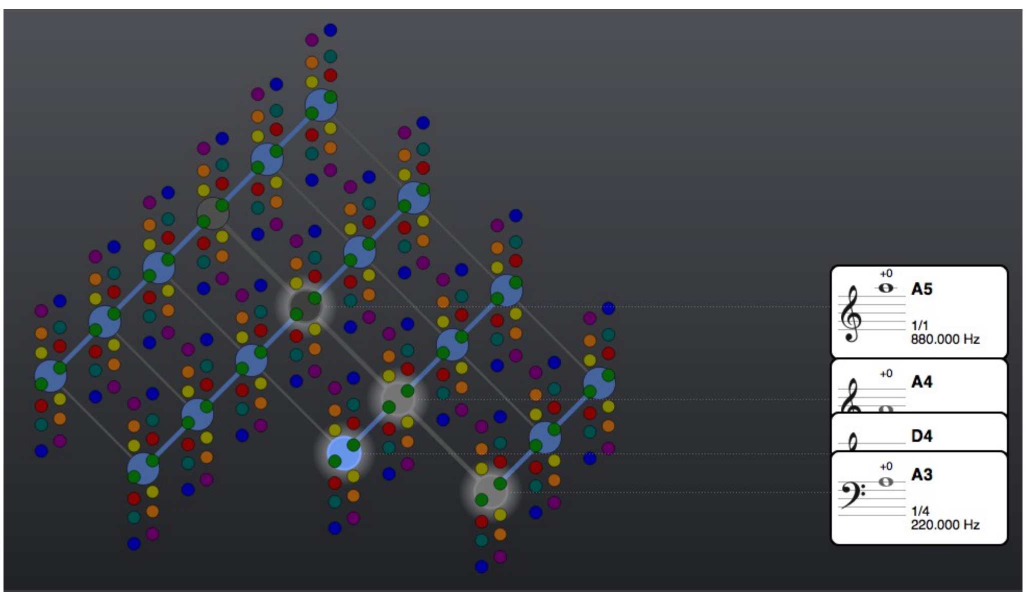
Now click on the central black ball, in order to play the first subharmonic:



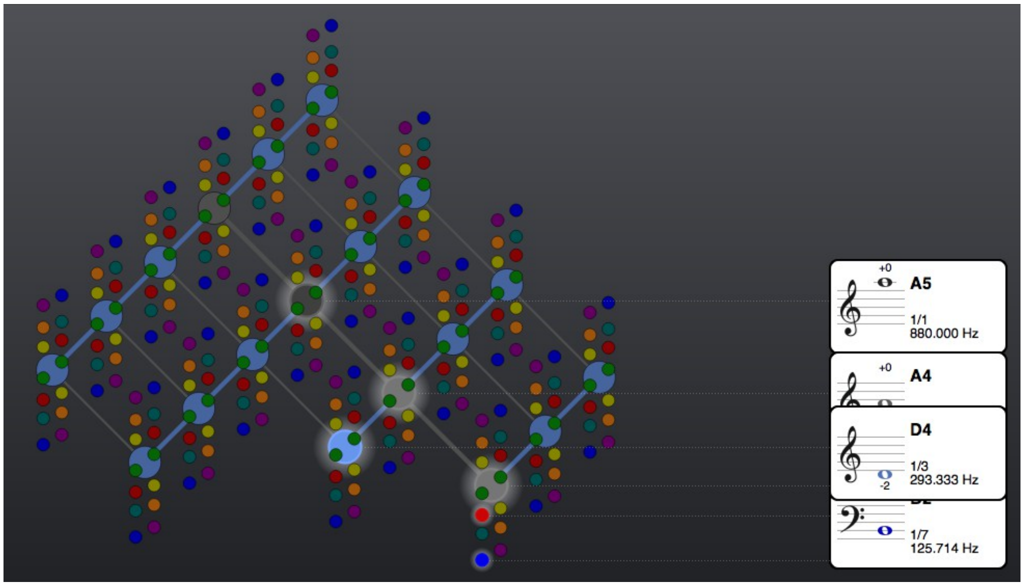
The second subharmonic is positioned one octave below:



Continuing down the subharmonic series, the third and fourth subharmonics are respectively a perfect fifth and an octave below the second subharmonic:



To play the fifth and seventh subharmonics, click on the red and dark blue balls directly below the fourth subharmonic:



As you can see, mapping the subharmonic series onto the Hayward Tuning Vine is really just a question of inverting the mapping of the the harmonic series. By using the transposition feature you are now free to continue further down the subharmonic series into its fifth octave.

Harmonic and subharmonic series may be started from anywhere within the Hayward Tuning Vine, not just from the central black ball. In fact, the Hayward Tuning Vine may itself be seen as the result of the various harmonic and subharmonic series all starting at different positions within the Vine.

Guide to colour-coding

The colour-coding of the prime numbers contained within the Hayward Tuning Vine is based on free association rather than any strict system. Nevertheless, some knowledge of these associations may help speed up the process of learning which colour is associated with which prime number.

The central '1/1' ball is coloured black because it is the source of all the other intervals, and therefore the source of all the other colours. Although it could also have been coloured white, this would have been impractical in combination within the notation system, as white notes set against a white background would be invisible.

The octaves, based on prime number 2, are coloured grey because they do not imply a categorical shift away from the central black '1/1' – the pitches maintain their basic identity when they are transposed into different octaves.

Prime number 3, which opens up the family of intervals based on the perfect fifth, is coloured light blue as it provides the rational framework upon which other intervals are fitted.

Intervals based on prime number 5, which include the major and minor thirds, are coloured red as these intervals are often associated with emotion in music.

The reason for colouring prime number 7 dark blue 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, fitting to a hot, bright colour such as orange.

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. An everyday colour such as green therefore seems well suited to it. On top of this, it is 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' is even closer to the tempered interval of the minor third. But as it is higher up within the fifth octave of the harmonic series than prime number 17, and also a minor third, the autumnal colour of yellow seems well suited to it.

