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GNU Psychosynth

A framework for modular, interactive and
collaborative sound synthesis and live music
performance

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DEPARTAMENTO DE CIENCIAS DE LA COMPUTACIÓN E
INTELIGENCIA ARTIFICIAL

—

Granada, Junio de 2011



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GNU Psychosynth: A framework for modular, interactive and collaborative sound synthesis and live music performance

Juan Pedro Bolívar Puente

Palabras clave:

Resumen

GNU Psychosynth: A framework for modular, interactive and collaborative sound synthesis and live music performance

Juan Pedro Bolívar Puente

Keywords:

Abstract

Yo, **Juan Pedro Bolívar Puente**, alumno de la titulación Ingeniería en Informática de la **Escuela Técnica Superior de Ingenierías Informática y de Telecomunicación de la Universidad de Granada**, con DNI 48941569F, autorizo la ubicación de la siguiente copia de mi Proyecto Fin de Carrera en la biblioteca del centro para que pueda ser consultada por las personas que lo deseen.

Fdo: Juan Pedro Bolívar Puente

Granada a 1 de Junio de 2011.

D. **Joaquín Fernández-Valdivia**, Catedrático del Departamento de Ciencias de la Computación e Inteligencia Artificial de la Universidad de Granada.

Informan:

Que el presente proyecto, titulado *GNU Psychosynth: A framework for modular, interactive and collaborative sound synthesis and live music performance* , ha sido realizado bajo su supervisión por **Juan Pedro Bolívar Puente**, y autorizamos la defensa de dicho proyecto ante el tribunal que corresponda.

Y para que conste, expiden y firman el presente informe en Granada a 1 de Junio de 2010.

El director:

D. Joaquín Fernández-Valdivia

AGRADECIMIENTOS

Sinceramente gracias.

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PREFACE — A PERSONAL, HISTORICAL AND AUDIOPHILE DISSERTATION

I am going to let the formalities, both in form and content, of a final project aside in this section to give an initial background on the historical development of the conception of GNU Psychosynth. After all, the story of this project is, in many ways, the story of my own learning and maturing process and specially the evolution of my interest in music.

In 2006 I was a young computer science student who had just moved to Granada, a city full of youth, joy and cultural activities. At that time, I was not keen at all in electronic music —maybe biased by my prejudices on the rave subculture that surrounds a wide part of it, even though eventually I happened to appreciate it in some way. At that time I was more of a punk and ska fan and rejected the artificiality and production process of electronic music; this was actually a contradiction with my interest in programming. However, I eventually got specially interested in the wild 70's explosion of musical experimentation, and concretely in progressive rock.

I can vividly remember my first positive contact with electronic music. It was a chilled and psychedelic evening at a friend's place —one of those old and rundown but magical flat, with rather high ceilings and wooden windows, where many students live in Granada— when we Youtubed a video where Keith Emerson virtuously performed “Knife Edge” on a keyboard attached to a big wooden box full of

wires and knobs. By rearranging the wires or playing with the knobs, he would radically change the sound that his keyboard emitted. That magical sound machine was a Moog modular synthesiser, and that was the birth of a true love for electronic music that would later conceive Psychosynth —is not love, they say, the true means for conception?

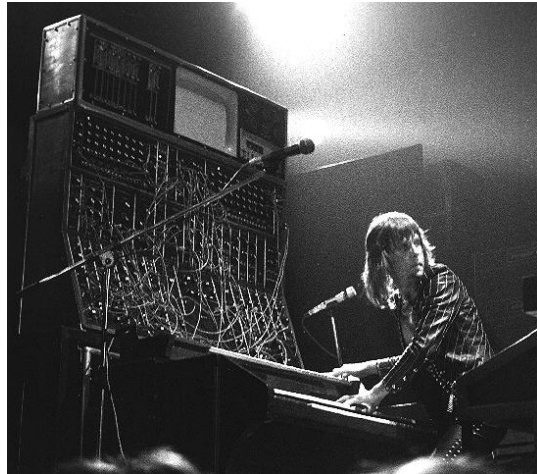


Figure 0.1.: Keith Emerson playing a modular Moog. The keyboard is connected to a big rack of modules, interconnected with each other with wires. Each module generates or processes the sound carried in analog form in the interconnecting wires, therefore having an exponential number of possibly different sounds by combining modules and settings.

After that, I started to listen to more and more music made with electronic devices — an exploration that happened, actually, following electronic music's own history. From the synthesiser-full rock of Soft Machine, King Crimson or The

Nice I opened my ears to the purely synthetic orchestral compositions of Wendy Carlos, Vangelis or the early Jean Michelle Jarre. Kraftwerk's own evolution from rock to drum-pads, vocoders and synthesisers allowed me to open my ears to more modern electronic music.

It was still my first year of university when I watched a video, under circumstances probably similar to that before, of a new device being developed in the University Pompeu Fabra, in Barcelona: the ReacTable [1]. In a dark room only illuminated by a bright blue table, several performers placed tagged objects on the table. The table automatically arranged a connection graph among the objects based on their nature and relative distance and it displayed it but, more interestingly, the sound was evolving as this graph did. I just thought: wow, that must be fun, I want to play with that! — well, Do It Yourself.

That was the birth of Psychosynth. At the beginning it was just a toy. I did know nothing on how to process real-time audio, so I wrote many experiments. When I was bored of testing the dynamic range of my speakers and ears with all sorts of sinusoids, triangle and square signals I started to read more and more source code of other audio Free Software and eventually started to write a digital modular synthesizer and play with Ogre3D.¹ By the summer of 2007 I had some very primitive synthesis code and also some user interface experiments². While I was an average C developer when I started my studies, I did not have any clue on C++. During the development of these initial experiments, I also

¹ Torus Knot Software Ltd. <http://www.ogre3d.com>

² As this video can show, <http://blip.tv/file/325103>, the software was just a bunch of buttons with a 3D blue table like Reactable's and no sound.

had to learn about inheritance, what virtual means, etc. but of course the design was flawed all the time and I had to rewrite the code many times.

Something happened then at the beginning of my second year of university: I applied as a contestant to the Spanish Free Software Contest for University Students, and Psychosynth was the project I would develop. At that time I was already interested in experimental electronic music from the 90's, and late programming nights were accompanied by Autechre's fractal glitches and Aphex Twin and Squarepusher's spastic patterns³. At that time, this cruise in the most experimental side of electronic music and my ignorance in proper music making made me believe in scoreless generative music produced from evolving continuous signals, and that influenced the lack of proper synchronisation mechanisms in Psychosynth. At some point, Shaker08⁴, a music producer and DJ from Malaga, developed some beat loops to distribute along with the software and helped in early showcase performances. He also tough me a lot on how music is traditionally made.

The project won a price in that Free Software contest and he got some reviews in blogs. it then became part of the GNU project — an attempt to assure its long-term development and that it would remain Free Software in the future.

³ If there is something I am grateful for during the early development of Psychosynth is the patience of my flatmates during those noisy programming nights. Psychosynth was long-time nicknamed "the ambulance siren sound maker" because it was only able to produce recursively modulated sinusoids.

⁴ <http://soundcloud.com/shaker08>

After that, however, the development stalled a bit. I had big refactoring ideas that never got the motivation to be accomplished. In that seek for perfect code motivated by an increasing interest in programming language theory and functional and generic programming, I also became more and more conscious of the flaws of the code —i.e. the lack of synchronisation mechanisms, MIDI (Music Instrument Digital Interface) support, pluggable modules, patch persistence, etc. make any serious non-experimental attempt to make music with it very hard. During these last 2 years I have learnt much more on the music production workflow and terminology, a process parallel to a final step in opening my ears to current electronic music, specially Drum and Bass, Dubstep, and even some Minimal and Techno. During last summer I got a MIDI DJ controller that got me to better understand the limitations and possibilities of Psychosynth for music mixing and I became a casual contributor of the best Free Software DJ software: Mixxx [3]. Also, the people at ArtQuimia⁵, the music production school where Shaker08 was educated, became interested in the project and has offered lending gear for testing and supervision, guidelines and insight from a musician point of view.

So here we are now, in the fall of 2010. Still quite ignorant in music making but pretending to be a “digital luthier” motivated by passion for music. And trying to turn all this personal game into a final master thesis project. Lets see how it goes...

