

The Prophecy Software Synthesiser

Having used synthesisers extensively in my compositions, I was eager to learn how to build a software synthesiser of my own. I chose Reaktor 6, Native Instruments as the engine for building a synthesiser. I was drawn to Reaktor after viewing the demonstrations from Tileyard's Phelan Cane, describing the deep level of detail and how intuitive Reaktor is. Comparing Reaktor to Max MSP – another engine for building synthesisers - I felt that Max required more objects and modules to achieve similar levels of sound and detail to Reaktor. Not having previous experience of designing a synth, Reaktor appeared to be more genial when it comes to designing and then discussing synthesisers.

When working in Reaktor, there are three levels of building. Working within the base "Blocks" level allows the user to build an analogue synthesiser from ready-made accessories or devices that can be linked together via wires, like a physical synth. The middle level is named "Primary", the level I have chosen to build my synth and it works within the modular level of synth building whilst connecting those modules together. Finally, there is "Core" – a deep level of building where graphical programming at circuit level is used and digital signal processing is explored.

Reaktor names files as ensembles. This is a quaint term for how Reaktor sets itself up. In traditional terms an ensemble is made up of multiple instruments. The same goes for Reaktor. The 'ensemble' can contain any number of instruments. Inside an individual instrument are the modules and user macros used to build an instrument – modules and macros are the instruments building blocks.

My favourite software synthesiser is Sonic Academy's ANA 2.0. This is a versatile wavetable synthesiser whose sound source is produced from a combination of three wavetable oscillators and an additional three sample-based oscillators. It features forty-six filter types, three regular envelopes, three LFOs and twenty-four different effects, as well as a sixty-four step arpeggiator. This wavetable style synthesiser was my inspiration for building the Prophecy soft synth.

During this process I have learnt much regarding additive, subtractive and FM synthesis, whilst also learning of the different school methodologies of West Coast versus East Coast synthesis. It was this inspiration and research I decided to add subtractive synthesis using filters to the Prophecy.

Oscillators are a generator module that outputs periodic waveforms at specified frequencies. For my own interest, I included an oscilloscope representing the waveform, helping me learn a deeper understanding of synthesis, making for informed decisions musically. I decided to employ four oscillators to provide a vast range of sonic options.

"Another good way to add depth and richness to your synth patches is to use multiple oscillators slightly detuned against each other. If you were making a two-oscillator string sound, say, you might choose to detune one oscillator up 5 cents, and the other down 5 cents. For even thicker sounds - especially big trance-style synth chords - you could use more oscillators and a greater range of detuning."

Musicradar (2010)

Each oscillator was made using "Macro's" to be original, better organised and to not fill up the "panel" view too much. Within each oscillator, I wanted to include options in each for employing the

most widely used waveforms, so decided upon sine, triangle, pulse and sawtooth waves and created a switch to select these options. This is the order in which they appear in my instrument to be clear to the user of their ascending order of harmonics created.

“Common oscillator waveforms are:

Saw Wave – shaped like the teeth on a saw blade, this produces a very common sharp, biting tone.

Square Wave – looks like a (near) perfect square, produces a reedy, hollow sound.

Pulse Wave – a variation on the above, the pulse wave is half as wide as a square wave, and has the unique ability to have its width modulated (called ‘Pulse Width Modulation’).

Triangle Wave – unsurprisingly shaped like a triangle, this sounds somewhere in between a saw wave and a sine wave.

Sine Wave – a smooth rising and falling shape (like a horizontal ‘S’), this produces a mild, soft tone.