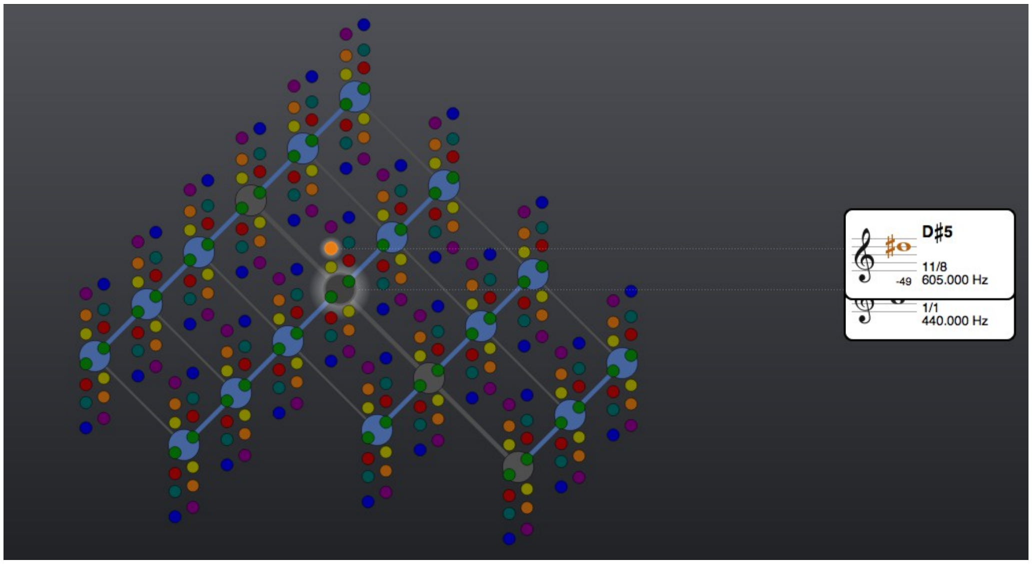
23 is the highest prime contained within the Hayward Tuning Vine. The colour turquoise, based on a mixture between two of the colours used for lower primes, therefore seems an appropriate choice for this unfamiliar interval.

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

Enharmonic notation and double accidentals

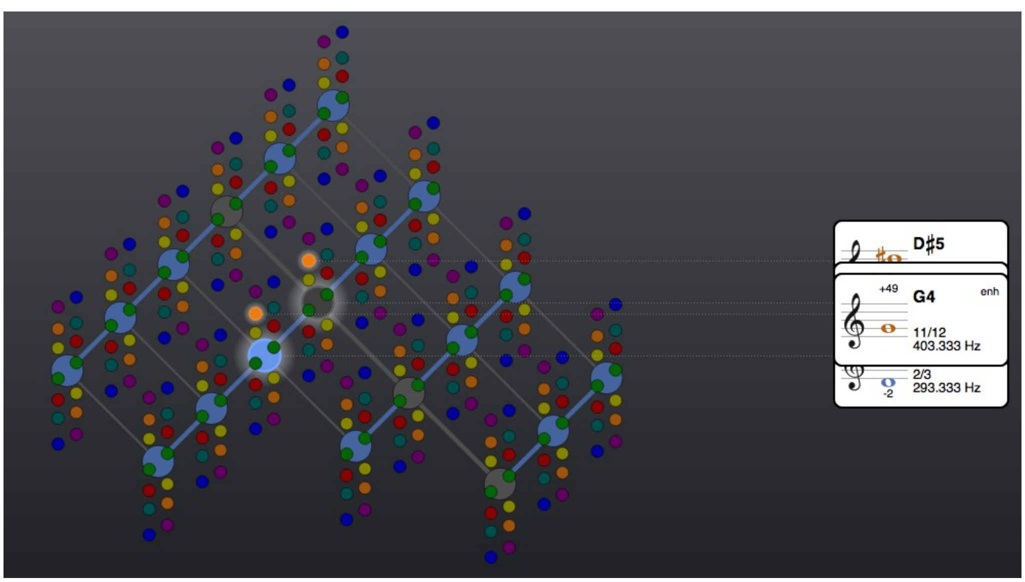
If you look closely at the spelling of the accidentals of the various microtones within the Hayward Tuning Vine - for example, whether a pitch is notated as a ‘B♭’ or an ‘A♯’ - you’ll notice that the same interval is sometimes spelled differently according to where it occurs within the Vine.

An example of this is provided by prime number 11, colour-coded orange within the Vine. Try clicking on the central black 1/1 ball, and then on the orange ball above it:



As shown in the card, the interval you’re hearing 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 note heads are written as ‘A’ and ‘D♯’.

Now click on the light blue ball a perfect fifth below the central black ball, and then on the orange ball above it:

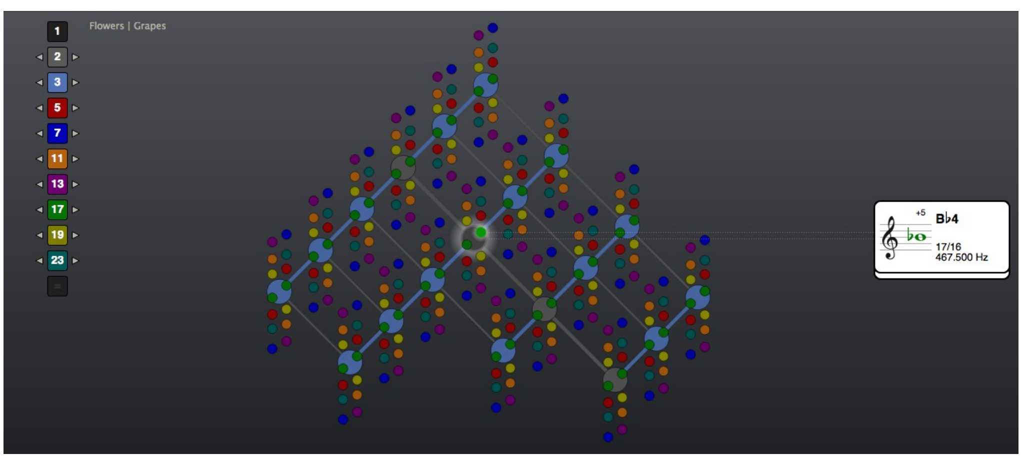


Although the ratio of this interval is clearly still 11/8, the note heads are written as ‘D’ and ‘G’, which is a perfect rather than an augmented fourth. The reason for this different spelling is that as the ‘D’ now has a cents deviation of -2, the orange note head, if it were to be notated as a ‘G♯’, would 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 tuning machines, indicating cents deviations within a range of -50 to +50 cents[5]. Cents deviations that exceed these limits are ‘flipped over’, which is why in the current example the strictly harmonically correct spelling of ‘G♯ -51 cents’ is re-notated as ‘G +49 cents’.