⁵ <http://www.artquimia.net/>

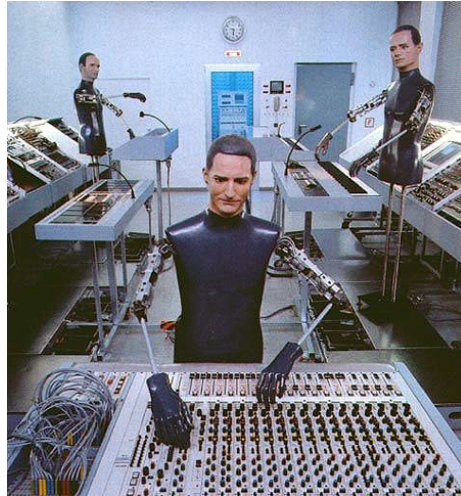


Figure 0.2.: Artwork for the music of Kraftwerk, with robotic representations of the band members playing with electronic instruments. On the front we can see an old analog sequencer. As opposed to a synthesizer —this is, a virtual instrument, which is in charge of producing sound of whatever note you tell it to— a *sequencer* is an electronic score that can not produce sound by itself. The notes are programmed in the device—in an analog sequencer, by toggling switches and knobs— and it sends them at the appropriate time and duration to the electronic instruments (synthesizers) it is connected to. While current digital sequencers are very powerful, at that time they had important limitations that influenced Kraftwerk's robotic but charm sound. Kraftwerk was one of the first pop bands to produce its music entirely with electronic devices and is considered the father of modern electro and techno and has heavily influenced many other styles like house and hip-hop.

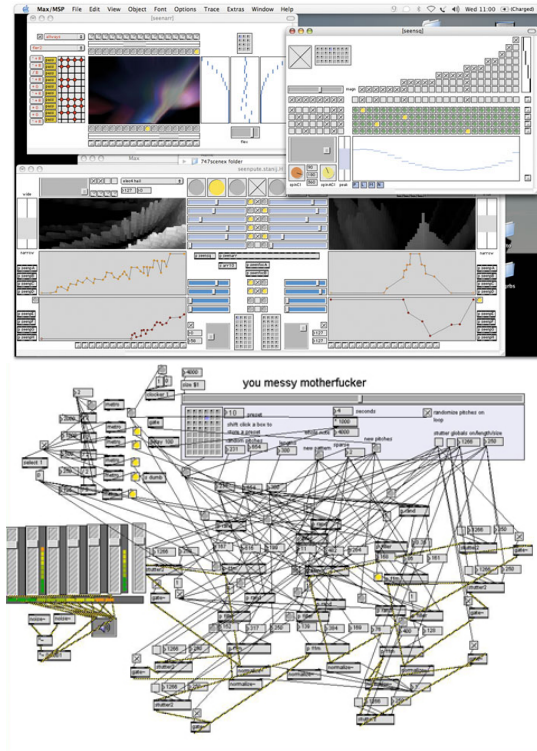


Figure 0.3.: The first picture is a Max/MSP claimed to be made by the electronic music duo Autechre[2]. The second is a Max/MSP patch made by Robbie Martin that *generatively* reverse-engineers Autechre’s song Powmod. Music is said to be *generative* when the whole composition itself is performed by pseudo-random algorithms programmed to produce well-sounding evolving non-repeating patterns. Autechre are known to have explored generative music. Max/MSP and its Free Software counterpart Pure Data are graphical data-flow programming software, which can be considered a low-level modular synthesizer, that is often used to write arbitrarily complex musical software and is specially interesting for generative music.

1

INTRODUCTION, DEFINITION AND GOALS

La utopía está en el horizonte. Camino dos pasos, ella se aleja dos pasos y el horizonte se corre diez pasos más allá. ¿Entonces para que sirve la utopía? Para eso, sirve para caminar.

Eduardo Galeano

1.1 PROBLEM DEFINITION

Our problem definition is well expressed in the title of this project: “a framework for modular, interactive and collaborative sound synthesis and live music performance”. Lets elaborate this by describing its parts.

1.1.1.1 *A modular synthesiser*

A modular synthesiser is one where the sound generation and manipulation process is described as a directional graph where each link represents the flow of sound signal from one node to another, and each node transforms or generates those signals.

A node with no input is often called a *generator*. A node with one input and one output is often called a *filter*. A node can have different *parameters* that in analog hardware can be set with knobs and potentiometers. Often, these parameter can be controlled with other optional input signals that are called *modulators*. A concrete interconnection of a set of modules is commonly referred as a *patch*. Note 1.1 lists some of the most common modules in analog modular synthesisers.

Note 1.1 (Standard modules in an analog modular synthesizer)

Software modular synthesizers have usually similar ones in their default module too, while they quite often use different terminology not related to this voltage based signal like in this case.

[The following text is extracted from the Wikipedia article on "Modular Synthesizer," as checked on December 12th 2010.]

VCO *Voltage Controlled Oscillator, which will output a pitched sound (frequency) in a simple waveform (most usually a square wave or a sawtooth wave, but also includes pulse, triangle and sine waves).*

NOISE SOURCE *A generator that supplies "hiss" sound similar to static, which can be used for explosions, cymbals,*

or randomly generated control signals. Common types of noise offered by modular synthesizers include white, pink, and low frequency noise.

VCF *Voltage Controlled Filter, which attenuates frequencies below (high-pass), above (low-pass) or both below and above (band-pass) a certain frequency. VCFs can also be configured to provide band-exclusion, whereby the high and low frequencies remain while the middle frequencies are removed.*

VCA *Voltage Controlled Amplifier, which varies the amplitude of a signal in response to a supplied control voltage.*

EG *Triggering an Envelope Generator produces a single, repeatable shaped voltage pulse. Often configured as ADSR (Attack, Decay, Sustain, Release) it provides the means to shape a recognizable sound from a raw waveform. This technique can be used to synthesize the natural decay of a piano, or the sharp attack of a trumpet. It can be triggered by a keyboard or by another module in the system. Usually it drives the output of a VCA or VCF, but the patchable structure of the synthesizer makes it possible to use the envelope generator to modulate other parameters such as the pitch or pulse width of the VCO. Simpler EGs (AD or AR) or more complex (DADSR—Delay, Attack, Decay, Sustain, Release) are sometimes available.*

LFO *A Low Frequency Oscillator is similar to a VCO but it usually operates below 20 Hz. It is generally used as a control voltage for another module. For example, modulating a VCO will create vibrato while modulating a VCA will create tremolo.*

RM *Ring modulator, two audio inputs are utilized to create sum and difference frequencies while suppressing the original signals. This gives the sound a “robotic” quality.*

MIXER *A module that combines multiple signals into one.*

S&H *Sample and hold, which takes a “sample” of the input voltage when a trigger pulse is received and “holds” it until a subsequent trigger pulse is applied. The source is often taken from a noise generator. Sequencer, which produces a sequence of notes, usually a music loop.*

SLEW LIMITER *Smooths off the peaks of voltages. This can be used to create glide or portamento between notes. Can also work as a primitive low-pass filter.*

CUSTOM CONTROL INPUTS *Because modular synthesizers have voltage-driven inputs, it is possible to connect almost any kind of control. Pitch can be varied by room temperature if you wish, or amplification varied by light level falling on a sensor.*

Analog modular synthesizers were invented in parallel 1968 by R. A. Moog Co. and Buchla in 1963 [4]. There, sound signal is more often represented by oscillating voltage levels running through wires—the links—and manipulated by analog signal processor modules. Usually these modules were arranged in big racks.

One of the biggest problems of modular synthesizers is their limited ability to cope with *polyphony*. We say that a synthesizer is polyphonic when several different notes can be played at the same time. The basic implementation tech-

nique for this is to have several copies of the synthesis logic—each is called a *voice*—and dispatch each keystroke to an unallocated voice (if present, otherwise, some note priority logic is to be implemented). In old analog modular synthesisers this was achieved by having multiple root oscillators, maybe 2 or 4, but this multiplied the complexity of connecting the synthesis graph. That is one of the main reasons why modular synthesis was gradually abandoned for analog devices, as a naturally sounding keyboard-controlled instrument should have a much higher grade of polyphony and should remain usable—note that the required polyphony level is higher than the maximum number of keys that we want to be able to press simultaneously, because a note remains playing after the key is released during a *decay time* while the sound softly fades out.

Nowadays, the increasing power of computers allows us to build modular synthesisers by software. Even further, we are no longer limited by wires and we can use arbitrary data types as processing and instantiate copies of the modules as we wish only constrained by our memory and computation power. On software, it is easier to achieve polyphony but it is still a non-trivial problem to make it efficiently.

1.1.2 *An interactive synthesiser*

Even though Keith Emerson virtuously manipulated the wires and knobs of his Moog in the middle of his performances, old-school modular synthesisers have the inconvenience that they are rather static. It is very hard to control all the parameters during the performance. Changing the topology of the synthesis network is almost impossible, and in

most systems it causes clicks and other inconvenient noises as a result of abruptly connecting and disconnecting the wires —whether software or analog.

We should design our engine with care so no noise is generated as a result of manipulating the system live. But we should also provide other means to enable easier manipulation of the topology.

