likely music

Probabilistische Musiknotation

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Zusammenfassung

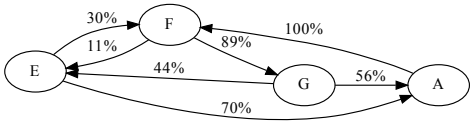
likely music ist eine Software, um probabilistische Musik zu notieren und abzuspielen. Probabilistische Musik bedeutet in diesem Falle, dass die Interpretation der vorliegenden Notation deutlich freier ist als bei herkömmlicher Musik und auch die Reihenfolge der Noten betrifft. Um dies zu erreichen, wird ein eigenes Modell von Musiknotation verwendet. Anstelle von linearer Reihenfolge von Noten bzw. Akkorden tritt ein gerichteter Graph, in dem die Noten (bzw. Akkorde) die Knoten und die möglichen Übergange zwischen diesen die Kanten darstellen. Jeder Kante ist eine gewisse Wahrscheinlichkeit zugeordnet. Dieses Modell ist unter anderem sehr gut von einem Computer zu fassen, wodurch es möglich wird, solche Notationen automatisch zu „interpretieren“ oder abzuspielen: Eine konkrete Notenabfolge wird gemäß der Notation ausgewürfelt.

Die Software *likely music* kann sowohl probabilistische Noten erstellen und editieren, als auch mittels MIDI diese abspielen oder als Audiodateien exportieren.

Idee

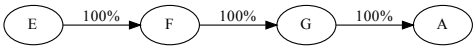
Der eigentlichen Idee ging ein mehr oder minder gescheitertes Projekt für diesen Wettbewerb voraus. Im Frühjahr diesen Jahres entschied ich mich, dieses – eine Demo [1] – abzubrechen, einfach weil ich befürchtete, es nicht bis zur Frist fertigstellen zu können. Die damalige Motivation für das Projekt speiste sich aus meiner Faszination für Demos an sich. Die Begeisterung für das neue speiste sich aus einer weiteren Faszination von mir, nämlich einer für Kunst, die durch Zufall entsteht. Ich erinnere mich besonders oft an Kunstinstallationen, die jeweils ihr gestaltendes Element aus Zufälligem, einen undurchschaubaren oder chaotischen Prozess bezieht. Beim Nachdenken über Zwölftonmusik, die – aus meiner Perspektive – ein wenig jenen Elements hat, kam mir die Grundidee für *likely music* auf dem Gang zwischen zwei Schulstunden: Nämlich ein Modell, um Musik zu beschreiben, die zufällig im Vortrag ist.

Das Modell, das ich aus Angst es zu vergessen, mehrmals aufschrieb, sieht Musik als gerichteten Graphen, wobei die Knoten Musiknoten einer bestimmten Länge und die Kanten zwischen ihnen die Wahrscheinlichkeit des Wechsel von der einen Note zur anderen sind. Vorstellen kann man sich es in etwa wie in der folgenden Grafik.

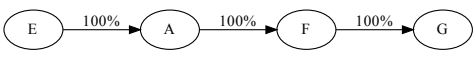


In diesem konkreten Graphen sind die Noten E, F, G und A als Knoten vertreten (der Einfachheit halber sind die Notenlängen weggelassen). Beispielsweise vom E führen zwei Kanten weg, eine zum F mit dreißigprozentiger Wahrscheinlichkeit und eine zum A mit siebzigprozentiger Wahrscheinlichkeit, d. h. nach dem E kommt in sieben von zehn Fällen das A und in den drei übrigen das F. Analog verhält es sich mit den anderen Noten.

Diese Darstellung ist in gewisser Weise auch nur eine ausdrucksstärkere Form einer normalen Notation, denn ein Weg durch den obigen Graphen könnte so aussehen:



Diese Interpretation, die eine Wahrscheinlichkeit von ca. 15% hat, entspricht einer einfachen, linearen Notation, wie sie in einem Gesangsbuch stehen könnte. Wir sehen also, dass solche probabilistische Noten (wie unser Graph von vorhin) durch ein Verfahren, das ich einfach in einer Erweiterung des Begriffs als Interpretieren bezeichne, auf eine lineare Notation reduziert werden können, die mit einem Instrument oder vom Computer gespielt werden können. Es ist sogar nicht nur eine lineare Notation, sondern – je nach vorgegebenem Graph – eine Vielzahl ihrer möglich. Beispielsweise wäre eine weitere:



Ähnlich enthält der ursprüngliche Graph weitere Möglichkeiten von klassischen Tonabfolgen. Insofern stellt eine probabilistische Notation eine ausdruckstärkere und mächtigere Notation dar, da sie beliebig viele klassische fassen kann.

Zu beachten ist bei den beiden Beispielinterpretationen noch: Sie sind nach vier No-

ten abgeschnitten, denn, da von jedem Knoten mindestens eine Kante ausgeht, könnte man den Graphen potentiell unendlich lang ablaufen und würde somit eine unendlich lange Interpretation generieren.

Was aus dieser Grundidee zu machen war, schien mir von Anfang an recht klar: Als Software implementieren, um ein graphisches Interface bereitzustellen, das es erlaubt, probabilistische Notation zu erstellen, zu editieren und abzuspielen.

Umsetzung

Gleich zu Beginn war klar, dass Haskell die Programmiersprache der Wahl werden sollte. Sie ist die Sprache, die ich in den letzten Jahren am aktivsten verwendet habe und mir einiges bietet: Statische Typisierung, um Fehler vorzubeugen, ein expressives Typsystem, das es erlaubt, Daten besser zu strukturieren, und funktionale Programmierparadigmen, die sich für mich sehr natürlich anfühlen und das Testen von Programmen erleichtern.

Zunächst konzentrierte ich mich darauf, den Graphen und den Interpretationsalgorithmus als Bibliothek zu implementieren. In der ersten Iteration dieser Bibliothek, noch *probable music* genannt, begann ich auch einen eigenen Softwaresynthesizer zu implementieren, der flexibel auf verschiedenen Plattformen und zu verschiedenen Zwecken verwendet werden kann. Der Synthesizer konnte jegliche Darstellungen von Klängen, Tönen oder Musik dank flexibler Architektur in tatsächliche Töne bzw. Audiowellen umwandeln. Dies ergab interessante Möglichkeiten, sich außerhalb des Zwölftonsystems zu bewegen. Die Tonerzeugung basierte dann auf einer freien Monade [2], die die Instruktionen ›Warten‹ und ›Abspielen‹ kannte. Indem man diese Instruktionen für verschiedene Audiosystem, wie SDL [4], Jack [3] oder auch Audiodateien wie WAV [5] implementierte, konnte man verschiedene Plattformen unterstützen. Allerdings gestaltete es sich schwierig, einen gut klingenden Synthesizer zu schreiben, denn die Messlatte ist im Vergleich zu realen Instrumenten hoch. Hinzu kamen noch einige Performance-Probleme mit meinem maschinennahen Audio-Code.