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’ card. The implications of enharmonic spelling may be seen most clearly in the current example if you hover your mouse above the two highlighted orange balls, in order to compare their cards. The interval between the ‘G +49 cents’ and the ‘D♯ -49 cents’ is a Just perfect fifth, even though the note heads give the first impression of an augmented fifth. The ‘enh’ acts as a flag in such cases, warning the user to be on their guard and examine the cents indications carefully, rather than relying on the harmonic implications of the note heads, 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 Hayward Tuning Vine. This has to do with double sharps and double flats, and may be demonstrated most clearly by examining prime number 17, colour-coded green within the Vine.

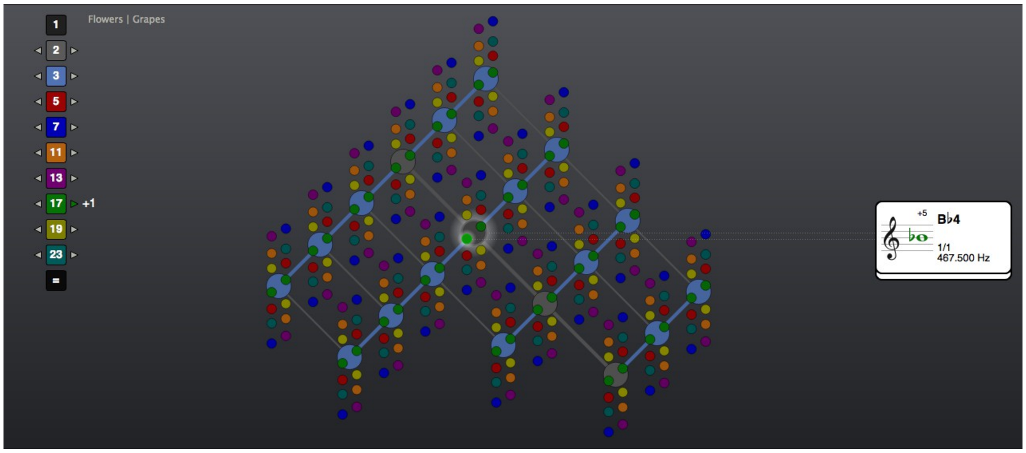
First click on STOP ALL in order to turn off the currently sounding pitches. Then click on the central black ball, along with the green ball positioned along its upper right hand border:



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

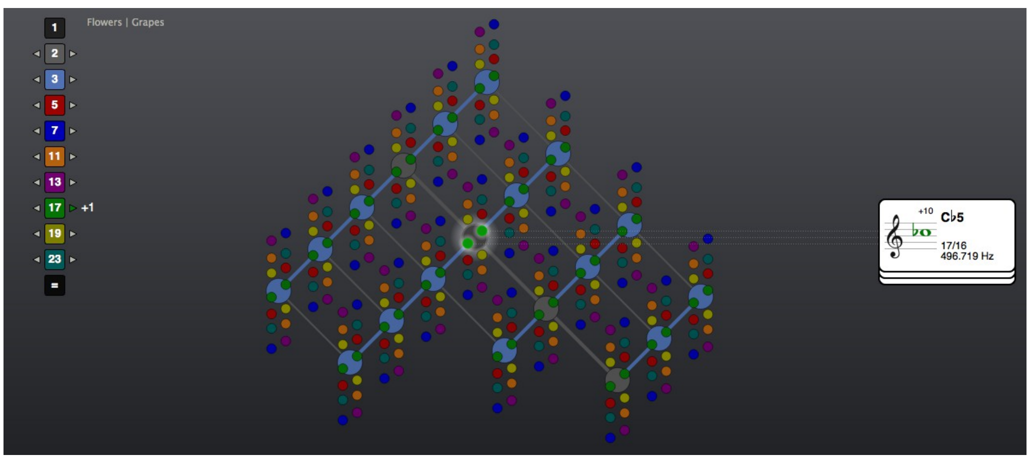
[5] The Hayward Tuning Vine also follows the convention that cents values of ‘-50’ are automatically flipped over to ‘+50’.

Next, click on the transposition arrow to the right of the green number box 17. The position of the sounding pitches within the Vine has now been shifted to:



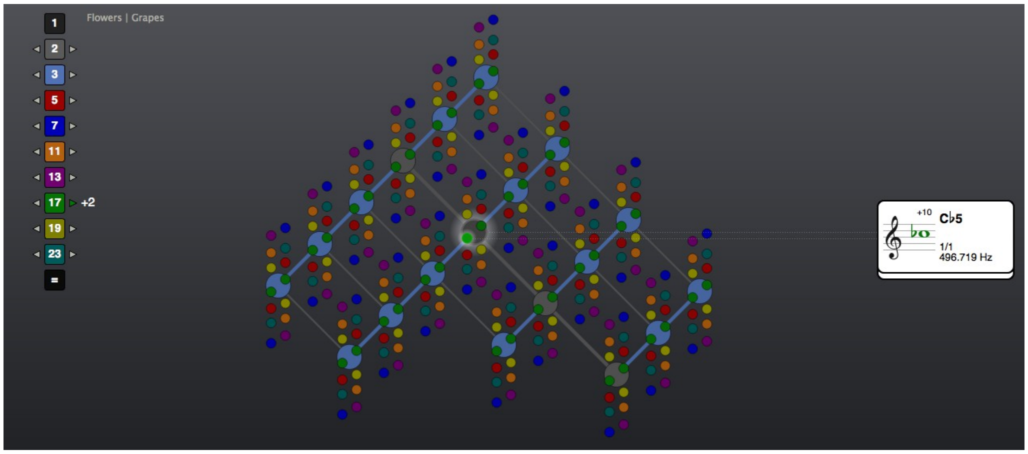
The ‘A’ is now associated with the green ball at the lower left border of the central black ball, and the the ‘B♭’ with the central black ball itself.