1.1.2.1 *Dynamic patching*

The *dynamic patching* [5] technique was first introduced in the ReacTable project and offers means to automatically interconnect the modules of a software modular synthesiser. When present, modules are laid out in a bi-dimensional space and each output automatically connects to the nearest available input of its same kind. The sink node that leads the output to the speakers is situated in the centre and the synthesis graph grows as a radial tree around it, as shown in figure 1.1. By simply moving one module from one position to another the user can radically change the topology of the network without doing a lot of plugging and unplugging of wires. A clever disposition of the modules on the space can help the artist to achieve new innovative ways of producing variations in his music.

1.1.2.2 *Touchable interfaces*

An specific problem for music software is that its interface is highly limited by the keyboard and mouse as interface. While a person has 20 fingers¹ she is limited to manipulate only one parameter at a time with the mouse.

¹ She must be very skilled to use all of them at the same time!

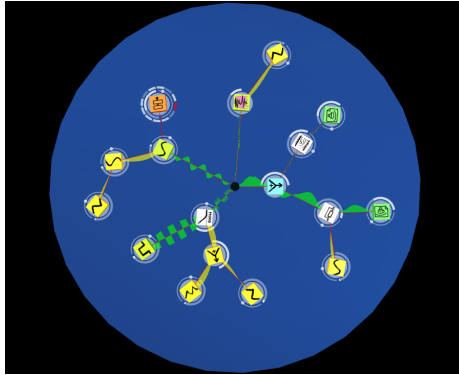


Figure 1.1.: A screenshot of Psychosynth 0.1.1 using dynamic patching to connect a complex graph.

There is an increasing availability of touchable interfaces, either specifically designed for music performance like the Lemur (figure 1.2) or general purpose ones like the iPad. There, one is no longer constrained by the single-click paradigm and not only can she manipulate various parameters at a time, different multi-tap gestures can expand the possibilities of a spatially limited user interface as several functions can be reached in the same points.

1.1.2.3 *Instrument simulating controllers*

While touchable interfaces might be better for manipulating the continuous parameters of the synthesis and dynamically manipulate a sequencer, many musicians would prefer more traditional interfaces to interpret part of their work in the “old-fashioned” way of playing an instrument [6]. There exists many kinds of electronic devices that simulate the feel of a keyboard or a drum-kit (figure 1.3) but instead



Figure 1.2.: The JazzMutant's Lemur touchable music interface. All the on-screen controls can be configured with an UI designer program, and later mapped to any program via OSC messages.

of producing any sound they send MIDI [7] messages to a synthesiser that reproduces the notes.

Our software should be able to interpret MIDI messages such that it can be controlled with such a device, making it more natural and creative for many musicians.

1.1.3 *A collaborative environment*

Since the beginning of times, music performance have been a collaborative act, with each performer contributing to the global rhythm and harmony by playing one instrument. Psychosynth should serve the purpose of producing arbitrarily complex music by itself as modules that implement not only synthesis, but also sampling and sequencing are added.

This integrated environment should be able to be manipulated by several people at the same time to allow a



Figure 1.3.: A conga-alike MIDI controller. When pressing different parts of its surface it will emit different MIDI note messages, that a synthesiser or sampler could use to either simulate a real conga or to produce any other sound.

collaborative experience. After all, it would be very hard for one person to control in a live performance all the subtleties of the sound generation by herself.

1.1.3.1 *Tangible interfaces*

One approach to achieve this is by using a user interface that is big enough to accommodate several performers around it. A tangible interface is one where the different elements are represented by physical objects that one can touch and move in physical space. The ReacTable implements such an interface where the modules of its synthesis engine are plastic blocks that are laid out over a round table that provides visual feedback thanks to a projector under it. As shown in figure 1.4, with such an intuitive and physically unconstrained interface several people can stand around the device and manipulate it.



Figure 1.4.: An example of the Reactable being used collaboratively by several people.

1.1.3.2 *Networking*

Networking support even further releases a device from the space constraint by allowing several instances of the software intercommunicate over a computer network —i.e. IP. At some point, latency problems can still be a drawback for this technique, but it can be useful for some kinds of collaboration that do not require perfect timing. When playing in a local range, this becomes perfectly valid even under high latency requirements.

This has long time been a main goal in Psychosynth. When running in collaborative mode, all the clients that connect to a server share the same synthesis graph and whenever an object is moved, added or deleted, or a parameter is changed, all are notified such that they keep the same view of the scene. Figure 1.5 shows an example of this feature being used live.



Figure 1.5.: An example of Psychosynth 0.1.4 being used collaboratively over the network. The picture was taken in a showcase performance held by Shakero8 and the author in the Open Source World Conference in 2008.

1.1.4 *A framework*

Music making and audio processing software and interfaces are evolving very fast. Abstracting the common core functionality needed by developers in a layered and abstracted programming API and development of a Free Software [8] framework is crucial to enable further focused research on the different areas previously discussed. Results of that research can be later integrated in the framework as they are stabilised.

Such a framework should enable the development of modular audio applications with an abstracted interfacing mechanism, probably following a Model-View-Controller paradigm, general enough to be able to support all the previously described qualities. If this task is properly accomplished, the framework could become the basis of a wide range of unexpected future Free Software applications.

1.2 OBJECTIVES

Taking all that into account, we should next define the concrete objectives for our present project. We should note that we depart from the basis of the current state of the GNU Psychosynth project—as of its version 0.1.7—and we assume that as previous work, not our current target.

1.2.1 *Main objective*

Objective 1 *Re-focus the GNU Psychosynth project as a development framework for the development of professional-quality modular, interactive and collaborative synthesisers.*

In the long-term we would like GNU Psychosynth to include innovative user interfaces, and some might even be developed as a side effect of this project—or we might just update the older one to rely on the new framework. However, that is not the purpose of this project, instead we will concentrate on the development of the underlying core architecture and implementation of its API.

This is so mainly because of time constraints. Also, if we were to miss some features in the core in order to allocate more time for the user interface, we have to take into account that this will probably hard to fix afterwards when a lot of code depends on the broken design. Also, user interface development is easier to do in a non-disciplined, voluntary and heterogeneous team. If we achieve a nice framework now we can still develop the user interfaces later with the help of other the people collaborating on the Internet; but, as these two years of stalled development have shown, it

is hard without the pressure of an external deadline and a project plan to invest a lot of time in rewriting the “invisible” but crucial parts of the system.

1.2.2 *Preconditional objectives*

There are two objectives of this project that can also be considered as a precondition for the success of our main goal. These are:

Objective 2 *Collaborate with professional musicians to get a defined understanding of the meaning of “professional quality” and their real needs.*

The students participating in this project have an amateur knowledge of music production. It is important to communicate and allow supervision by professional musicians and experts in digital music to assure the suitability of the software for use in a professional environment.

We are working in collaboration with the ArtQuimia Music Production School², which has long time been educating successful producers and is currently participating in the European Cross-Step project³, and his director David García, a musician with professional experience in the industry as music composer and sound designer for video games.

Objective 3 *Research and apply the latest techniques in modular design and implementation and explore the boundaries of the underlying implementation devices.*

² <http://www.artquimia.net/>

³ <http://www.cross-step.org/node/4>

The success of an framework relies on the proper decomposition of its features and its extensibility. Moreover, the authors of this project have a special fascination for programming languages, design patterns and software modularity. Even more, there is an active research community questioning and re-developing the modularisation and abstraction techniques of the underlying programming language C++, a fact that is more true as we approach the final resolution of the standarisisation committee on the new C++0x standard. All this suggests that research and application of the state-of-the-art and even development of our new design and coding patterns will be one of the leading objectives during the project and play a leading role in its overall success.

1.2.3 *Partial objectives*

A more concrete subdivision of our main goal should be given. Note that these are not yet the detailed requirements, but an overall initial objectives vaguely elicited from the problem definition, the previous experience with the GNU Psychosynth software and our personal interests.

Objective 4 *Improve the framework to be able to load modules dynamically from plug-ins, satisfying our own API and/or third-party standards.*

This is a common feature in most industry standard applications and ours should support it. Many layers of the framework, specially those related to the dynamic patching, will require vast modifications to enable customisation to understand third-party modules.

Objective 5 *Improve the framework to be able to communicate with music controllers via MIDI or other industry standards.*

While not explicit in this wording, this adds the requirement for *polyphony* as in most cases such feature would be useless without it.

Objective 6 *Add basic synchronization and sequencing support to the framework.*

If we want to understand the software as a full live performance environment and not a bare synthesiser, this currently lacking feature is fundamental.

Objective 7 *Include common modular audio system utilities into the framework. Some of the most important being patch hierarchy and persistence.*

1.3 BACKGROUND AND STATE OF THE ART

1.3.1 *Modular synthesis*

The history of modular audio generation starts with the Moog analog synthesiser in 1967 [4]. Since then, a wide variety of analog modular synthesisers have been developed commercially, but retaining some limitations as described in the introduction in section 1.1.1.

