



Hayward Tuning Vine

Documentation for v2.0

Copyright Robin Hayward 2026

Table of Contents

Introduction.....	4
System Requirements.....	4
Installation.....	5
Mac.....	5
Windows.....	5
1. Learning the Interface.....	6
The Hayward Tuning Vine: Flowers / Grapes view.....	6
Number boxes and shift arrows.....	7
MONO / POLY modes.....	8
Patch selection and parameters.....	8
Master volume.....	8
Scientific Pitch Notation.....	8
Options.....	9
Maximum number of voices.....	9
Audio Device.....	9
MIDI Output.....	9
Calibration.....	13
1/1 Note.....	13
1/1 Frequency.....	14
Glissando range (one way).....	14
Vine: Allow zoom.....	14
Nodes: Soft reset.....	14
2. How the Hayward Tuning Vine works.....	14
Prime number two: the octave.....	14
The ‘shift’ function.....	16
Prime number three: the perfect fifth.....	16
Absolute and relative modes.....	20
Prime number five: the major third.....	20
Soundgrape notation.....	22
Prime number seven: ‘blues’ intervals.....	23
Normalize ratios.....	28
Prime numbers 11 and above: complex intervals.....	28
Chord Memory.....	29
Change parameters in real-time.....	30
Glissando.....	30
Summary of keyboard shortcuts.....	31
Chord memory.....	31
Lattice, number boxes, glissando and Options.....	31
Master volume.....	32
Notation.....	32
Patch selection.....	32
Select, reset and deselect nodes.....	32
3. Using the software.....	34
Just Intonation.....	34
The harmonic series.....	34
The subharmonic series.....	42
Guide to colour-coding.....	47
Enharmonic notation and double accidentals.....	48

4. Custom voice patches.....	52
Creating your own voice patch.....	52
How voice patches are structured.....	52
Links and resources.....	53
Acknowledgements.....	53

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.

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 show you how to install the software (System Requirements & Installation) and become familiar with the user interface (1. Learning the Interface).

Next 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 will be ready to embark on 3. Using the software, after which should have a thorough understanding of the *Hayward Tuning Vine* and start using for your own projects. In case you'd like to make your own custom voice patches, 4. Custom voice patches guides you through the process of doing this.

Please feel free to share your experiences and projects with the Hayward Tuning Vine on the website [Forum](#), where you can also post suggestions for future updates. And if you find the software useful please consider linking to the [website](#). The more people using it the more resources become available for future updates.

System Requirements

Supported operating systems:

- Windows 10, 11
- 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

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 its contents. Drag the application 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. 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.

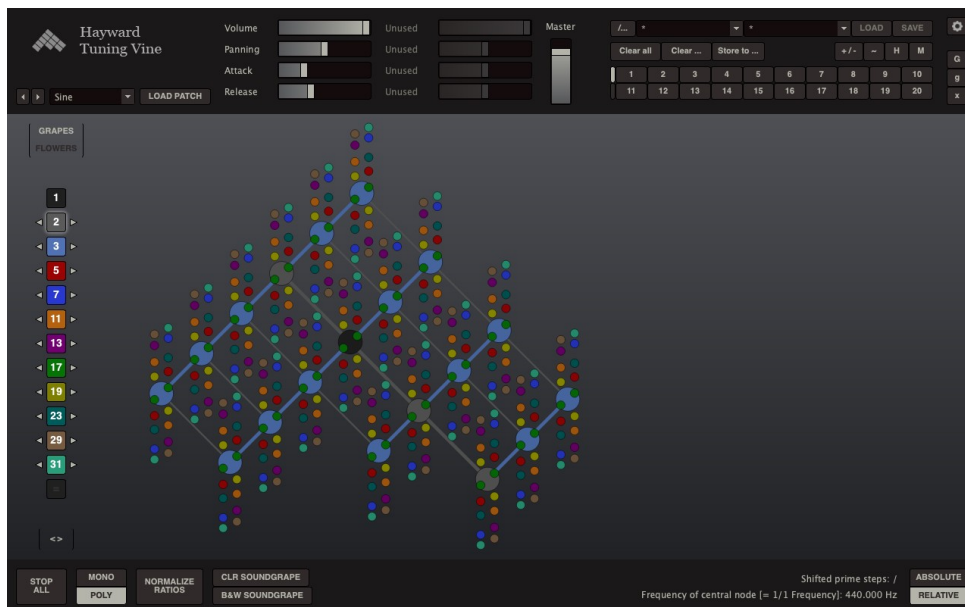
To uninstall

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

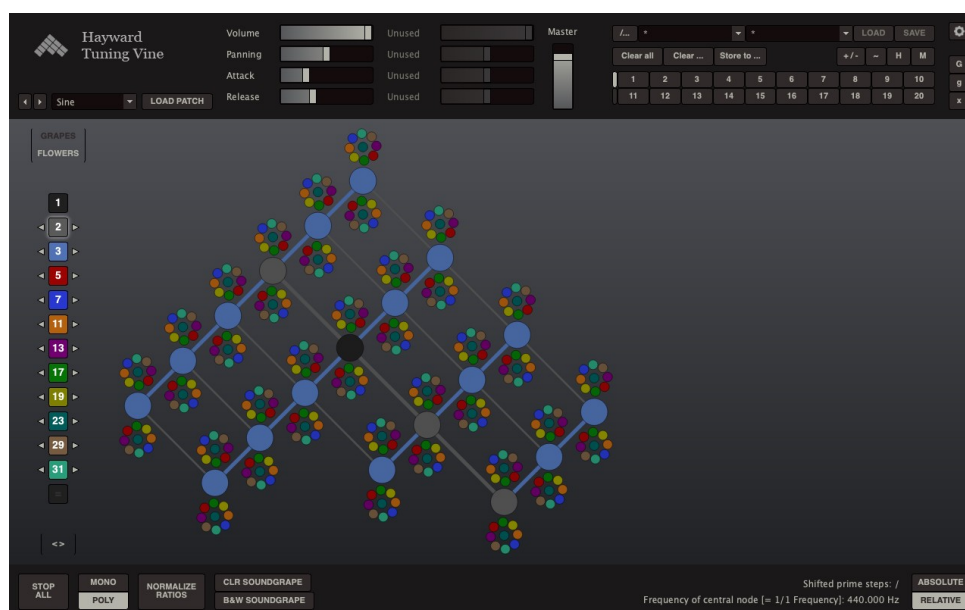
The Hayward Tuning Vine: Flowers / Grapes view

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, or press the 'esc' key on your computer keyboard, to turn off any currently sounding pitches.

Next, click on 'Flowers' above and to the left of the tuning vine lattice, or press the 'f' key on your computer. The screen now looks like this:



¹ In case you can't hear any sound, click on the 'Options' icon at the upper right corner of the screen, or use the keyboard shortcut 'cmd,.'. Make sure the correct audio interface is selected, and that the volume slider is not turned all the way down. If you are experiencing audio clicking, try reducing the Maximum number of voices.

Although they look different, the two views display 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, or between the 'f' and 'g' keys on your computer keyboard.

Now toggle to 'Flowers' view and press the 'esc' to stop all nodes from sounding 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 number boxes may be deactivated apart from '1', '2' and '3'.

Number boxes may be selected with the 'arrow up' and 'arrow down' keys on your computer, whereby the currently selected number box is highlighted. Selected number boxes from '5' and above may then be deactivated and reactivated by pressing the 'x' key on your computer.

With the exception of the black number box marked '1', all of the number boxes also have arrows placed left and right of them. These are 'shift'² arrows, which enable you to shift the tuning vine along the direction of any of the numbers. We'll come a more detailed explanation in the section The 'shift' function. For now you can start exploring it by activating the central black node, and then clicking on the arrows to the left and right of the grey number box marked '2', and the light blue number box marked '3'. You can also access the arrows of a highlighted number box through pressing the 'arrow left' and 'arrow right' keys on your computer keyboard. Notice how this changes the position of the sounding pitch within the lattice, and sometimes moves it outside the lattice.³ Meanwhile the central node turns pale, providing a visual reminder that shift arrows are currently activated.⁴

Now reset all the shift arrows by clicking on the '=' sign beneath the number boxes, or by pressing the '=' or 'backspace' key on your computer. 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 either by clicking again on the black node, on 'STOP ALL' at the lower left of the screen, or pressing the 'esc' key on your computer.

2 In the manual for v1.0.8 these were referred to as 'transposing' arrows. This 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 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.

4 If you'd rather the central black node stays black when shift arrows are active, press 'cmd,' to open the Options dialogue box, and uncheck 'Central node turns pale when shifting in relative mode'. If the black node itself moves around the lattice you are in 'ABSOLUTE' rather than 'RELATIVE' mode. Switch to 'RELATIVE' mode with by clicking on it at the lower left of your screen or by using the keyboard shortcut 'r'.

MONO / POLY modes

The 'MONO / POLY' buttons are located next to 'STOP ALL'. 'POLY' mode is ideal for building 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. You can also select each mode by pressing 'p' and 'm' on your computer keyboard. Before moving onto the next section, make sure you are in 'POLY' mode.

Patch selection and parameters

The patch selection buttons are located at the upper left of the screen. Here you can select which sound will be played by using the drop-down menu, toggling through the arrows to the left it, or pressing 'cmd1' (NoAudio),⁵ 'cmd2' (sawtooth wave), 'cmd3' (sine wave), 'cmd4' (square wave) or 'cmd5' ('triangle wave'). You can also synthesize your own sounds using the free software Pure Data, and enter them into the application using the 'LOAD PATCH' button (see Creating your own voice patch)

To the right of the 'LOAD PATCH' button are the parameter settings. Here you can adjust the volume, panning, attack and release times of the sine waves, along with a lowpass filter when using more complex waveforms. The inbuilt parameter settings always affect the pitches you're about to play, rather than those that are already sounding, unless you specifically select nodes in order to Change parameters in real-time.

Master volume

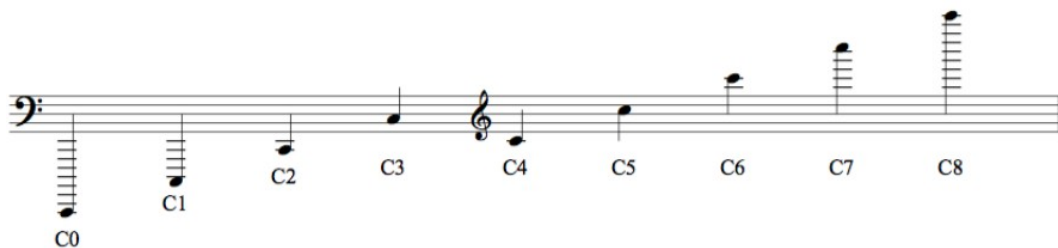
The 'Master volume' slider is situated directly to the right of the Parameter controls. Before each session play the maximum number of pitches you anticipate using simultaneously. If the resulting chord causes the sound to distort, lower the 'Master Volume' level until the distortion disappears. The session will then be free from distortion.

The volume may also be raised and lowered by pressing the 'o' and 'k' keys on your computer. To turn the volume down completely select 'cmd k'; to raise it to standard level press 'cmd o'.

Scientific Pitch Notation

The Hayward Tuning Vine uses Scientific Pitch Notation (SPN), in which the lowest 'C' on the piano is written as 'C1', and the chromatic scale immediately above it as 'D♭1', 'D1', 'E♭1'... up to 'B1'. The second lowest 'C' is then notated as 'C2' and the chromatic scale above it as 'D♭2', 'D2'... up to 'B2'. This is repeated over the 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 may be summarised as:



5 For MIDI Out.

Options

At the top right hand corner of the screen is the Options icon. Click on it or press 'cmd,' (command + comma) to open the dialogue box.

Maximum number of voices

Here you can select the maximum number of voices according the number of nodes you want to have simultaneously available. The number you select will be permanently running in the background, so if for example you select 128 voices, there will always be 128 voices running even if you only play up to 16 nodes simultaneously. The larger the number selected the more of demands are made on the computer's CPU. If you experience digital clicking whilst playing the tuning vine this probably means you need to reduce the maximum number of voices. Note that you need to restart the software in order for the maximum number of voices to take effect.

Audio Device

If you're using your computer speakers or headphones plugged directly into your computer, this needs to be set to 'Core-Audio: Built-in Output'. If you're connecting to external speakers via a sound card select it here. In case the sound card isn't listed try restarting the software along with checking the sound card is properly connected.

MIDI Output

MTS-ESP

By far the easiest way of connecting the Hayward Tuning Vine to a MIDI synthesizer is through the MTS-ESP plug-in developed by Aphex Twin and Oddsound, which once installed automatically appears within a DAW⁶ environment. Not all DAWs support the MTS-ESP plug-in, which may only be used with compatible synthesizer plug-ins. Standalone synthesizers may however be played from the tuning vine if they are equipped with MTS (MIDI Tuning Standard) or MPE (MIDI Polyphonic Expression), as described below.

DAWs that do support MTS-ESP and compatible synthesizer plug-ins include Reaper, Logic Pro and Ableton Live. Whilst the following example is based on Reaper, the principles for connecting the tuning vine to a synthesizer remain the same for all MTS-ESP compatible DAWs.

Start by downloading and installing the free 'MST-ESP Mini' plug-in from oddsound.com. In order to receive messages from the tuning vine the plug-in's 'MIDI Input' needs to match the tuning vine's 'MIDI Output', for which the corresponding driver needs to be activated. If you're using an Apple computer, first open 'Spotlight Search' by clicking on the magnifying glass symbol located in the menu at the top right of your computer screen. Type 'midi' in the popup menu and select 'Audio MIDI setup', then select 'Show MIDI Studio' from the 'Windows' tab. Double-click on 'IAC Driver' and check 'Device is online' on. If you're using Windows you need to download a third party software such as loopMIDI to create virtual MIDI ports.

Next open Options in the Hayward Tuning Vine software. In the dropdown menu next to 'MIDI Output', select 'IAC Driver Bus 1' for Apple or 'loopMIDI Port 1' for Windows, and then select 'MTS Ch1' in the dropdown menu to the right of that. Now select 'NoAudio' by using the keyboard shortcut 'cmd 1' (Apple) or 'ctrl 1' (Windows). This enables you to hear MIDI alone rather than mixed with whichever inbuilt waveform is selected.

6 Digital Audio Workstation.

Now open your DAW, insert a new track and add the 'MTS-ESP Mini' plug-in. In Reaper the plug-in may be added to the track by clicking 'FX':



Once the 'FX window' is opened the MST-ESP plug-in is listed under 'VSTi' and 'VST3i', as well as under 'ODDSound'. Double-clicking on either versions opens the plug-in, which then appears as:

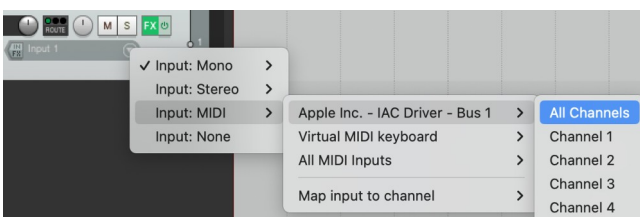


Switch 'SYSEX RCV' to 'ON'. 'WAVE' may be toggled between 'OFF', 'SINE' and 'SAW'. The two waveforms are generated by the plug-in so you can check the tuning of the synthesizer you're sending MIDI messages to. Leave it on 'SINE' for the time being.

'FX' is highlighted green to show that a plug-in has been added:



Now click on 'Input 1' and select 'Input: MIDI, IAC Driver, All Channels':



Then arm the track for recording by clicking on the red record symbol, and activate on the loudspeaker symbol to turn Record Monitoring on:



7 Because MIDI In is set to receive on all channels, the MTS channel in the Hayward Tuning Vine may actually be set to any channel.

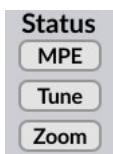
Try clicking on some nodes in the tuning vine lattice. The sine waves you should be hearing are not generated from within the tuning vine, but from the MTS-ESP plug-in which is receiving MIDI messages sent from the tuning vine. You can check this by clicking again on the track 'FX' and toggling 'WAVE' to 'OFF' within the MTS-ESP plug-in. You should no longer be hearing sound when you click on the nodes in the tuning vine.

In order to connect MTS-ESP Mini to a synthesizer you need to download and install a synthesizer plug-in that supports MTS-ESP. One such synthesizer that is available for free is [Surge XT](#). After you've downloaded and installed it you need to load it into your DAW. In Reaper this is accomplished by opening the FX Browser, either by selecting it from the View menu or by using the keyboard shortcut 'shift F'. Once the FX Browser is open select 'Scan for new plug-ins' from the 'FX' menu. 'VST3i: Surge XT' should then appear among the list of plug-ins under 'VST3i'.

To open the plug-in click again on the FX button:



Click 'Add' at the lower left of the FX window and select 'VST3i: Surge XT' (not 'Surge XT Effects'). Then select 'Tune' under 'Status' towards the upper right of the Surge synthesizer plug-in:



From the toggledown menu select 'Use MTS-ESP if available'. Now select the 'MST-ESP Mini' plug-in, and observe how the the information at the bottom of the plug-in has changed from '0 CLIENTS CONNECTED' to:

1 CLIENT CONNECTED

This signifies that Surge is now connected to the MST-ESP plug-in. Sounding nodes on the tuning vine lattice now directly plays the Surge synthesizer, which you can verify by selecting different patches with the synthesize and changing their parameter settings.

Because the parameters may now be changed within the syntheizer, most of the macros within the tuning vine are greyed out when 'NoAudio' is selected. 'Volume' however becomes replaced by 'Velocity', which effects how loud a node is played. In some VST-ESP compatible synthesizers, including Surge, the Hayward Tuning Vine Glissando sliders continue to work for selected nodes for MIDI Out messages.

An extensive selection of VST-ESP compatible plug-ins are listed at oddsound.com. The following plug-ins have been tested with the tuning vine:

Synthesizer	Glissando operable from Hayward Tuning Vine sliders
Audiodamage: Continua	Yes
Audiodamage: Phosphor	Yes
Arturia: Augmented Strings	Yes
Arturia: Augmented Voices	Yes
Arturia: Clavinet V	Yes

Arturia: CS-80 V	Yes
Arturia: DX7 V	Yes
Arturia: Emulator II V	Yes
Arturia: June-6 V	Yes
Arturia: Jup-8 V	Yes
Arturia: OP-Xa V	Yes
Arturia: Piano V	Yes
Arturia: Pigments 4	Yes
Arturia: Prophet-5 V	Yes
Arturia: Prophet-VS V	Yes
Arturia: SO80 V	Yes
Arturia: Stage 73 V	Yes
discoDXP: OB-Xd	Yes
fbm: FB-7999 (free)	No
fbm: Fury-800 (free)	No
fbm: ModulAir (free)	No
fbm: WhispAir (free)	No
HY-Plugins: HY Poly (free version)	Yes
HY-Plugins: HY Poly (full version)	Yes
Modartt: Pianoteq	No
Newfangled Audio: Pendulate (free monosynth)	Yes
Surge Synth Team: Surge XT (free)	Yes
TAL: TAL-J-8*	Yes
TAL: TAL-MOD*	Yes
TAL: TAL-Sampler*	Yes
TAL: TAL-U-No-LX*	Yes
u-he: Podolski (free mono synth)	Yes
u-he: Repro-1 (free mono synth)	Yes
Xfer: Serum	Yes

*'Default, Microtuning, MTS' needs to be selected for these synthesizer plug-ins.