Also entschied ich mich, die Library vor allem auf den Graphen und die dazugehörigen Algorithmen zu fokusieren und zur Tonerzeugung eine geeignete Abstraktion zu verwenden, um diese zu vereinfachen. Ich habe hierfür MIDI gewählt, eine Technologie, die schon lange in allen Arten von Software und Hardware zur Musikproduktion verwendet wird. MIDI basiert auf einer Abfolge von zeitlich abgestimmten Nachrichten, wie zum Beispiel ›Note C an‹ oder ›Note C aus‹. Aufgrund dieser Nachrichten kann man die Erzeugung und das Abspielen von Musik zwischen mehreren Programmen aufteilen. Außerdem erlaubt es, die bereits existierende Infrastruktur für MIDI-Verarbeitung zu verwenden, die sehr beachtlich ist. Für MIDI verwendet *likely music* die Open-Source-Bibliothek Euterpea[1] [8], die unter anderem eine kleine Abstraktion über MIDI enthält. Sie erlaubt es, in einem internen Format Musik zu konstruieren und anschließend als MIDI zu exportieren bzw. an ein anderes Programm zur Weiterverarbeitung zu schicken.

Bei der Darstellung des Graphen habe ich mich vor allem darauf konzentriert, den Interpretationsalgorithmus, also das (zufällige) Ablaufen des Graphen, möglichst effizient zu gestalten. Da es sich um einen gerichten Graphen handelt, ist es besonders wichtig zu wissen, wohin man von einem gegebenen Knoten aus gelangen kann bzw. welche Kanten von einem Knoten weggehen. So gelangt man in unserem Beispiel aus dem vorherigen Kapitel vom Knoten mit dem E zu den Knoten mit F und A. Es muss also möglichst effizient sein, die Kanten nachzuschlagen, die von einem Knoten *wegführen*. Mit der Datenstruktur *Map* [11] (im deutschen Sprachgebrauch typischerweise *assoziative Datenfeld*) kann genau das sehr leicht realisiert werden: Man verwendet die Knoten als Schlüssel und eine Liste von Kanten, die vom Schlüssel weggehen, als Elemente. Wenn der Algorithmus nun einen Knoten nachschlägt, erhält er direkt die Kanten, die von diesem Knoten weggehen und somit auch die nächsten möglichen Knoten. Dies ist die einzige Information, die in jedem Schritt des Algorithmus benötigt wird. Die Operation des Nachschlagens hat in einem *Map* die Komplexität $O(\log n)$ [12], d. h. die Zeit, die benötigt wird, um ein Element nachzuschlagen, steigt mit dem Wachsen der Datenstruktur logarithmisch (d. h. weniger starkes Wachstum als lineares!). Damit bleibt auch das Interpretieren großer Graphen ziemlich schnell. Der Code für die Datenstruktur findet sich im Abschnitt Library, Zeile 30 bis 43.

Der Interpretationsalgorithmus selbst ist rekursiv [15] gestaltet und findet sich in der Funktion `interpretation`, siehe Abschnitt Library, Zeile 52 bis 60. Diese Funktion benötigt einen initialisierten Pseudozufallszahlengenerator [13, 14], den zu interpretierenden Graphen in der eben besprochenen Datenstruktur und einen Startknoten. Nach Ablauf der Berechnung gibt die resultierende Interpretation im MIDI-Format von Euterpea [8] zurück. Zunächst wird der Startknoten im Graphen nachgeschlagen, so werden die Kanten bzw. die nächsten möglichen Knoten erhalten. Nun gibt es zwei Möglichkei-

[1] Ich musste allerdings aufgrund von Inkompatibilitäten mit den aktuellen Haskell-Paketen diese selbst beheben [9]. Diese Änderung wartet [10] aktuell (Stand 23.09.2017) darauf, vom Hauptentwickler in den Code von Euterpea übernommen zu werden.

ten für den weiteren Verlauf:

1. Es gibt keine Kanten, die von diesem Knoten ausgehen. Also wird die bisher generierte Interpretation einfach zurückgegeben, die Funktion terminiert.

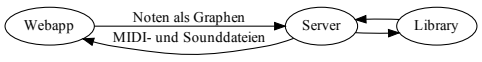
2. Wenn es eine oder mehr Kanten vom Knoten aus gibt, wird eine (reelle) Zufallszahl zwischen 0 und 1 berechnet und mittels der Hilfsfunktion `edgeForRoll` (siehe Abschnitt Library, Zeile 62 - 67) die Kante erhalten, die gemäß des zufälligen Ergebnisses als nächstes abgelaufen werden soll. Nun ergibt sich das gleiche Problem wie zu Beginn der Interpretation: Man kennt einen Knoten und will wissen, wie es weitergeht. Also wird nach der Ermittlung des zweiten Knotens die MIDI-Nachrichten aus dem Startknoten extrahiert und dann der Interpretationsalgorithmus nochmal bzw. rekursiv aufgerufen – nur mit dem Folgeknoten als Startknoten. Dessen Ergebnis wird an die aktuellen MIDI-Nachrichten angehängt, was jener Aufruf auch seinerseits wieder macht. So entsteht rekursiv eine (potentiell unendliche) Verkettung von MIDI-Nachrichten, die letztlich die finale Interpretation ergeben.

Da die meisten Graphen vermutlich vollständig untereinander verbunden sein werden, wie zum Beispiel der Beispielgraph im ersten Abschnitt, entstehen unendlich lange Interpretationen. Diese zu erstellen benötigt naturgemäß auch unendlich viel Zeit – der Interpretationsalgorithmus terminiert also nicht. Die einfache Antwort auf dieses Problem ist die Begrenzung der Länge der Interpretation auf eine gewisse Anzahl von Noten, was sich dank eines Sprachfeatures von Haskell – Lazy Evaluation [16] – leicht umsetzen lässt. Denn mit Lazy Evaluation wird nur das berechnet, was im Moment benötigt wird. Somit werden zum Beispiel nur die ersten vier benötigten Noten berechnet und nicht die unendlich vielen, die eigentlich noch darauf folgen würden – genau dies wird durch die Funktion `takeNotes` (siehe Abschnitt Library, Zeile 79 - 86) realisiert.

Nun können wir probabilistische Musik in Graphen darstellen, diese automatisch interpretieren und dank Euterpea nach MIDI exportieren. Was fehlt, ist eine angenehme Benutzerschnittstelle.

Zur Technologie für die Benutzerschnittstelle gab es für mich folgende Überlegungen: Zum einen sollte es leicht portabel bzw. auf jedem System laufen sowie außerdem einen begrenzten Entwicklungsaufwand mit sich bringen. Ich selbst entwickle meine Software auf GNU/Linux, aber zur Abgabe müsste es auf macOS und / oder Windows laufen. Alle größeren Frameworks für Graphische Interfaces für GNU/Linux, wie zum Beispiel Qt [21] oder GTK [22], laufen auch auf den anderen großen Betriebssystemen. Allerdings bin ich nicht besonders vertraut mit irgendeinem dieser Frameworks. Außerdem war ich mir nicht sicher, wie stressfrei die Verwendung dieser von Haskell aus sein würde (denn klassischerweise verwendet man C oder C++). Also entschied ich mich, *likely music* als Webapplikation, die einfach in gängigen Browsern läuft, zu implementieren. Das hat einige Vorteile für mich, unter anderem, dass es leicht zu testen ist, weil die Browser eigentlich überall gleich sind, und, dass ich schon einige Erfahrung in Webentwicklung hatte.