Noise – not exactly a waveform, but a source of sound produced by a certain colour of noise.”
(Hakim,2017)

In Reaktor, the default module for the pulse wave includes the ability to alter the pulse-width, so I included this with a pulse width knob. Increasing the sonic capabilities, I created the option of being able to turn each oscillator on and off, thus having the ability of running one, two, three or four oscillators at any one time. Being able to mix the individual oscillators volume to create unique waveforms was important. *“If you reduce the level of the detuned oscillator it becomes less dominant, acting more like a harmonic of your main sound and less like an obvious interval”* (Keyboard Magazine, 2020) This is not strictly “additive synthesis” - a technique where simple waveforms are combined at different frequencies, amplitudes and phases to create complex waveforms – as I have already started with combining complex waveforms. A way of employing “additive synthesis” could have been to create multiple sine wave modules and adding them together, but for my purposes in creating an instrument from scratch with no prior experience, I felt it cleaner to begin with subtractive synthesis using complex waveforms from the outset. *“The basic idea of subtractive synthesis is to start with a waveform that is being generated by an oscillator, then remove certain frequencies with a filter until you get the desired sound.”* (Rise, 2014).

Adding to my oscillators was a musical decision to provide more opportunities to make a unique sound palette. Including a “noise” generator to each sound is counterproductive as it is a random, non-periodic waveform that is not defined by a pitch. The noise itself sounds like white noise, but the reason for adding this to the oscillators was to create sound effects and a warmth. This becomes more apparent when shaped using filters.

“By filtering white noise you can produce all sorts of percussive and drum type sounds along with wind, rain, sea and thunder. Noise can also be mixed in with the outputs of oscillators and can be separately enveloped to add noise chiffs and effects to notes.”

(MusicElectronic, 2021)

As a pianist, I opted to make my instrument polyphonic, limited to 16 playable notes at any one time so the musician can accompany themselves. I then included a transposition facility to each oscillator,

making it possible to transpose each note down or up by four octaves. This is akin to how a pipe organ works and makes for a wide sound with many possibilities. This is a classic synth sound – *“produce yet another octave, so you could get 16', 8', and 4' “footages” in the same patch.”* (Keyboard Magazine, 2020). Added to this is a fine-tuning knob, capable of creating eerie beating effects through constructive and destructive interference of the waveform. This function allows the musician to fine tune anywhere from a semitone below, to a semitone above and the beating becomes more pronounced and faster the wider the interval. I have made these options available across all four oscillators.

Warmth is a word spoken of when discussing the difference between the digital and analogue domain. I am fond of analogue technology and the sound it imparts in fields such as electric guitar effects pedals and hardware synthesisers. *“When adding warmth to a track, the aim is to make it feel analog, real, and uniquely human”* (Native Instruments, 2018). To create warmth, I chose to add the randomiser module to each oscillator. Essentially, this takes the input note and randomly adds a different tuning to that note to create a unique effect on each note. Playing the same note multiple times will create a different note and tone every time. I believe this does add a certain human and analogue flavour.

“Subtractive synthesis” was the next decision I made to increase the Prophecy’s capabilities - a synthesis technique based on the alteration of specific frequencies with a filter. When positioning the filters, I opted for placing it after the oscillator mixer so I could filter my combined oscillators as one – this is the closest I came to recreating the characteristics and resonances of an acoustic instrument.

The first filter contains some of the most common filters. This is to not complicate matters when first playing my instrument. The options in this filter are high pass, band pass, low pass and notch (band reject) filters. The filters can be swept through the frequencies using a pitch cut-off knob (to control the cut off frequency) and a resonance knob (to control the resonance of the filter). The “noise” function really comes alive with this filter and can create a great number of effects such as mimicking an ocean (please refer to the above quote concerning noise). White noise also creates interesting harmonics in a note and when filtered provides a rich harmonic overtone to chords or individual notes.

The next filter was deliberately more detailed. Before building this, I wanted to be able to fade the volume between the two filters, giving the option of having one filter louder (or quieter) than the other filter – thus increasing the uniqueness. In this second filter, I opted for a more nuanced sound, making available a two-pole high pass, two-pole band pass and a two-pole low pass filters. In addition are a four-pole high pass, four-pole band pass and another band pass output for a three-pole high pass/one pole low pass filter producing asymmetrical wild tones. Provided is a switch to be able to bypass each or both filters.