This list is by no means exhaustive and the number of MTS-ESP compatible plug-ins is rapidly expanding.

MTS

If your synthesizer is MTS-compatible you should in principle be able to play it directly from the Hayward Tuning Vine. A list of MTS-compatible synthesizers is given at https://en.wikipedia.org/wiki/MIDI_tuning_standard. Installing and connecting these synthesizers is however considerably more involved than for the MTS-ESP compatible plug-ins listed above, and not all if they are regularly updated. Successful implementation does however mean that the tuning vine can connect to standalone rather than the plug-in synthesizer.

[Pianoteq](#) is an example of a MIDI synthesizer that is available both as an MTS-ESP plug-in and an MTS-compatible standalone synthesizer. In order to receive MTS messages correctly 'MIDI Tuning' in Pianoteq's 'Options' must be set to 'Yes' in the standalone version.

MTS uses a single MIDI channel rather than rotating between channels. This means the maximum number of voices that may be simultaneously sounded equals the amount defined by the synthesizer or chosen in Options. To use MTS first select 'MTS Ch 1' in the second dropdown menu to the right of 'MIDI Output'. Then check that the synthesizer's 'MIDI Input' for the first track matches the tuning vine's 'MIDI Output',

that 'Chan' is set to '1', and select which patch you'd like it to play.⁸ Then test the MIDI tuning is working correctly by playing some notes on the lattice.

If you want to be able to build a chord with more than one patch you may either select different patches for the track as you build the chord or add more tracks. The maximum number of tracks is limited to the number of ports listed in 'MIDI Out'. It's likely that only two buses are currently listed – 'IAC Driver Bus 1' and the name of the synthesizer you're using. To add more than two tracks go back to 'MIDI Studio' in 'Audio MIDI Setup', double-click on 'IAC Driver' and add more ports ('IAC Bus 2', 'IAC Bus 3'...). These will then appear in the 'MIDI Output' dropdown menu in Options, and a different synthesizer patch may be assigned to each of them. The channel number you assign each track will then correspond to the MTS channel number you select from the second dropdown menu to the right of 'MIDI Output'. If you set a track's channel to 'OMNI' in the synthesizer settings it will continue receiving messages whatever MTS channel is selected in the tuning vine.

If you're getting sound then MIDI is connected. If you're not getting sound then your synthesizer's 'MIDI Input' may not be set to 'IAC Driver Bus 1'. See if you can change this setting, otherwise find out what is listed as 'MIDI Input' and if see if it also appears in Options under in the dropdown menu next to 'MIDI Output'. You may need to restart the software for the correct name to appear in the dropdown menu. If the matching name does appear select it and try playing the tuning vine lattice again.⁹

MPE

MPE rotates the first 16 MIDI channels¹⁰ so to avoid different sounds as you build up chords you may need to set these channels the same instrument on your synthesizer. For the tuning to work properly you need to enter the correct 'MIDI MPE limit', which appears further down the Options dialogue box below 'Glissando range (one way)'.¹¹ The MPE limit must always be set 50 cents less than the pitch bend setting in your MIDI synthesizer. So if for example the pitch bend is set to 200 (allowing the pitch to be raised and lowered by up to a tempered whole tone), the MPE limit needs to be set to 150. If it's not possible to access the pitch bend setting on your synthesizer the correct MPE limit is probably 150, as a common pitch bend setting is 200. The only way to be completely sure though is through listening and adjusting the MPE limit accordingly.

As the lower the MPE limit the higher tuning resolution, setting the pitch bend to 50 and the MPE limit to zero leads to the most precise tuning. This also however reduces the MIDI Glissando range (one way) to zero. The higher the pitch bend and corresponding MPE limit the larger the possible MIDI glissando range, but the coarser the MIDI tuning resolution.

Calibration

As on standard tuners, 'Calibration' is the reference frequency on which the tuning is based. By convention this is set to 'A4'. The factory setting of this pitch is 440 Hz, but you choose any number from 349 to 499 Hz.¹²

8 If the synthesizer's MIDI channel is set to 'OMNI' it will receive messages sent from all MTS channels.

9 If you still can't hear anything try restarting both the tuning vine and the synthesizer and check that your audio is working. It may however be that your synthesizer is not compatible to receive messages from the Hayward Tuning Vine.

10 For this reason the maximum number of simultaneously sounding voices is restricted to 16 when using MPE.

11 This will only work if your synthesizer is MPE-compatible!

12 'Hz' is an abbreviation for 'Hertz' which means 'number of vibrations per second'.

1/1 Note

'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. If 'Split octaves and scales' is selected, you can first select the pitch and then the octave position of the 1/1.¹³ Deselecting 'Split octaves and scales' allows you to select the pitch from a single dropdown menu from 'A0' to 'A8'. 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'. The dropdown menus also allow you to select enharmonically equivalent pitches, for example 'Bb' and 'A#'. All other pitches are then spelled in relation to the 1/1.

1/1 Frequency

To the right of the '1/1 Note' dropdown menu is its associated cents deviation, which is normally be set to zero. In case you want assign a different cents deviation, you can do so by toggling the up-and-down arrows to the right of the '1/1 Frequency' setting. '1/1 Note' then turns red to indicate that it has been overridden by the '1/1 Frequency'. If '1/1 Frequency' is moved outside the range of '1/1 Note' the cents deviations are no longer displayed.

If you want to adjust the cents deviation more precisely you can do this by entering the '1/1 Frequency' directly. The corresponding cents will only then appear to the right of '1/1 Note' when you press 'Enter', which remains the case if you then revert back to using the up-and-down arrows. Reselecting '1/1 Note' returns to its original setting. It will not however respond to '1/1 Frequency' without pressing 'Enter' unless the dialogue box is closed and reopened.

You may also wish to enter a frequency regardless of its staff notation, for example 100 Hz. If the deviation from '1 /1 Note' exceeds 50 cents it no longer appears to the right of it, but are replaced by '...'.

Glissando range (one way)

Here you can set the ranges of the G- and g-sliders (see Error: Reference source not found). Once you've entered the desired range, you need to press 'Enter' or close the Options window for the change to take effect. Note that the corresponding glissando slider is then automatically reset.

Vine: Allow zoom

Activate this to use 'pinch to zoom' on you trackpad to zoom in and out of the tuning vine lattice.

Nodes: Soft reset

When parameters or glissando settings are altered for selected nodes, resetting them occurs rather abruptly unless 'Nodes: Soft reset' is selected. Soft reset toggles uses new voices to toggle the nodes back on. The slight overlap doubles the number of voices being used, so if you for example you are using internal patches and have set the maximum number of voices to 16, soft reset can only be applied to up to eight selected nodes. Since MIDI messages have no decay value, soft reset toggles them off and on again without any overlap. So even though MIDI MP3 restricts you to using up to 16 channels, it's possible to select all 16 nodes, alter their glissando settings, and soft reset them to initial states.

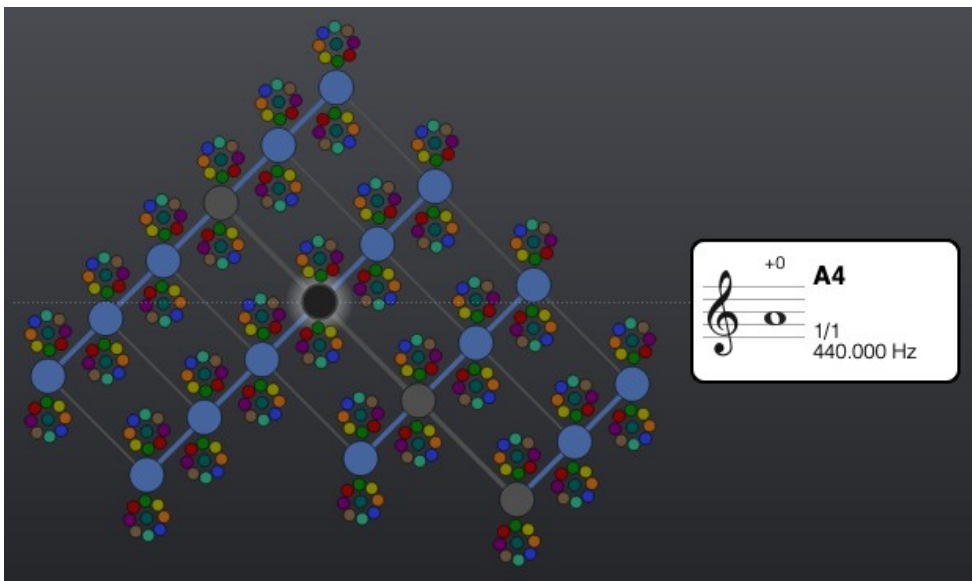
13 See [Scientific Pitch Notation](#)

2. How the Hayward Tuning Vine works

We will now take a closer look at the differently coloured nodes and how they relate to the system of tuning known as Just Intonation. Check that 'FLOWERS' view is selected, 'Calibration' set to '440 Hz' and '1/1 Note' to 'A4'. Make sure to spend some time exploring and experimenting as you work your way through the following sections to get a feel for how the software works.

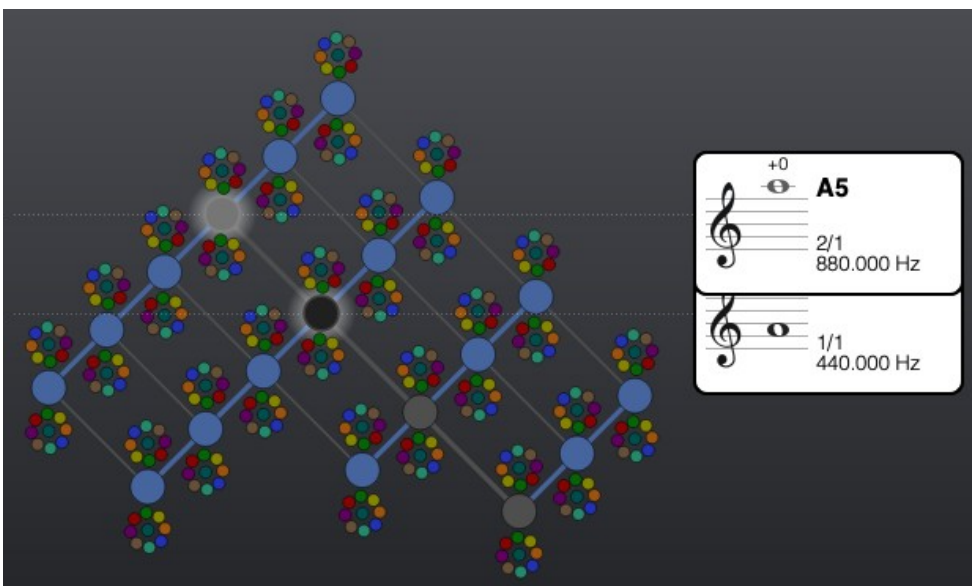
Prime number two: the octave

Start by clicking on the central black node. Along with sounding a musical tone, the node lights up and a notation card appears:



The staff notation reveals the pitch to be the 'A' above the 'middle C' on a piano keyboard, and is therefore referred to as 'A4' in Scientific Pitch Notation. This is 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 Just Intonation this ratio refers to the pitch from which all other pitches are derived, which is why it is placed at the centre of the lattice.

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 of the black node. Because it is an octave higher it is now referred to as 'A5' rather than 'A4', and its frequency has been doubled from 440 to 880 Hz. This is reflected in the ratio indication of '2/1'¹⁴ (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.¹⁵

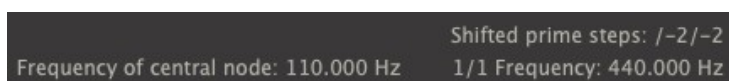
Now try clicking on the other grey nodes. Listen to the resulting tones and observe the information in the cards. (Remember that the ratios are always pronounced 'higher number to lower number', so for example the ratio '1/2' is not pronounced as 'half' but rather as 'one to two'). As you've probably 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 at the left of the screen contains the digit '2'.

The 'shift' function

So far it has only been possible to play pitches within a three octave range from 'A2' to 'A5'. In order to extend beyond this first play the central black node, and then click on the arrow to the right of the grey number box (or activate this number box and press 'right arrow' on your computer). Notice how the 'A4' is now placed an octave lower than the central node, which turns pale to indicate that a shift has taken place.¹⁶ Now try clicking on the pale central node. Its pitch has changed from 'A4' to 'A5', bringing into view 'A6' an octave above it, which was previously out of the range of the visible lattice.

In order to bring yet higher octaves into range, continue activating the arrow to the right of the grey number box. Each time this arrow is activated the frequency of the central node is doubled, bringing higher octaves into view. Activating the arrow to the left of the grey number box reverses these steps, which may also be immediately reset by clicking on the '=' sign beneath the number boxes, or by pressing the '=' sign or 'backspace' key on your computer.

Continuing to activate the arrow sign to the left of the grey number box brings lower octaves into view by halving the frequency of the central node. You can verify this both by clicking on the central node itself, and by observing the information at the bottom right hand corner of the screen, as in the following example in which the tuning vine has been shifted down two octaves:



Frequency of central node: 110.000 Hz Shifted prime steps: /-2/-2
1/1 Frequency: 440.000 Hz

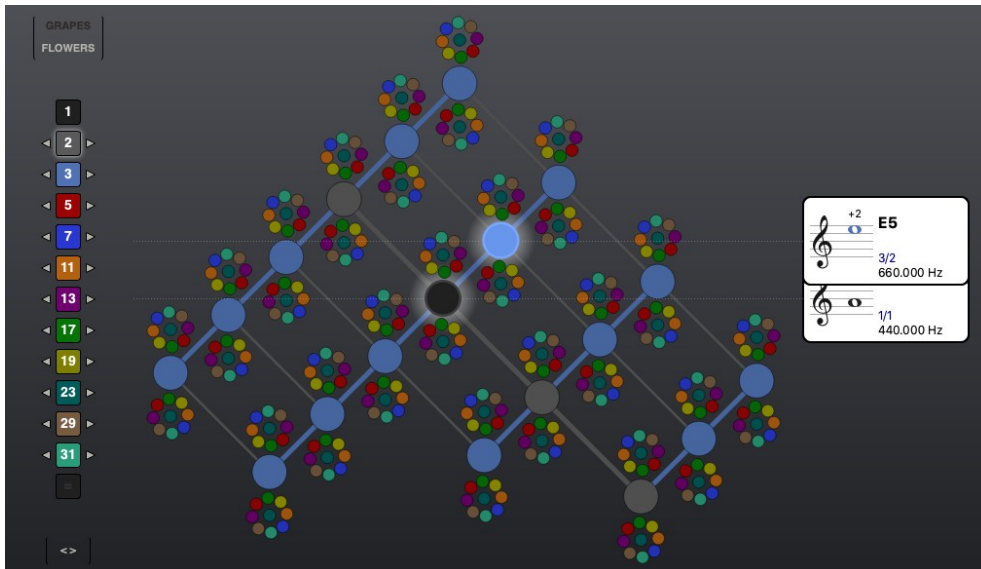
Prime number three: the perfect fifth

Now click on the black node again, and then on the light blue node above and to the 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:

14 In case the ratio in the notation card is '1/1', deactivate 'NORMALIZE RATIOS' at the lower left of the screen or use the keyboard shortcut 'n'.

15 In case the notehead remains black either 'CLRD SOUNDGRAPE' or 'B&W SOUNDGRAPE' are highlighted in the corresponding buttons beneath the lattice. Click on the highlighted button to deactivate it before continuing.

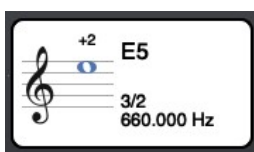
16 Make sure you are in relative mode by highlighting the 'RELATIVE' button at the bottom left of the screen, and that 'Central node turns pale when shifting in relative mode' is selected in 'Options'.



This interval is a 'perfect fifth', as may be confirmed by examining the notation cards to the right of the screen. Because a perfect fifth is smaller than an octave the cards now overlap, but any given card may be brought to the fore either by hovering the mouse over its corresponding highlighted node or over the card directly. So for example if you want 'A4' to be foremost, hover your mouse over the central black node or the corresponding card; to revert 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.¹⁷ Whenever you play a node 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 to 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.¹⁸ This is an indication of the pitch's 'cents deviation'. A cent is an extremely small musical interval, just 1/100th of 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.

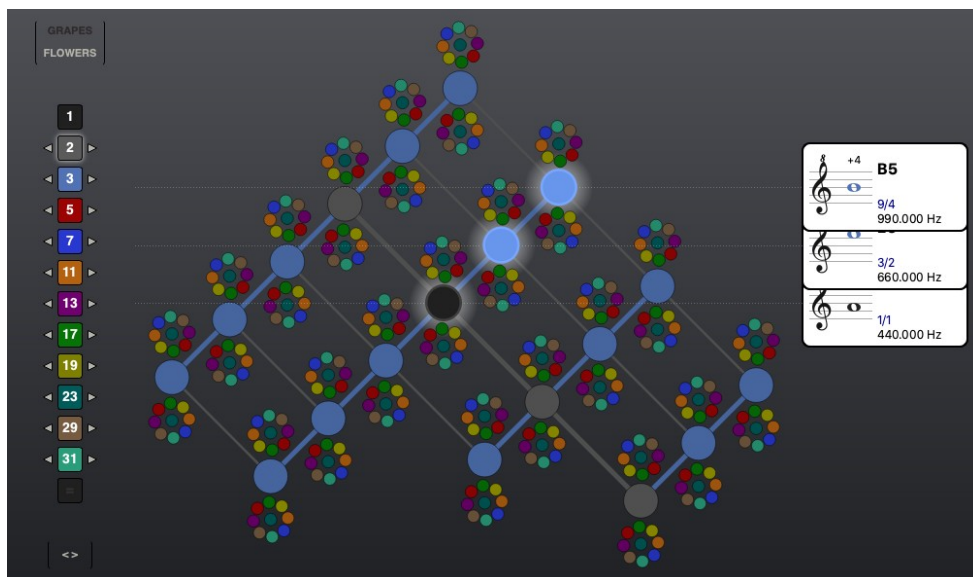
The semitones generally found on a piano keyboard are 'tempered' because they are not based on whole number ratios. Whereas the 'E5' in the card shown above arises from multiplying the black node's '1/1' by the ratio '3/2', the tempered perfect fifth between 'A4' and 'E5' on a piano keyboard can't be described by

¹⁷ See [Scientific Pitch Notation](#).

¹⁸ This value is rounded to the nearest cent. More precise cents values may be displayed by selecting 'Cards: Cents display rounded to one decimal' or 'Cards: Cents display rounded to two decimals' in 'Options'. 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.