Ich hatte die Library allerdings in Haskell implementiert, in Browsern läuft jedoch nur JavaScript (ohne größeren Aufwand zumindest). Also musste ein Programm her, um die Kommunikation zwischen der Library und der Webapplikation zu realisieren. Ich entschied mich für eine Client-Server-Architektur [17], also einen Server, der die Interpretation und den Export von Sounddateien für den Client, also die Webapplikation, übernimmt. Der Client wiederum müsste sich ausschließlich um ein ansprechendes Interface kümmern. Die ungefähre Gesamtarchitektur sieht also nun so aus:



Der Server basiert auf den Libraries servant [18] als Webframework. Wie im Abschnitt Backend zu sehen, besteht das Serverbackend aus zwei Dateien Quelltext: In `Api.hs` wird die Struktur der REST-API [19] definiert, mittels der die Webapplikation mit dem Server kommuniziert. In `Main.hs` wird die Funktionalität konkret implementiert. Die API bietet folgende Funktionalität an:

- `/interpretation/mid` An diesen Endpunkt schickt die Webapplikation einen Graphen plus einiger Parameter in Form von JSON [20] und erhält eine Interpretation auf Basis des Algorithmus als MIDI-Datei zurück.

- `/interpretation/wav` Gleich wie der obige Endpunkt, allerdings wird vorher noch das MIDI mittels des MIDI-Synthesizers fluidsynth [23] in eine WAV-Datei konvertiert, so dass man die Interpretation direkt anhören kann.

- Außerdem liefert der Server die statischen Dateien der Webapplikation, wie das nötige HTML, JavaScript und CSS.

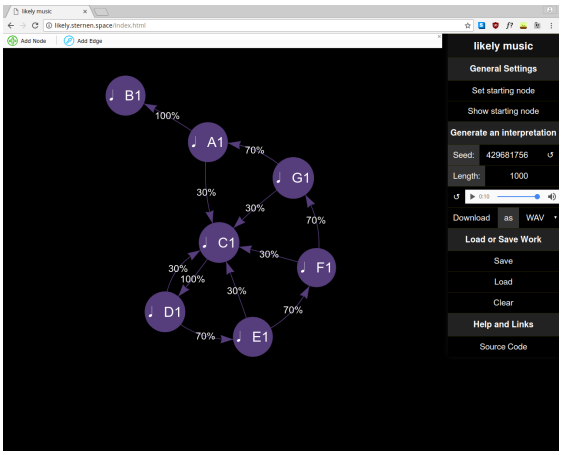
Die erwähnten Parameter sind folgende drei:

- Der Anfangsknoten der Interpretation im Graphen, den der Algorithmus benötigt (wie oben besprochen).

- Die Länge der Interpretation als die maximale Anzahl an Noten in der Interpretation.

- Der Startwert für den Pseudozufallszahlengenerator [14], der für die Interpretation verwendet werden soll. Da derselbe Startwert in dieselbe Interpretation resultiert, erlaubt dies, sich interessante Interpretationen zu merken und zum Beispiel zu einer Interpretation noch die MIDI-Version zusätzlich herunterzuladen.

Dies ist auch schon alles, was das Serverbackend tut, denn es ist nur als minimaler Aufsatz auf die Library konzipiert. Das meiste für Benutzer*innen relevante passiert in der Webapplikation, die folgendermaßen aussieht:

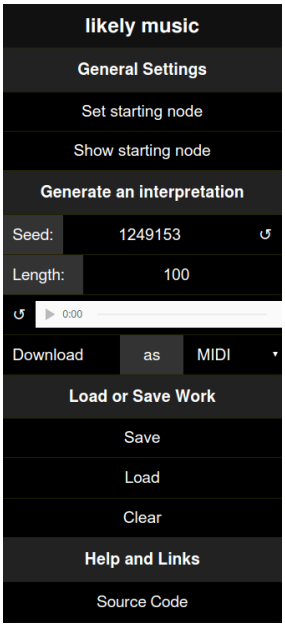


Sie ist komplett in Englisch gehalten und sollte so in allen modernen Browsern laufen, getestet habe ich sie mit den aktuellen Versionen von Chrome [27] und Firefox [28].

Den Kern der Applikation bildet der Graph-Editor links, der auf der Library vis.js[2] [24] basiert. vis.js kümmert sich um einen sehr gut anpassbaren Graph-Editor, in dem der*die Benutzer*in Knoten und Kanten hinzufügen, löschen und ändern kann. Da die Library Callbacks [26] bereitstellt, ist es leicht, den Rest der Applikation mit dem Editor zu integrieren.

Wenn ein Knoten oder eine Kante geändert wird, wird diese Änderung in eine Zustandsvariable der Applikation mitübernommen und die Zusatzinformationen der Knoten und Kanten, also Notenlänge und Tonhöhe (Knoten) bzw. Wahrscheinlichkeit (Kante), von dem*der Benutzer*in in einer Einblendung abgefragt und ebenfalls abgespeichert. So gelingt es, den Graph-Editor so zu integrieren, dass der Graph zur Kommunikation mit dem Server und sonstiger Verarbeitung zur Verfügung steht. Die doppelte Speicherung der reinen Graphdaten kommt daher, dass vis.js es leider nicht erlaubt, die bereits im Editor vorhandenen Daten abzufragen. Daher büßt die Architektur der Applikation leider ein wenig an Eleganz ein.

In der Seitenspalte passiert dann alles, was relevant für die Verarbeitung der links entstehenden Notation ist. Zum einen kann der Notationsgraph abgespeichert oder ein gespeicherter geöffnet werden, zum anderen ist es möglich, Interpretationen generieren zu lassen, diese direkt im Browser abzuspielen oder als MIDI oder WAV herunterzuladen. Die Seitenspalte ist im Folgenden abgebildet.



Das Speichern und Öffnen von Notationen basiert auf JSON-Dateien [20] in bestimmtem Format, die als `<dateiname>.score.json` abgespeichert werden. Eine solche enthält eine Liste aller Knoten plus Zusatzinformationen und eine Liste aller Kanten plus Zusatzinformationen. Wie eine solche aussehen kann, sieht man im Abschnitt Web (letzte Datei). Genau dieses Format wird übrigens auch zur Kommunikation mit dem Server verwendet, da es den Graphen verlustlos beschreiben kann.

