

# **SonicSketch – sonic sketching in the modern web browser**

Kevin Nolan

Music & Media Technologies  
School of Engineering  
&  
School of Drama, Film and Music  
Trinity College Dublin



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## 1 Introduction

### 1.1 Introduction

### 1.2 Summary of work completed

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## 2 Background to study

### 2.1 Introduction

### 2.2 The idea generation stage of music production

### 2.3 Discussion of DAW Metaphors

One of the primary tools used by electronic musicians today for the production of music is DAW and it's inherent metaphors based on analog system still reign supreme in the field (Bell, Hein and Ratcliffe, 2015). The familiar concepts of analog tape machines and mixers benefit the novice user by offering a network of familiar and tangible real world metaphors in which to carry out their creative work. However, as well as the benefits that these types of metaphors bring, they also impose some limitations and bring about certain biases. Musical ideas that are difficult to realise can be left unexplored.

A particular criticism of the DAW is the difficulty in maintaining and managing the editing of complex automation information. Automation is the term given to the continuous altering of aspects of the sound and is usually represented in lanes separate to the primary note pitch information. It may be recorded in or drawn in by the producer. Difficulties can arise, when multiple subtly interacting lines of automation, such as pitch bends and filter changes are being manipulated. William Coleman gives a particularly clear example of this and outlines the difficulty of representing "portamento time", the time it takes a note to slide from one to the next. The visual results can be jarring, unintuitive and not reflective of the audio results.

Duignan (2008) describes a similar problem in his study that monitored professional producers working in DAW environments (Duignan, 2008, p. 156). The particular problem identified by Duignan was that of processing one off effects for single musical events. A number of convoluted processes were observed, including bouncing the affected portion to audio, duplicating the track, setting up a particular auxiliary for the effect and controlling the effect with automation. In these cases, the hierarchy imposed by the DAW gets in the way, where it could be modeled quite elegantly in a more open program such as Max Msp. This, unfortunately, raises the issue of drifting into the area of analytic thinking and away from creative thinking, a combination that John Cage advises against: "Don't try to create and analyse at the same time. They're different processes." (Popova, 2012) The need to explore alternative metaphors is clear. A description of a promising alternative metaphor, that of drawing/sketching will now be discussed.

### 2.4 Discussion of more open systems

### 2.5 Music in the browser: a new frontier

Discuss drum machines, etc available on the web. Note the accessibility that they provide. Perhaps introduce tone.js here.

## 2.6 Conclusion

While the dominant metaphors used in DAWs have their uses they can lead to limitations in the creative process particularly at the early stage of ideas creation. More open system give too much power and impede the creative process.

## 3 Similar work

### 3.1 Introduction

As is pointed out by Levin (2002), the exploration of synchrony between audio and visuals is a practice going back centuries, being variously termed “ocular music, visual music, color music, or music for the eyes” (Levin, 2000). The twentieth-century technique of the optical soundtrack, however, brought these ideas to a new level of sophistication. The technique, which involved placing marks via photography or direct manipulation to specify audio properties, was explored by such luminaries as Oskar Fischinger, Norman McLaren and Daphne Oram. Oram’s particular take on the technique will now be discussed as her system most closely resembles that of a piano roll.

### 3.2 Sonic sketching from a historical perspective

#### 3.2.1 Oramics

A primary motivating factor behind Daphne Oram’s development of the Oramic’s machine was to bring more human-like qualities to the sounds generated by electronic means. The machine worked by playing back multiple lanes of film tape in unison, defining a monophonic series of notes as well as control signals to shape their timbre, pitch and amplitude. She details the thought process behind this in her hugely insightful and broad ranging journal style book, “An Individual Note” (???).

The aspects of the sound that she wishes to control are volume, duration, timbre, pitch, vibrato and reverb. In order to do this she describes a simple musical notation language based on the freehand drawing of lines combined with discrete symbols. The lines, which she describes as the analog control, are used to define volume envelopes. Interestingly, the default and preferred method for the parameters she wishes to control is the continuous line rather than discrete note symbols. For instance, she avoids the use of a static velocity per note and instead only specifies the use of a control envelope to change amplitude.