Whilst I was building the Prophecy, I was becoming conscious that the sounds I was creating was too computerised. I researched building a formant filter giving the option of making sounds akin to the human singing voice. *“A formant filter is used to shape sounds into a spectrum that is similar to the human voice producing vowel sounds. As such, they can be used to create ‘talking’ synth lines.”* (ADSR) Formants are spectral peaks of the sound spectrum in the human voice. Three formant filters are needed to make vowel sounds. I used the Pro-52 Filter three times, a fourth order (24db/octave) resonant filter. It is easy to find on the internet the resonant frequencies of human vowel sounds (of the English language). For example, to make the ‘ee’ sound for feet (phonetic symbol ‘iy’), setting

the three resonant formant filters to 270hz, 2290hz and 3010hz will create the desired sound. This adds a singing quality to the Prophecy.

Incidentally, within Reaktor it is possible to map the controls of the Prophecy to the musicians own MIDI keyboard – something I found to be incredibly useful and fun.

Every synthesiser and virtual instrument that I have played allows the musician to control parameters for the attack, delay, sustain and release (ADSR) of a note. This was next on my list of controls to add. The reasoning for adding this ADSR envelope and placing it at the beginning of my signal chain, was to add expression, sophistication and a sense of reality to the notes – being able to control these parameters allows for a rich musical quality and can mimic the characteristics of acoustic instruments. Collectively, these series of parameters are commonly referred to as time-variant controllers. I included a display that would allow the musician to see the changes they made to be visually represented. *“An ADSR envelope determines how a sound unfolds over time.” (Seydel, 2016)*

Along similar lines but placed later (in amongst my first two filters in the signal chain) I created an envelope filter to facilitate creating an instrument suitable for funk music. I own an envelope filter guitar effect pedal and desired the same modulation here. For this filter, I decided upon the Ladder Filter module – this is a kind of low pass fourth order (24db/octave) resonant filter modelled on the classic circuit patented by Bob Moog and I used the Low Pass 4 pole option to create a wide filter effect, which is the steepest option available. I have again included a display to show how this filter is behaving when changing its parameters. The envelope filter is also controlled by the ADSR envelope. I have multiplied the range of the filter cut off within the envelope filter to be able to sweep through eight octaves above and below the fundamental. I believe this envelope filter does conjure up funky tones. *“Few other effects bring down the funk in such healthy portions”.* (Hochstrasser Electronics)

Guitar effects pedals have a similarity to a synthesiser's signal chain. This has inspired elements of my synthesiser, so I researched how to include them. The purpose of effects is to increase the capabilities of the instrument and making the sound more realistic or human. I decided to include options for tremolo, vibrato and an auto wah. These are all classed as modulation effects. Vibrato is modulation of pitch; tremolo is modulation of amplitude and auto wah is modulation of filter cut off. These are all designed using LFO's (Low Frequency Oscillators) modules and all contain similarities in their build.

Wanting vibrato to sound like a human voice, I included options to manipulate the wave form of the vibrato, specifically sine and triangle waves or a pulse wave (when using the pulse wave in the oscillators). Tremolo contains the options of tremolo rate and depth. When employing different parameters for these effects whilst using them together, they become out of phase with each other, creating interesting sounds that are constantly changing. I have housed the auto wah within the first filter, to make the wah effect able to sweep up and down through the filter's cut off frequency and have the ability for the wah to be used to sweep through the high pass, band pass, low pass or notch filter options of the first filter. These three modulation effects allow my instrument to be musically expressive.

Incidentally, a lot of mathematics was required to create the different ranges of these three modulation effects – an area in which I was not expecting to have to delve into.