Der Rest der Applikation kümmert sich vor allem um Interpretation und Export dieser. Oben in der Seitenleiste kann man die drei erwähnten Parameter setzen. Der Startknoten wird über Markieren desselben im Editor und klicken des entsprechenden Buttons gesetzt und kann durch Hervorhebung im Graphen auch angezeigt werden. Der Startwert kann manuell eingegeben (etwa, wenn man sich einen besonderen notiert hat) oder ein zufälliger durch Betätigung des Buttons neben dem Feld generiert werden. Die maximale Interpretationslänge ist dann darunter und wird ganz unspektakulär eingegeben.

Darunter befindet sich ein Audioplayer, mit dem erstellte Interpretationen direkt im Browser angehört werden können. Wenn man den Aktualisierungsbutton links betätigt, nimmt die Applikation alle Parameter sowie den aktuellen Graphen und sendet mithilfe der JavaScript Fetch API [29] den Graphen mitsamt der Parameter an den bereits erwähnten Endpunkt `/interpretation/wav`. Nach diesem Vorgang, der merklich Zeit benötigt, da fluidsynth [23] erst

[2] Eigentlich nur ein Teil von vis.js namens *network* [25], aber ich werde vis.js immer der Kürze halber synonym für *vis.js network* verwenden.

das WAV generieren und die Webapplikation dieses erst über das Netzwerk geladen werden muss, wird die Audiodatei in den Player geladen und kann direkt angehört werden.

Gleich unter dem Player kann man die Interpretation als MIDI oder WAV herunterladen. Dazu wählt man rechts eines der beiden Formate aus und klickt links auf „Download“. Intern funktioniert dies genau gleich wie der Player, bloß dass jeweils der Endpunkte für das entsprechende Format verwendet und die Datei dann direkt heruntergeladen wird statt im Browser weiterverwendet wird.

Des weiteren werden der aktuelle Graph und die Parameter regelmäßig mittels LocalStorage [30] zwischengespeichert, die beim Öffnen der Webapplikation abgefragt wird. So ist gleich der letzte Stand vom letzten Mal geladen und man kann direkt weiterarbeiten.

Lizenzierung

Der gesamte Quelltext von *likely music* ist unter der *GNU Affero General Public License Version 3*, deren Text sich im Anhang im Abschnitt Lizenz findet, lizenziert. Die AGPL ist eine Freie-Software-Lizenz [32], das heißt, sie sichert dem*der Benutzer*in gegenüber dem Entwickler verschiedene Rechte (typischerweise nennt man vier) zu. Diese Rechte haben alle emanzipatorischen Charakter für den Nutzer: Das Recht die Software so auszuführen, wie der Nutzer es mag, natürlich offensichtlicherweise. Das Recht, den Quellcode zu erhalten und zu untersuchen. Das hilft vor allem dem*der Benutzer*in zu verstehen, was eigentlich auf seinem*ihrem Computer vor sich geht, und kann auch der Weiterbildung dienen. Die Freiheit, die Software frei und ohne Lizenzgebühren an andere weiterzugeben, ist mir besonders wichtig. Aufgrund diesen Umstandes kann freie Software unentgeltlich an jede*n weitergegeben werden, was Zugang zu Software unabhängig des eigenen Geldbeutels erlaubt – vorausgesetzt man besitzt einen Computer. Diese Freiheit geht sogar noch weiter, dahingehend, dass auch die Modifikation ausdrücklich erlaubt (und erwünscht) ist. Somit kann nicht nur jede*r freie Software erhalten, sondern auch mitgestalten und verbessern. Auch andere freie Software kann profitieren, indem sie von anderen Projekten Code übernimmt. Dank der restriktiven Weitergabeklauseln kann aber nie freie Software verwendet oder verändert werden, ohne dass sie wieder freie Software wird. Freie Software erhält sozusagen ihre eigene Freiheit.

Mir ist dies an dieser Stelle ein besonderes Anliegen, weil ich – mit Sicherheit im Gegensatz zu den allermeisten anderen Wettbewerbteilnehmer*innen – mein Projekt komplett mit freier Software erstellen konnte. Ich war nicht auf eine von drei teuren Softwarelösungen großer Konzerne angewiesen, um meinen Beitrag anzufertigen, wie das zum Beispiel im Bereich Videoschnitt der Fall ist (auch weil es kaum ausgereifte freie Software in dem Bereich gibt).

Insofern sehe ich auch den emanzipatorischen Charakter von freier Software, denn Zugang zu Computern ist größtenteils auch dank von öffentlichen Bibliotheken selbstverständlich geworden, Zugang zu Software, die mehrere hundert Euro kostet, aber mit Sicherheit nicht. Der Preis von Software, die ein Konzern vielleicht auch irgendwann verwahrlosen lässt, ist sicher für viele eine Hürde, vielleicht sogar eine Hürde an diesem Wettbewerb teilzunehmen.

Ideen für die Zukunft

likely music als fertig zu bezeichnen wäre nicht ganz falsch und nicht ganz richtig. Es handelt sich zwar um eine voll funktionsfähige Software, aber dennoch ist noch einige Weiterentwicklung, für die ich keine Zeit mehr hatte, denkbar. Folgende Gedanken hatte ich bisher:

- **Unterstützung für Akkorde im Interface.** Zwar unterstützen Euterpea und die Library beide Akkorde, aber im Frontend gibt es keine Möglichkeit, solche hinzuzufügen, da ich die Euterpea-MIDI-Datenstruktur nicht vollständig in JavaScript nachgebaut habe. Dies zu beheben wäre für die Zukunft auf jeden Fall wünschenswert.
- **Mehrstimmige bzw. parallele probabilistische Musik.** Denkbar wäre es, eine Möglichkeit hinzuzufügen mehrere Startknoten auszuwählen, von denen dann zwei gleichzeitige Pfade durch den Graph ausgingen. Dies scheint mir die interessantes Möglichkeit zu sein, Mehrstimmigkeit für *likely music* zu implementieren.
- **Import bereits durchkomponierter Musik.** Indem man die Möglichkeit schafft, bereits in konventionellen Notationsprogrammen erstellte Musik zu importieren, könnte man ein für den*die Benutzer*in angenehme Möglichkeit bieten, konventionell notierter Musik ein probabilistisches Element zu geben bzw. sie probabilistisch umzusetzen.

Diese Änderungen stehen nicht im Konflikt mit dem bisherigen Grundkonzept und -aufbau von *likely music*, dürften daher ohne größere Probleme umgesetzt werden können.