Modular synthesis became more interesting with the up-rising of computer based electronic music. One of the most important examples in this development is Max/MSP [9]. This is a dataflow based visual programming environment mainly targeted at music applications. In such software one

can add boxes where one types the name of the function that it should perform. When the name has been written some connection plugs appear on its corners depending on the module name, and one can draw lines connecting those plugs. Figure 0.3 showed an example of its functioning. The author of Max/MSP later developed a Free Software counterpart called Pure Data[10] that also has video processing and synthesis support.

Since then, many user-oriented commercial modular synthesisers have been developed. One of the most famous ones is Native Instrument's Reaktor (figure 1.6). In its version 5 it included the new *core-cell* technology, which allows the visual and modular design of the lower level parts of the DSP (Digital Signal Processing) programming, which transparently compiled to efficient machine code. Later, Plogue's Bidule is gaining special recognition for its simpler interface. A new interesting software is XT Software's EnergyXT, a DAW (Digital Audio Workstation) that has a "modular view" where one can route through wires all the MIDI and audio signals that flow behind the traditional sequencing view. Finally, Sensomusic's Usine is remarkable for introducing a highly customisable multitouch graphical interface on top of a modular synthesis environment.

On the Free Software side few modular synthesisers exist. Also Modular Synth⁴ is one of the most popular. Ingen⁵ is a more modern one whose code we praise for its quality. Most of these software still lack some of the features of their privative counterparts, with the ability to create customised user interfaces being the most relevant. Still, Free Software offers a very interesting modular approach to the sound

⁴ <http://alsamodular.sourceforge.net/>

⁵ <http://drobilla.net/blog/software/ingen/>

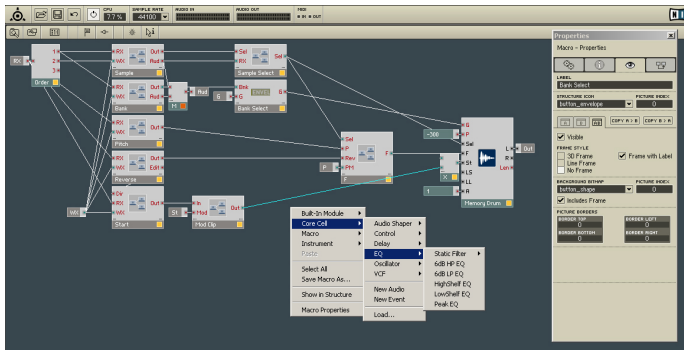


Figure 1.6.: Native Instrument's Reaktor editing a *core cell* based patch.

system management that has a similar rival only in latest OSX versions: Jack[11]. Jack is an audio server providing zero-latency interprocess communication that acts as a patch-bay among any supporting audio applications. The user can route the output of one program to the input of any other program, or the soundcard sink, or whatever exposes a Jack port. It can be used to route MIDI signals too and recent versions include very nice features, like collaborative routing over the network for distributed performances [12].

1.3.2 Touchable and tangible interfaces

In the last decade, the development of touchable and tangible user interfaces have been of rising interest. An interesting but not very updated survey that gives some taxonomical background and analyses a wide variety of products can be found here [13]. One of the first attempts in using them for improved interaction in musical software is the Audio

Pad[14], where the user places and moves tagged pucks on a bidimensional surface. This is an example of an interface with active tangibles, because the pucks have an RF transmitter to allow their recognition. The Jam-o-Drum, on the other hand, offered a percussive collaborative approach where performers sit on the corner of an interactive table [15]. Many videogames and other kinds of application have been developed on top of the Jam-o-Drum hardware too. Since then, a huge number of different table based interfaces have been made, an example listing can be found here⁶.

Maybe the most interesting example, which inspired the whole development of GNU Psychosynth, is the Reactable project[1]. Its user interface is based on modular synthesis and uses the dynamic patching technique for easily manipulating the patch topology. It uses innovative digital image processing techniques to detect the position and rotation of passive tangibles [16]. In the Reactable system a translucent round surface hides a projector and a high resolution camera underneath, as shown in figure 1.7. Finger-tips and the specially designed tags called *fiducials* that are placed on the table surface are captured by the camera and recognised by the ReaTIVision system on a computer. This system sends OSC[17] (Open Sound Control) based messages to a synthesiser following the TUIO (Tangible User Interface OSC) protocol [18]. The literature describing the initial prototypes used Pure Data as the underlying implementation language for this synthesis engine, but conversations with the authors of the Reactable suggest that the current commercial implementation is written in C++. This synthesis engine is connected to a visual engine that generates visual feedback

6 <http://mtg.upf.edu/reactable/related.htm>

and sends it through the projector. The picture is reversed so it can be correctly visualised through the translucent surface.

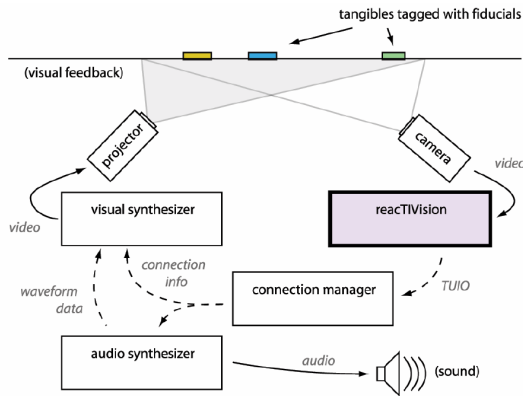


Figure 1.7.: A typical Reactable setup. Source: The Reactable project.

The Reactable has been very successful and a very interesting fact is that the computer vision component of the system is Free Software, so it could be integrated with GNU Psychosynth in the future.

Some other remarkable tangible and highly interactive user interfaces that were released around 2007 too are the JazzMutant's Lemur and the Iwai-Yamaha's Tenori-On [19]. The former offers a fully customisable OSC based multi-touch interface, where one can design interfaces with sliders, virtual-knobs, X-Y pads and all kinds of multi-touch controls that are mapped to OSC messages that can be interpreted by the audio engine of choice. The latter is a 16x16 matrix of LED illuminated buttons that can be configured in different modes that provide innovative sequencing mechanisms (figure 1.8).



Figure 1.8.: Electronic music artist Four Tet performing with a Tenori-On

Nowadays, multitouch interfaces are the main trend, specially after the explosion of the tablet market, but big music software companies still have to catch up the latest hardware developments. Specially interesting for the GNU Psychosynth projects is the Indamixxx 2 tablet, which is based on the Meego OS⁷ and oriented towards music production and live performance — we should definitely keep an eye on it and develop a multi-touch enabled user interface for it.

1.3.3 *Audio synthesis libraries and frameworks*

One of the first synthesis libraries that were evaluated before the development of GNU Psychosynth started is the STK (Synthesis ToolKit) [20] but it lacks proper dynamic signal routing mechanisms and some details, like the sample format being hard-coded to float, seem too constrained.

⁷ Nokia and Intel's joint effort to provide a GNU/Linux based operating system for embedded devices, mobile phones, netbooks and tablets.

A popular sound synthesis and music composition DSL (Domain Specific Language) is CSound, which later was extended with a C and C++ programming API[21]. Many DSP oriented DSLs have been developed, but they are not general enough to support the development of the fully featured applications that we wish on top of GNU Psychosynth. Still, some of them are worth mentioning. Notable examples are SoundCollider [22], which was for a long time the reference sound synthesis DSL; Chuck [23], that adds concurrency and time control in an elegant and boilerplate-less fashion, and the newer Faust [24], which is based in a functional and data-flow paradigm and interfaces easily due to its compilation to C++.

While we are focusing on C and C++, many languages have music related libraries. Impromptu⁸ is a Scheme environment for live-coding, this is, live music performances where the programming is done in front of the audience while the programmer writes and mutates the code⁹. It supports video manipulation too, but sadly is available for OSX only. Its heavy modularity and dynamism is what make Lisp dialects so interesting for live-coding and music composition. Common Music[25] was started in 1989 and it is a highly featured Common Lisp framework that, among other things, provides a very elegant embedded score notation.

Maybe the most similar project to GNU Psychosynth in its approach is CLAM (C++ Library for Audio and Music) and award winning library based on modular synthesis[26].

⁸ <http://impromptu.moso.com.au>

⁹ The video *Algorithms are thoughts, chainsaws are tools*, by Stephen Ramsay is a great introduction to this technique.

<http://createdigitalmusic.com/2010/07/>

[thought-and-performance-live-coding-music-explained-to-anyone-really/](http://createdigitalmusic.com/2010/07/thought-and-performance-live-coding-music-explained-to-anyone-really/)

Its design will be carefully taken into account during the redesign of few of Psychosynth core components. Still it does not precisely fit our needs as it is too oriented toward research simulations and does not support polyphony.

2

ANALYSIS AND PLANNING

As I see it, criticism is the prime *duty* of the scientist and of anyone who wants to advance knowledge. Seeing new problems and having new ideas, on the other hand, are *not* one's duty: originality is, rather, a gift of the gods.