After creating and researching the Low Frequency Modulators (LFO's) to manipulate the signal for the vibrato, tremolo and wah, I saw a way to create an expanded level of detail to my pulse width,

vibrato and wah facilities - my attempt at creating a multi-faceted instrument that has many possibilities in giving it an analogue feel. The pulse width is developed upon to give options for depth and rate, providing modulation to the pulse width. With the vibrato section, I felt my existing macro I built sounded arbitrary. Singers and instrumentalists do not use a constant vibrato from their note's outset. Instead, it comes in gradually and increases over the length of the note. After researching ways in which I could make my vibrato more human, I created an envelope within my vibrato macro to contain an attack function – thereby allowing the musician to manipulate how and when the vibrato begins to appear. Of all the options and as subtle as this is, I believe this one facility to be the most useful in successfully replicating human touch.

“In music, vibrato is the subtle oscillation between different pitches. The sound of vibrato, both in instruments and the human voice, can produce warmth and depth that sometimes exceed that of straight tone performance (where sustained notes do not wobble between pitches).”

(MasterClass, 2021)

The auto wah was modified to have the ability to tempo synchronise the effect to the tempo of a session. This was of noteworthy importance to me when building this instrument and when used within a DAW. There is a module named ‘Tempo Info’ that again required mathematics to achieve the subdivisions per beat of a crotchet, quaver, triplet quaver and semiquavers. This is useful in funk music when the musician requires a defined unit per beat for the wah effect – a quite common way of using this effect in that genre but also within synth wave or dubstep music.

Part of the feedback on my last assignment of Writing to Commercial Brief was including the use of FM synthesis in one of my tracks. I researched how to integrate FM synthesis into the Prophecy. However, I quickly realised that it was not the most appropriate facility given the rest of my wave table synth and it would be better to design a new instrument with FM synthesis at its heart. I wanted more modulation capabilities though so instead went with a ring modulator as this integrated better to my project. I decided to add this to each of the oscillators rather than as a plugin style insert effect at the end of the chain. I found this to be successful and sounded better used before the filter modulation than after (so that the ring modulator can be filtered too). Also, individual oscillators can be selected to employ the ring modulator instead of all at the same time. A ring modulator is a remarkably interesting effect and can create other-worldly sounds. My thinking here was to create an instrument whereby sound effects were possible – sci-fi and multi-dimensional sounds are effective here. *“You’ve probably heard the distinct sounds of a ring modulator before. They tend to sound metallic or robotic, and sci-fi shows love to use them (“Exterminate!”).” (Rise, 2015).* A ring modulator multiplies two signals together to create two brand-new frequencies which are the sum and difference of the input frequencies.

Delay is an essential synthesiser effect. It can create a reverb effect, slap back effect and long cavernous delays amongst many others. I decided to include a delay instead of reverb as an insert effect to kill two birds with one stone. Having delay transformed my instrument to such an extent that I researched topics on how to build a tape delay into the module. Tape delay adds an analogue feel to the overall tone and extends the human quality of my instrument.

Taking inspiration from my guitar effects pedal, I wanted the ability to blend the wet and dry signal. Mathematics play a role here and provides the feedback response of the delay. This analogue feel is added to by running an LFO to the feedback or delayed notes. Having the filter bright sounds akin to a digital delay and lowering the filter – resulting in the delayed notes sounding muffled – enhances the analogue sound. I find it makes for a pleasing sound that is easier to blend with other

instruments. Tape delay units often contain a wobble on the delayed notes, resulting in a pitch drift effect. I have included controls to determine the rate and depth of the tape delay effect. This is much like the modulation on my MXR delay pedal. Eerie sounds are aplenty and the modulation adds a sense of movement.

“Not only does tape delay give you a cool, lo-fi, vintage delay sound, but it also warms up your mix with some saturation. It can add a chorus-like effect or some slapback delay, depending on your settings. Overall, it can add harmonics and complexity to your audio.”