Links

- Der gesamte Quelltext als Git-Repository `https://github.com/sternenseemann/likely-music`

- Eine laufende Instanz[3] von *likely music* https://likely.sternen.space

Literatur

[1] https://de.wikipedia.org/wiki/Demoszene

[2] http://www.haskellforall.com/2012/07/purify-code-using-free-monads.html

[3] http://www.jackaudio.org/

[4] https://www.libsdl.org/index.php

[5] https://de.wikipedia.org/wiki/RIFF_WAVE

[6] https://www.midi.org/

[7] https://de.wikipedia.org/wiki/Musical_Instrument_Digital_Interface

[8] https://hackage.haskell.org/package/Euterpea

[9] https://github.com/sternenseemann/Euterpea2

[10] https://github.com/Euterpea/Euterpea2/issues/16

[11] https://hackage.haskell.org/package/containers-0.5.10.2/docs/Data-Map-Lazy.html#t:Map

[12] https://hackage.haskell.org/package/containers-0.5.10.2/docs/Data-Map-Lazy.html#v:lookup

[13] https://hackage.haskell.org/package/random-1.1/docs/System-Random.html#t:RandomGen

[14] https://en.wikipedia.org/wiki/Pseudorandom_number_generator

[15] https://de.wikipedia.org/wiki/Rekursion

[16] https://de.wikipedia.org/wiki/Lazy_Evaluation

[17] https://en.wikipedia.org/wiki/Client%E2%80%93server_model

[18] https://hackage.haskell.org/package/servant

[19] https://de.wikipedia.org/wiki/Representational_State_Transfer

[20] http://json.org/

[21] https://www.qt.io/

[22] https://www.gtk.org/

[23] http://www.fluidsynth.org/

[24] http://visjs.org/

[25] visjs.org/docs/network/

[26] https://en.wikipedia.org/wiki/Callback_(computer_programming)

[27] https://www.google.com/chrome/

[28] https://www.mozilla.org/en-US/firefox/

[29] https://developer.mozilla.org/en-US/docs/Web/API/Fetch_API

[30] https://developer.mozilla.org/en-US/docs/Web/API/Web_Storage_API

[31] https://www.gnu.org/licenses/agpl-3.0.html

[32] https://www.gnu.org/philosophy/free-sw.de.html

[3] *likely music* ist bisher noch nicht auf Performance optimiert worden. Ich glaube nicht, dass genannte Server einen größeren Ansturm vor allem wegen des Exports zu WAV (fluidsynth [23] ist ziemlich langsam) aushalten würde. Daher möchte ich darum bitten, diesen Link nicht zu veröffentlichen, sondern, falls etwas in der Art gewünscht sein sollte, mit mir Rücksprache zu halten.