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:

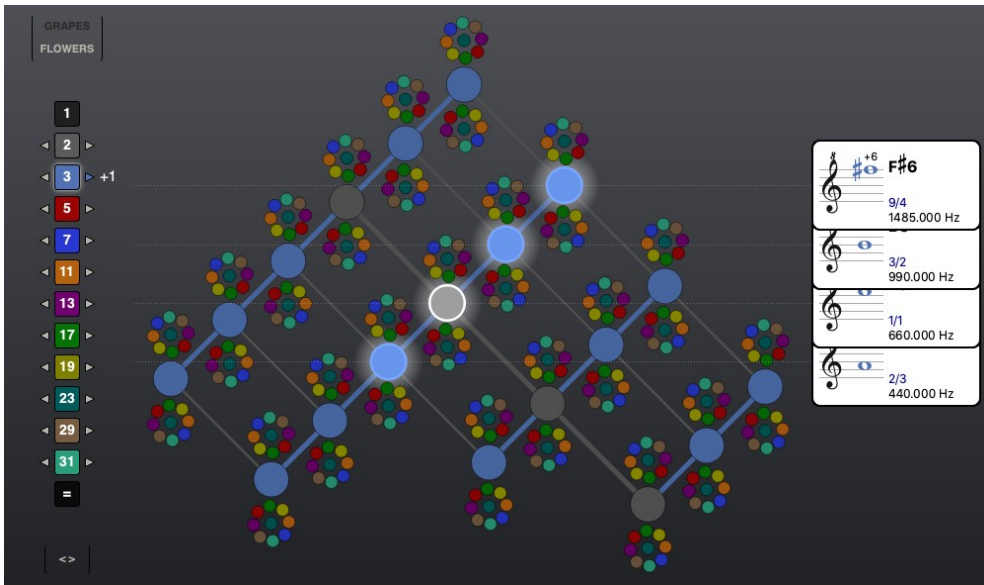


Notice how the ratio contained within the corresponding card is now '9/4'. This is because it lies two light blue struts away from the central black node, and each of these steps represents a ratio of '3/2'. The ratio associated with the 'B5' is therefore '3/2 x 3/2', which equals '9/4'. This principle 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 when moving up another perfect 5th to 'F#6', it is first necessary to bring the 'F#6' within visible range by activating on the 'shift' arrow to the right of the light blue number box:



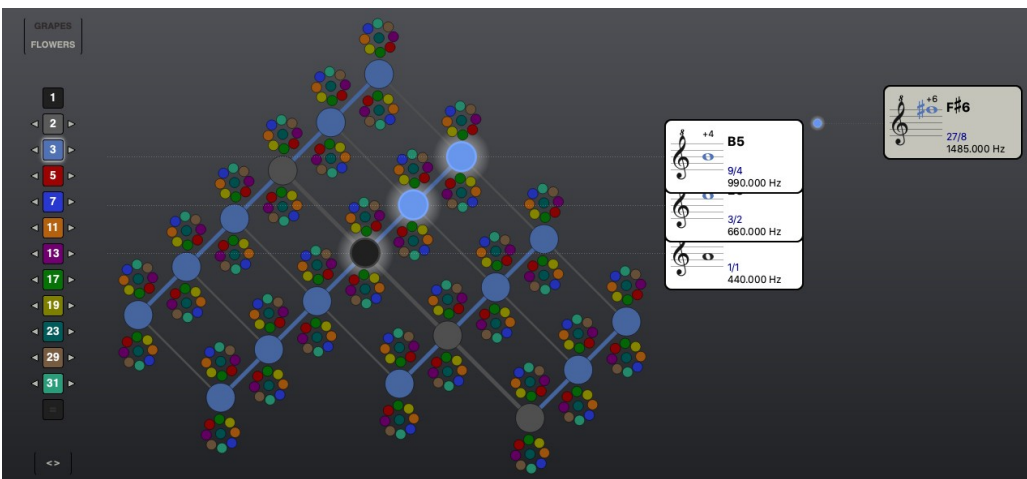
The central node turns pale to signal that a shift has been activated. The entire tuning vine has in fact been shifted up a perfect 5th, thus bringing the 'F#6' into visible range. Clicking on it reveals the following information:



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.¹⁹ This applies not just to those intervals based on prime number three, but to all the intervals within the tuning vine.

Now click on the shift arrow left of light blue number box to undo the right shift. Notice how the central node turns black again, signifying that no shifts are currently activated. Because the 1/1 realigns with the central node, the 'F#6' now lies outside the lattice. Its node is therefore moved to the right of the first row of notation cards, with its own notation card extending further to the right:



You can turn this node off by clicking on it, or by double- or cmd-clicking on its notation card.²⁰ The node remains visible allowing you to sound it again, until the shift function is deactivated. You can also make the suspended node disappear by right-clicking on it, or tapping on it with two fingers simultaneously on the trackpad.

¹⁹ This is because 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.

²⁰ Double- or cmd-clicking the other notation cards turns their associated nodes off too.

Absolute and relative modes

With the 'F#6' node still activated, try toggling back and forth between the shifted and unshifted positions whilst observing the information in its notation card. Whereas its ratio is displayed as '27/8' in the unshifted position, in the shifted position it is displayed as '9/8'. In both cases the ratio is calculated in relation to the central node. In the unshifted position, '27/8' represents three steps along the pale blue struts rising to the right of the central node, as $27 = 3 \times 3 \times 3$ and $8 = 2 \times 2 \times 2$, so $27/8 = 3/2 \times 3/2 \times 3/2$. In the shifted position, '9/4' represents only two steps from the central node, as $9 = 3 \times 3$ and $4 = 2 \times 2$. The 'A4' corresponding to the central black node in the unshifted position is now displayed on the light blue node below and to the left of the central pale node, and its ratio has changed from '1/1' to '2/3', as this ratio too is displayed in relation to the current central node.

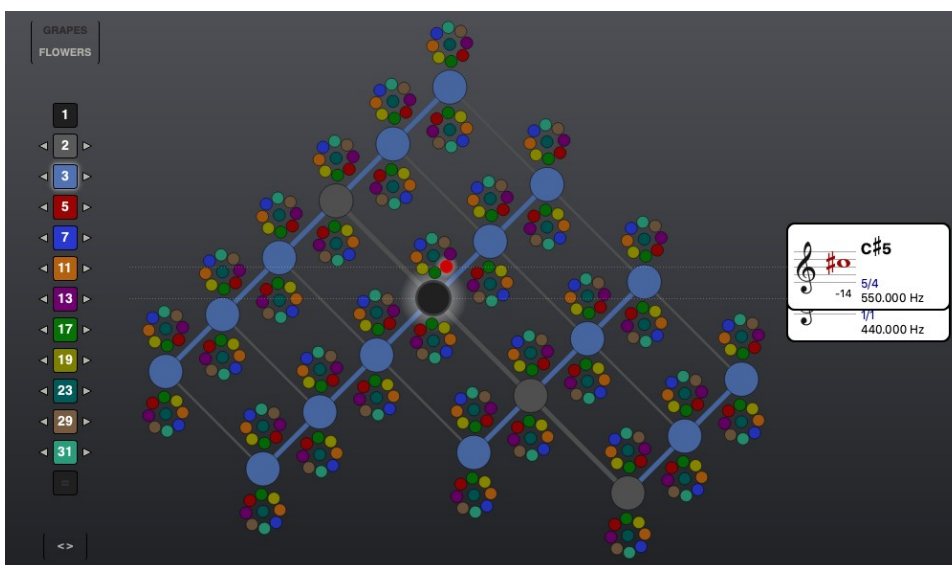
The ratios change in this way because the tuning vine is currently in 'relative' mode, in which all ratios are displayed in relation to the current central node, regardless whether the original '1/1' node has shifted position or not. In order for the ratios to stay consistent they must be displayed in relation to the original '1/1' node. This is accomplished by switching to 'absolute' mode, either by clicking on the 'ABSOLUTE' button at the lower right of the screen, or by pressing the 'a' key on your computer. To switch back to 'relative' mode, either click on the 'RELATIVE' button or press the 'r' key on your computer keyboard.

Whilst keeping the shift active, first deselect the two sounding nodes lying between 'F#6' and 'A4', and then try toggling between absolute and relative modes whilst observing the lattice and information in the notation cards. Notice how in absolute mode there is no longer any need for the central node to turn pale, as the black node itself now shifts position. Notice too how the ratio associated with 'F#6' now remains consistent at '27/8', regardless of whether the shift arrows are used or not.

Before moving onto the next section, click on the 'backspace' key to reset the shift arrows, and the 'esc' key to turn off the nodes that are still sounding, and the 'a' key to remain in 'Absolute' mode.

Prime number five: the major third

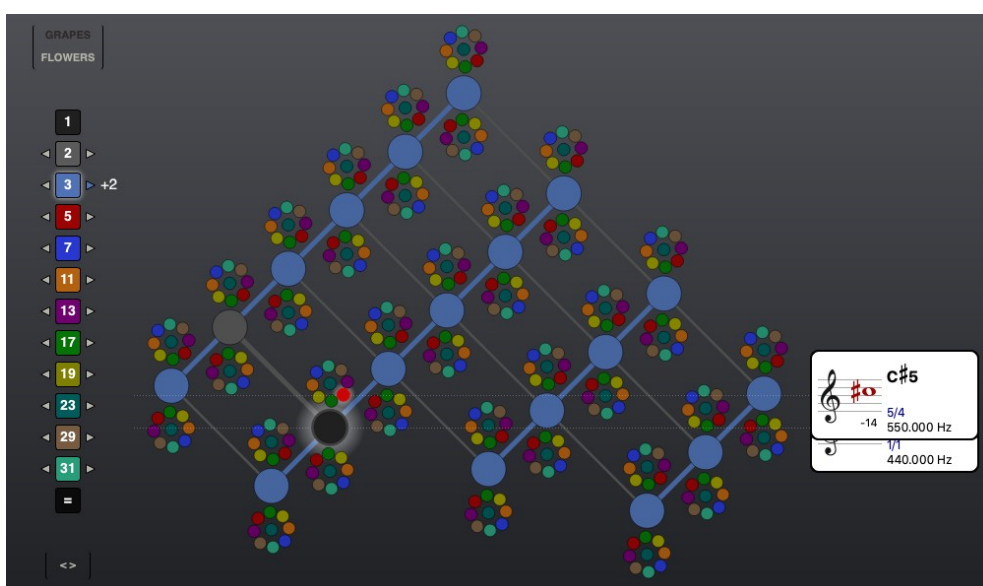
Start by clicking on the black node together with the small red node above and slightly to the right of it:



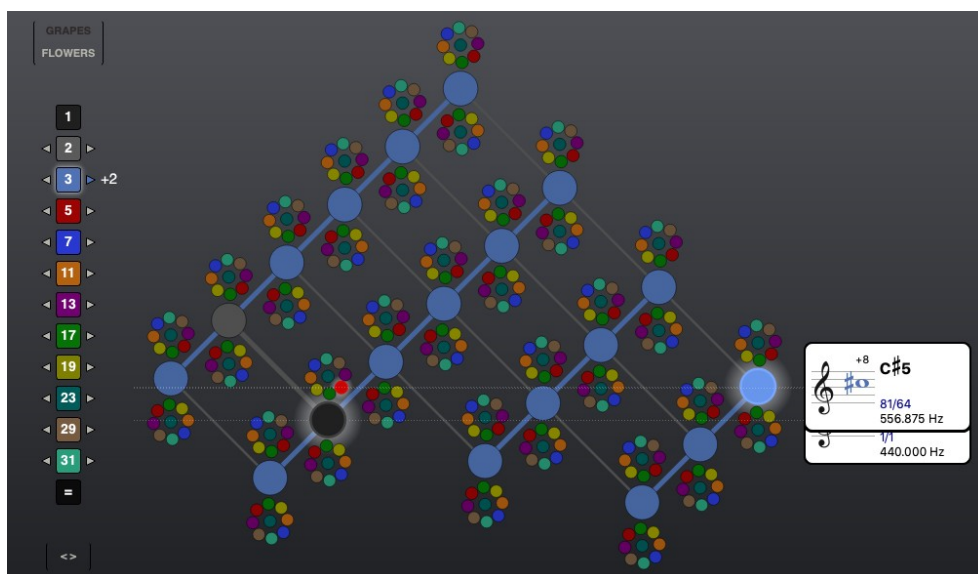
The ratio shown in the card is '5/4' (pronounced '5 to 4'). This means that the 440 Hz of the central black node has been multiplied by 5/4, resulting in 550 Hz. This interval is known as a Just major third. The cents deviation of '-14' reveals it to be significantly smaller than the tempered major third 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, first make sure you are in 'Absolute' mode by pressing 'a' on your computer. Then activate shift arrow to the right of the light blue number box twice. The tuning vine has now shifted been up by two perfect fifths, moving the highlighted nodes representing 'A4' and 'C#5' to the lower 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 the corresponding 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.

The ratios displayed in the notation cards of the two 'C#'s are '5/4' and '81/64', reflecting the positions of these two pitches in relation to the 1/1. In the case of '5/4', the ratio shows that the 1/1 frequency has been multiplied by five and divided by four; for '81/64' the 1/1 frequency has been multiplied by 81 and divided by 64. As noted earlier in Prime number three: the perfect fifth, moving upwards to the right along one light blue strut results in a perfect fifth with the ratio '3/2'. Moving up four such struts therefore results in the ratio $(3/2)^4 = 81/16$. (You can verify this by sounding this node on the tuning vine). Dividing this ratio by two results in '81/32', situated an octave below '81/16' and therefore at the bottom of the grey strut descending to the right of it. Dividing this ratio again by two results in the Just major third '81/64'.

Soundgrape notation

All nodes on the tuning vine may be traced as a series of steps from the '1/1'. In order to help keep track of these steps, a notational system called Soundgrape is included in v2.0 of the software. First try activating 'CLRD SOUNDGRAPE', either by clicking on the button at the bottom of the screen or by pressing 'c' on your computer. Observe the information in the notation cards of the three sounding nodes. The notation card of the '1/1' remains unaltered, as the notation traces the steps from the '1/1' to any given node, and obviously there can be no steps between the '1/1' and itself. But in the notation card for '5/4' an ascending red arrow now rises from the notehead, reflecting the route from the '1/1' to the numerator '5'. No grey arrows appear reflecting the route to the denominator '4', because the octave position of the pitch is already given by the staff and scientific pitch notation.

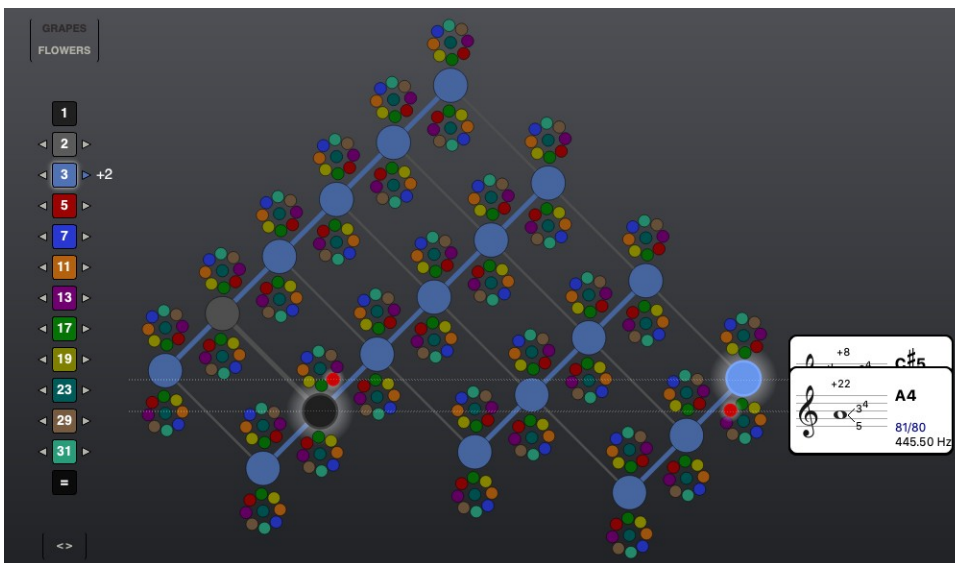
For '81/64', a light blue arrow extended by three arrow heads ascend from the notehead. Together these indicate the four steps along the light blue struts implied by the numerator '81', as $81 = 3^4$. Again, no grey arrows are necessary to indicate the denominator '64 = 2^6 ', as the octave position is already implied by the staff notation.

Now activate 'B&W SOUNDGRAPE', either by clicking on it or pressing 'b' on your computer. The coloured arrows are replaced by a black strip, at the end of which the prime number associated with the numerator appears. In the case of '81/64', the prime number three is raised to the power of four, reflecting the four steps along the light blue struts.

As you start exploring more complex ratios the Soundgrape notation will prove invaluable for orienting within the lattice. Just like the ratios, the notation is displayed in relation to the shifted '1/1' only in 'Absolute' mode. In 'Relative' mode it is displayed in relation to current central node, as you can verify by toggling between the two modes and observing the notation cards.

The difference between the major thirds tuned as '81/64' and tuned as '5/4' is known as a 'syntonic comma'. In order to see and hear this comma directly in relation to the 1/1, follow the horizontal line

extending from the black node until it intersects the red node beneath the highlighted pale blue node '81/64', activate this red node and examine its notation card:



The ratio in this card is '81/80', the ratio of the syntonic comma. The Soundgrape notation now includes a line descending from the notehead indicating that the denominator '80' is comprised of prime factors '2' (not directly displayed in the notation) and '5', as $80 = 2^4 \times 5$.²¹ Just as the line ascending from the notehead reflects the prime factors of the numerator, so the descending line reflects the prime factors of the denominator. The notation card reveals the syntonic comma to be the interval of a unison plus 22 cents.

The syntonic comma formed between prime numbers three and five 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 be featured when making music in Just Intonation, and the various speeds of beatings they result in offers a 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.²² 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 western 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, press 'esc' to turn currently sounding pitches off, and the '=' or 'backspace' key to reset the shift arrows.

Prime number seven: 'blues' intervals

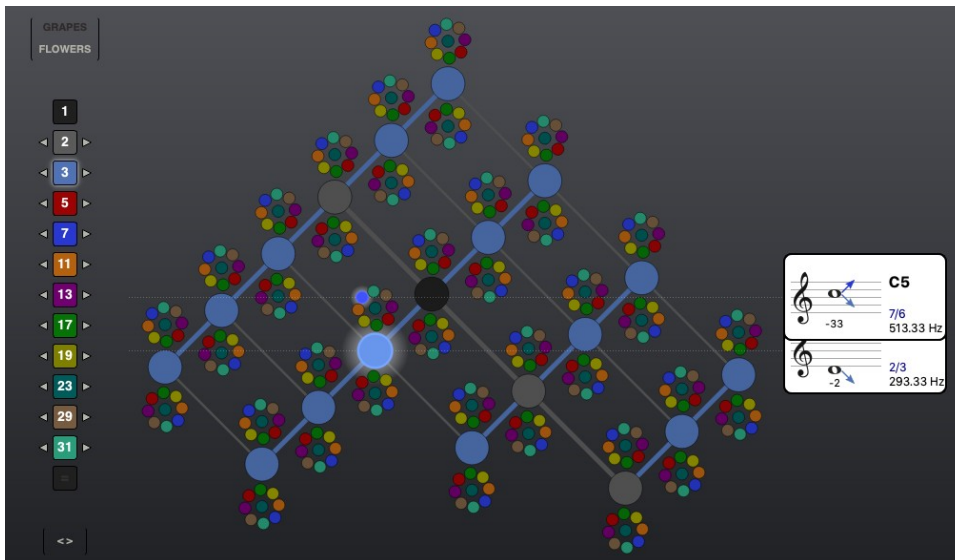
The harmonic theory of western classical music since the Renaissance has generally been restricted to 'five-limit' musical intervals, which means that it is based on intervals derived exclusively from the prime numbers two, three, and five covered in the previous sections. Whilst the tempered intervals 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

²¹ The 'prime factors' state the number as multiples of prime numbers. So for example the prime factors of ten are '2 x 5', of eight are '2 x 2 x 2', and of 15 are '3 x 5'.