Now, click again on the green ball positioned along the upper right hand border of the central black ball:

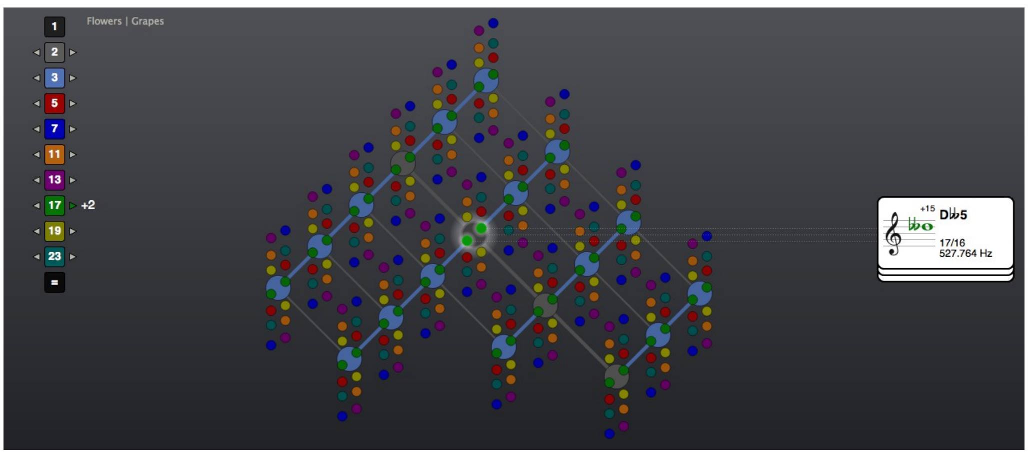


This pitch is notated as ‘C♭’ rather than as ‘B’, because it is a minor second higher than the ‘B♭’ now associated with the central black ball. Notating the upper green ball as ‘B’ would imply the relationship of an augmented unison with the ‘B♭’ of the central black ball, which would be harmonically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

Now click once more on the transposition 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 ball, so that the 'A', the pre-transposition pitch of the central black ball, is no longer visible on the Vine, and the lower green ball and central black ball are now associated with 'B♭' and 'C♭' respectively:

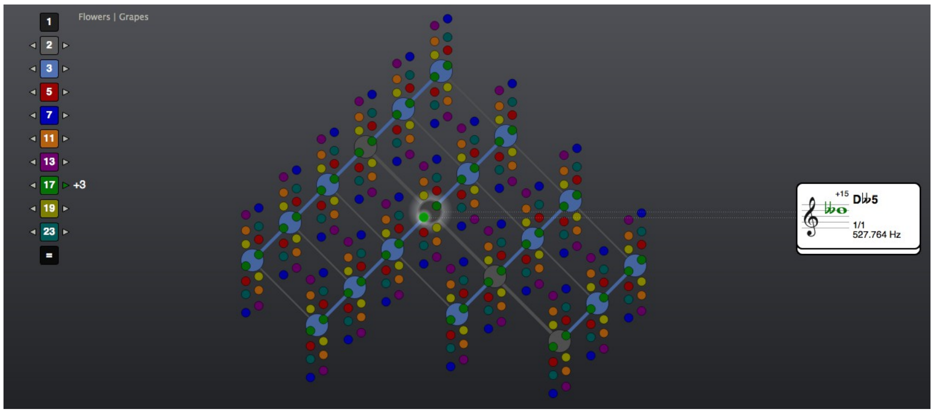


Now click once more on the green ball positioned at the upper right hand border of the central black ball:

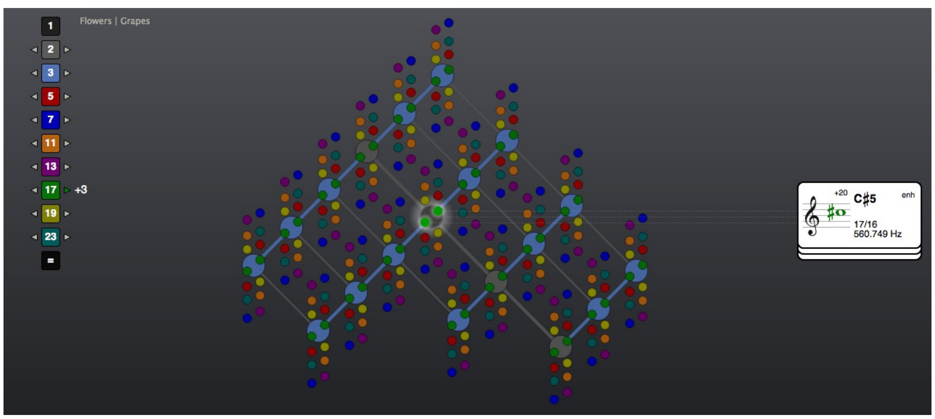


This pitch is notated as 'D♭♭' rather than as 'C', because it is a minor second higher than the 'C♭' now associated with the central black ball. Notating the upper green ball as 'B' would imply the relationship of an augmented unison with the 'C♭' of the central black ball, which would be harmonically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

Now click once more on the transposition 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 ball, meaning that both the 'A', the pre-transposition pitch of the central black ball, and the 'B♭', the pre-transposition pitch of the upper green ball, are no longer visible on the Vine, and the lower green ball and central black ball are now associated with 'C♭' and 'D♭♭' respectively:



Click once more on the green ball positioned along the upper right hand border of the central black ball:

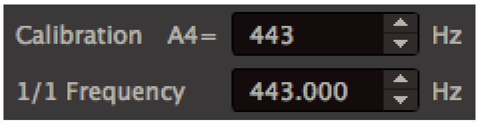


According to the logic of the previous two transpositions, this pitch should be notated as 'E♭♭♭', to indicate the harmonic relationship of a minor second above the 'D♭♭', currently associated with the central black ball. But with the aim of striking the right balance between what is theoretically correct 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♯'.