Anhang

Screenshots

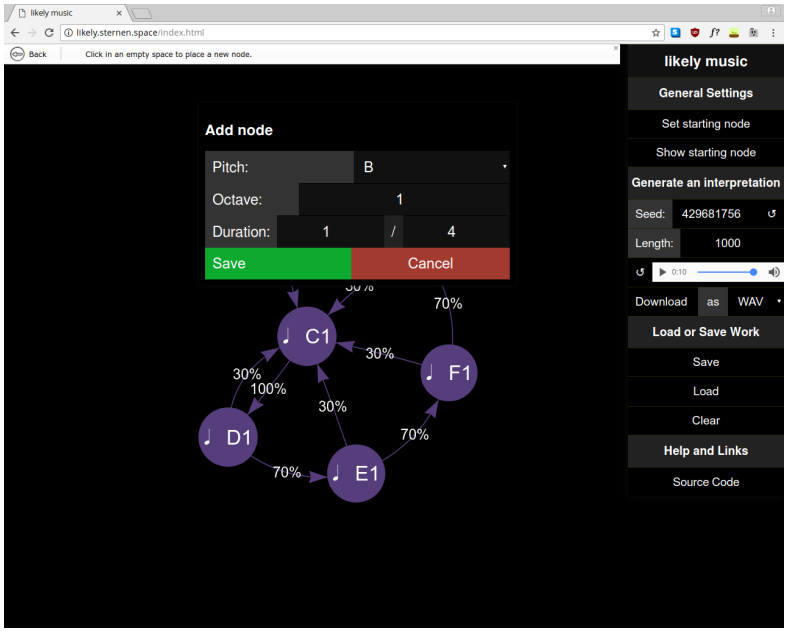


Abbildung 1: Hinzufügen eines Knotens

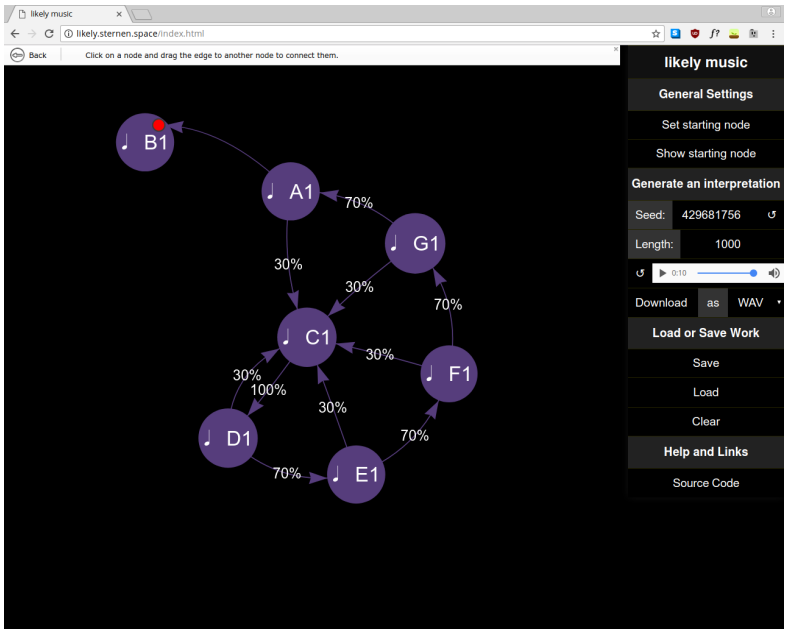


Abbildung 2: Verbinden zweier Knoten mit einer Kante

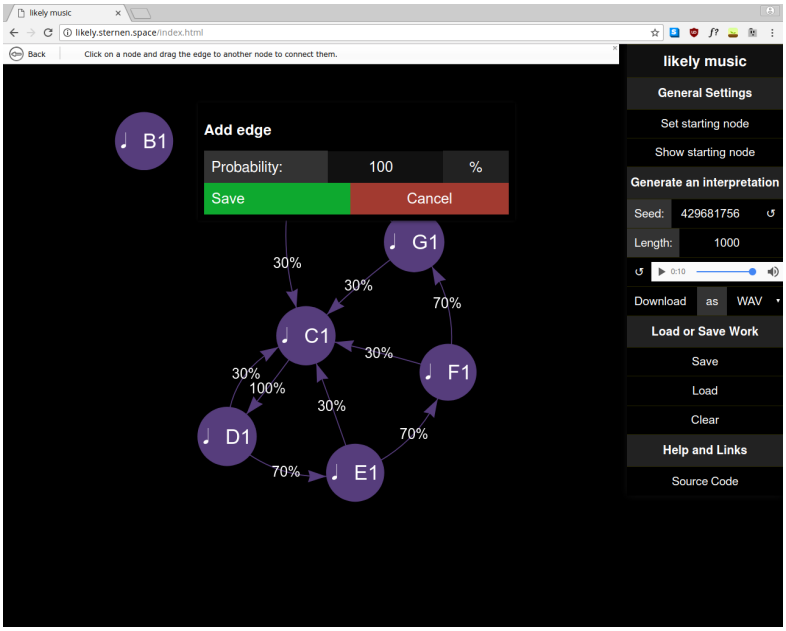


Abbildung 3: Setzen der Kanteneigenschaften

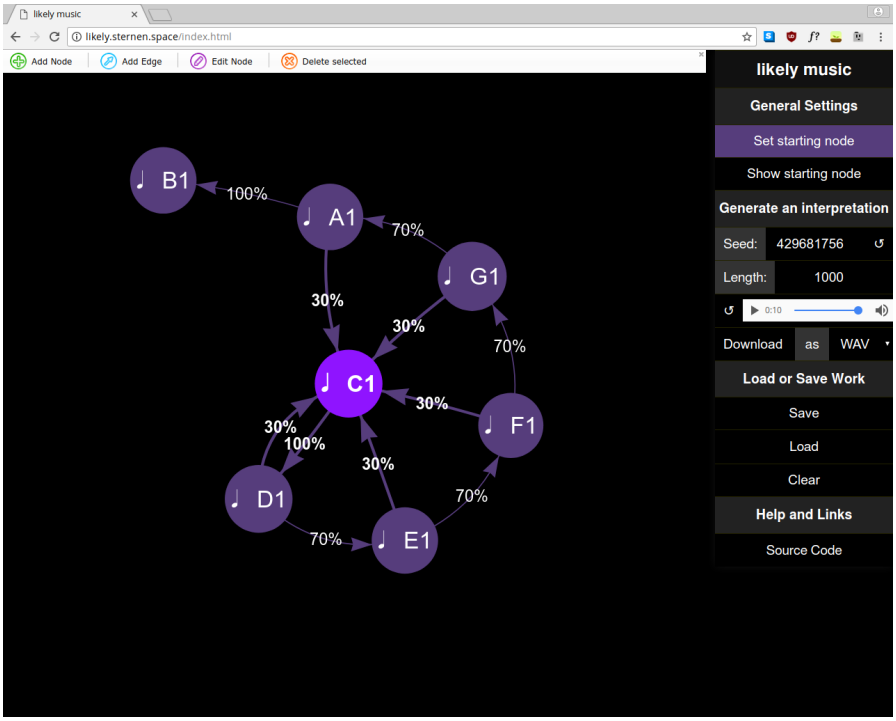


Abbildung 4: Setzen des Startknoten durch Auswählen desselben

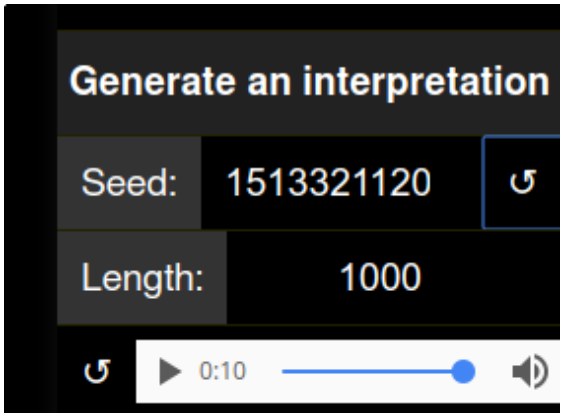


Abbildung 5: Auswürfeln eines neuen Startwerts per Knopfdruck

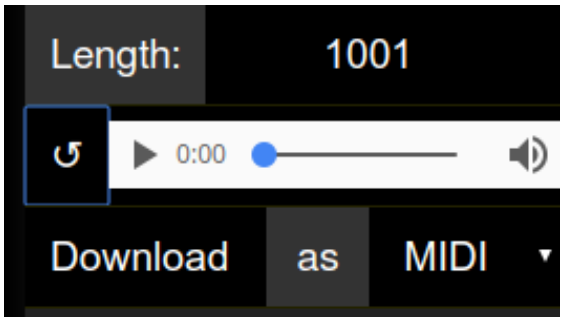


Abbildung 6: Laden der Interpretation in den Player

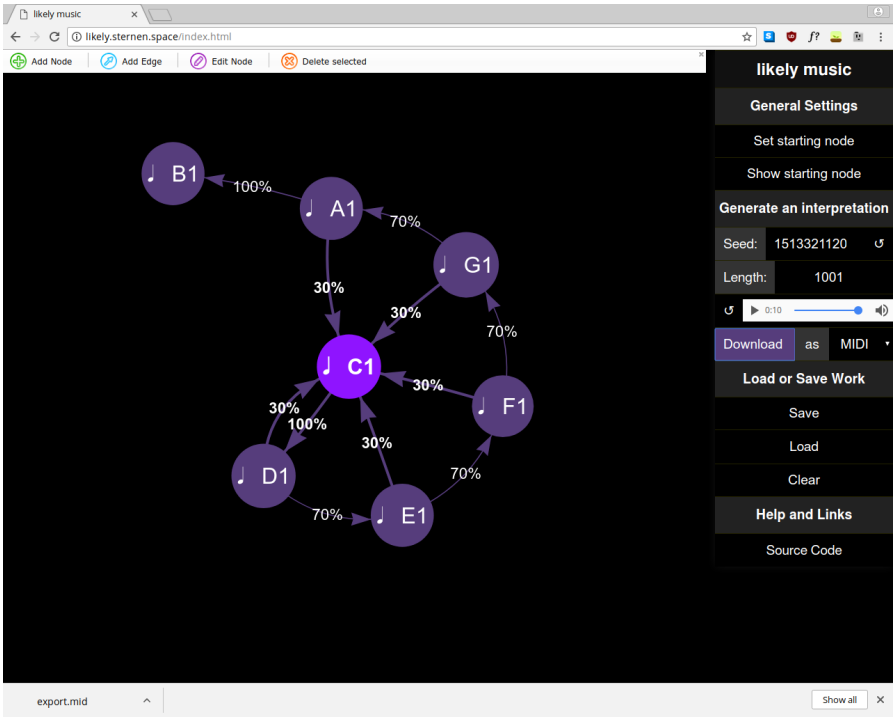


Abbildung 7: Download der Interpretation als MIDI-Datei

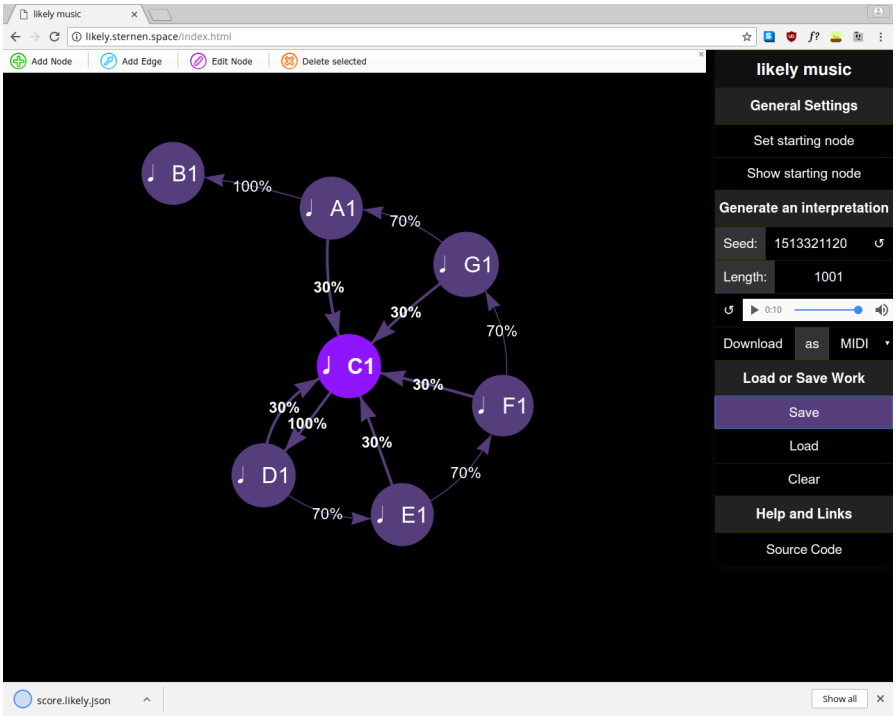


Abbildung 8: Speichern der Notation

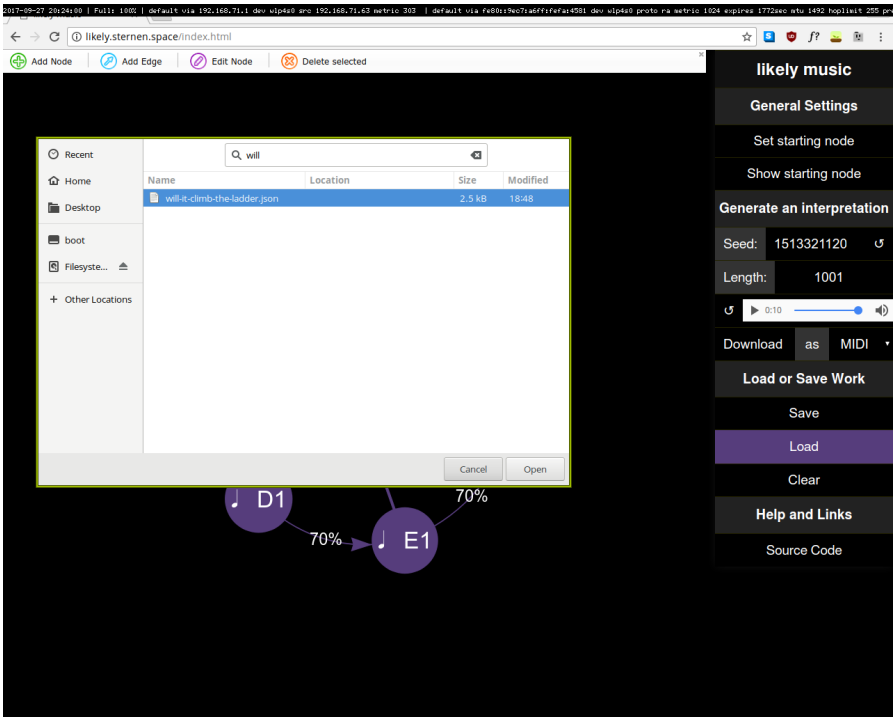


Abbildung 9: Laden einer Notation

Quelltext

Library

lib/Sound/Likely.hs

```
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17
18 {-# LANGUAGE OverloadedStrings #-}
19 {-# LANGUAGE FlexibleInstances #-}
20 module Sound.Likely
21   ( Probability
22   , ID
23   , Node (..)
24   , Edge (..)
25   , Graph (..)
26   , insertNode
27   , insertEdge
28   , interpretation
29   , takeNotes
30   , emptyMusic
31   , exampleGraph
32   ) where
33
34 import Control.Monad
35 import Data.Aeson
36 import Data.Aeson.Types (Parser ())
37 import Data.Maybe
38 import Data.Text (Text ())
39 import Euterpea
40 import System.Random
41 import qualified Data.Map as M
42 import qualified Data.Set as S
43
44 type Probability = Double
45 type ID = Text
46
47 data Node
48   = Node
49   { nId :: ID
50   , nMusic :: Music Pitch
51   } deriving (Show, Eq, Ord)
52
53 data Edge
54   = Edge
55   { eTo   :: Node
56   , eProb :: Probability
57   } deriving (Show, Eq, Ord)
58
59 newtype Graph = Graph { unGraph :: M.Map Node (S.Set Edge) }
60   deriving (Show, Eq, Ord)
61
62 insertNode :: Node -> Graph -> Graph
63 insertNode t = Graph . M.insertWith S.union t S.empty . unGraph
64
65 insertEdge :: Node -> Edge -> Graph -> Graph
66 insertEdge n e =
67   insertNode n . Graph . M.insertWith S.union n (S.singleton e) . unGraph
68
69 interpretation :: RandomGen g => g -> Graph -> Node -> Music Pitch
70 interpretation gen graph n = (nMusic n) :+:
71   recurse (fromMaybe S.empty (M.lookup n (unGraph graph)))
72   where (prob, gen') = randomR (0.0, 1.0) gen
73         recurse edges =