The discrete symbols, which she categorizes as digital control, are used to define individual pitches and are termed neumes. She highlights that notes shouldn’t remain static and, thusly, an analog control of each note is also specified. Similarly to amplitude and vibrato, timbre is also defined by the freehand drawing of lines and is something that with practice the “inner ear” can develop an intuition as the sonic results of different line shapes. It is Oram’s belief that the hand drawn nature of the lines make the results slightly inaccurate and to some extent unpredictable but in this also lies the possibility of bringing more humanity to the cold and precise machines generating the electronic signal.

### 3.3 Sonic sketching in the twenty first century

#### 3.3.1 A Golan Levin’s AVES

Golan Levin created the interactive audio visual system, AVES, a series of audio visual installations in the late nineties and represented a landmark in the field of visual music. It is an attempt to move away from the diagrammatic approach to musical interfaces and to present an interface that



is painterly in approach. Taking strong influence from visual artists such as Paul Klee, he presents a system that maps user input from a graphics tablet and mouse to visuals and to music. The intention is to create a strong visual correlation between the visuals and the music. A variety of approaches are taken to achieve this, all of them involving an algorithmic approach to one degree or another. For instance, in the piece “Aurora”, he maps visuals of a large amount of particles to a granulated sound synth sound source. He didn’t take the approach of an exact mapping of visual particles to audio particles however and instead used a statistical control approach to approximate the correlation in between the visual and aural. (Levin, 2000)

For Levin, the digital pen input in combination with it’s infinite variability represents an ideal instrument for creative expression in his digital temporal audio visual paintings. (???) The reason he gives for this is, similar to a musical instrument such as a violin, the pen is instantly knowable in that a child can pick it up and start creating marks but infinitely masterable through practice and hard work, and ultimately a vehicle for creative expression after a certain amount of mastery. A set of criteria that he and John Maeda arrived at to evaluate the success of their experiments was: is it instantly knowable, how long did you use it, how much of your personality can be expressed through it and, finally, with practice is it possible to improve using it. These ideas foreshadow much of the ideas of the Natural User Interface and echo principles in game design and music instrument design.

Levin’s work is largely realtime and transitional in nature with gestures giving rise to visual and audio reactions that rise, fall and dissipate. A description that he uses of some of work is that of creating ripples in a pond. Therefore his work is very much geared towards an instrument like experience and is not concerned with the recording or visualization of the temporal unfolding of musical events as would be the function of compositional tools such as DAWs and musical notation. Indeed it is a conscious design decision to avoid such representations. Many of the principles and ideas of his work can, however, be applied in the context of a composition tool.

### 3.3.2 William Coleman’s sonicPainter

SonicPainter by William Coleman is a novel musical sequencer that seeks to address some of the shortcomings of traditional approaches to music sequencing found in commercial DAWs (Coleman, 2015). The focus of the line and node based interface (see figure) is to bring timbral shaping to the fore rather than being hidden away in miscellaneous automation lanes. The design takes influence from legacy musical systems, in particular, UPIC and incorporates ideas from visual music and embodied cognition.

Similarly to traditional sequencers the x axis represents time and the y axis pitch. Note information is input via keyboard and mouse but more as an intermediary prototype stage. The default mode for input is to click to create a node and follow that with an additional click to continue to shape the note. The note can be ended by clicking a keyboard shortcut. By enabling the drawing notes as lines in this manner, the unfolding of the note can be explicitly represented visually. Other timbral aspects such as vibrato are represented by further visual manipulation of the line. For instance, an overlaid sinewave line indicates the timing and amplitude of the vibrato. In addition, the system allows for freehand input of notes.

Coleman recommends that the system could be further improved by multitouch input, specific elements for the control of other synthesis techniques, time/pitch grid quantization, and further visual timbre feedback representations. Many of these recommendations will be addressed and explored in SonicSketch through a system built using the guidelines of NUI (natural user interface).

### 3.4 Alternative music systems on the web

### 3.5 Summary of currently available music creation systems

### 3.6 Conclusion

## 4 My approach

### 4.1 Introduction

### 4.2 Appraisal of options

### 4.3 Approach - theory

#### 4.3.1 HCI considerations

1. The natural user interface

NUI is an evolution of the concept of the graphic user interface and refers to an approach to human computer interaction beyond that of the traditional keyboard and mouse or what has been termed the WIMP model. It encompasses a set of guidelines and best practices which are set out most comprehensively by Wigdor (2014). Some of the basic tenets of NUI are as follows:

- Harness existing skills when possible without necessarily mimicing the real world tool or instrument (Wigdor and Wixon, 2011, p. 13).
- Be friendly and learnable by beginners but allow for mastery given enough practice (a sentiment shared by Levin, above) (Wigdor and Wixon, 2011, p. 13).
- Immediate feedback for all interactions should take place, most usually but not limited to, visual feedback. (Wigdor and Wixon, 2011, p. 87)

Furthermore, the interface should take advantage of the particular affordances offered by the input method. (Wigdor and Wixon, 2011, p. 115) An apt example of this is the early introduction of digital pens for windows laptops where the pen wasn't suited to the WIMP interface and failed to receive widespread usage. In this case, the interface forces the user to carry out awkward gestures for the medium, including double clicking and right clicking, failing to take advantage of the stroke gesture much more suited to it.

The system CrossY, referenced in Wigdor (2014), uses a cross gesture stroke to interact with buttons, menus, and widgets, as well as the painting functionality (???). The CrossY gesture system enables the user to, for instance, select brush size and colour in one stroke by dragging the pen from right to left across an icon and validating selection by dragging past the left or bottom selected leaf icon. This is illustrated clearly in the left-most diagram of the provided figure (fig. 3).

### 4.3.2 The Musical Interface Technology Design Space (MITDS)

### 4.3.3 Cross modal perception

## 4.4 Approach - practice

### 4.4.1 Delivery on Web Browser

### 4.4.2 Modern web browser as a delivery platform

### 4.4.3 Benefits of using tone.js Mann (2015)

### 4.4.4 Paper.js for the graphics system

### 4.4.5 FM synthesis :: give a brief overview of fm synthesis and why it was a

good choice for the application

### 4.4.6 Live coding workflow

1. [Introduction]
2. React.js framework

react is a web framework built by facebook that aids the developer in updating the dom (document object model), a process that is required when the state of the application changes. this was a role traditionally carried out on the server and served to users as a static page. this all changed however with the rise of single page applications (spa) around the 2000s. the value proposition of the spa is increased interactivity and responsiveness to user input, allowing the look and contents of the page to update dynamically as the user interacts with the system. to aid in the construction of these spa's a number of frameworks to help the process were introduced by the open source community. some popular early examples include *backbone.js* and *angular.js*. a technique that saw some popularity was a system called two way binding which created two way link between the current state in the model and the visual appearance of the view. this however has a number of issues including some serious performance issues, in addition to some conceptual problems (???ref). react offers a simpler one way binding system using what is termed the virtual dom. in this model a special virtual version of the dom is constructed and when the model changes is updated. the parts of the dom that require changing can thusly be pinpointed and the real dom can be efficiently updated. this system has proven to be particularly beneficial when paired with functional programming techniques, a style of programming that emphasizes the use of pure functions as the primary building block of programs. in the case of working with the dom, it can lead to not only an increase in efficiency in the rendering of the applications but also a simplification of the programming model. a number of projects have emerged that attempt to bring this benefits of the react model beyond the realm of the dom including writing console programs (???ref), writing web audio applications (???ref) and even arduino projects (???ref).

3. Clojurescript
4. Managing state with re-frame

## 4.5 Conclusion

# 5 Execution

## 5.1 Introduction

The following chapter gives an outline of the process that was undertaken to build out the final application. A description of early prototype work is given to give context to the construction of the final working prototype version. This is followed by a description of the technical architecture of the system as well as an outline of the sometimes tricky setup process of getting the live reload system working (as described in the previous chapter). Some detailed discussion of the the core functionality of the system is then given. The core of the system primarily consists of timeline events, which visually manifest themselves as strokes on the canvas and aurally as fm synthesized frequency modulated sounds. As will be discussed an important aspect of any well constructed software system is a good degree of separation of concerns, a characteristic espoused to and evident in the resulting code. To this end, the code that brings the central functionality to life can conceptually divided into a data or entity layer, a business logic or use case layer and an output layer which in this case consists of the visual output into a html canvas element and the audio output through the web audio api. In this sense the architecture conforms to the principles of the Clean Architecture as presented by Bob Martin (Martin, 2012).