(Murphy, 2021)

The final effect I wanted to incorporate was a classic for a guitarist building their first synth, distortion. Distortion is a versatile effect that if used in a subtle manner, adds warmth and character but can mean all out destruction. I wanted the distortion to add to the analogue flavour, providing the ability to add subtle saturation and colour. For this reason, I have placed the distortion module at the very end of the effects chain as an insert effect (much like a plugin on a mix bus on a DAW) and after the delay.

After researching distortion, I decided to use wavefolding as my distortion. After an email exchange with Johan Englund, I now realise that going with wavefolding, rather than a traditional saturation or overdrive, is overcomplicating my instrument and musicians would be more comfortable with an overdrive module. It is also a staple of ‘west-coast synthesis’, something I was unaware of when creating my distortion module – I had created the rest of my instrument to be free from a particular school. However, after much debate and creating traditional distortion units, I preferred the spectrum of sound and versatility of the wavefolding, so committed to this.

“Wavefolding is a great way of taking a basic tone like a sine wave and adding enough harmonics to create a totally new sound, the result is also a more complex yet easily controllable waveform.”

(Glitch, 2018)

Wavefolding is a distortion of a waveform where when the input amplitude exceeds a certain threshold, it becomes inverted. Traditional distortion involves hard clipping of an input signal where the signal goes beyond what can be represented on my scope. Wavefolding on the other hand takes that signal and folds it back over in on itself introducing expressive harmonics. This creates a more sophisticated saturation than all out clipping.

I used the Mirror 2 module – the official description here: signal Modifier, ‘reflecting’ the input signal at two controllable levels. Looking at the scope when increasing the gain, one can see the waveform folding back on itself instead of clipping the signal. The offset knob allows for different and interesting waveform shapes to be created, making the fold in the waveform either lower or higher. The max and min controls shape where the clipping of the signal can happen and allows the folding process to occur many times. Placing multiple Mirror 2 modules within the macro (in series) allows for the process of folding the waveform to sound even more pronounced. A make up gain knob has been added – when folding the waveform, the signal becomes quieter and thinner. Employing the different waveforms of the oscillators is interesting. The sine and triangle waves make the wavefolding explode with harmonics. The potential for sci-fi sound effects here is obvious. The pulse and saw waves do not sound as affected but generate the kind of analogue warmth that I desired when wanting a distortion insert. It does however make each waveform expand from simple to harmonically complex.

Finally, I have included a master volume, so the instrument is fully interactive and capable of playing with others.

Reflecting upon the Prophecy, I am happy with how it has turned out. As I have mentioned, this is my first attempt at building a software instrument and though it took me a great deal of time to get to grips with Reaktor, the mathematics and the actual design stage, I enjoyed the process. I believe the instrument is versatile, sounds good and is useable and easy to navigate. FM synthesis would be a brilliant asset – I admit this would test my limited skills to include it. A reverb section would also add depth and versatility – again, this has been a steep learning curve and I would not be happy in including a ready-made reverb module into an assignment instrument where thorough research is needed. I think the delay is versatile enough to create a reverb effect though and with the tape delay effect to add, the analogue feel pleases me. A more versatile distortion section would make the Prophecy yield more tones and I believe would be a more user-friendly synth, as Johan Englund pointed out. This could include a more traditional saturation or overdrive. However, the experience of designing wavefolding was remarkably interesting and challenging.

I invited the synth player, Steven Stapleton, of my rock band to test the Prophecy. Steven is used to high-end Nord, Prophet and Moog synthesisers and uses Arturia software synths, so I was nervous of his reaction. He knew this was my first attempt at a software synth and with this in mind, he gave the following feedback:

“I enjoyed playing the Prophecy software synthesiser. The range of sounds I could get from it are impressive. I have tried running it simultaneously with some of my hardware synths and it performs well. I like the wide range of filtering and the delay is a good effect. I found the overall sound good and I appreciate the effort that has been taken to make the tone more analogue. I think that some arpeggiators and other note effects would transform this instrument into something more useful for composition. The distortion was a little hard to get my head around at first, but after playing with the controls for a short while, I was able to get used to this. Perhaps the vibrato sounds a little computerised too. But overall, I think you have done a great job, especially from having no previous experience.”