74           case edgeForRoll prob edges of
```

```
75              Nothing -> emptyMusic
76              Just nextEdge ->
77                interpretation gen' graph . eTo $ nextEdge
78
79  edgeForRoll :: Probability -> S.Set Edge -> Maybe Edge
80  edgeForRoll prob set =
81    if S.null set
82      then Nothing
83      else let curr = S.elemAt 0 set
84             in if prob <= eProb curr
85                  then Just curr
86                  else edgeForRoll (prob - eProb curr) (S.delete curr set)
87
88  emptyMusic :: Music a
89  emptyMusic = Prim (Rest 0)
90
91  exampleGraph :: Graph
92  exampleGraph = Graph $ M.fromList
93    [ (Node "bla" (c 4 qn), S.fromList [ Edge (Node "blub" (d 4 qn)) 1 ] )
94    , (Node "blub" (d 4 qn), S.fromList [ ])
95    ]
96
97  -- | Take the first @n@ notes of a 'Music'
98  takeNotes :: Integer -> Music a -> Music a
99  takeNotes _ m@(Prim _) = m
100 takeNotes n (Modify c m) = Modify c $ takeNotes n m
101 takeNotes _ m@(_ :=: _) = m
102 takeNotes n (m1 :+: m2)
103   | n <  1    = emptyMusic
104   | n == 1    = m1
105   | otherwise = m1 :+: takeNotes (n - 1) m2
106
107 instance FromJSON Node where
108   parseJSON = withObject "Node" $ \v ->
109     Node <$> v .: "id" <*> (Prim <$> v .: "music")
110
111 lookupNode :: Text -> [Object] -> Parser Node
112 lookupNode id nodes = do
113   matches <- filterM (fmap (== id) . (.: "id")) nodes
114   case matches of
115     [node] -> parseJSON (Object node)
116     _ -> fail "Couldn't␣match␣node␣by␣id"
117
118 buildMap :: [Object] -> [Object] -> Graph -> Parser Graph
119 buildMap _ [] m = pure m
120 buildMap nodes (e:es) m = do
121   toId <- e .: "to"
122   fromId <- e .: "from"
123   edge <- Edge <$> lookupNode toId nodes <*> e .: "prob"
124   from <- lookupNode fromId nodes
125   buildMap nodes es $ insertEdge from edge m
126
127 instance FromJSON Graph where
128   parseJSON = withObject "Graph" $ \v -> do
129     edges <- v .: "edges"
130     nodes <- v .: "nodes"
131     buildMap nodes edges $ Graph mempty
132
133 instance FromJSON (Primitive Pitch) where
134   parseJSON = withObject "Primitive" $ \v -> do
135     -- TODO Ratio _Integer_ is easy DOSable
136     -- RAM consumption
137     duration <- v .: "dur"
138     octave <- v .: "octave"
139     pitchClass <- v .: "pitch"
140     case pitchClass of
141       "Rest" -> pure $ Rest duration
142       p -> pure $ Note duration (read pitchClass, octave)
```