## 5.2 Early prototype work

### 5.2.1 Melodypainter

Melodypainter is an early prototype built out in Max MSP that allows users to draw freehand lines, which are converted into break point function data and used to generate a melodic profiles using Bach for Max MSP. Bach is a suite of composition tools that allow for a number of computer aided composition techniques (CAC) and provides similar functionality to IRCAM’s Open Music system. These melodic profiles are then filtered to only includes notes from a pentatonic scale, to give reasonably pleasing aural results. Some notable flaws in the system include the following. It is limited to strictly western tonal music styles. It has no allowance for rhythm and plays only eight notes giving results a noticeably bland and predictable quality. The freeform nature of sketched input however was quite a pleasing means of inputting the control information.

### 5.2.2 Sonicshaper [0/1]

A separate application was created in Processing which allowed users to draw shapes, using either mouse or ideally, pen input and have a sound that is associated with each shape played back. As the sound of each shape plays back, it is lit up using animation, creating a strong connection between the shape and it’s resulting sound. The application uses the “gesture variation follower” system (Caramiaux *et al.*, 2015), which while promising in principle, didn’t have a high rate of accuracy in recognizing the shapes.

### 5.2.3 TODO Web version of William Coleman’s SonicPainter [0/1]

A potential starting point that was considered was using the code from William’s SonicPainter and porting it to the web platform. This process proved to be quite straightforward. The processing code could more or less be embedded in a webpage as is using “processing.js”, a web version of the Processing library that enables users to run processing sketches in the Web Browser. Some notable changes that had to be made were removing the OSC functionality as this is not technically possible to use in a browser. In addition, some other pieces of code had to be commented out and tweaked. As it’s not possible to run Max MSP patches in the browser, the audio system was re-implemented

using Tone.js. As SonicPainter uses simple FM synthesis, a very close approximation to the original version could be created. In the end, it was decided not to build on this codebase however as there were some issues with functionality and useability that would be difficult to resolve in an inherited codebase. A fundamental issue was that transitions between certain states would cause crashes or unpredictable behaviour. An example of this is when a user attempts to use the vibrato tool while in the process of creating a note. Instead of either finishing the note and starting the vibrato tool or disallowing the behaviour, the program would crash. This is a common problem in software development and is evidence even in commercial products. To alleviate such issues in the new codebase a more disciplined approach would be taken to managing transitions between states. The process of porting the code did however give a more in depth incite into Coleman's implementation incuding the pitfalls mentioned above. In addition, the basic visual look and conceptual functionality would form the basis of the workings of SonicSketch.

## 5.3 Actual implementation

### 5.3.1 Setting up the architecture

#### 1. Clojurescript and javascript npm modules

Despite the fact that clojurescript has existed for six years(???), some areas of the development process are still difficult, particularly when building out a more complex real world application. It should be noted that a good deal of work is being carried out to make this a smoother experience and thusly these pains are likely to become less of an issue in the near future (???ref). It should also be noted that building applicatons using plain javascript is not a trivial process and in all likelihood will include a build process using a system like webpack or browserify. A primary issue that had to be resolved to allow the application to be built out was the incorporation of javascript npm modules. NPM is the module system used by node.js originally for more server oriented technologies but increasingly for rich clientside applications. For a purely javascript application, it would be a matter of simply adding the desired libraries as dependencies. However, with the use of clojurescript some extra steps needed to be carried out. In addition to adding the dependencies, a javascript file was created that imported these into a “deps” object. This deps object could then be referred to in clojurescript using the standard interop syntax `js/deps.myDependency`. At the time of development an alpha feature that allowed npm dependencies to be declared as part of the `project.clj` file was experimented with but was not used in due to difficulties getting it to work. While the project setup was not as elegant or succint as might be wished, it did provide a stable base to build on and a means to harness the rich resource that is the NPM ecosystem and use such tools as Paper.js and React.js.

#### 2. Paper.js and react.js (paper.js bindings)

As has been outlined in the previous chapter, a declarative coding style would be employed to enable a live coding workflow and to avoid a building a codebase that is increasingly difficult to understand. In other words the code should as much as possible describe the “what” of the functionality rather than the “how”. These qualities emerge quite naturally when using the *React.js* architecture. Paper.js however runs in the context of a canvas element and thusly it is not possible to directly use *React.js* with it. This shortcoming has been addressed in projects such as *three.js react bindings* and *pixi.js react bindings* which allow the use of react's declaritive programming style for 3d and 2d scenegraph oriented systems that run in the html canvas element. These solutions both work by creating dummy empty dom elements and hook into the *React.js* lifecycle events to the real work of updating the scenegraph. In many ways the scene graph structure of projects like these and indeed Paper.js exhibit a high resemblance to DOM structures and APIs making React a good fit for them. A similar approach to the above mentioned libraries approach was taken to integrate paper.js for use in SonicSketch and worked reasonably well but required quite a bit of setup. During the development of the project, a more suitable solution emerged from the open source community at an opportune

time. This used the next version of *React.js* which has better support for render targets that are not the DOM and has the distinct advantage of not requiring the creation of redundant DOM nodes. The library was far from comprehensive and thusly a custom version of the library was used that included some custom functionality required for SonicSketch.