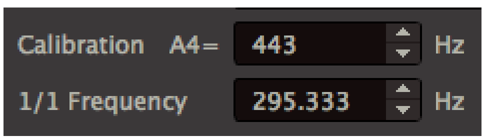
Now click on STOP ALL, reset the transpositions using the '=' sign below the number boxes, and activate the central black ball and the green ball positioned along its *lower* left border. By clicking on the arrow to the *left* of the green number box, the equivalent process as described above may now be repeated by transposing *downwards* through prime number 17. Exactly the same logic is then applied to the double sharps (notated as 'x' rather than as '♯♯') as was applied to the double flats when transposing upwards through prime number 17.

Guide to setting the 1/1 frequency

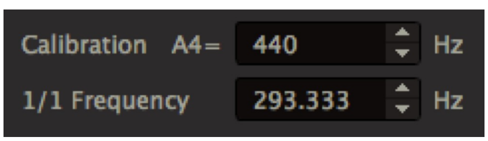
Once you have familiarised yourself with the Hayward Tuning Vine, you may wish to set the central black '1/1' frequency to something other than A440. If you still wish the '1/1' frequency to be set to an 'A4', such as A338 or A443, simply set the both the 'Calibration A4' and the '1/1 Frequency' to this number. For example, setting the central '1/1 Frequency' to A443 would require the following Options settings:



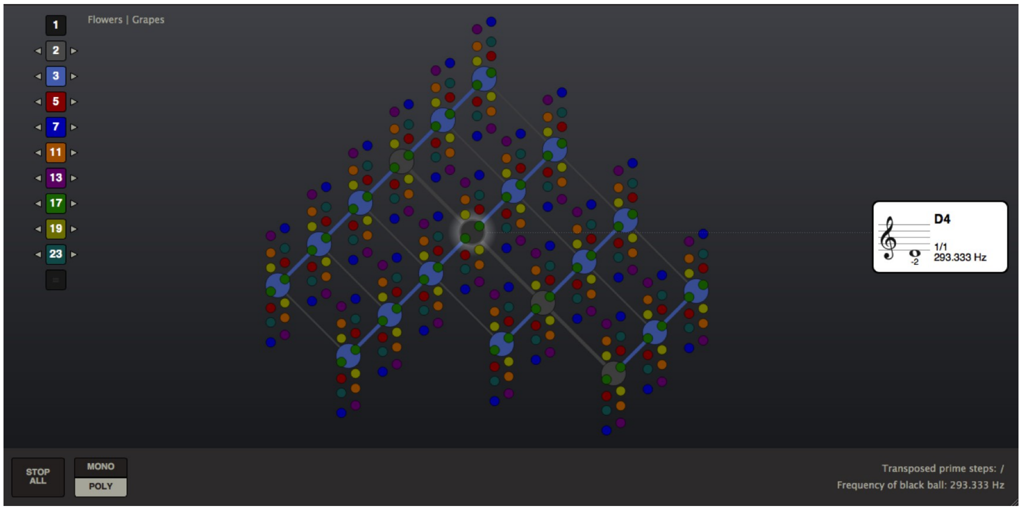
If you wish to set the '1/1' frequency to something other than 'A4', you nevertheless need to set the 'Calibration A4', as this provides the reference tuning against which the '1/1 Frequency' is measured. If for example you wish to set the central '1/1 Frequency' to 'D4', tuned a Just perfect 5th below a 'Calibration A4' set at A443, you need to multiply the Calibration frequency of 443 Hertz by '2/3', and enter the result in the 1/1 Frequency setting:



If on the other hand you set the 'Calibration A4' frequency to 440 Hz, then this is the number you need to multiply by '2/3' in order to set the '1/1' Frequency. As 440 multiplied by 2/3 gives 293.333, Options would now be set to:



Try entering these settings, then close Options and click on the central black '1/1' ball. You should now be hearing D4 as your central '1/1' frequency:



Note that although the '1/1' is now set to 'D4', the *tempered* reference pitch – the pitch with zero cents deviation – still remains set to A440. This is the reason why the card attached to the 'D4' indicates its deviation from tempered tuning to be -2 cents. The tempered reference pitch is now assigned to the light blue ball a perfect fifth above the central black '1/1' ball, rather than directly to the black ball itself.

Let's now consider how to set the central '1/1' frequency to a *tempered* D4. The arithmetic involved in calculating tempered intervals is considerably more involved than that needed for Just intervals, because tempered intervals are based on a logarithmic scale. Fortunately, it's not necessary to understand all the mathematical detail in order to set the central '1/1' frequency to a tempered pitch. As long as you have access to a scientific calculator, you can set the '1/1' frequency to any pitch within the tempered chromatic scale as follows:

- count the number of semitones the pitch you which to allocate as your '1/1' is away from 'A'. For example, 'B♭' is one semitone away, 'B' two semitones, 'C' three semitones etc. 'D', the pitch we're currently calculating, is five semitones away from 'A'.

- next, divide this number by 12. So, 'B♭' would give the ratio '1/12', 'B' '2/12', 'C' '3/12', and 'D' '5/12'.

- now, raise the number 2 the power of the fraction arrived at in the previous step. As the current aim is to set the '1/1' frequency to a tempered 'D', you would enter $2^{5/12}$ into your scientific calculator[6], which rounded to four decimal places gives 1.3348398… (make sure to leave this number at the highest decimal place your calculator can give you, as this will make the calculation of the Hz number in the next step more accurate).