Karl Popper — 1982
Preface to “Quantum
theory and the schism in
physics”

2.1 REQUIREMENT MODELLING

In the following section we discuss the requirements that we want to impose on the resulting framework. Note that functional requirements are hard to express for an API, but a vague description of the desired qualities and features is still possible will guide or development process.

Quite often, we will focus on the final feature that should be implementable through the framework. Also, note that the framework already had many features at the beginning of the project, some of which we will discuss in section ??.

We will try to avoid describing the requirements related to those ready facilities in this section, as the only purpose of those is to aid the actual development of this thesis project. Still, some already satisfied requirements might be made explicit when some other related requirement follows, or because of their relevance to the user or just for the global consistency of the text.

As we suggested in our objective 2, these requirements have been elicited with the assistance of the ArtQuimia Music Production School in order to ensure the suitability of the software in a productive usage context.

2.1.1 *Functional requirements*

2.1.1.1 *Basic audio support*

Requirement 1 *The library must provide data-structures and basic algorithms for manipulating audio signals.*

Requirement 2 *The library must provide means to output and input audio data to and from files in various formats, including, at least: Microsoft WAV, Apple AU and OGG Vorbis.*

Requirement 3 *The library must provide means to output and input audio data to and from sound-card devices in an asyn-*

chronous real-time fashion, supporting, at least, the following audio systems: ALSA¹, OSS², Jack³.

2.1.1.2 Node graph support

Requirement 4 *The library must include means for producing the audio as the result of executing a dataflow-graph.*

Requirement 5 *The library user must be able to define his own processing nodes.*

Requirement 6 *Each node should have an arbitrary number of named signal and control input and output ports. The difference between signal and control ports are that the later are sampled at much less frequency.*

Requirement 7 *Both signal and control ports should be able to process information in arbitrary datatypes. Signal ports may have practical limitations as for the real-time constraints is concerned.*

Note 2.1 (Realtime constraints)

All the processing done inside the nodes should satisfy soft real-time constraints. This is so because in order to produce sound with low latency (see requirement ??) the sound processing should be done in blocks (buffers) as small as possible that are delivered to the sound-card as soon as possible. If the deadline is not met, a disturbing “click” sound will be heard because of the zeroes assumed by the sound-card during the period that

¹ Advanced Linux Sound Architecture: <http://www.alsa-project.org/>

² Open Sound System: <http://www.opensound.com/>

³ <http://jackaudio.org/>

it did not have any audio to output. For example, for a 44100 Hz sampling rate and a 128 frames block size, it should take less than

$$\frac{1\text{s}}{44100 \text{ frames}} \cdot 128 \frac{\text{frames}}{\text{block}} = 2.90 \frac{\text{ms}}{\text{block}}$$

to process and deliver an audio data block.

In practice, this means that the processing algorithms should take an amount of time proportional to the amount of data to process —i.e. they are $O(n)$. This in turn disallows writing and reading files and most operations that cause non deterministic hardware operations or force context switching (mutexes might be unavoidable but should be used scarcely). Also, allocation of memory on the heap should be avoided as it has a non-predictable and potentially non-linear time consumption. Of course, the framework should provide hooks to do those forbidden operations outside the audio processing thread, but we consider that a design issue that should be addressed later.

Requirement 8 *Each output port must be connectable to arbitrary number of input ports. Each input port must be connectable to one output port.*

Requirement 9 *Ports may be defined statically —i.e. at compile time— or dynamically —i.e. at runtime.*

Requirement 10 *The system must allow the hierarchical composition of nodes, with special input and output nodes that are exposed as ports in the parent level.*

Requirement 11 *Nodes can be either monophonic or polyphonic. A polyphonic node internally has a number of copies of its processing state, called voices, that are dispatched accordingly through trigger signals.*

Note 2.2 (On the scope of polyphony)

We will avoid specifying here details on how polyphony works that are still quite important as a usability concern. For example, should monophonic ports be connectable to and from polyphonic ports? Should there be polyphonic and monophonic nodes in the same patch hierarchy level? How are the voices dispatched and mixed? Because answering this issue highly affects performance and implementability trade-offs, these issues are left open until the design stage of these components.

2.1.1.3 Dynamic loading of nodes

Requirement 12 *The system must be able to dynamically load modules developed with standard interfaces, at least using the LADSPA standard⁴, but LV2⁵ and VST⁶ are proposed too in this order of priority. Note that in some cases this implies the automatic fixing of the semantic impedance among the interfaces of Psychosynth nodes and the third-parties’.*

Requirement 13 *The system should be able to dynamically load modules developed using the same native interface exposed to library users to define their own modules.*

⁴ Linux Audio Developer’s Simple Plugin: <http://www.ladspa.org/>

⁵ LADSPA Version 2: <http://lv2plug.in>

⁶ Steinberg’s Virtual Studio Technology: <http://ygrabit.steinberg.de/>

2.1.1.4 *Dynamic patching*

Requirement 14 *The system should optionally release the library user from arranging the interconnections among nodes by using dynamic patching. When using dynamic patching an output port is connected to one input port. The input port is the closest (in the sense of euclidean distance, we assume that the modules are laid out in the space) input port of the same type not belonging to the same node that is free —i.e. is not connected already to a closer node.*

When combining dynamic-patching with dynamically loaded modules using standard interfaces like LADSPA, one might need extra information to correctly perform the dynamic patching.

Requirement 15 *The system should be able to locate and automatically load if present special description files containing the required information for some dynamically loaded modules to work correctly. This file should specify which ports are eligible and to which ports they are connectable to.*

While this may change due to design considerations, we suggest specifying a set of tags for each port, with the following connectability rule for port A and B : $connectable(A, B) \Rightarrow tags(A) \cap tags(B) \neq \emptyset$.

2.1.1.5 *View independence*

The following requirements are here to suggest an observable interface for the synthesis model satisfying a model-view-controller architecture. This is one of the key concepts in achieving a network-based shared environment that is

transparent to a wide range of graphical interface experiments or external MIDI controls.

Requirement 16 *The system must enable the development of graphical interfaces—or any other instance of the more abstract concept of view—that can coexist with each-other.*

2.1.1.6 Synchronisation and sequencing

Requirement 17 *The system should include a notion of tempo such that external imprecise events can be quantised and synchronised to.*

Requirement 18 *Parameters of various node kinds, specially time related ones, should be controllable as a factor of the current tempo.*

I.e. the frequency of an LFO should be fixable such that the wave length is a factor of the tempo, and the phase should be synchronisable to beat.

Requirement 19 *The system should be able to synchronise to the MIDI clock.*

2.1.1.7 Collaborative support

Requirement 20 *The system must be able to receive, process and use as control source MIDI events coming from other software or external hardware devices.*

Requirement 21 *The system must be able to receive, process and use as control source OSC events coming from other software, computers or external hardware devices.*

Requirement 22 *The system must be able to use a specially crafted OSC based protocol to enable the collaborative manipulation of the same node graph among different computers connected through the network.*

Note 2.3 (Relaxing the “shared-environment” requirement)

Requirement 22 is currently implemented by broadcasting all events among all the participants in a shared session. In presence of audio input nodes, dynamically loaded modules and other sources of non-determinism —this is, sound that might not depend only on the sequencing of certain events— this gets harder to implement. We do have some solutions in mind, like placeholder nodes that stream the local non-deterministic signals through the network too, but it might be too hard to implement in the context of this master thesis project and only a proof-of-concept implementation will be required.

2.1.1.8 *Persistence*

Requirement 23 *The system must be able to store and load the graph layout and control values the node graphs. Sub-graphs in the graph hierarchy should be storable and loadable individually.*

2.1.1.9 *Optional functionality*

Requirements in this section are not such, but instead they are bare ideas that would be nice to have but are considered too time consuming, hard or not urgent enough to be considered a measure of the project success.

Requirement 24 *The highest level part of the API should have a Python —or any other dynamic language of choice— binding for the rapid prototyping of audio applications and user interfaces on top of it.*

2.1.2 Non-functional requirements

2.1.2.1 Free Software

Requirement 25 *Unless constrained by very specific hardware, the system should not add any non-Free Software dependency — i.e, it must be able to compile and run without executing any privative software bit.*

2.1.2.2 Professional quality sound

Requirement 26 *The software must be able to work at different sampling rates up to 96000 Hz.*

Requirement 27 *The software should be able to use arbitrary precision samples. Up to 64 bit floating point samples are required.*

2.1.2.3 Performance

Requirement 28 (Latency) *The software should be able to work with a block size as low as possible down to 64 frames, as long as the underlying hardware permits it.*

2.2 OPEN, COMMUNITY ORIENTED DEVELOPMENT

The developers of this software are strong proponents of Free Software development. This is specially relevant in an academic and public environment like ours. Therefore, the software not only is distributed under a Free Software license, it also follows an open community development model, where everyone can read, use and modify the source code as it is developed and there are means for online communication promoting development among volunteering distributed peers.