### 3. Tone.js and react.js

In some ways audio output can be thought of in a similar way to the visual output of the app and thusly can be treated in similar way by *React.js*. It can use the declarative data oriented system of react to configure the particular settings and connections in the audio graph and hook in to its lifecycle events to instantiate the various audio generating and processing web audio nodes. This addresses a notable (by design) omission in Tone.js which does not allow the code to query the state of the audio graph once it has been setup. It is down to the userland code to keep track of this and manage it accordingly. The value proposal offered by introducing react.js into this part of the system is that it maintains the simple relationship between state and generated output. Conceptually the flow of change is:

- (a) The state updates
- (b) The react wrapper objects update their properties accordingly
- (c) The lifecycle events are triggered which takes care of altering, adding and removing web audio nodes (thus altering the audio being output)

The design of this part of the application is influenced by *react music*, a system that uses *React.js* with *tuna.js*, a web audio library similar to *tone.js* (???ref).

### 4. Reagent and react.js paper.js bindings

The final piece of the jigsaw in the underlying technology stack is the integration of react with clojurescript via the *Reagent* library. The core syntax of this system is simple clojurescript vectors similar to the following: This would result in the following html output: As can be seen the vectors begin with a keyword that corresponds to the tagname of the html. Additionally, instead of using html tag keywords, function calls can be made to generate html to allow for code reuse and logic. It was unclear how the paper.js bindings would work within this system due to the fact that it required a different version of react and uses non standard tag names for elements that can be drawn on screen such as “circle” and “rectangle”. This however turned out to be much more straightforward than expected and the provided paper.js primitives could be simply using the relevant paper.js keywords. Complex scenegraphs could be constructed by using the following succinct clojurescript syntax to describe the playback indicator:

As can probably be inferred from the code the `position` and `height` are properties that are passed into the hiccup and trigger updates to the visual display when they change: in the case of position, when the playback position changes and in the case of the height, when the user resizes the browser window. The path element describes the triangle that is placed at the top of the screen.

The current state of the art in live code reloading in the browser is still not as comprehensive or as easy to setup as might be wished. Once it has been configured it is difficult to return to the compile and run workflow, and is in most cases a worthwhile investment of time. With these underlying elements in place the process of creating the core functionality application could begin and will now be described.

## 5.3.2 Core functionality - timeline events (or notes)

At the core of the application is the creation of timeline events which unfold in a looped fashion. These events are created based on the input of the user with a mouse or mouse like input device. On the production of a valid input gesture, the screen is updated immediately with a visual display of this content. The details of this gesture is stored in memory and the event that will eventually create the sound is registered with *tone.js*. Much of the events that occur in the system are captured

in a main “View” component which houses the central html canvas element. To aid in organising the large amount of functionality associated with the component, higher order components are used to separate this out into logical groupings. A higher order component is a component that wraps a normal component to add functionality to it and accepts the same properties as the component it wraps (???ref-react). In this case the most logical grouping is by tool and so there are higher order components setup for each of the tools: draw, vibrato, delete, move, resize and probability.

#### 1. Add timeline event

This is the default tool that is activated when the user opens the application and enables the user to add timeline events by drawing them onto the screen. It is added to the system when the “draw” tool is activated and a mouse drag operation is carried out from left to right within the bounds of the canvas element. The event is captured in the main canvas view and is initiated when the user left clicks the mouse triggering the following function:

This function receives a hashmap with a reference to a *ClojureScript* atom which can is **reset!** to contain a temporary visualisation of the newly created note. This function uses a heavy amount of javascript interop to directly instantiate paper.js objects and add them to a shared group.