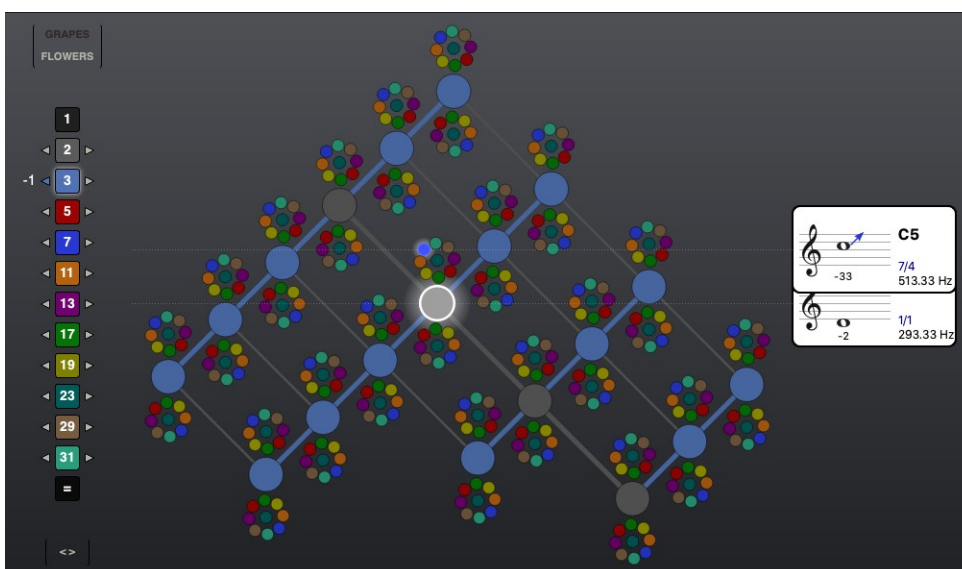
²² These terms derive from the Ancient Greek mathematician and philosopher Pythagoras (c. 570 – c. 495 BC) and mathematician, astronomer, geographer and music theorist Claudius Ptolemy (c. 100 – c. 170 AD).

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 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:

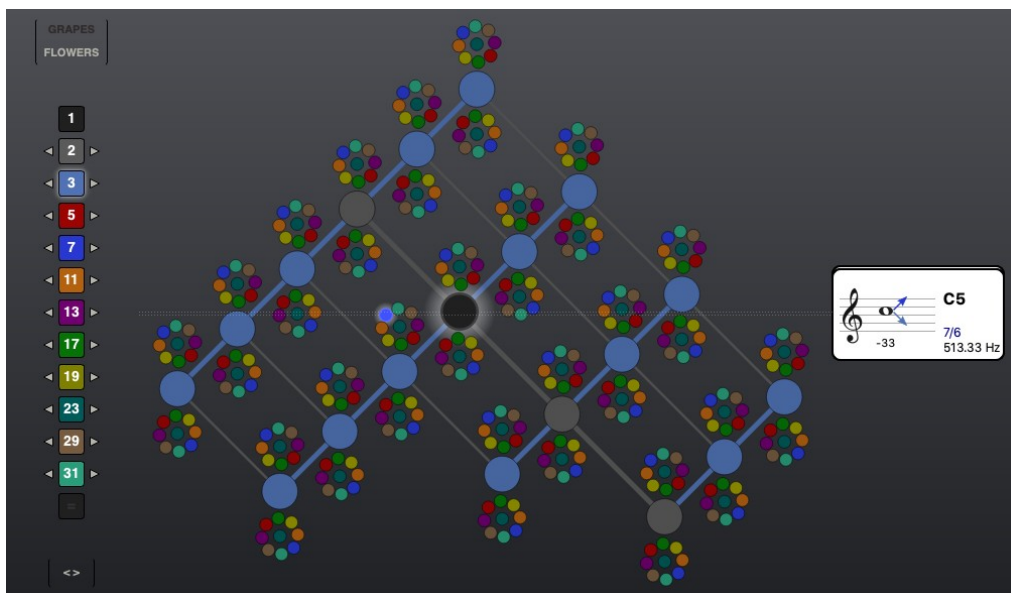


This interval is known as a 'septimal minor seventh'. Because neither of the two highlighted pitches is the central black node the interval's ratio is not directly indicated in the tuning vine. Whilst it may be deduced from the two ratios contained within the notation cards, a quicker way of calculating it is to shift it to a position that does include it. First press 'r' on your computer to make sure you are in 'Relative' mode. By activating the arrow to the left of the pale blue number box the septimal minor seventh is displayed directly in relation to the central pale node. The septimal minor seventh ratio '7/4' may now be read directly from the card corresponding to the highlighted dark blue node.

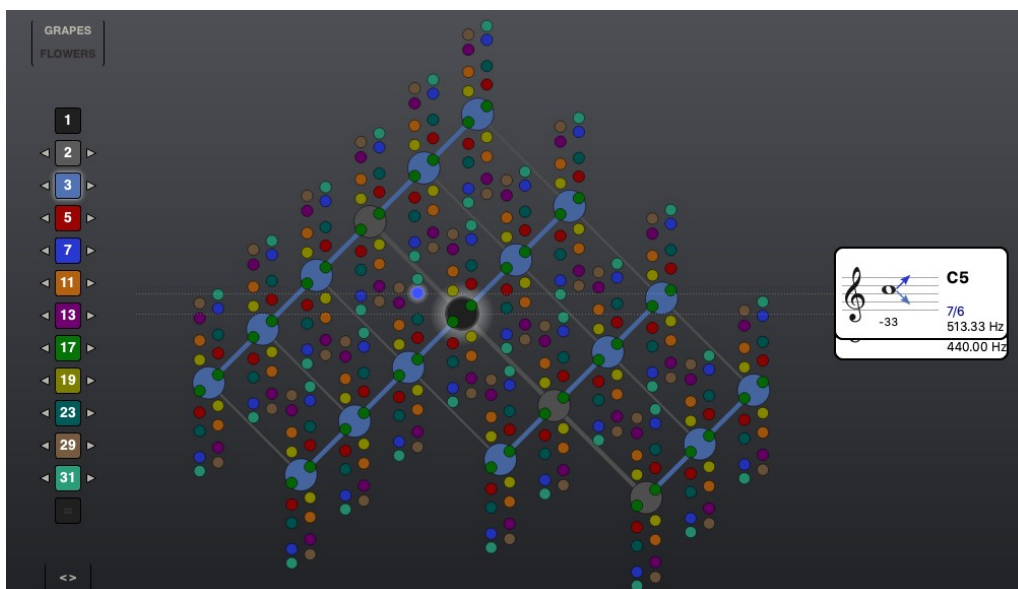


To reset the shift function, either activate the shift arrow to the right of the light blue number box or press 'backspace' on your computer.

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



As indicated by the '-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. It is in fact the flattened minor third often associated with Blues music. Yet in 'Flowers' view, the dark blue node currently appears slightly lower than the black node, even though it signifies a septimal minor third above it. Try switching to 'Grapes' view, either by selecting the corresponding button above the number boxes or by pressing 'g' on your computer. Observe how the dark blue node is now repositioned significantly higher than the black node, reflecting the actual pitch heights of the respective pitches.



'Flowers' view, which may be reselected by pressing 'g' on your computer, is good for grasping the harmonic relationships within tuning vine. In the above example it is immediately clear in 'Flowers' view that the highlighted dark blue node is connected harmonically to the larger light blue node below it. Once these

harmonic relationships have become evident, 'Grapes' view then shows how they correspond to the melodic relationships. The horizontal dashed line that extends to the left and right of each highlighted node enables you to see which other nodes are melodically close to it, even when they may be quite distant harmonically.

Once you become familiar with the interface you'll probably only use 'Grapes' view, as the immediate connection between harmonic and melodic relationships is what makes the tuning vine so intuitive to use. For learning purposes it's useful though to alternate between both views.

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 of 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 consecutively, first click on both the dark blue and red nodes to turn them off. Then toggle to 'MONO' by pressing 'm' on your computer, and click again on the dark blue and red nodes to alternate between them. 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 to understand the interface in more depth. Breaking a ratio into its prime factors 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 31.²³

In order to locate the Pythagorean minor third, first reduce '32/27' to its prime factors:

$$32 = (2 \times 2 \times 2 \times 2 \times 2)$$

$$27 = (3 \times 3 \times 3)$$

'32/27' may be rewritten as

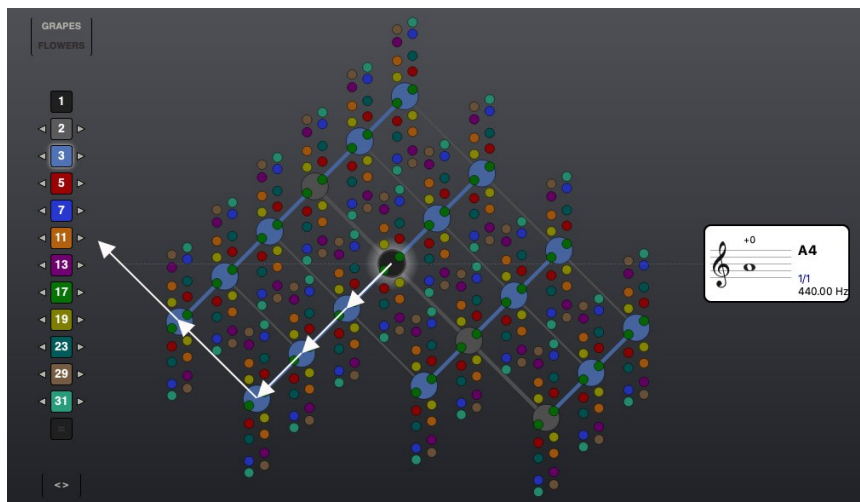
$$(2 \times 2 \times 2 \times 2 \times 2) / (3 \times 3 \times 3) = (2 \times 2 \times 2 \times 2 \times 2) / (3 \times 3 \times 3 \times 1 \times 1)$$

Next, break this compound ratio into the five simple ratios

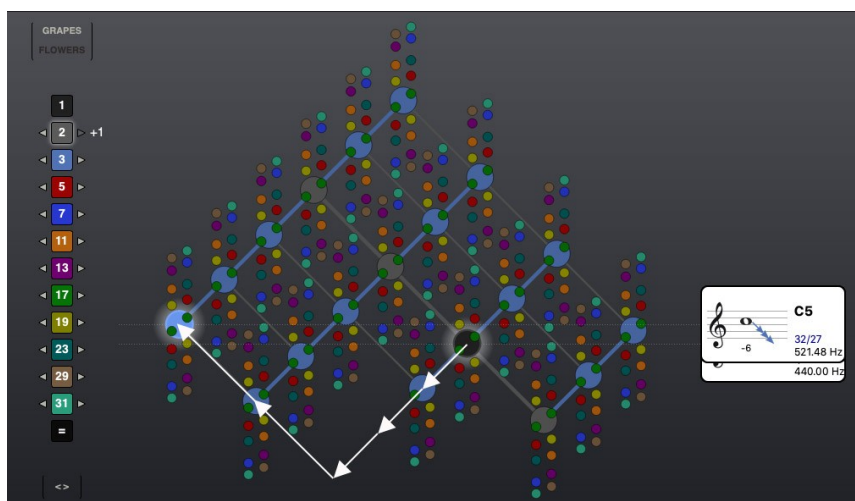
$$2/3 \times 2/3 \times 2/3 \times 2/1 \times 2/1$$

²³ As the highest prime number shown on the tuning vine is 31, ratios which contain prime numbers higher than this may not be displayed on it. As higher prime numbers are very hard to distinguish by ear they are generally of less musical use.

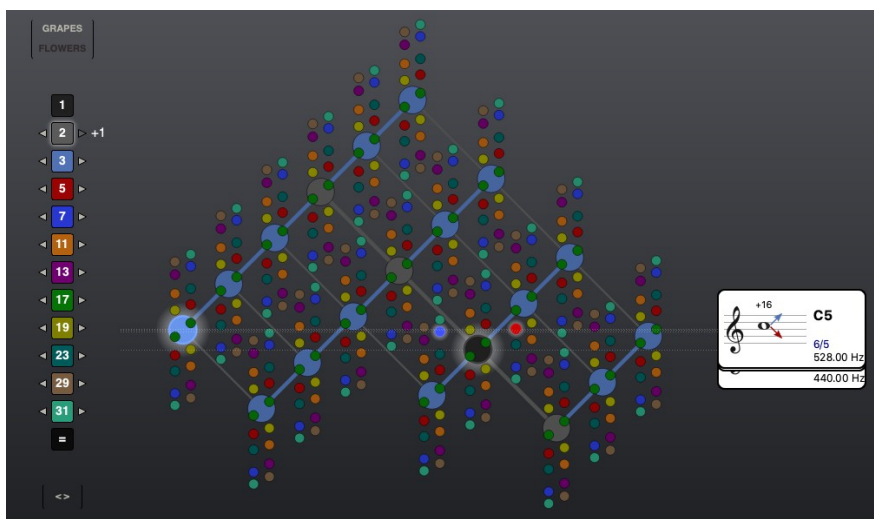
Now, starting from the central black 1/1 node, consider how each of these ratios represents a step within the tuning vine. As '2/3' indicates a step down a perfect 5th, and '2/1' a step up an octave, the five ratios translate into a movement down three light blue struts and up two light grey struts:



To bring the final node into visible range, first check you are in absolute mode by pressing 'a' on your computer. Now shift up an octave by activating the arrow to the right of the grey number box. Then click on the large light blue node at the far left to hear the Pythagorean minor third '32/27':



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



By selecting 'MONO' mode and clicking successively on the highlighted light blue, dark blue and red nodes you can also alternate between them.

Normalize ratios

So far all ratios have taken into account the octave position of any given node in relation to the '1/1' in absolute mode or the central node in relative mode. An octave above '1/1' is therefore displayed as '2/1', an octave below as '1/2', and two octaves below as '1/4' etc. Whilst this is useful for gaining a clear understanding of the routes through the lattice it leads to an impractically large number of ratios, as each node is assigned a unique ratio. The convention in Just Intonation is therefore to transpose all pitches to within an octave above the '1/1'. All octave transpositions of '1/1' therefore maintain the label '1/1', and the octave transpositions of '3/2' ('3/1', '6/1', '3/4' etc) are similarly all referred to as '3/2'.

This octave-blind ratio notation is sometimes referred to as 'normalized' notation, and you can access it by clicking on the 'NORMALIZE RATIOS' button at the lower left of the screen, or by pressing 'n' on your computer (pressing 'n' repeatedly toggles 'NORMALIZE RATIOS' on and off). Try sounding some nodes throughout the range of the lattice and observe how ratios become identical for octave transpositions when this button is activated.

Prime numbers 11 and above: complex intervals

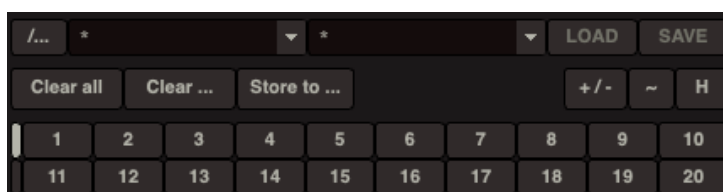
You are now in a position to explore the musical intervals based on prime numbers 11, 13, 17, 19, 23, 29 and 31. Each new prime number opens up a unique family of intervals, each with its own peculiar set of flavours. And once you become familiar with the intervals associated with each prime number, you can start exploring intervals based on combining them. By studying the notation cards you can familiarise yourself with the various ratios and how much they deviate from the tempered intervals typically 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, reset the shift arrows and activate 'STOP ALL' in order to turn all the sounding pitches off. Then press 'g' on your computer to make sure the tuning vine is set to 'Grapes' view.

Chord Memory

Chord Memory is situated at the upper right of the screen. Any combination of nodes played on the tuning vine may be stored to the memory buttons and saved as a preset into a memory bank. The upper row of memory slots may be selected by pressing 'u' and the lower row by pressing 'j' on your computer.



To use Chord Memory first play a pitch or chord you would like to save. Then click on the 'Store to...' button or press 'cmd t' on your computer, and select the memory slot you would like to store the chord to, either by clicking on it or by pressing the corresponding number on your computer. Continue this process for further chords. Once you've stored a given number of chords, deactivate the 'Store to...' button either by reselecting it or by repressing 'cmd t'. The chords may now be recalled by clicking on the highlighted memory slots or pressing the corresponding numbers on your computer.

The series of chords will still be available if you close and reopen the application, but will be overridden if you store new chords into the same memory slots. If you would like to store them more permanently you need to save them as a preset to a memory bank. Once the chords have been assigned to their given slots, click the dropdown menu above the 'Store to...' button and select 'create new bank'. Enter a name for the bank, and then click on the dropdown menu immediately to the left of the 'LOAD' button and select 'create new preset'. You can now save your preset by clicking on the 'SAVE' button or pressing 'cmd s'. The bank and preset are automatically saved to the 'chord_presets' folder, which you can access by clicking the '/...' button at the upper left of the Chord Memory display. Any given stored preset may be loaded by selecting its bank and preset name in the dropdown menus, and then either clicking on the 'LOAD' button or pressing 'cmd l'.

To clear any given chord, click on the 'Clear...' button or press 'cmd c' on your computer, and select the corresponding slot. Be sure to deselect 'Clear...' in order to recall rather than delete the remaining chords when you select them! To clear all chords at once click on the 'Clear all...' button or press 'alt c'. A popup menu appears asking if you really want to clear all the chords. Once you've cleared them you are now free to assign new set of chords to the memory slots, which may either be stored alongside the previous preset or within a different memory bank. Both memory banks and presets may be deleted by first selecting them in the dropdown menus, and then selecting 'remove last chosen bank' or 'remove last chosen preset'. Deleting a memory bank automatically deletes all of the presets contained within it.

Stored chords may also be altered in real time by playing or removing nodes and pressing 'alt' along with the number assigned to the corresponding slot. This is also an alternative way of clearing chords when no nodes are currently sounding, as pressing 'alt' plus the number of any given slot will automatically clear it. If you don't save the altered chords, you can load original chords again by clicking on 'LOAD' or pressing 'cmd l'.

Chords are recalled successively unless the '+/-' or 'tilda' buttons are selected (it is also possible to toggle through these buttons by repeatedly pressing 'cmd a'). With '+/-' activated, selecting the same memory slot in succession turns the chord on and off. Selecting first one memory slot and then another leaves both chords sounding unless they have nodes in common, in which case all common nodes are turned off and the remaining nodes of the second memory slot muted. Reselecting it then plays both chords simultaneously, and selecting it again then turns the second chord on and off whilst the remaining nodes from the first chord are sustained. Any nodes added to the chords during this process are left unaffected by the selection of the memory slots.