Previous versions of the software are available on the Internet for download and it has an official web page: <http://www.psychosynth.com>

2.2.1 *Software License*

The software is licensed under the GPL license version 3, offering strong copyleft requirements — i.e. derived works and software linking against the library must be distributed under the same terms. The full description of the license is included in the appendix B.

While the GPL₃ is often misunderstood as inadequate for a library, that is not true in the context of libraries that provide unique features, as it motivates the release of third-party software that is attracted by these as Free Software too [27]. This is not only personal belief, it is also the official guideline in the GNU project.

2.2.2 *The GNU project*

Since October 2008, Psychosynth is part of the GNU project. GNU was started in 1984 by Richard Stallman with the long term goal of providing a fully free —as in speech— operating system [8]. Under the umbrella of GNU, Psychosynth gets access to a broader community, technical support and it is a recognition of its attachment to the Free Software ideals.

2.2.3 *Software forge and source code repository*

A *software forge* is an online service targeted at aiding the development of Free Software. It offers a series of tools to aid the community participation and distributed development, such as *bug trackers*, *support trackers* and *mailing lists*. One of the most important features is the *revision control system* that serves as source code repository.

GNU Psychosynth is hosted in the Savannah software forge, and its project page can be accessed here:

`http://savannah.gnu.org/projects/psychosynth`

The project is using GNU Bazaar as distributed revision control system. One can fetch a copy of the latest version of main development branch by executing the command

`bzr branch http://bzr.sv.gnu.org/psychosynth/trunk`

2.2.4 *Communication mechanisms*

Fluent distributed communication is essential for the advancement of a free project. For this purpose we offer the following tools.

2.2.4.1 *A blog*

The blog serves as an informal and easy way of getting the latest news on the development. It is most of the time technically oriented and can serve as source of motivation for external people to contribute to the project and as a summary of the current status of the project. It can be accessed through:

<http://planet.gnu.org/psychosynth/>

2.2.4.2 *Mailing lists*

Mailing lists are multi-directional broadcast based communication means and the main spot for discussion of development (from the developer point of view) and getting news or asking for help (from the spare user point of view).

GNU Psychosynth has two mailing lists.

- Users mailing list:

<http://lists.gnu.org/mailman/listinfo/psychosynth-user>

- Developers mailing list:

<http://lists.gnu.org/mailman/listinfo/psychosynth-devel>

Because being registered in many mailing lists can cause management issues to some users, the Gmane project⁷ offers

⁷ <http://www.gmane.org/>

a newsgroup gateway that can be used by Free Software projects to allow participation in their mailing lists with Usenet capable software. Psychosynth mailing lists are registered there and can thus be accessed through:

- `gmane.comp.gnu.psychosynth.user` for the users mailing list.
- `gmane.comp.gnu.psychosynth.devel` for the developers mailing list.

2.3 DEVELOPMENT ENVIRONMENT

The development environment is very important for the project success. This section should clarify our choices and explain the rationale behind such decisions.

2.3.1 *Programming language*

Psychosynth is developed using C++. This decision is based on the following facts:

- It is a stack based language with fine grained control over memory management. As we introduced in note 2.1, this is crucial during the development of live audio processing software.
- It is a mature language with widespread tool support and a very good Free Software compiler: GCC.
- Apart from its low-level mechanisms it has powerful means for abstraction, most of which are designed to pay zero cost.

- It is multi-paradigm, and as such it can easily adapt to the natural way of expressing the concepts of a heterogeneous system as this, where we want to go to from low level DSP programming to high level interface design.
- It is compatible with C, which gives us direct access to the widest range of libraries available. Most audio-processing libraries are written in C and thus we can save a lot of time in implementing mathematically complex algorithms.

Of course, it also has its flaws, like unnecessary complexity and unsafety in some corners, most of which are justified by its backward compatibility to C and evolutionary design. Some of this flaws are nonetheless going to be solved in the next standardisation of the language, to be released in 2011 [28].

Compilers are starting to support it and we are very interested in exploring the benefits and new programming patterns and design benefits that it can provide. Because Psychosynth is an ongoing and forefront project we do not fear portability — and after all, GCC is very portable! — and as such we are going to use the facilities in C++0x as soon as they are supported by the latest version of GCC included in the Debian Sid.

2.3.2 *Operating System*

The project is mainly targeted at GNU/Linux, which is the most widespread free operating system, therefore, compliance with it is the highest priority. That is also the operating

system of choice of the authors of this project so it feels like a natural environment and there is no extra effort needed.

Still, we will try to comply with POSIX such that porting to other Unix operating systems is easy. Sadly, there is no universal high performance and fully featured cross-platform audio output engine and thus that is an important portability boundary. In the future, maybe with some financial aid, we might be able to port the software to OSX, which is near to be the most used operating among musicians [6]⁸.

2.3.3 *Third party libraries*

In this section we give an overview of the external libraries used in the software. Note that they have to be chosen in compliance with requirement 25.

2.3.3.1 *Boost*

Boost⁹ is a set of libraries for C++ that are peer-reviewed and specially crafted to integrate well with the paradigms and abstraction techniques of the standard library. Many of its modules are, actually, going to be part of the standard library in the future C++0x standard.

⁸ The cited survey dates back to 2006. Given the recent rise in popularity of Apple products, we speculate that OSX might be even more popular than Windows among musicians nowadays.

⁹ <http://www.boost.org>

We use few of the Boost facilities, some of them including `boost::filesystem`, `boost::thread`¹⁰, `boost::mpl`, `boost::test`¹¹ among others.

It is extremely portable and licensed under the permissive Boost Software License.

2.3.3.2 *Libxml2*

We use Libxml2¹² for parsing the XML configuration files. It is very portable and licensed under the permissive MIT License.

2.3.3.3 *LibSndFile*

We use LibSndFile¹³ for loading different uncompressed sound formats. Note that from version 1.0.18 it also supports OGG and FLAC formats, and thus we plan to use this instead of LibVorbis in the future. It is very portable and is licensed under the LGPL 2 and 3.

2.3.3.4 *LibVorbis*

We use LibVorbis¹⁴ for reading OGG files. It is released under the BSD license and is very portable.

¹⁰ We plan to replace this with the new threading facilities in the standard as soon as they are implemented in GCC.

¹¹ A wonderful unit testing framework.

¹² <http://xmlsoft.org/>

¹³ <http://www.mega-nerd.com/libsndfile/>

¹⁴ <http://xiph.org/vorbis/>

2.3.3.5 *SoundTouch*

We use SoundTouch¹⁵ for time-stretching, this is, changing the pitch and tempo of a song independently. It is licensed as LGPL and works on mayor operating systems.

Some people claim to obtain better results in performance and sound quality with the Rubber Band library^{16 17} and we will probably replace SoundTouch by this one in the future.

2.3.3.6 *ALSA, OSS and Jack*

In accordance to requirement 3 we use ALSA, OSS and Jack respectively. Licenses are LGPL2+ for all of them. ALSA is Linux only, Jack works on GNU/Linux and OSX and OSS works on Linux and some other POSIX operating systems.

2.3.3.7 *LibLO*

LibLO¹⁸ is used for OSC support. It is licensed as LGPL2+ and is POSIX compliant.

¹⁵ <http://www.surina.net/soundtouch/>

¹⁶ <http://www.breakfastquay.com/rubberband/>

¹⁷ The DJ software Mixxx, where sound stretching quality is very relevant, is moving towards RubberBand and their developers support the above claims: <http://www.mail-archive.com/mixxx-devel@lists.sourceforge.net/msg03103.html>

Also, Ardour later moved tater moved to this library: <http://www.ardour.org/node/1455>

¹⁸ <http://liblo.sourceforge.net/>

2.3.3.8 *The user interface libraries*

The user interface included at the beginning of the project is based on Ogre3D¹⁹, using OIS²⁰ (Open Input System) for keyboard and mouse input and CEGUI²¹ as widget toolkit.

During the development of the previous Psychosynth versions CEGUI has proven to be extremely painful with an overengineered API and bugfull implementation. Also, the 3D interface, while being fancy it is confusing for some users and did not offer anything new to the experienced musician, as some blog reviews showed. It contains some interesting concepts — zoomability being the most important — but it is too distracting after-all. Thus, while we are going to keep this interface during the development of this project, we want to later rebuild the GUI using Qt, which is multi-touch enabled and could open us the door to the yet-to-come wide range of Meego based tablets.

2.3.3.9 *Build system*

We use GNU Autotools²² as the build system for the project. It is extremely portable and the de-facto standard among Free Software, even though some interesting alternatives are emerging. Nonetheless, Autotools are suggested in the GNU Coding Standards[29] that we shall follow during our development due to our affiliation to GNU.