As the user continues to move the cursor further points are added to the path created in the **pointer-down** function. Some constraints however are placed on the creation of the path and only points that are past the last previous from left to right are added. If the users backtracks it lead to a deletion of points, providing an intuitive undo like behaviour and implementing a recipricol HCI interaction pattern recommended by NUI principles. Completion of a note occurs when the user releases the button and triggers the **pointer-up** function: This function simplifies the path by calling the paper.js **simplify** method on the path object and dramatically reduces the amount of data captured while preserving the basic characteristic of the user’s stroke (???ref-simplify-fn). Most importantly it calls the *re-frame* **dispatch** function to add the note to the app database. A **path->note** function is used to convert the stroke from the domain of euclidean space on the visual space of the canvas to the domain of time-pitch space for use with the audio synthesis system. The path->note function can be seen below: The domain of time-pitch is used to store the notes in memory and makes it possible to maintain a relative relationship between the screen size and the drawn notes.

The dispatched note event is handled by a *re-frame* **reg-event-db** handler which describes the alteration that is required to be made to the database. It also uses a series of interceptors, to perform validation of the database and to remove some of the boilerplate from the event handler functions. Interceptors are similar conceptually to middleware and is the place where all of the side effects arising from an event are actioned. Moving application side effects to this placed ensures that they are isolated and means that the majority of the program can be kept as pure logic improving to make it easier to test, debug and reason about. As can be seen the handler function is very simple: This does a simple check to make sure that note has a minimum duration and if so alters the notes vector to include the new vector which will instruct *re-frame* to update it’s internal atom with this new state.

The structure of the note hashmap is defined using *clojure.spec*, a core library to perform data validation and a tool that may be used similarly to types in strongly typed languages. The note specs are defined as follows: Although note specified here, notes also have an **envelopes** key that stores frequency and vibrato envelopes. For example: The update in state spins *re-frame*’s subscription system into action and any views that are subscribed to the changed application state are now re-rendered. The **graphics-notes** view for instance is subscribed to **:notes**, **:graphics-stage-width**, **:graphics-stage-height**: and **:mode**: When a note is added this render function will run which will call the **[graphics-note\*]** component for each of the notes, and update the visual display of the screen to show the new note. A similar process happens in the audio system except, in this case, new web audio nodes are created, timeline events are queued up at the correct time and audio envelopes are setup that traces the curve of the drawn lines. (Adenot, 2017) The above shows the **fm-synth** which sits at the heart of the audio generating part of the system. Potential parent components of this would

be audio effects or the master bus. It's child components are comprised of note events and envelopes that drive frequency changes over the course of the note playback. The composition of events, envelopes, synths, effects and channels is shown in truncated form:

## 2. Editing notes

Once created, a number of editing operations can be performed on the notes. Apart from the **delete** action all of these operations involve first selecting the note on the **mouse down** event, carrying out the editing of the note and completing the action with the mouse up event. The particular tool can be activated by clicking the icon the right-hand side of the screen (see ??). Clicking one of these dispatches the **:change-mode** event and changes the **app-db** to the specified mode as well as setting the application to state **:pending**. Flowing from this change are a number of changes:

- (a) The relevant `paper.js` tool is activated which will route further mouse events to the appropriate dispatch handlers. For instance, when the **:resize** mode is selected, **mouse move** events will be handled by **:resize-tool-pointer-move**.
- (b) It updates the visual look of the cursor to remind the user which of mode they are in.
- (c) A visual indicator is shown around the icon of the selected mode

The overall effect of this is an activation of a number of different modes, each of which will now be discussed.

In the case of deleting notes, the event is simply raised in the **click** event of the note, which takes care of dispatching the **:note-delete** event.

This is handled by a very simple handler, (`dissoc notes note-id`) that instructs *re-frame* to remove the note in question from the database. Similar to the process that occurs when a note is added, the visual display is now updated to no longer show the note. In addition, the signal generator, effects, envelopes and events associated with the note are removed from the audio component tree with *React.js*'s lifecycle events taking care to clean up any synth's and effects by calling their **dispose** methods.

Moving notes and resizing notes work very similarly and both follow the most basic pattern described above of selection, manipulation, and completion. The note selection event is raised from the note's **mouse down** event handler, dispatching the **:note-select** event with the **note-id**. This updates the **app-db** to set the **:active-note-id:** to the received id, sets the app state to **=:active**, sets the note state to be **:active** and resets previously active notes to state, **:normal**. This state update changes the visual display of the active note to be highlighted by slightly lightening the colour of the note's surrounding glow. More importantly, the note now becomes the active item on which further user interactions are performed on. In the case of the **move** tool the stored onset and pitch properties of the note are altered to reflect the position of the user's mouse. This, in turn, updates the visual display of the note and causes the audio system to re-queue the note events to the new onset and pitch values. The **resize** tool, on the other hand, changes the size of the starting node of the note and alters the velocity accordingly. The altered size is calculated from the coordinates of the **mouse down** event and is clamped to a maximum size that corresponds to the maximum velocity of the note.