I will take this feedback on board. Comparing the Prophecy to my favourite soft synth, ANA 2.0, is interesting. In certain respects, I can create sounds that are close and it has similarities with the filters and number of oscillators. However, the ANA is clearly far superior. I enjoy how the ANA allows for three extra oscillators that are user sample based. The filter section has forty-six options available – clearly far more than mine. Mentioned previously, the ANA has a 64 step arpeggiator and over 500 presets. This is a professional grade instrument, so a true comparison is unfair. Overall, I am pleased with the Prophecy – the journey it has taken me on and the depth of understanding I now possess is immeasurable.

Bibliography

- Musicradar (2010) *8 essential synthesis tips for beginners*. Available at: <https://www.musicradar.com/tuition/tech/8-essential-synthesis-tips-for-beginners-245904> (Accessed: 08 June 2021)
- Hakim, D (2008) ‘Basic Synthesis:Part 1 Oscillators’ *Innovative Synthesis* [blog]. 13 May. Available at: <https://www.innovativesynthesis.com/basic-synthesis-part-1-%E2%80%93-oscillators/> (Accessed: 08 June 2021)

- Music Radar/Keyboard Magazine (2021) *3 top tips for tuning synthesizer oscillators*. 01 April. Available at: <https://www.musicradar.com/how-to/3-top-tips-for-tuning-synthesizer-oscillators> (Accessed: 11 June 2021)
- Rise, S (2014) *Subtractive Synthesis*. Available at: <http://synthesizeracademy.com/subtractive-synthesis/> (Accessed: 10 June 2021)
- MusicElectronic (2021) *Noise Generator*. Available at: <http://www.musicelectronic.co.uk/noise-generator/> (Accessed: 10 June 2021)
- Native Instruments (2018) *How to add warmth to your software synths*. 14 December. Available at: <https://blog.native-instruments.com/how-to-add-warmth-to-your-software-synths/> (Accessed: 15 June 2021)
- ADSR Reaktor Tutorials *Advanced Formant Filter in Reaktor*. Available at: <https://www.adsrsounds.com/reaktor-tutorials/advanced-formant-filter-in-reaktor/#:~:text=A%20formant%20filter%20is%20used%20to%20shape%20sounds,such%20a%20sound%20is%20to%20use%20bit%20crushers%29>. (Accessed: 15 June 2021)
- Seydel R, (2016) 'ADSR Envelopes: How to Build The Perfect Sound'. *Landr* [blog] 1 November. Available at: <https://blog.landr.com/adsr-envelopes-infographic/> (Accessed: 16 June 2021)
- Hochstrasser Electronics *An Introduction to Envelope Filters: Controlling the Funk*. Available at: <https://www.hochstrasserelectronics.com/news/introductiontoenvelopefilters> (Accessed: 16 June 2021)
- MasterClass, (2021) *Guide to Vibrato Technique: 7 Types of Vibrato*. 24 June. Available at: <https://www.masterclass.com/articles/vibrato-voice#what-is-vibrato> (Accessed: 18 June 2021)
- Rise, S (2015) *Ring Modulator*. Available at: <http://synthesizeracademy.com/ring-modulator/> (Accessed: 18 June 2021)
- Murphy, C.J. (2021) *Tape Delay: The Secret Weapon for Retro Mix Flair*. Available at: <https://www.musicianonamission.com/tape-delay/> (Accessed: 18 June 2021)
- Glitch, D (2018) *What is Wavefolding? And how to create a similar effect in Serum*. 21 December. Available at: <https://idmmag.com/tech/tutorials/wavefolding-create-similar-effect-serum/> (Accessed: 19 June 2021)