¹⁹ <http://www.ogre3d.org/>

²⁰ <http://www.ogre3d.org/>

²¹ <http://www.cegui.org.uk/>

²² We use mainly Autoconf (<http://www.gnu.org/software/autoconf/>), Automake (<http://www.gnu.org/software/automake/>), and Libtool (<http://www.gnu.org/software/libtool/>).

2.3.3.10 *Documentation system*

Because we are developing a framework, it is specially important that the public interfaces are properly documented. We are going to use Doxygen²³ to embed the API documentation in code comments. A reference manual generated by Doxygen should be attached to this document.

2.4 ARCHITECTURE AND CURRENT STATUS

The Psychosynth project was started in 2007 and since there has been some relevant developments. The screenshot in figure 2.1 gives a broad perspective of the current features of the project. For a more detailed description from the user point of view, please refer to the user manual that can be checked online on the project webpage²⁴, where there are also demonstration videos and other multimedia material. The article [30] can serve as an introduction to the project too.

2.4.1 *A critique on the term framework*

The term *framework* is used many times in this and other projects and is becoming a techie buzzword. In many contexts it is abused as a synonym for the term *library*. Instead, we believe that a framework is something different, following the definition given in the famous design patterns book by the gang of four [31].

²³ www.doxygen.org

²⁴ <http://psychosynth.com/index.php/Documentation>

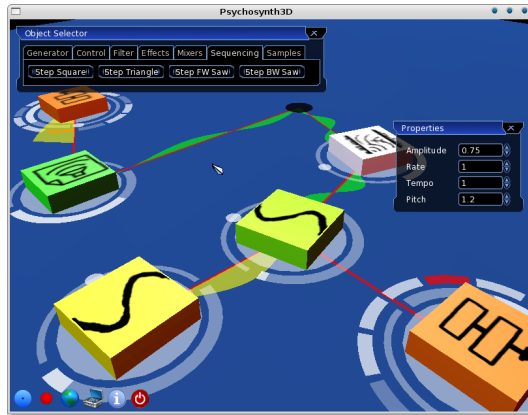


Figure 2.1.: A screenshot of GNU Psychosynth 0.1.4. On the bottom we can see some buttons for popping up different menu windows, such as for settings, recording the sound into a file or connecting several instances over the network. The window on the top of the screen is used to add elements to the processing graph. The smaller *properties* windows contains a listing of all the actual parameters of a node and allows us to give numeric values to them. All around the screen, sinusoids, step sequencers, file samplers and echo filters are interconnected as represented by the 3D blocks.

We use the term *library* when the root of the call graph is on the client side and she invokes the library function sparsely to obtain some concrete functionality. Instead, a *framework* stands in the root of the call graph and the client code is called through extension hooks in the framework,

following the “Hollywood principle” — “Don’t call us, we’ll call you.”.

Because the Psychosynth system is layered, one can just use the bottom layers as a library, or rely on the upper layers that properly use inversion of control like a framework.

2.4.2 *The layered architecture*

At the current stage, GNU Psychosynth implements a layered architecture [32]. This intends to promote a more decoupled design, as calls between modules are only allowed from top down.

Also, the library has many features, many of which some users may not need. This layered approach could allow a potential user to avoid any special overhead when he is only using some bottom layers. Still, note that the library is now compiled with all layers bundled in the same shared-object file, so this is not a fact now. Because the heavy redesign ongoing during this project, we shall postpone that until the late development stages when the layer interactions are clear and stable.

Figure 2.2 represents the current layered architecture. Lets make a bit more in-depth discussion of each layer.

2.4.2.1 *The base layer*

The base layer includes basic facilities that may be reusable in any other part of the application. Some of the most relevant examples:

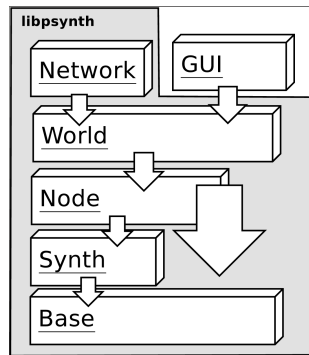


Figure 2.2.: The Psychosynth layered architecture.

CONFIGURATION PERSISTENCE Classes for representing program settings in a hierarchical manner. This configuration system can use interchangeable backends and has an observable interface.²⁵

In fact, we do not recommend using this module in the core of the intermediate layers of the library because it can cause unexpected coupling, but this is not too clear and we keep it here for historical reasons.

IMPLEMENTATION OF DESIGN PATTERNS While the term *design pattern* means reusable design structure, not reusable code, language abstractions can make them implementable as code in some cases. Andrei Alexandrescu proves this point for C++ in [33]. Thus, we provide implementations, quite often similar to Alexandrescu's, to various recurring design patterns such

²⁵ We use quite often the term *observable interface* which is rare in the literature. By this, we mean that it provides signals, listeners or other event mechanisms, instances of the *observer* design pattern[31].

as *factory* or *singleton*. Some implementations are not inspired in Alexandrescu's, like the generic *composite*.

COMMAND LINE ARGUMENT PARSING While we have considered moving to Boost's Program Options library, our own implementation have different trade-offs and is rather extensible.

LOGGING SYSTEM A hierarchical and multi backend logging system for registering messages from other modules. It should be used instead of direct output to `std::cout/cerr` in all the code.

FILE MANAGEMENT TOOLS That ease the task of finding resources in the hard-drive and can cache results.

Some other minor classes and tools are excluded from this list. During the development of the project we will drop in this layer classes that feel interesting at any abstraction level.

2.4.2.2 *The synth layer*

This layer contains classes for the *static* construction of synthesisers and sound processing. The audio input and output facilities are considered to be in this layer, and as well audio processing data structures —like ring buffers, multi channel buffersm, etc.—, basic implementations of filters, oscillators and audio scalers.

By static, we mean that this code does not provide any dynamic routing facilities, instead, the programmer is in charge to assign buffers and call the processing elements manually.

Requisites 1 to 3 should be implemented here. Non functional requisites 26 to 27 are specially relevant in this layer too.

2.4.2.3 The *node* layer

This layer provides the facilities for the *dynamic* construction of synthesisers. It includes the mechanisms for describing and executing the modular synthesis graph with the signal flow and so on. Figure 2.3 represents the main concepts behind the current design. Ports are considered as “signal ports” using the terminology in requirement 6 — “control ports” are similar to “parameters”, but parameters are not a precise model of “control ports” as they can not be routed and are intended for communication between the client user interface code and the audio thread state.

The communication system used to propagate values between the audio processing thread and the client thread is represented in figure 2.4. Values are copied to and from an intermediate channel between the audio processing blocks.

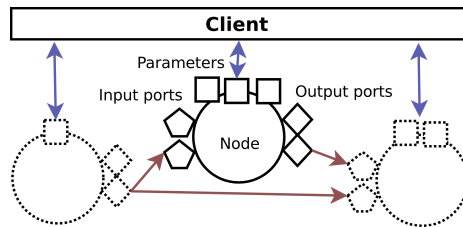


Figure 2.3.: Representation of the node graph as in Psychosynth 0.1.7. Input ports are represented as pentagons, output ports as rombus and parameters as squares.

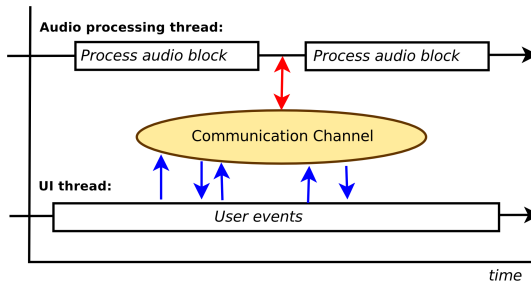


Figure 2.4.: Communication between the audio and user interface thread as in Psychosynth 0.1.7

Requisites 4 to 11 should be implemented in this layer. A heavy redesign of its API and many of its internal implementation is to be expected for that to be accomplished.

2.4.2.4 *The world layer and the Model View Controller architecture*

This layer simplifies the interface exposed to the previous layer and makes it *observable*. This is fundamental for the Model View Controller that the system implements. Figure 2.5 represents this architectural style. On the following, we can refer to this observable interface abstracting the synthesis engine as *the model*.

Several views can coexist independently—for example, a GUI user interface and a web client—, that get updated whenever a value has changed in the model. They register themselves on the model at the beginning and then become passive entities that get called by the model. The model changes when controllers invokes methods on it, several controllers can coexists too. Usually, models and views

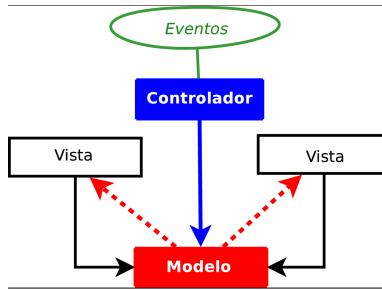


Figure 2.5.: The Model View Controller architectural style. Dashed arrows represent indirect invocation — i.e. via the *observer* design pattern— and normal lines represent normal method calls and data access.

come in pairs. For example, a GUI view has an associated controller that triggers the manipulation of the model in the eventuality of certain user actions like clicking a button; in this case the representation (the buttons) and the action (clicking it) are strongly related, but this is not necessarily true for other situations.