The slightly more esoteric **probability** tool works in a very similar fashion to the **resize** tools and again creates adjustments that work relative to **mouse down** coordinates. The visual effect that this creates, however, is a dulling of the saturation of the note. Its effect is to add an element of randomness and depending on how saturated the note is, it will cause the note to randomly skip. The code for this is below: `#=INCLUDE: "ch5-code.org::probability-queueing"` If the probability is set to 1.0 (which is the default) or fully saturated the note will play on every loop. If however, it is below this it will skip in a random but probabilistic fashion, adding a small amount of stochasticism to playback.

The vibrato tool is the most complex in its implementation and involves a small popup UI element that allows the user to draw in a vibrato envelope which is visually reflected in the



note lines as an overlaid sinewave. After selection occurs, in the usual way, **mouse move** events dispatch to the **:vibrato-continue** handler which updates a vibrato modulation parameter in the note, a single float value that represents the current real-time vibrato value. This modulation parameter is passed back to the view through properties where triggers a **:component-did-update** function call. It is here that a dispatch is made to the **:vibrato-envelope-point** to create the envelope point. The reason for the back and forth between the view and the event handlers is to allow the event handlers to manage the state changes but deal with the specifics of the geometry of the vibrato overlay in the view. It is probably best illustrated in the provided figure (??).

A visual overlay is shown to the user when a vibrato action is started, that shows a 10 point envelope, whose points are all set to 0.0 by default. The user can then drag at varying heights at various horizontal points on the axis and create the time-varying vibrato envelope. This envelope is visualised (and remains visible after the vibrato operation has completed) with a sinewave that tracks the curve of the frequency envelope and varies its amplitude depending on the strength of the vibrato at that particular point. The code to achieve this is below:

### 5.3.3 Secondary functionality

Aside from the core functionality of note creation and editing, a number of other use cases had to be catered for to make the application useable. This included transport controls, to allow the user to start and stop playback; some simple animation to show which notes are being played and to tighten the link between the visuals and the audio; undo and redo functionality; a fullscreen toggle to maximise the immersiveness; as well as the ability to save and load sketches. While not central to the concept, standard usability features such as undo/redo would be a noticeable omission that would decrease beginner friendliness. Some of these extra features were made more straightforward than would normally be the case due to the architecture of placing the state in a single place, the *re-frame* **app db**.

Both the transport and the fullscreen mechanism consisted of a simple finite state machine (FSM) that whose transitions are caused by user actions. The transport state machine responds to both the button click and **spacebar** keypresses to toggle its state between playing and stopped and based on this, triggering playback in *tone.js*. The fullscreen FSM transitions occur not only when the user clicks the fullscreen button but also when the browser fullscreen status changes. This keeps the UI in a correct and consistent state at all times, regardless of how the state is reached.

Undo/redo and save/load functionality was relatively straightforward to implement for the reasons mentioned above (centrally located state) as well as the ease of serialising *clojurescript* data. Adding undo/redo was as easy as adding an additional dependency and adding it as an interceptor to any events that needed to be undoable such as adding or deleting notes.

The particular parts of state that needed to be restored were also configured and included the **notes** collection and the **tempo**. Both of these elements were saved and restored by the save/restore functionality which worked by serialising this data as a string and restoring with a single function call to *clojurescript*'s **reader/read-string**.

Animation...