The 'tilda' button acts identically to the '+/-' button for chords without any common nodes. Common nodes continue to be turned off when the next memory slot is sounded, but its remaining nodes are simultaneously turned on. Selecting the second memory button successively then alternates between the nodes shared with the first memory button and the nodes not shared with it. Any nodes sounded directly in the lattice are again left unaffected by this process.

The '+/-' and 'tilda' buttons provide a playful way of interacting with stored chords, whilst also making it possible to select subsets within this chords. The 'H' button, which may also be selected by pressing 'h' on your computer, places a visual pin at the centre of all currently sounding nodes. This makes it possible sustain a given chord or node whilst alternating between different chords. Toggling 'H' off then unpins the nodes, and toggling it on again repins all currently sounding nodes. Pressing 'esc' turns off all unpinned nodes but leaves pinned nodes sounding; in order to turn off all nodes press 'cmd esc'. If a pinned node is resounded it will remain pinned until 'H' is toggled off.

Change parameters in real-time

A node must be 'selected' in order for its parameters to be changed in real-time. To select a node 'alt-click' on it, thereby forming a halo around it. Press 'alt m' to reset the parameters to their factory settings, which are read from the patches.

The parameter sliders continue to affect selected nodes even when they are not currently sounding. When such a node is replayed it will then automatically adopt the parameters defined by the current slider positions. In order to freeze a selected node's parameters 'alt-click' on it again. The halo leaves a shadow to indicate that the node has been altered. If the node is then replayed after the parameter settings have been changed, it will still play at the settings of its altered state, and only continue responding to further parameter changes if it is reselected. To return an altered node to its original pitch 'cmd-click' on it.

Glissando

The two glissando sliders may be activated by clicking on 'G' and 'g' at the upper right of your screen. They may be also brought into view simultaneously with the keyboard shortcut 'cmd g'. When both sliders are activated 'G' is positioned right of 'g'. In factory settings 'G' may be used to slide the pitches of selected nodes up and down and octave, and 'g' to slide the, up and down a tempered semitone.²⁴ As is the case for the parameter settings, the glissando sliders only affect selected nodes.²⁵

Along with the mouse you can also use the arrow keys to operate a glissando slider, which needs to be brought into focus either by clicking on it directly or by pressing the 'Tab' key on your computer to scroll between the lattice and two sliders. The right / up arrow key moves the slider up, and the left / down arrow moves it down. As it moves divides the one way range into 200 parts, in the factory settings the 'g' slider moves in 0.5 cents steps and the 'G' slider in 6 cent steps. Each slider may be returned to its default position by alt-clicking on its marker. To return both sliders to their default position click on the 'x' button below the 'G' and 'g' buttons or use the keyboard shortcut 'alt g'.

Summary of keyboard shortcuts

Chord memory

Clear...	'cmd c'
Clear all	'alt c'
H (pin nodes)	'h'
LOAD	'cmd l'

²⁴ These ranges may be changed in Options.

²⁵ For a complete list of keyboard shortcuts concerning selected nodes see Select, reset and deselect nodes.

Memory slot rows	'u' or 'j' for upper or lower row
SAVE	'cmd s'
Store to...	'cmd t'
Store in real time	'alt' plus slot number
+/- & tilda	'cmd a'

Lattice, number boxes, glissando and Options

MONO / POLY	'm' / 'p'
Reset shift arrows	'=' or 'backspace'
Select a number box	'up arrow' / 'down arrow'
Select shift arrows	'left arrow' / 'right arrow'
STOP ALL	'esc'
STOP ALL including pinned nodes	'cmd esc'
Remove free floating nodes	'right click'
Glissando sliders	'cmd g'
Toggle between lattice and each glissando slider for arrow key focus	'tab'
Options	'cmd ,'
Turn off node	'double-click' or 'cmd click' on the node's notation card
Make shifted node disappear	'right-click' on node

Master volume

Decrease incrementally	'k'
Increase incrementally	'o'
Mute	'cmd k'
Reset	'cmd o'

Notation

ABSOLUTE / RELATIVE	'a' / 'r'
B&W SOUNDGRAPE	'b'
CLRD SOUNDGRAPE	'c'
NORMALIZE RATIOS	'n'

Patch selection

NoAudio	'cmd1'
Load sawtooth wave	'cmd 2'
Load sine wave	'cmd 3'
Load square wave	'cmd 4'
Load triangle wave	'cmd 5'

Select, reset and deselect nodes

Select node / toggle between selected and altered node	'alt click'
Reset pitch of selected or altered node	'cmd click' (Windows 'ctrl click')
Reset pitch of selected or altered node and deselect	'alt cmd click' (Windows 'alt ctrl click')
Reset all pitches	'alt n'
Reset all pitches and deselect	'alt cmd n' (Windows 'alt ctrl n')
Reset pitches of selected nodes	'alt z'
Reset pitches of selected nodes and deselect them	'alt cmd z' (Windows 'alt ctrl z') / 'alt x'
Reset all nodes and sliders	'alt r'
Reset all nodes and sliders and deselect nodes	'alt cmd r' (Windows 'alt ctrl r')
Select all sounding nodes	'alt a'
Toggle all selected nodes	'alt t'
Turn all selected nodes into altered nodes	'alt esc'
Reset single slider	'alt click' soft reset no
Reset glissando sliders	'alt g' soft reset no
Reset parameter sliders	'alt m' soft reset no
Reset all sliders	'alt s' soft reset no
Change unselected unaltered sounding node to current parameter settings	'cmd click'

3. Using the software

Just Intonation

All intervals within Just Intonation may ultimately be derived from combinations of the harmonic and subharmonic series. The harmonic series is based on *multiplying* a given frequency by positive integers (1, 2, 3...), and the subharmonic series on *dividing* by such integers. Before starting check you are in 'ABSOLUTE' and 'POLY' modes, 'CLR D SOUNDGRAPE' selected, and 'NORMALISE RATIOS' *not* highlighted.

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:

Staff	Note	Frequency Ratio	Key Signature	
V	16	+0	C4	
	17	+5	C#4	
	18	+4	D4	
	19	-2	D#4	
	20	-14	E4	
IV	8	+0	C3	
	9	+4	C#3	
	10	-14	D3	
	11	-49	D#3	
	12	+2	E3	
III	4	+0	C2	
	5	-14	D2	
	6	+2	E2	
	7	-31	F2	
	II	2	+0	C1
3		+2	C#1	
I		1	+0	C0

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 open the 'Options' window by pressing 'cmd ,' set 'Calibration' to '440' and '1/1 Note' to 'C1'. Then click on the central black node:

Hayward Tuning Vine

Volume: Unused
Panning: Unused
Attack: Unused
Release: Unused

Master

Grid: 1-20, 11-20

Options: Sine, LOAD PATCH

GRAPES FLOWERS

1-31

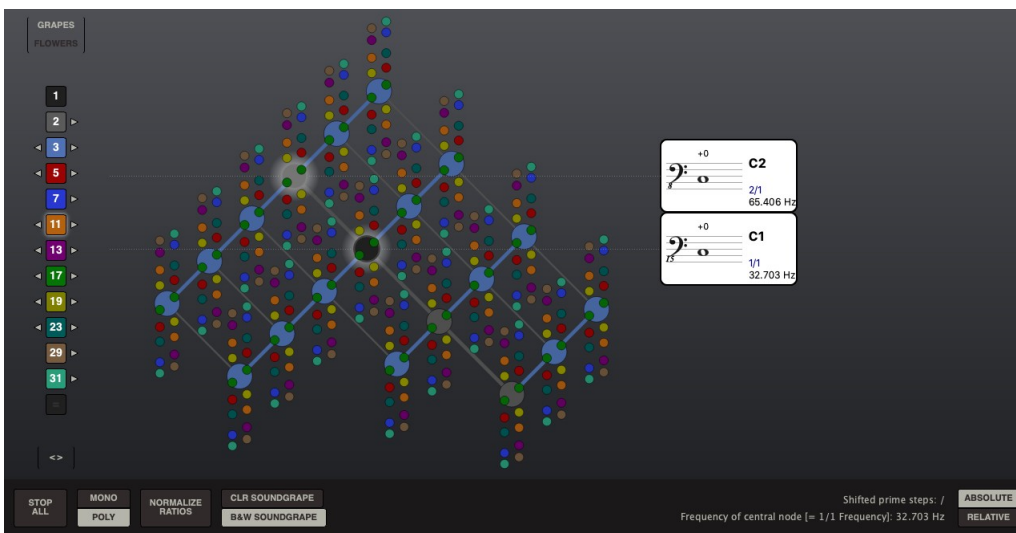
STOP ALL, MONO, NORMALIZE RATIOS, CLR D SOUNDGRAPE, B&W SOUNDGRAPE

Frequency of central node (= 1/1): 32,703 Hz

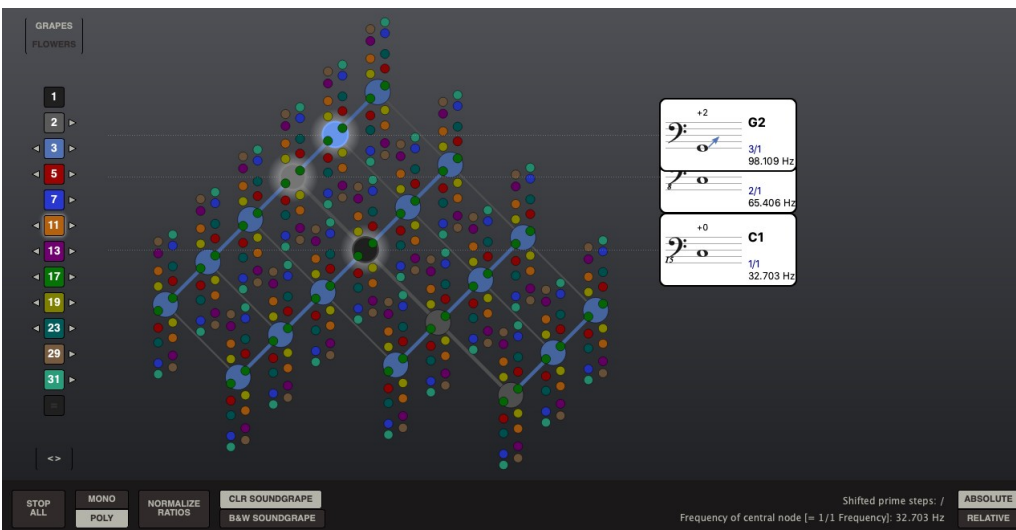
ABSOLUTE, RELATIVE

Although you can see that the central black node is set to 'C1', you may not be able to hear it as its frequency is lower than computer speakers can play a sine wave. Press 'cmd 2' to set the waveform to 'Saw'. If you find the tone now too harsh 'alt-click' on the node and adjust 'Lowpass' at the top of the screen.²⁶

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 the interval '2:1' (pronounced 'two to one'). It's useful to follow this convention as it keeps things consistent when dealing with more complex ratios.²⁷ To perform this operation on the tuning vine, click on the grey node attached to the grey strut upwards and to the left of the central black 1/1 node:



In order to play the third harmonic, follow the light blue strut upwards and to the right from the highlighted grey node, and click on the light blue node at the end of it:



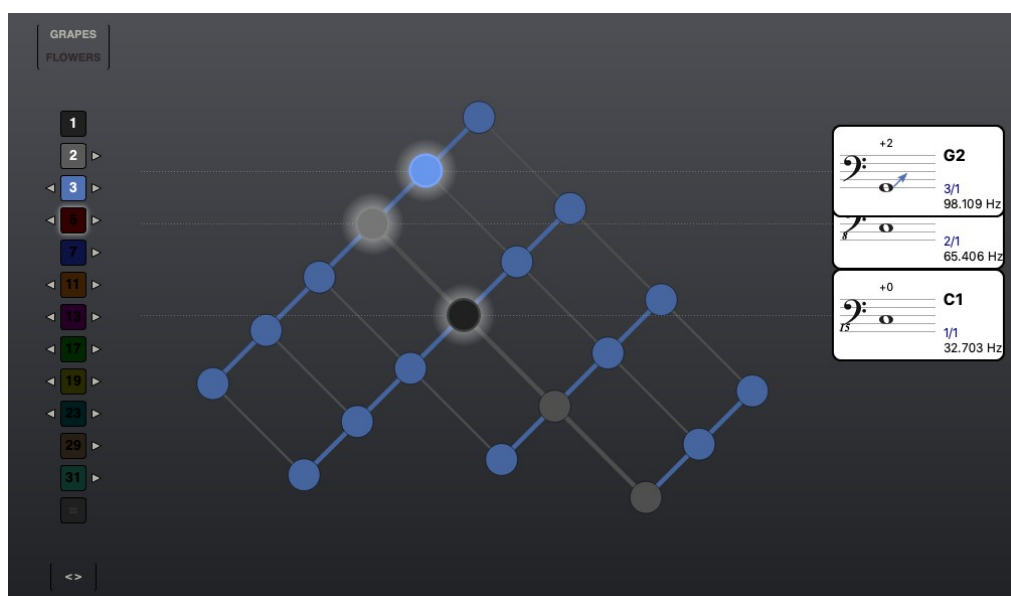
26 If you toggle back to the 'Sine' waveform by pressing 'cmd 3', you'll see that 'Lowpass' is now greyed out. This is because a sine wave is a single frequency without any upper partials, so its timbre cannot be altered. If you're using speakers on which the 'C1' can be heard as a sine wave it's better to use this setting to build up the harmonic series, as the spectra of all pitched sounds can be analysed in terms of si

27 This manual follows the practice 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' and '2/1' 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'.

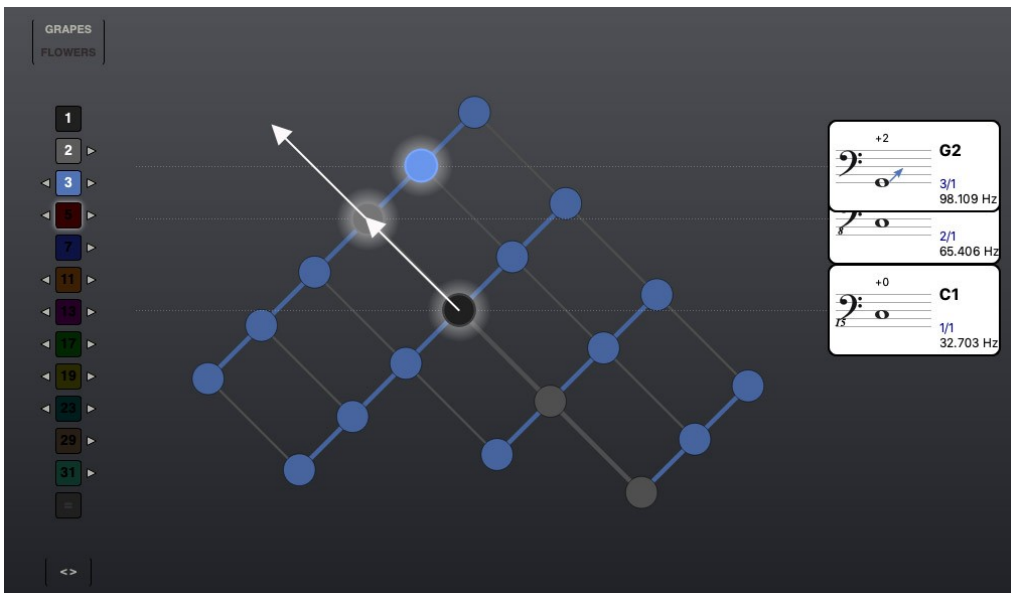
The first octave of the harmonic series contains only one pitch, the fundamental '1/1'. The second octave contains two pitches, the octave '2/1' and the octave-plus-fifth '3/1'. Compare how this information is displayed on the tuning vine with the lowest two staves of the five-octave harmonic series displayed at the beginning of this section on [The harmonic series](#).

In geometrical terms, the '1/1' represented by the black node embodies 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. This may be seen most clearly by toggling off all number boxes containing prime numbers higher than '3', either by clicking on them or by selecting them with 'arrow up' and 'arrow down' keys on your computer and then pressing 'x':

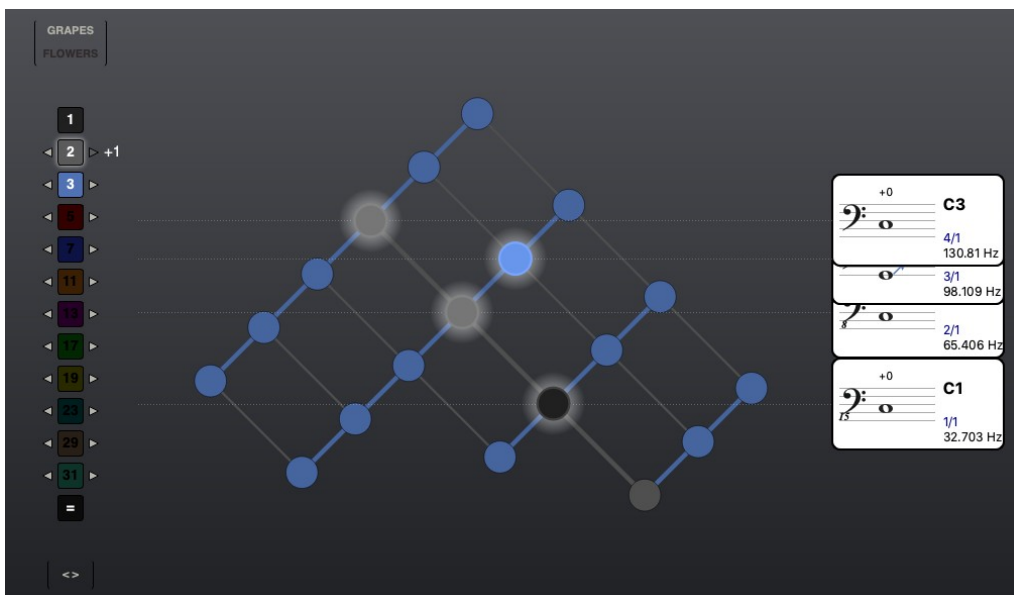


Focusing on the rectangle formed immediately above the black node, the third harmonic is reached by jumping from the '1/1' at the rectangle's lowest corner to the '3/1' at its highest corner. The '3:1' interval thus formed remains constant for all such rectangles within the tuning vine. Once you become 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:

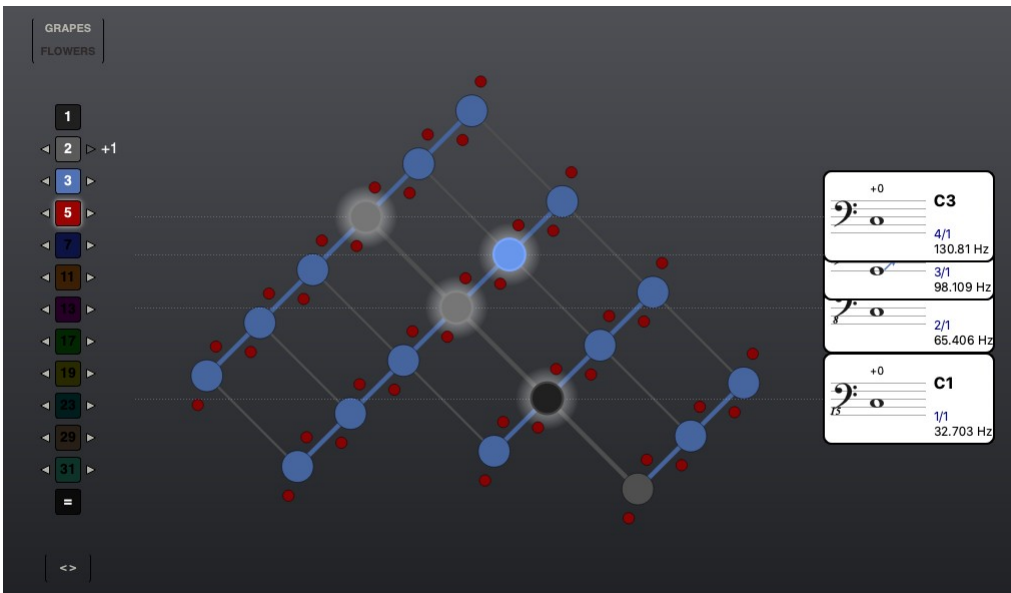


In order to bring it within the lattice first use the 'arrow up' key to select the grey number box, and then the 'arrow right' key to shift the tuning vine up one octave. The fourth tone may now be sounded by clicking on the highest grey node, whilst the 1/1 'C1' has been shifted down an octave within the lattice:

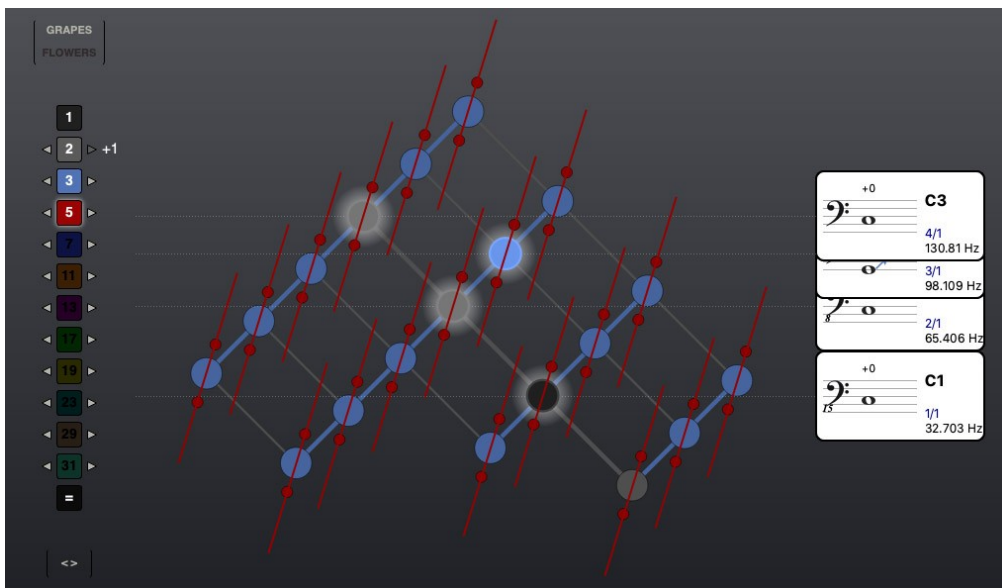


The fourth pitch within the harmonic series forms a '4:1' (two octave) interval with the '1/1', a '2:1' (octave) interval with the '2/1', and a '4:3' (Just perfect fourth) interval with the '3/1'. Notice how the Just perfect fourth '4:3' entails jumping from the lower right to upper left corner of the rectangle formed between the grey and light blue axes.

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 selecting the red number box containing '5' with the 'arrow down' key and pressing 'x' to activate it:

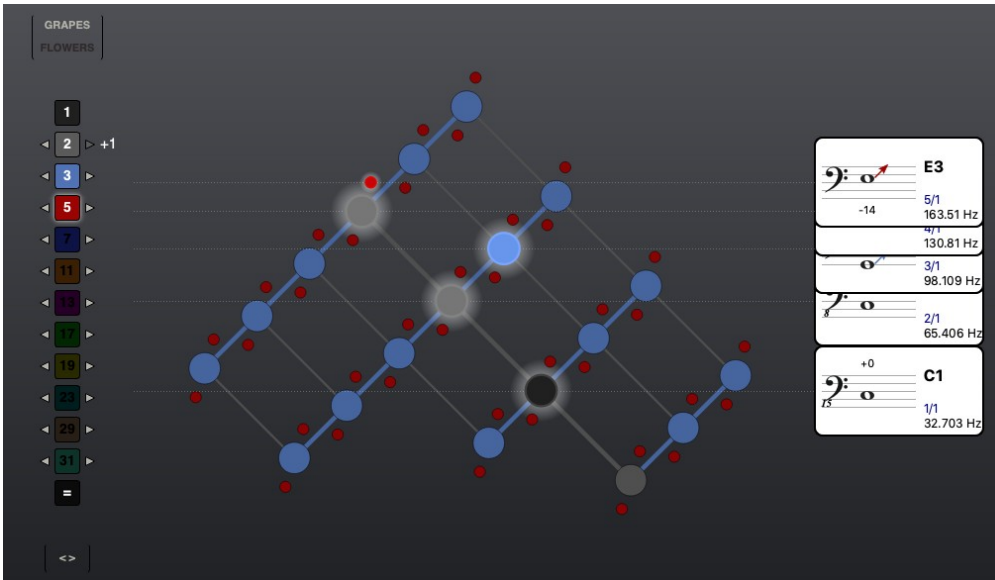


This third dimension is of course depicted in two dimensions on the computer screen. It may be visualised by imagining parallel red lines connecting each of the small red nodes via the larger node between them:



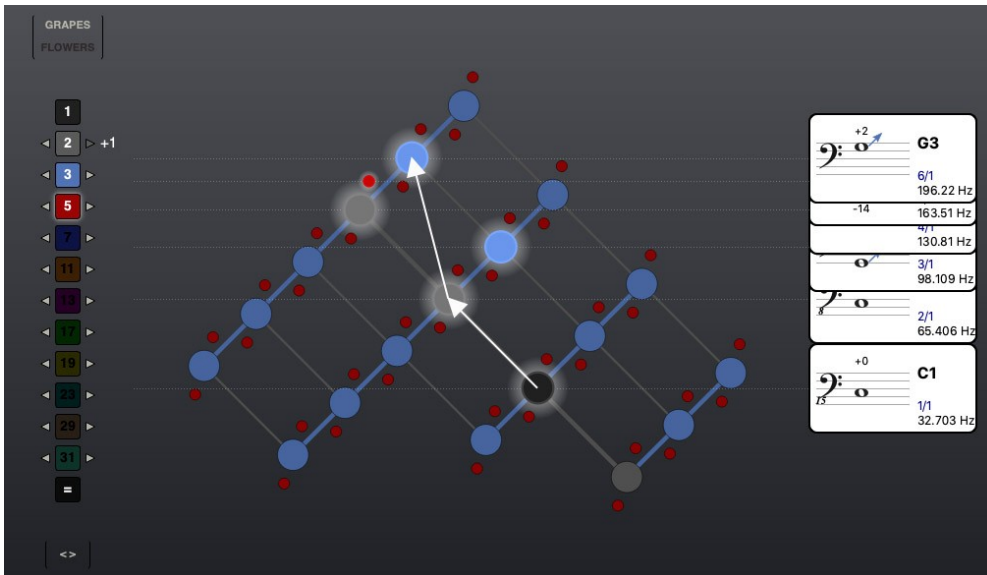
If it were practical to do so, these red struts punctuated by further red nodes would be included in the visible lattice. As higher prime numbers are introduced this becomes increasingly less feasible however, as the interface would fast disintegrate into visual chaos. All prime numbers from five upwards are therefore placed as pairs of smaller nodes above and below each of the larger nodes of the two-dimensional grid. Nodes lying beyond the immediately visible lattice may be then accessed through The 'shift' function.

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

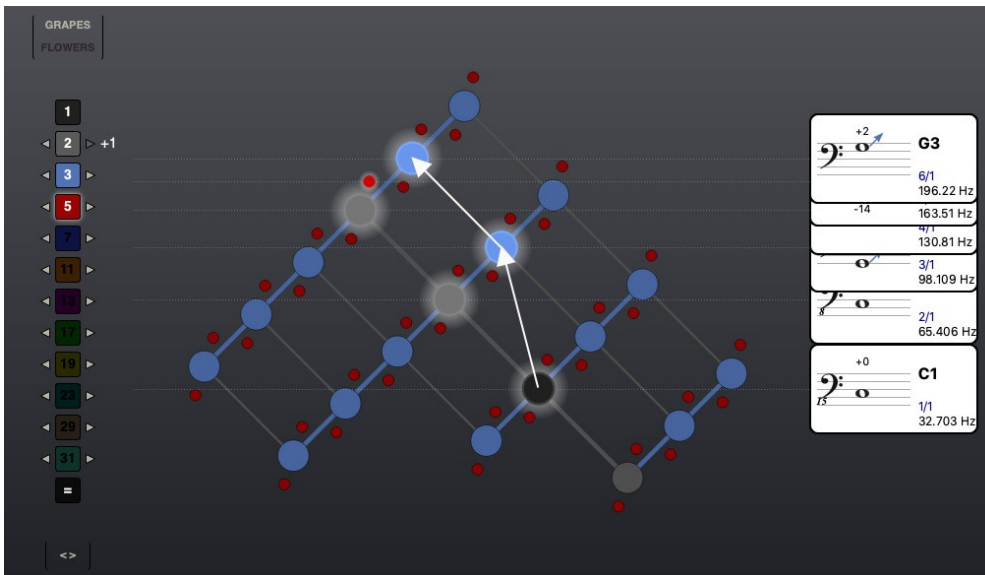


The fifth harmonic forms the intervals '5:1' (two octaves and a Just major third) with the first tone, '5:2' (one octave and a Just major third) with the second tone, '5:3' (a Just major sixth) with the third tone, and '5:4' (a Just major third) with the fourth tone of the harmonic series. Each of these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

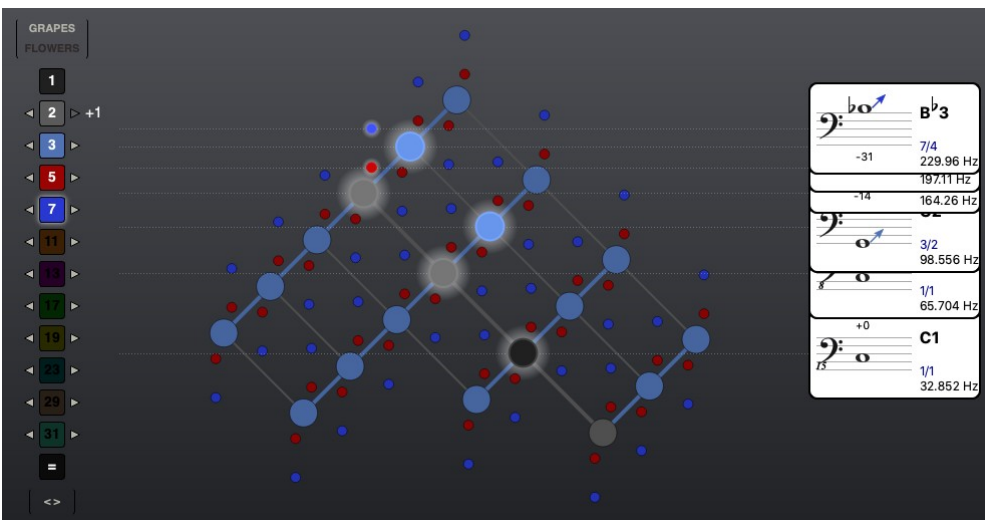
As $6/1 = (2 \times 3)/1$, the sixth tone in the series does not introduce any new prime numbers, but is contained within the two-dimensional grid formed between the grey and light blue nodes. Breaking the ratio into two gives $2/1 \times 3/1$, which provides the first of two routes by which the sixth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



The second route reverses the order of the two ratios to $3/1 \times 2/1$:

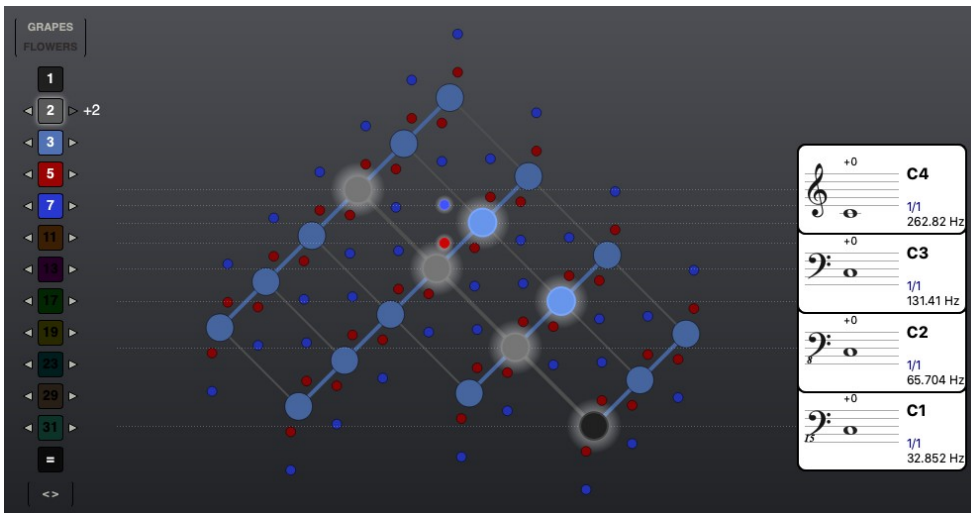


As seven is a prime number, the seventh tone in the harmonic series opens up a fourth dimension in harmonic space, activated by selecting the dark blue number box with the 'arrow down' key and then pressing 'x'. To sound the seventh tone click on the dark blue node suspended above the fourth tone:

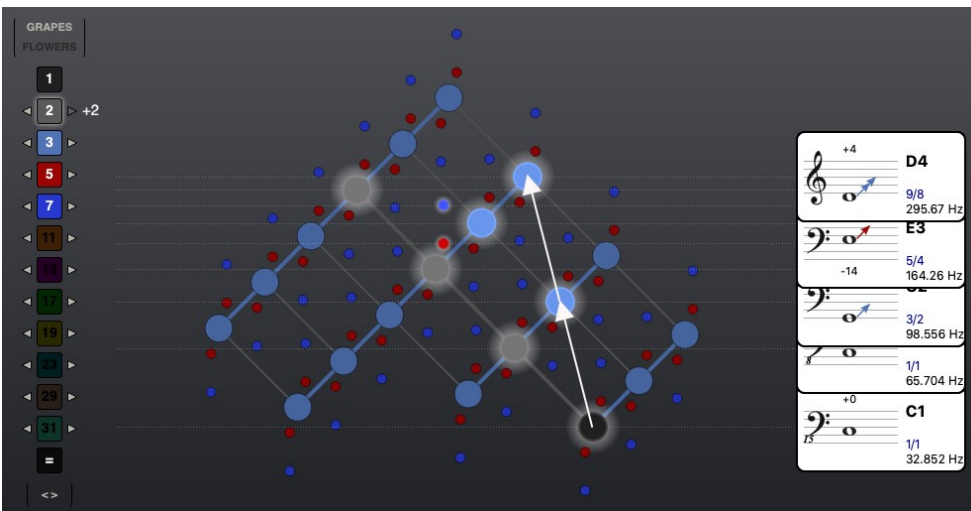


Before locating and playing the eighth pitch in the harmonic series, it's worth comparing the first three octaves displayed on the tuning vine with the lower three staves shown at the start of this section on [The harmonic series](#). The first octave contains one tone, the second octave two tones, and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

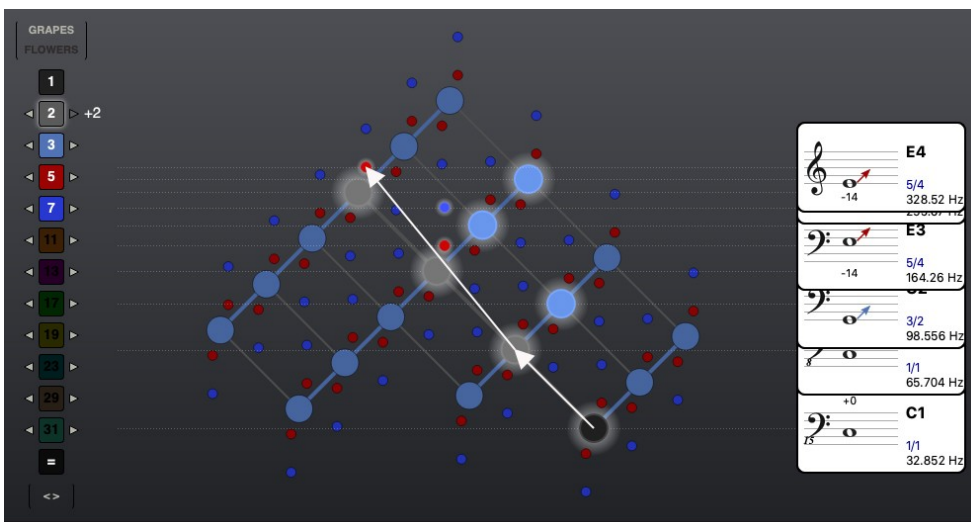
The eighth pitch in the harmonic series is described by the ratio '8/1'. Written as prime factors this is '(2 x 2 x 2)/1', which split into separate ratios becomes '2/1 x 2/1 x 2/1'. As this represents moving up three grey struts from 'C1', and there are currently only two such struts visible, the eighth harmonic may be brought into view by shifting one step further along the octave axis:



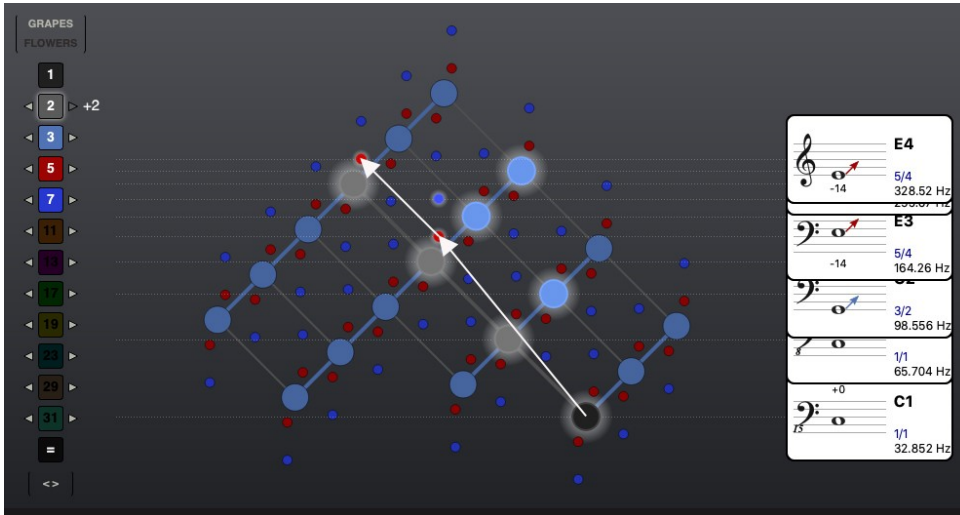
The ninth harmonic corresponds to the ratio '9/1'. Restated in prime factors this is '(3 x 3)/1', which split into two ratios becomes '3/1 x 3/1'. We noted above that '3/1' implies jumping from the lowest to highest corner in the rectangle formed between the grey and light blue struts. Following this principle, the ninth harmonic may be located as follows:



The 10th tone in the harmonic series 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', corresponding to the following route within the tuning vine:



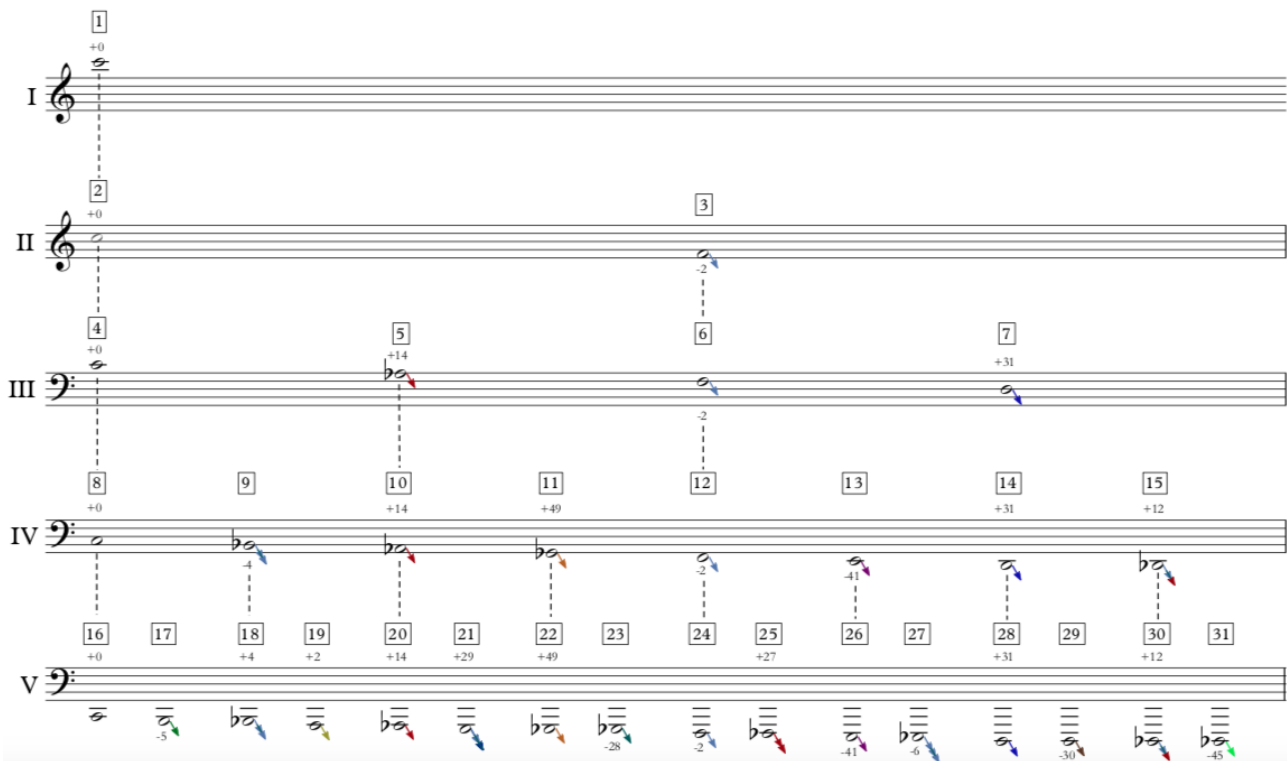
Reversing the order of the ratios to '5/1 x 2/1' alters the route to:



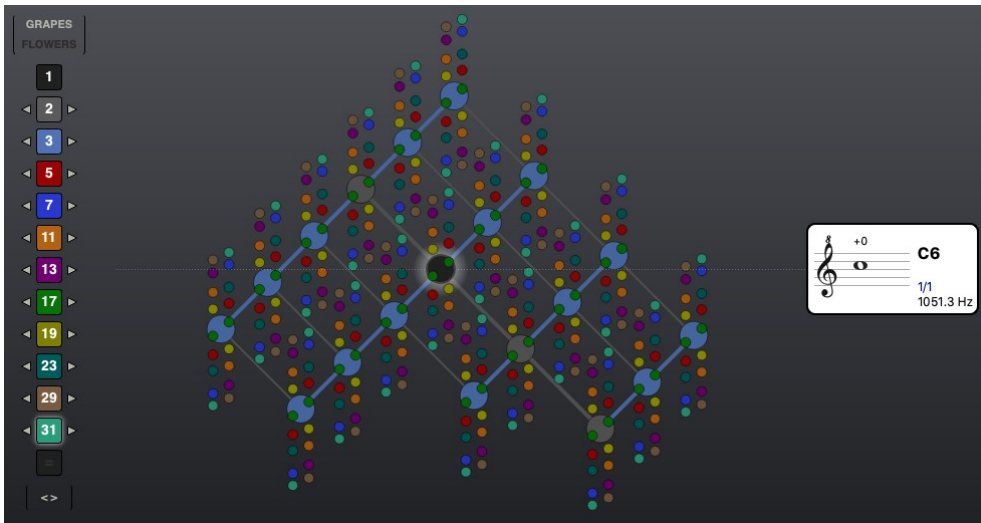
Now try continuing up the harmonic series until the 31st tone, toggling the number boxes to bring the higher primes into view as you need them. You can use the depiction of the first five octaves at the start of this section on [The harmonic series](#) to check that you're selecting the right nodes, and refer to the *Soundgrape* notation to help maintain orientation. The 21st harmonic entails moving along both the three and seven axis, as $21 = 3 \times 7$. The most challenging harmonic 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

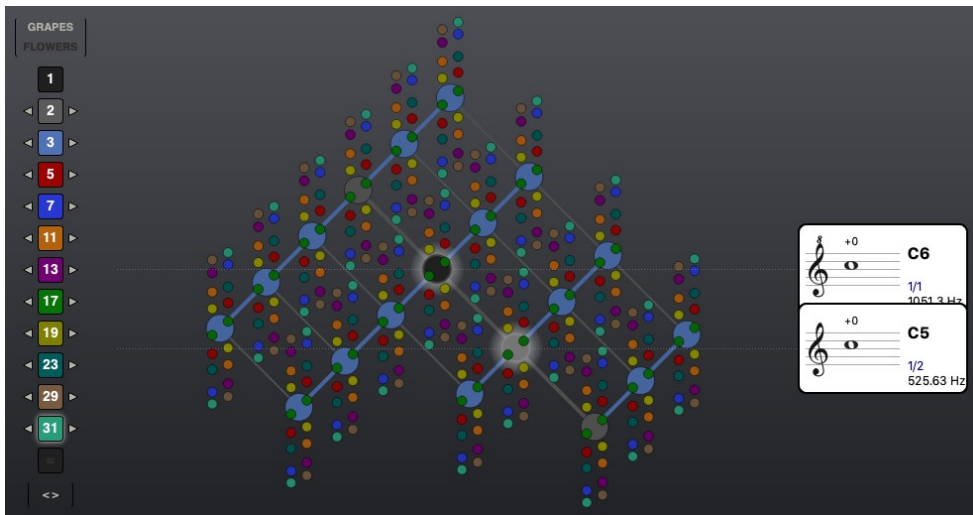
If the first note in a subharmonic series is defined as 'C6', the first five octaves may be written as:



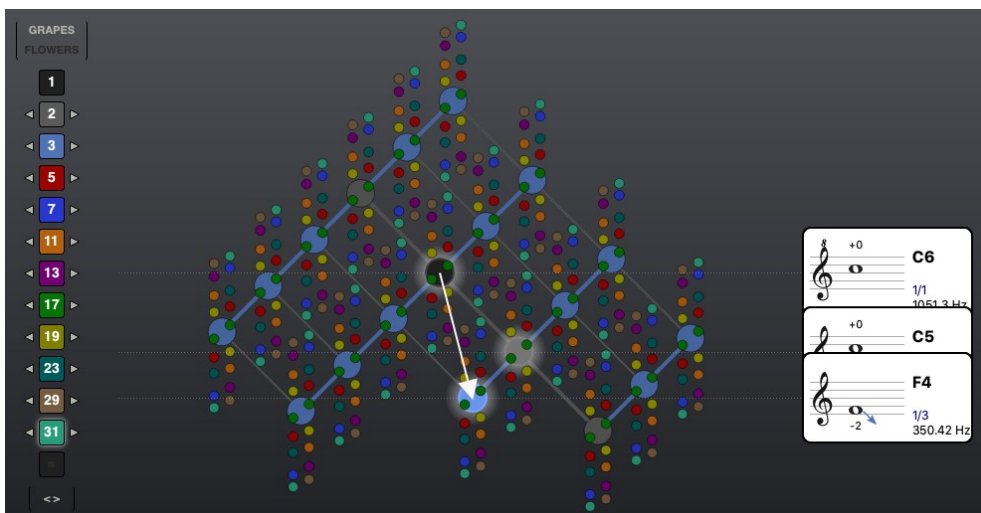
Before mapping of the subharmonic series onto the Hayward Tuning Vine press 'esc' to turn off any still sounding nodes and 'backspace' to reset the 'shift' function. Then set '1/1 Note' to 'C6' and click on the central black node to sound the first tone:



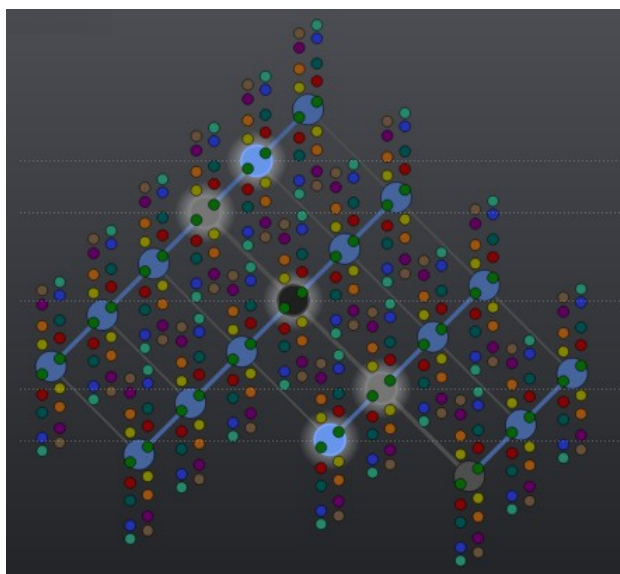
The second tone in the series is described by the ratio '1/2'. Just as '2/1' implies moving up one grey strut within the harmonic series, so '1/2' implies moving *down* one grey strut in the subharmonic series:



The third tone in the subharmonic series corresponds to the ratio '1/3'. In the harmonic series, '3/1' entails jumping from the bottom to top corner within the rectangle above the '1/1'. '1/3' in the subharmonic series therefore entails 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':

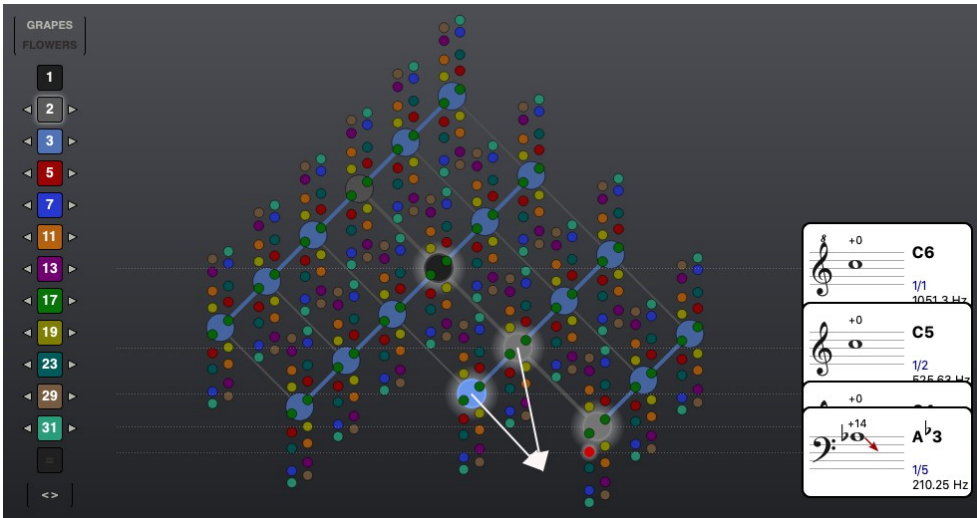


This symmetrical geometry is maintained throughout the subharmonic series because it is based on *dividing* a given frequency by whole numbers, whilst the harmonic series is based on *multiplying* a frequency by whole numbers. Whereas the octaves ascend the harmonic series they therefore descend the subharmonic series.

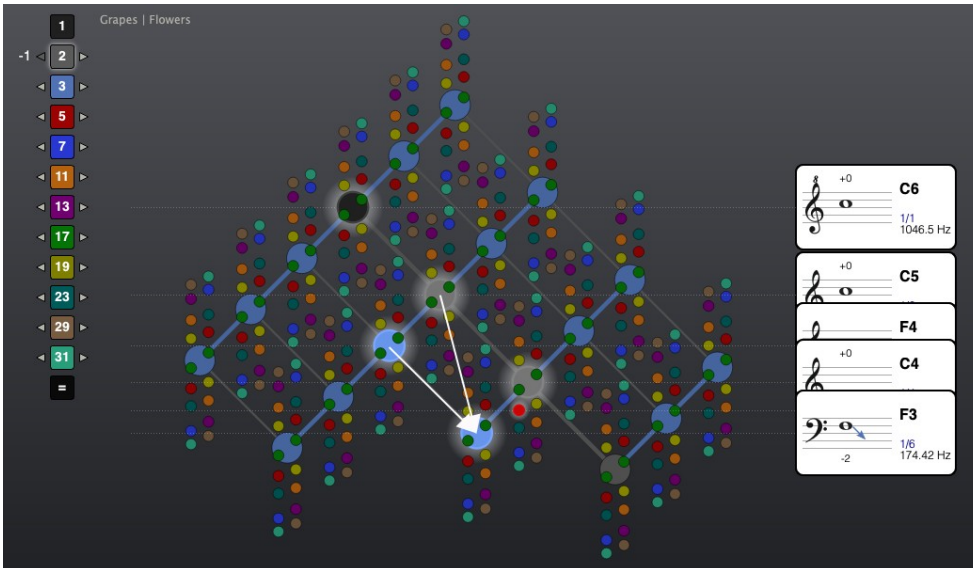
The fourth and fifth tones within the subharmonic series are mapped onto the tuning vine as follows:

The symmetrical geometry is also revealed in the cents values shown above and below the note heads in 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'.

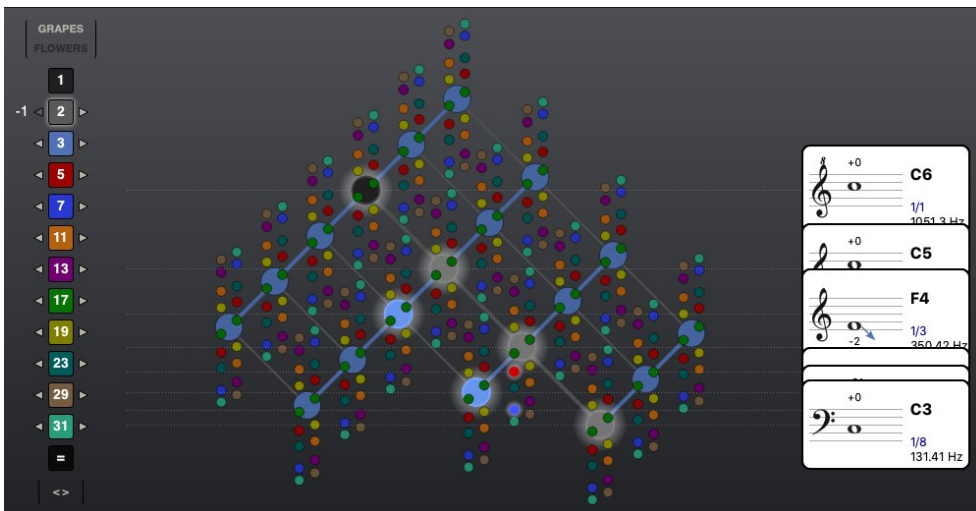
The sixth tone of the subharmonic series lies an octave and a fifth below the second tone, and an octave below the third tone:



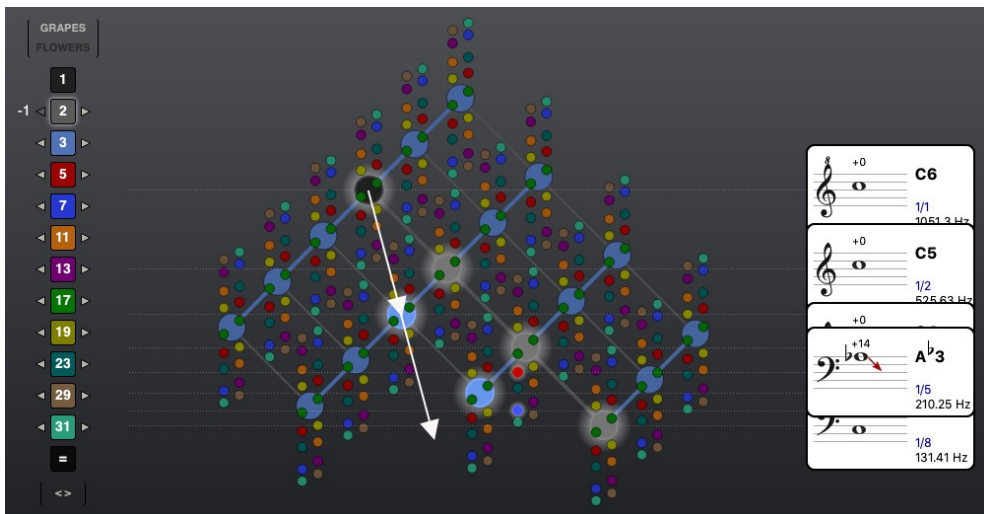
In order to bring it into view the tuning vine now needs to be shifted down and octave, by activating the shift arrow to the left of the grey number box:



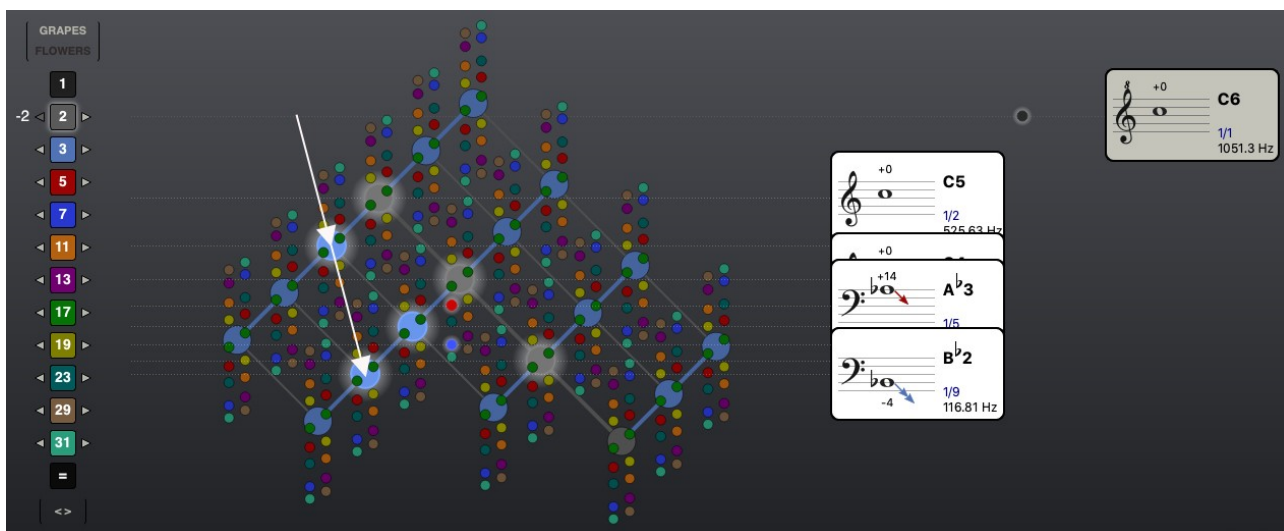
The octave shift has also brought the seventh and eighth tones into view:



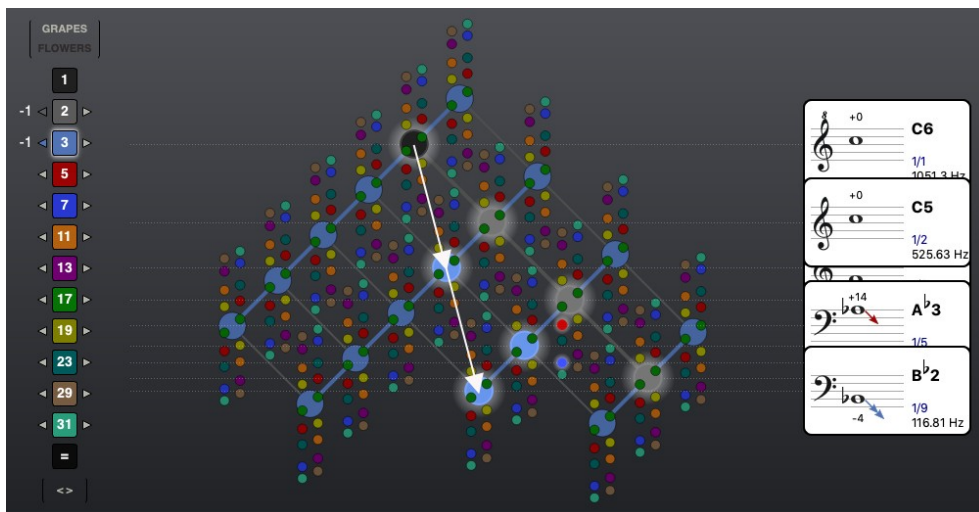
The ninth tone is described by the ratio '1/9'. Restated in its prime factors this is '1/(3 x 3)', which split into two ratios gives '1/3 x 1/3'. As '1/3' is mapped onto the tuning vine by jumping from the top to bottom corners within the rectangle below the (unshifted) '1/1', '1/9' therefore signifies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



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



...or along the light blue perfect fifth axis:



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 occupy the central position.

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 the process of learning which colour is associated with which prime number.

The central '1/1' node is black because it is the source of all the other intervals, and therefore the source of all the other colours.²⁸ The octaves, based on prime number two, are 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 is light blue as it opens up the rational two-dimensional lattice upon which the higher prime numbers are placed. The intervals based on prime number five are red because they include the major and minor thirds 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 contains 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. 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 slightly closer to a major than a minor sixth, the harmonic neutrality of '13/8' makes it very unfamiliar to ears used to the diatonic tonal system. 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 yellow 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 '29:24', corresponding to a tempered minor third plus 28 cents, can also be

²⁸ Colouring it white would have been impractical in earlier versions of the software as it is only with the introduction of the Soundgrape notations in v2.0 that the notehead no longer corresponds to the node colour.

perceived as a 'sweetened' version of the smaller minor thirds, for which an association with chocolate seems fitting.

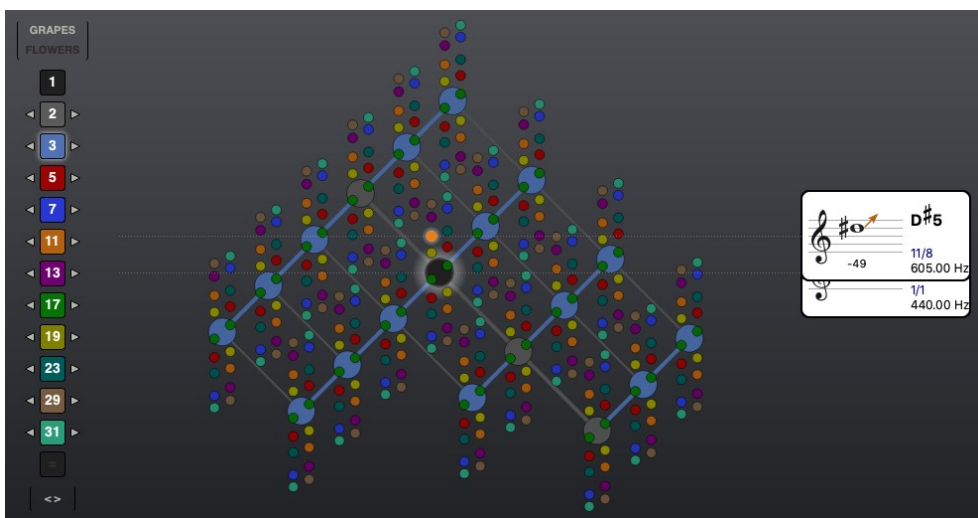


Representing a major seventh plus 45 cents, '31/16' has similarly biting character as the family of intervals opened up by 11. In contrast to 11, however, the major thirds based on 31 are sharpened rather than made neutral, suggesting a refreshing mint flavour. Mint also seems an appropriate choice to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

Enharmonic notation and double accidentals

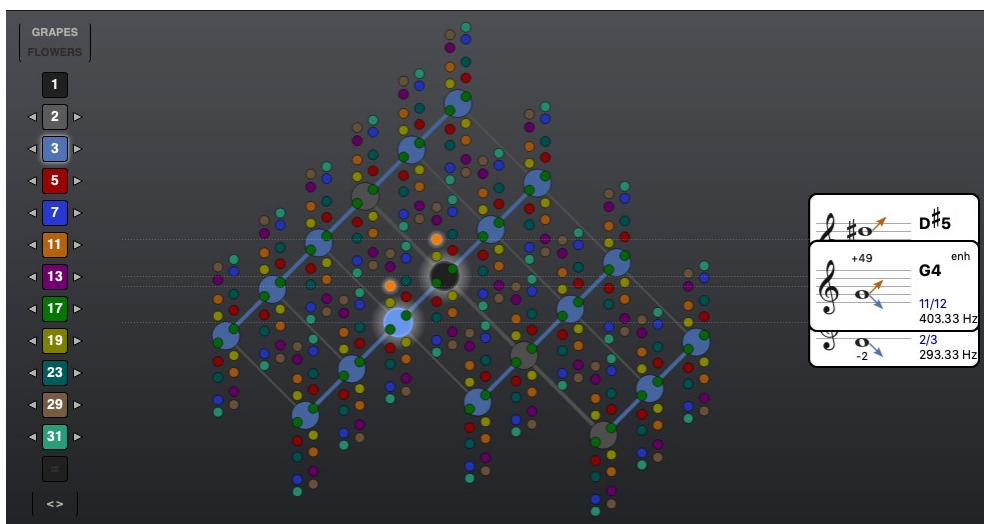
If you look closely at the spelling of the accidentals of the various microtones within the *Hayward Tuning Vine* - for example, whether a pitch is notated as a 'B \flat ' or an 'A \sharp ' - you'll notice that the same interval is sometimes spelled differently according to where it occurs within the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

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

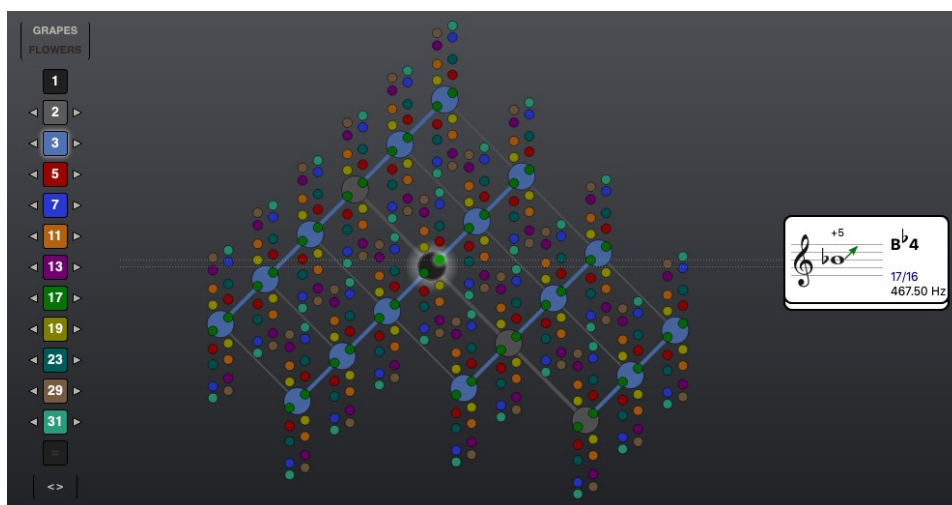


Although the interval between these two pitches remains '11:8', the noteheads are written as 'D' and 'G', which form a perfect rather than an augmented fourth. The reason for this different spelling is that as the 'D' now has a cents deviation of '-2', the orange node, if it were to be notated as a 'G#', 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 electronic tuners, indicating cents deviations within a range of '-50' to '+50' cents.²⁹ 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 renoted 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' 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 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.

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.

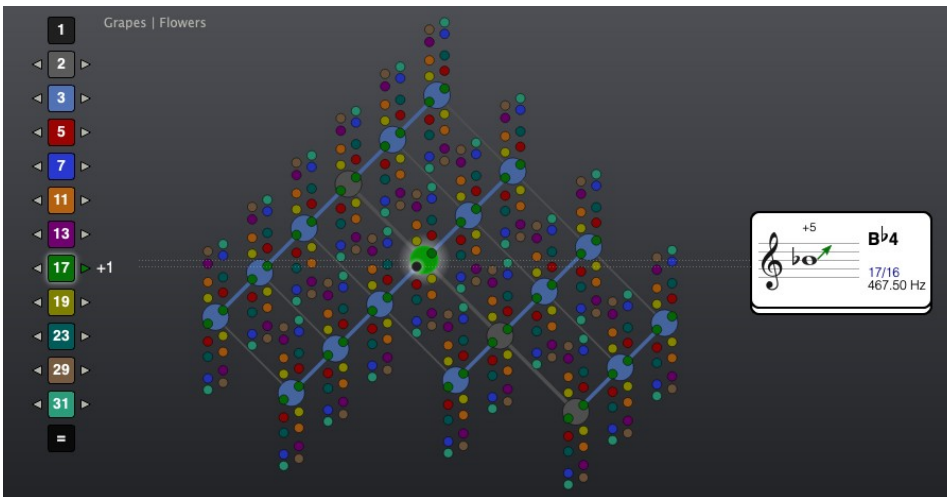
First press the 'esc' key on your computer to turn off the currently sounding tones, and 'a' to make sure you are in 'absolute' mode. Then click on the central black node, along with the green node positioned within its upper right border:



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.

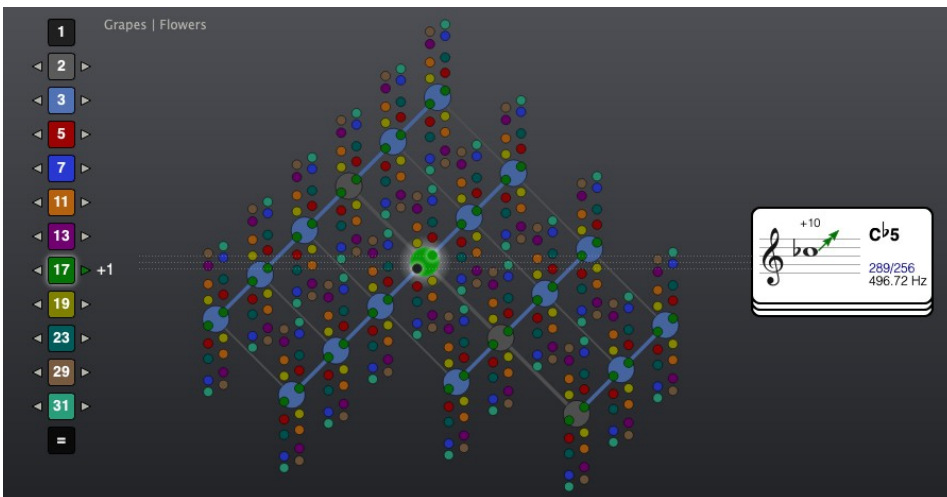
Next, activate the shift arrow to the right of the green number box containing '17'. The position of the sounding pitches has now been shifted to:

²⁹ The Hayward Tuning Vine also follows the convention that cents values of '-50' are automatically flipped to '+50'.



The 'A' still corresponds to the black node, and the central node turns green to indicate the '17/16' ratio corresponding to the 'B♭'.

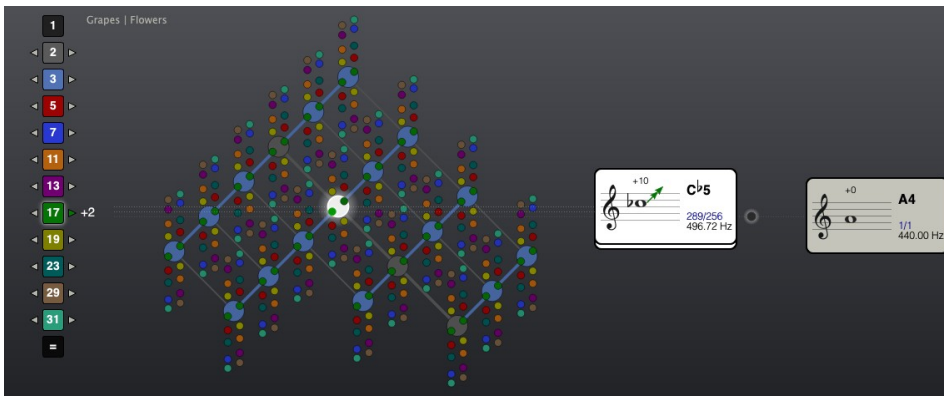
Now click on small the green node at the upper right of the central green node:



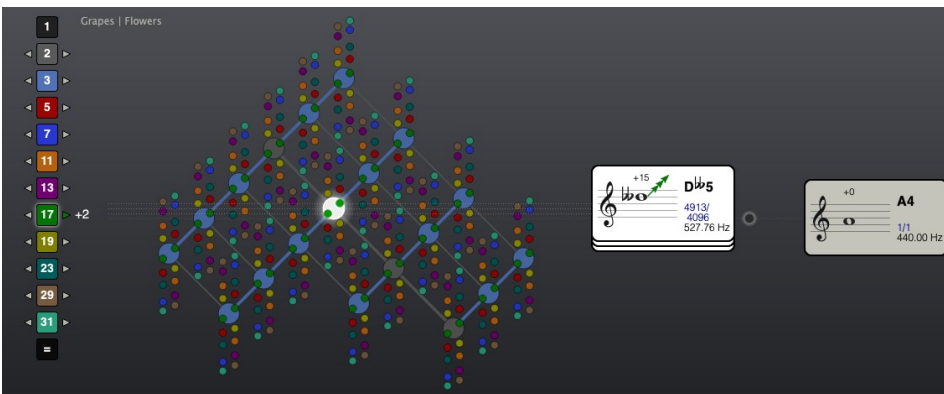
This pitch is notated as 'C♭' rather than as 'B', because it is a minor second higher than the 'B♭' now associated with the central green node. Notating the upper green node as 'B' would imply the relationship of an augmented unison with the 'B♭' of the central pale node, which would be harmonically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

Now again activate the shift arrow to the right of the green number box. The position of the sounding pitches is again shifted in the direction of the lower green node, so that the 'A' now appears in the second row of notation cards, and the lower green and central pale³⁰ nodes are now associated with 'B♭' and 'C♭':

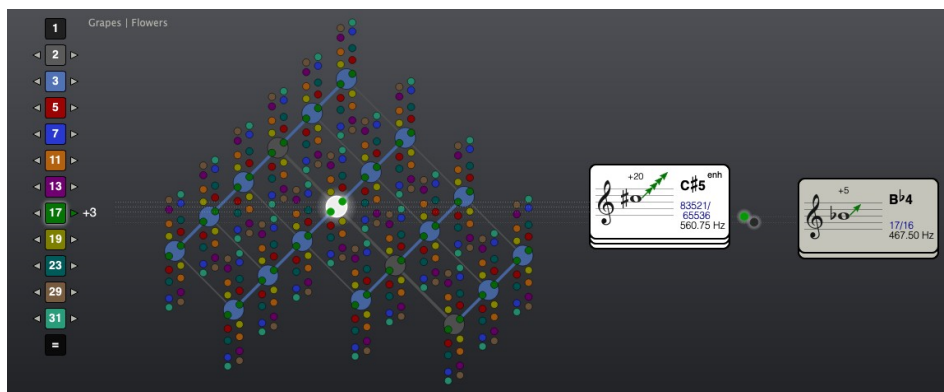
³⁰ The central node turns pale in 'Absolute' mode when more than one shift is activated for prime number five and above.



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



This pitch is notated as 'D $\flat\flat$ ' rather than as 'C', because it is a minor second higher than the 'C \flat ' now corresponding to the central pale node. Now again activate 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', and 'B \flat ' are moved outside the lattice to the second row of notation cards. 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 $\flat\flat\flat$ ', to indicate the harmonic relationship of a minor second above the 'D $\flat\flat$ ', currently associated with the central pale node. 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 renotates any pitch requiring more than two accidentals 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 \sharp '.

4. 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 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/>.³¹

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 folder³² for the subfolder called 'patches'. Duplicate one of the patches it contains and restart the software. The new patch should now appear together with the inbuilt ones.

There are additional patches located in the subfolder 'shell'. These are lower-level patches designed to handle the communication between the various numbers of 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 understand 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 the number of times according to the Maximum number of voices selected in 'Options'. 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 is how 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)

³¹ 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 for your project.

³² 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 parameters (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 inbuilt patches, all macros defined therein have generally been designed to work asynchronously unless nodes are specifically 'selected' within the lattice. This means that for unselected nodes 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.

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 (Versions 1.5 and 2.0)

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

Qt is licensed under open source licenses (GNU General Public License version 3 and GNU Lesser General Public License version 2.1)

[Pure Data license](#)

[PortAudio license](#)