This layer also abstracts the graph interconnection mechanism using the *strategy* design pattern. Concretely, dynamic patching is implemented here and the interface exposed in this layer hides the manual node interconnection mechanisms but provides observability for topological changes.

This layer should implement requisite 16.

2.4.2.5 *The application framework layer and the view and controller layers*

There is a thin layer, instance of the *facade* pattern, called `app`, that was hidden for simplicity in figure 2.2 representing the layered architecture. It sits on top of the `world` layer and is in charge of initialising the *world* and defines a configuration tree, using the facilities in the base layer, and setups the machinery using the observability of the configuration system to keep coherence between the user preferences and the status of the synthesis model — for example, if the “`psynth.output`” setting is changed, it automatically creates the appropriate output object instance, sets its values and substitutes the output node in the synthesis graph. This layer also sets up the command line argument parsing and installs some common audio setting arguments in the parser. This layer is where Psychosynth becomes a framework at its most pure level, as it offers a `psynth_app` class whose `run` method should be the only call in the program `main`, and in turn delegates the heavy work to user code that is hooked as method overrides of that same class.

Orthogonal to this layer and sitting also on top of the `world` layer the networking layer offers a set of views and controllers²⁶ that can be used to create the shared environment described in requirement 22 and thus allowing collaborative performances. This is an example of the value of the MVC architecture: because views and controllers are orthogonal, the user interface does not need to know about the presence of this to function properly; one could develop a new experimental and cool UI and it would automatically

²⁶ A primitive implementation of such at this stage of the development.

be able to work with third party clients over the network, even potentially using a different user interface.

On top of all this there is in the current version of Psychosynth the code of the 3D user interface and small and simple command line tools intended to be used as GUI-less network capable clients and servers. But all this code is not part of the framework, as it wants to be user interface agnostic, so we will not further describe that code.

2.5 PROJECT PLANNING AND METHODOLOGY

2.5.1 *Rationale — A critique on software engineering*

Choosing a well known software engineering process is considered one of the first steps to be taken in a final master thesis project. In our school we study with most detail the Cascade Process and the Unified Rational Process.

Those development processes propose a fordist software production model, targeted at huge development teams and the development of stable code bases in non innovative well defined fields. Martin Fowler makes a great point [34] criticising the often repeated argument stating that software engineering is like any other engineering where creative analysis and design is only the first step and thus coding is analogous to construction. As he says, the construction is done by the compiler and people involved in programming are actually doing an intellectual and creative work too — in computing, any systematic task can and must be automated. The *programming = construction* metaphor is alienating for the programmer, who is completely excluded from the task

of criticising and improving the software design, and thus this metaphor often leads, in the end, to bad software.

Moreover, fordist development models take risk control and client requirements satisfaction as most important factors. Because we are in an academic environment, there are two more important factors: the pedagogical value of the project —this is, that the student involved takes the risk of exploring the unknown by himself— and the research value —this is, that the student involved takes the risk of exploring the unknown by humanity.

Of course, this is neither a pure research project, so we can not substitute a software development project by the scientific method. But we can choose a more dynamic methodology that includes *falsification* in one way or the other; *agile* methodologies²⁷ propose many alternatives that could be valid for a master thesis project.

Still, these methodologies are, we believe, inadequate for this concrete project. The main reason is that this project is developed by only one person. Most methodologies, specially agile ones, put emphasis on the developer communication methods and collective decision making, so they are often inadequate and too constraining and time consuming for an unipersonal team. The Personal Software Process [35] proposes a methodology that is specially targeted at personal software developed by engineering students. Sadly, we are not very familiar with it —and do not have enough time to make that happen within the time constraints of the project— and it seems too be too specific and time consuming in its time tracking proposal.

²⁷ <http://agilemanifesto.org/>

Because we still believe that some rational planning and methodology is needed, we propose in the following a defined but unconstrained methodology that is specially tailored for our circumstances, capturing the most common elements in other software processes.

2.5.2 *An iterative development model*

Because of the size and complexity of the project, we should not consider developing it all at once. Moreover, the layered architecture of the starting code base and the variety of requirements that we want to satisfy favour an iterative development.

For all this, we want to split the development in iterations. Each iteration is composed by the following phases: *design*, *implementation*, *verification* and *integration*. Each iteration shall be assigned a set of requirements from the specification in section ?? that are to be satisfied after the successful accomplishment of that iteration.

2.5.2.1 *The design phase*

In the design phase we shall define the API that we would like the current subsystem have. Because we are developing a library and framework with a public interface, the design phase is specially relevant shall be done with care.

We do not enforce a particular method for documenting the design as different paradigms favour different documentation means. For example, in the first iteration we will develop a library heavily based on metaprogramming, where UML does not fit very naturally. Still, the documen-

tation should include rationale explaining why the design decision lead to the satisfaction of the requirements that we want to satisfy after this development iteration. Also, it may be found that a requirement may be impossible to satisfy on the current iteration or that this requirement is to be better integrated in some other iteration. The developer is free to reassign that requisite for later iteration properly documenting this as a post-analysis plan fix.

What we do enforce is that all the API is documented with Doxygen for the sake of completeness of the reference manual that you should receive along with this document.

2.5.2.2 *The implementation phase*

During the implementation phase the code implementing the design should be written. It is possible and even recommended to modify the design during this phase as inconsistencies and fundamental problems are found. Sometimes, this may even start as soon as design, specially when it is unclear the properties that such API should have and some “exploratory programming” is needed. This fact may or many not be documented at the beginning of the section — even though an API may be designed through an inductive empirical process, a deductive rational description may be more useful for its clear understanding.

2.5.2.3 *The verification phase*

In the verification phase we perform *unit tests* on the most important parts of the system. No iteration should be considered finished unless proper unit tests are written and

satisfied for its core components. For writing such tests the Boost Unit Testing Framework should be used.

When some elements are considered relevant to performance requirements, *performance tests* should be included. While we do not enforce a specific performance testing technique here, the tests should be reproducible and automatable whenever possible.

2.5.2.4 *The integration phase*

When a subsystem is added and it is to replace an existing subsystem in the project, the older code should be removed and the layers on top modified such that they use the new code. This might even be considered part of the verification, as older tests working on the upper layers should be checked to be working still.

Informal integration tests should be done on the final user interface to make sure that the older properties are preserved. Note that in most cases, we do not recommend to lose time editing the old user interface such that the new features in the framework are exposed to the user. Of course, that the new features are usable is the final objective, but as it was justified in 1.2.1, a completely new user interface will be developed as part of a future project.

2.5.2.5 *Recursive decomposition of iterations*

In practice, some of the expected requirements to be satisfied may be found orthogonal or maybe too big to be addressed at one. It is thus allowed to recursively decompose an iteration in sub-iterations when a first evaluation during the design phase suggests that.

2.5.3 *A project plan*

2.5.3.1 *First iteration: A metaprogramming based sound processing foundational library*

This iteration is here to deeply re-design the core data structures using the latest techniques in C++. This requires special research and performance requirements deeply rely on the success of this iteration.

Requirements 1 to 3 and 26 to 27 should be satisfied for its success.

Estimated time cost: 6 weeks.

2.5.3.2 *Second iteration: Redesign of the `node` layer for hierarchy and polyphony*

The node layer requires a redesign if we want to satisfy all our purposes. Polyphony and hierarchy would be specially tricky to implement directly on top of the current code base. A special evaluation of how the new design interacts with the MVC architecture and networking is required. The world layer may be affected too. All the design changes should be implemented too.

Requirements 4 to 11 should be satisfied for its success. Requirement 23 may be considered for its implementation in this iteration too.

Estimated time cost: 6 weeks.

2.5.3.3 *Third iteration: Dynamic loading of nodes*

In this iteration the plugin system is to be developed.

Requirements 12 to 15 should be satisfied for its success.

Estimated time cost: 4 weeks.

2.5.3.4 *Fourth iteration: Adding MIDI and synchronisation*

Synchronisation and MIDI support is one of the most important features and it is also one of the features we know the least about, thus, we should put special care on research and design. This will affect the node and world layers mostly.

Requirements 17 to 22 should be satisfied for its success.

Estimated time cost: 8 weeks.

2.5.3.5 *Post mortem analysis*

After the conclusion of all the previous iterations, we should write a conclusive report and evaluation of its success. Also, we should prepare a final presentation for its evaluation.

3

A GENERIC SOUND PROCESSING LIBRARY

3.1 ANALYSIS

3.2 DESIGN

3.3 VALIDATION

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Appendices



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