## 5.4 Conclusion

- Summarise the resulting artifact

## 6 Evaluation

### 6.1 Introduction

### 6.2 Initial pilot test

### 6.3 Exhibition

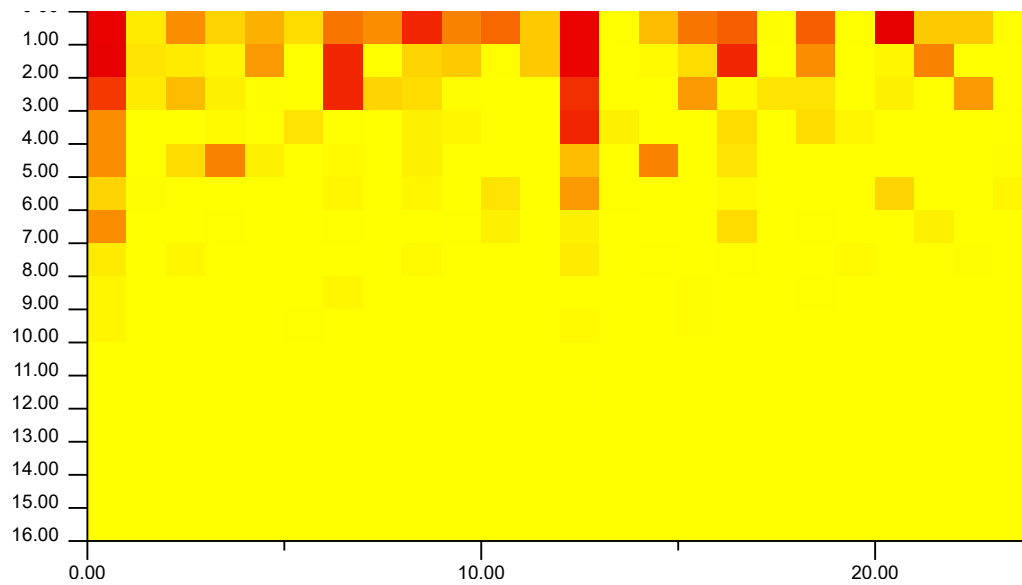


Figure 1: Heat graph displaying note start points

As you can see in the figure 1, the majority of activity is in the upper regions of the frequency spectrum and concentrated at the beginning and the middle of the screen.

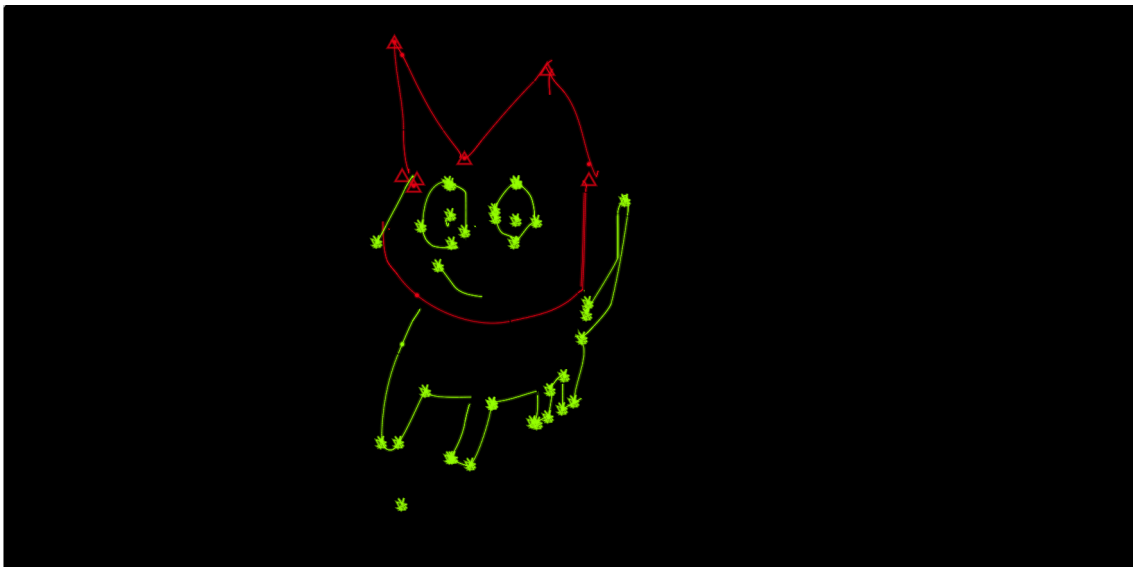


Figure 2: Some exhibit participants managed to draw figurative artwork!

## 6.4 Performance issues

## 6.5 Conclusion

# 7 Conclusion and further work

## 7.1 Summary of work completed

## 7.2 Broader implications of development

## 7.3 Future work

### 7.3.1 Performance improvements

### 7.3.2 Broaden visual language

### 7.3.3 Allow for larger structures

### 7.3.4 3D spaces, VR, spatial audio

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