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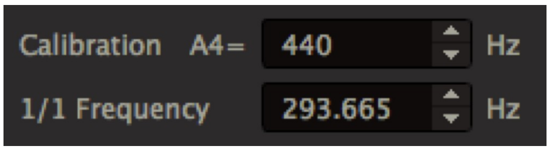
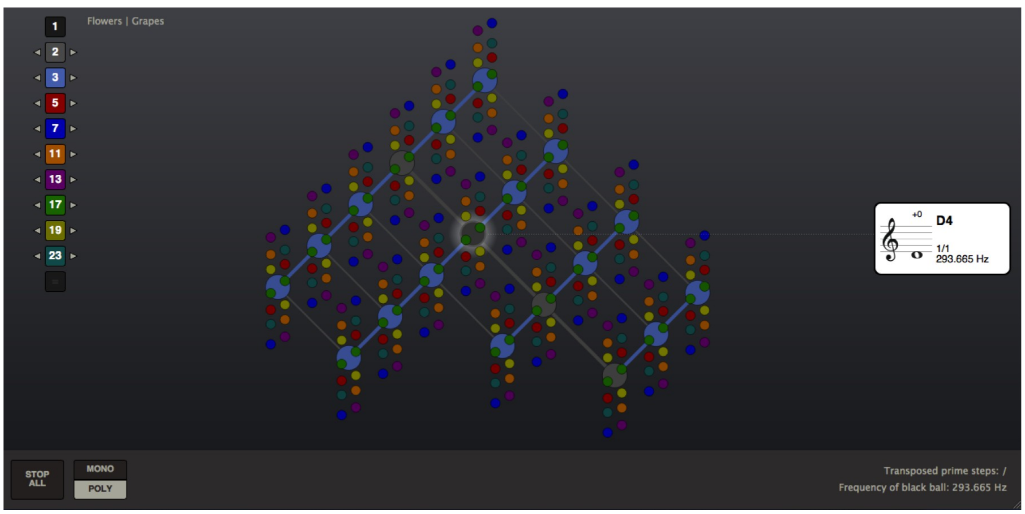
[6] Steps to follow on your scientific calculator: first enter '2', then press the y^x button, then the '(' button, then enter '5/12', then press the ')' button, and finally press the '=' sign.

- multiply the Calibration frequency by the number arrived at in the previous step. So for example, 440 multiplied by 1.3348398 gives 587.329512 Hz, the frequency of the tempered 'D5', a perfect fourth higher than the 'Calibration A4' frequency.
- we have now calculated the frequency of a tempered 'D5'. The pitch we are aiming for is however a tempered 'D4', which means the Hz number arrived at in the previous section now needs to be divided by 2, giving the frequency number 293.664756 for the tempered 'D4'. When entering this as the '1/1' Frequency it needs to be rounded to three decimal places, giving 293.665 Hz.

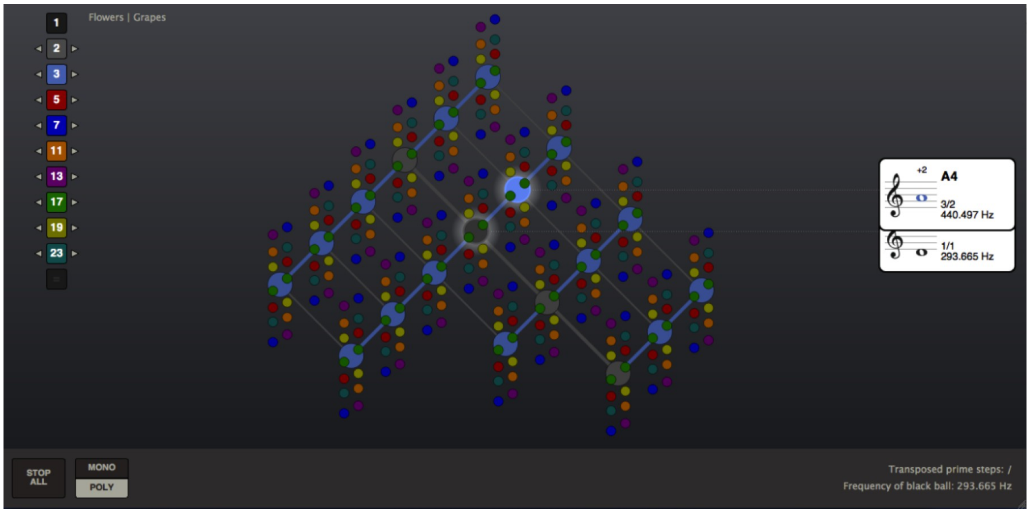
If you haven't already done so, enter this number now as the '1/1' Frequency:



Now close Options, and click on the central black '1/1' ball:

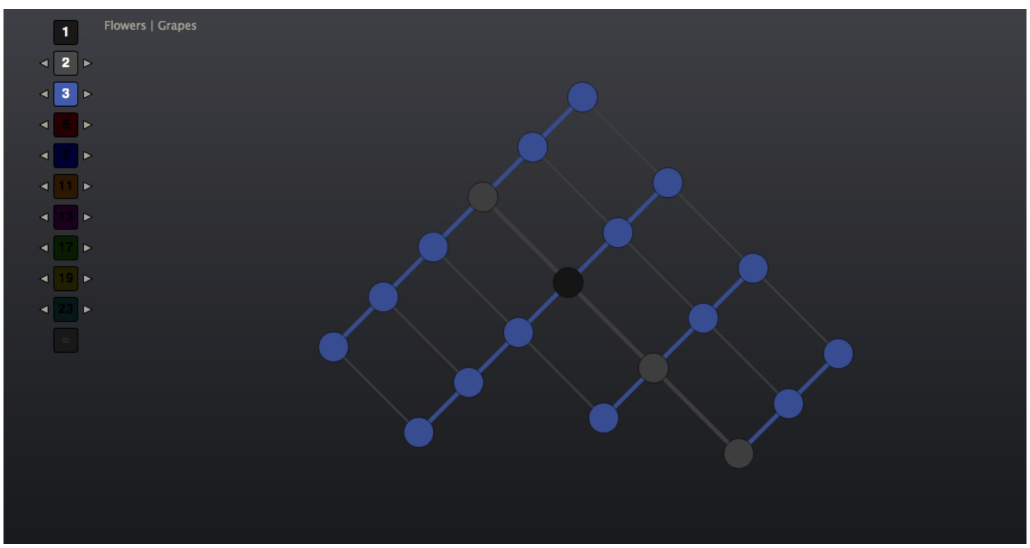


As the central black '1/1' ball is now set to a tempered D4, it is now the pitch with zero cents deviations. Try clicking on the A4, now positioned a perfect fifth above the central black '1/1' ball:

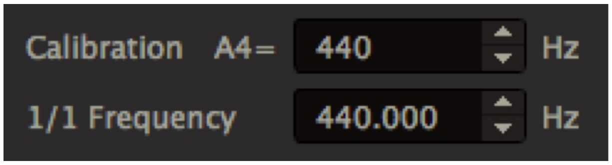


As expected, this is the pitch that is now assigned +2 cents, as it is a Just perfect fifth tempered reference pitch of 'D4'.

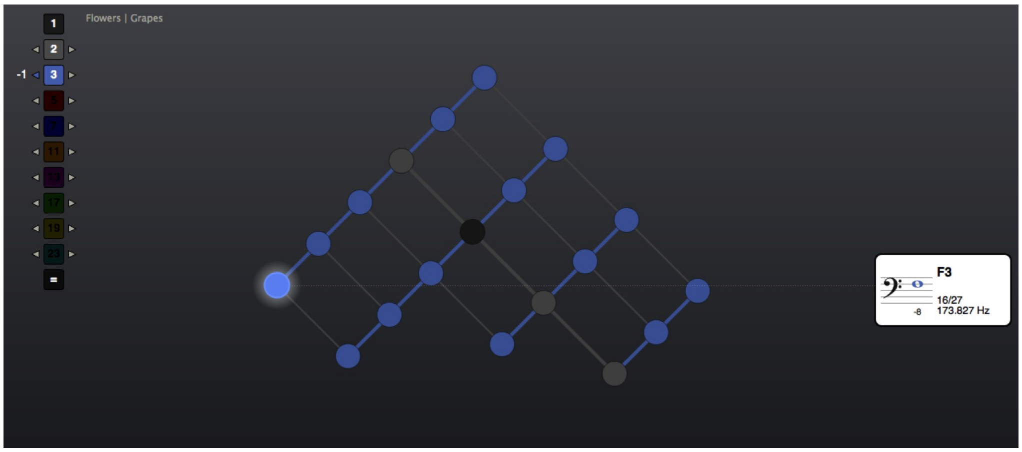
Whenever you assign a pitch other than 'A' to the central black '1/1' ball, you need to first consider whether you want it to be set to a *Just* or a *tempered* interval in relation to the 'A4' Calibration frequency. *Just* intervals will almost invariably be *Pythagorean* intervals, based on prime number 3 and therefore to be found in the light blue balls, which may be seen most clearly when all higher primes are toggled off:



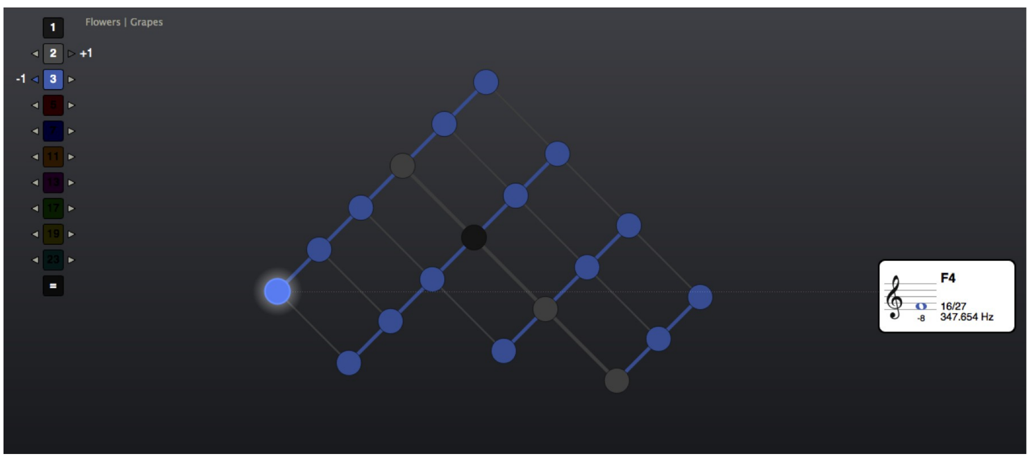
Through using the transposition arrows left and right of the grey and light blue number boxes, you can reach any Pythagorean pitch within the chromatic scale, thus using the Vine itself as a calculator for setting the ‘1/1’ Frequency in Options. For example, if you desire to set the 1/1 Frequency to ‘F4’, tuned a Pythagorean major third 81/64 below the central A440, first reset the ‘Calibration A4’ and ‘1/1 Frequency’ to 440:



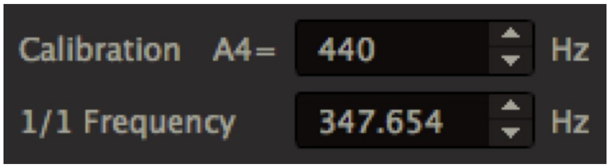
You now need to locate the Pythagorean ‘F4’ on the Vine. Untransposed, the Vine only reaches a Pythagorean ‘C’, so it needs to be transposed down a perfect fifth to reach a Pythagorean ‘F’:



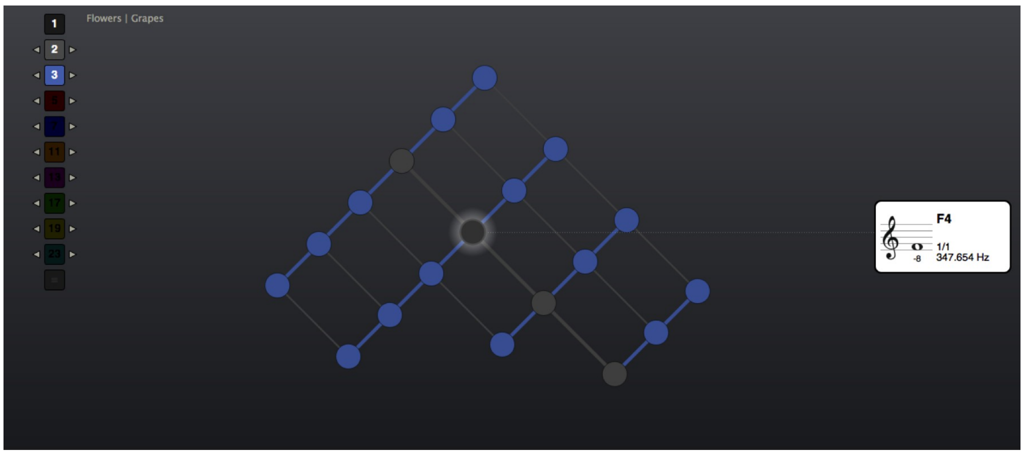
The highest ‘F’ available in this transposition is ‘F3’, a further octave transposition is needed in order to make available the desired ‘F4’:



By entering the Hz number of this ‘F4’ as the 1/1 Frequency in Options, the central black ‘1/1’ ball is now assigned to a Pythagorean ‘F4’:



Close Options, reset the transpositions and click on the central black ball to confirm that this is indeed the case:



Setting the ‘1/1 Frequency’ to a Just interval in relation to the Calibration frequency has the advantage that the tuning of ‘A’ remains constant regardless of the pitch to which the ‘1/1 Frequency’ is set. However, it may sometimes be more appropriate to set the ‘1/1 Frequency’ itself to zero cents deviation, in which case it should be set as tempered interval in relation to the Calibration frequency.

The following table provides a summary of the steps you need to take in order to set the ‘1/1 Frequency’ to any tempered chromatic pitch in relation to the Calibration frequency setting:

Pitch name	No. semi-tones	Multiply Calibration frequency by	Divide result by				Multiply result by		
			2 for	4 for	8 for	16 for	2 for	4 for	8 for
A4	0	1	A3	A2	A1	A	A5	A6	A7
B♭4 A♯4	1	$2^{1/12}$	B♭3 A♯3	B♭2 A♯2	B♭1 A♯1	B♭0 A♯0	B♭5 A♯5	B♭6 A♯6	B♭7 A♯7
B4	2	$2^{2/12}$	B3	B2	B1	B0	B5	B6	B7
C5	3	$2^{3/12}$	C4	C3	C2	C1	C6	C7	C8
C♯5 D♭5	4	$2^{4/12}$	C♯4 D♭4	C♯3 D♭3	C♯2 D♭2	C♯1 D♭1	C♯6 D♭6	C♯7 D♭7	C♯8 D♭8
D5	5	$2^{5/12}$	D4	D3	D2	D1	D6	D7	D8
D♯5 E♭5	6	$2^{6/12}$	D♯4 E♭4	D♯3 E♭3	D♯2 E♭2	D♯1 E♭1	D♯6 E♭6	D♯7 E♭7	D♯8 E♭8
E5	7	$2^{7/12}$	E4	E3	E2	E1	E6	E7	E8
F5	8	$2^{8/12}$	F4	F3	F2	F1	F6	F7	F8
F♯5 G♭5	9	$2^{9/12}$	F♯4 G♭4	F♯3 G♭3	F♯2 G♭2	F♯1 G♭1	F♯6 G♭6	F♯7 G♭7	F♯8 G♭8
G5	10	$2^{10/12}$	G4	G3	G2	G1	G6	G7	G8
G♯5 A♭5	11	$2^{11/12}$	G♯4 A♭4	G♯3 A♭3	G♯2 A♭2	G♯1 A♭3	G♯6 A♭6	G♯7 A♭7	G♯8 A♭8

3. Custom voice patches

The Hayward Tuning Vine comes with a number of voice patches for generating the very basic waveforms - Sine, Triangle, Square and Triangle waveforms. But with sufficient working knowledge, you can modify or create new synthesized voices for the Hayward Tuning Vine. The Hayward Tuning Vine is using a software called libPD to generate it's audio (based on Pure Data, or PD, which is an open-source visual programming language), and the patch editor is available as a free download from http://puredata.info/[7].

Creating your own voice patch

The easiest way to create a custom voice patch is to base it on one of the existing patches. So far, the Hayward Tuning Vine comes with four basic oscillators: Sine, Saw, Triangle and Square. These patches are fundamentally similar, with the Sine patch being a bit more simple than the rest.

If you look in the application program folder* and then the subfolder called "patches", it should contain all the basic patches. Take a copy of one of these patches and restart the Tuning Vine. The new patch should now appear next to the built-in ones.

* On Mac: right-click the Hayward Tuning Vine application and choose "Show Package Contents", then proceed into the subfolder Contents > MacOS. On Windows you navigate to the "Hayward Tuning Vine" folder in Program Files

There are additional patches located in the subfolder called '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 contain 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 introduced to the general 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 it's own audio signal, all of which are combined at the output stage. This means that you have a total of 128 unique voices playing in the Hayward Tuning Vine at any time.

Any voice patch will have a number of parameters that arrive via so-called 'inlets'. The amount of inlets are fixed, cannot be changed, and need 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')

[7] When downloading Pure Data, be sure to choose the 'vanilla' distribution. The reason is that libPD 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 in your project.

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)

Macros: User-specified commands (optional)

Each voice-patch can define between 1 and 8 “macros” that you can control via the Tuning Vine UI (the sliders located at the top). It is completely open-ended how you want to 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.

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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 also: Options and Master Volume)

Links and resources

David B. Doty: [The Just Intonation Primer](#)

Acknowledgements

Software development: Bjørn Næsby Nielsen, Erik Jälevik

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