Backend

backend/Api.hs

```
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17
18 {-# LANGUAGE OverloadedStrings #-}
19 {-# LANGUAGE FlexibleInstances #-}
20 {-# LANGUAGE DataKinds         #-}
21 {-# LANGUAGE TypeOperators     #-}
22 module Api where
23
24 import Data.Aeson
25 import Data.ByteString.Lazy (ByteString ())
26 import Data.Monoid ((<>))
27 import Data.Ratio
28 import Data.Text (Text ())
29 import GHC.Generics
30 import Servant.API
31 import Sound.Likely
32
33 type LikelyApi = "interpretation" :> Capture "format" OutputFormat
34                                   :> ReqBody '[JSON] GraphWithParams
35                                   :> Post '[OctetStream] ByteString
36                  :<|> "seed" :> Get '[JSON] Int
37                  :<|> Raw
38
39 data OutputFormat = Midi | Wav
40   deriving (Show, Eq, Ord)
41
42 instance FromHttpApiData OutputFormat where
43   parseUrlPiece "mid" = Right Midi
44   parseUrlPiece "wav" = Right Wav
45   parseUrlPiece x     = Left $ "Couldn't␣match␣" <> x <> "␣with␣{mid,␣wav}"
46
47 data GraphWithParams
48   = GraphWithParams
49   { gpParams :: Params
50   , gpGraph  :: Graph
51   } deriving (Show, Eq, Ord)
52
53 instance FromJSON GraphWithParams where
54   parseJSON = withObject "GraphWithParams" $ \v ->
55     GraphWithParams <$> v .: "params"
56                     <*> v .: "graph"
57
58 data Params
59   = Params
60   { pMaxHops      :: Int
61   , pStartingNode :: Node
62   , pSeed         :: Int
63   } deriving (Show, Eq, Ord)
64
65 instance FromJSON Params where
66   parseJSON = withObject "Params" $ \v ->
67     Params <$> v .: "maxhops"
68            <*> v .: "starting_node"
69            <*> v .: "seed"
```

backend/Main.hs

```
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17
18 {-# LANGUAGE OverloadedStrings #-}
19 module Main where
20
21 import Api
22
23 import Codec.Midi (buildMidi)
24 import Codec.ByteString.Builder
25 import Control.Monad.IO.Class
26 import Data.ByteString.Lazy (ByteString ())
27 import qualified Data.ByteString.Lazy as B
28 import Euterpea hiding (app)
29 import GHC.IO.Handle
30 import Network.Wai
31 import Network.Wai.Handler.Warp
32 import Servant
33 import Sound.Likely
34 import System.Directory
35 import System.Exit
36 import System.Environment
37 import System.FilePath.Posix
38 import System.IO
39 import System.Process
40 import System.Random
41
42 api :: Proxy LikelyApi
43 api = Proxy
44
45 midiString :: ToMusic1 a => Music a -> ByteString
46 midiString = toLazyByteString . buildMidi . toMidi . perform
47
48 server :: Server LikelyApi
49 server = genInterpretation :<|> randomSeed :<|> serveDirectoryWebApp "web/dist"
50
51 randomSeed :: Handler Int
52 randomSeed = liftIO newStdGen >>= return . fst . random
53
54 genInterpretation :: OutputFormat -> GraphWithParams -> Handler ByteString
55 genInterpretation Midi g = do
56   let params       = gpParams g
57       maxHops      = fromIntegral . pMaxHops $ params
58       randomGen    = mkStdGen $ pSeed params
59       song         = interpretation randomGen (gpGraph g) (pStartingNode params)
60   return . midiString $ takeNotes maxHops song
61 genInterpretation Wav g = genInterpretation Midi g >>= synthWav
62
63 synthWav :: ByteString -> Handler ByteString
64 synthWav midi = do
65   inName <- tempFile "mid"
66   liftIO $ B.writeFile inName midi
67   outName <- tempFile "wav"
68   (_, _, _, ph) <- liftIO $
69     createProcess_ "fluidsynth"
70       (proc "fluidsynth"
71         [ "-a", "file"
72         , "-F", outName
73         , "-i"
74 --        , "/usr/share/soundfonts/FluidR3_GM.sf2"
75         , "/nix/store/591834mz365ccwyj3ah2d66ncsqvp8w9-Fluid-3/share/soundfonts/
               FluidR3_GM2-2.sf2"
76         , inName ])
77         { std_in = CreatePipe }
78   code <- liftIO $ waitForProcess ph
79   case code of
80     ExitFailure _ -> throwError err500 { errBody = "fluidsynth␣failed" }
81     ExitSuccess -> do
```

```
82        out <- liftIO $ B.readFile outName
83        liftIO $ removePathForcibly outName
84        return out
85
86  tempFile :: String -> Handler FilePath
87  tempFile ext = try 0
88    where maxtries = maxBound
89          try :: Int -> Handler FilePath
90          try n
91            | n < maxtries = do
92              progName <- liftIO $ getProgName
93              let path = "/tmp" </> addExtension (makeValid progName ++ "-" ++ show n)
                      ext
94              exists <- liftIO $ doesFileExist path
95              if exists
96                then try (n + 1)
97                else pure path
98            | otherwise = throwError err500 { errBody = "no␣temp␣files" }
99  app :: Application
100 app = serve api server
101
102 main :: IO ()
103 main = newStdGen >> run 8081 app
```

Web

web/source/index.html

```
<!--

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-->
<!doctype html>
<html>
    <head>
        <meta charset="utf-8">
        <meta http-equiv="x-ua-compatible" content="ie=edge" />
        <meta name="viewport" content="width=device-width, initial-scale=1" />
        <title>likely music</title>
        <link rel="stylesheet" type="text/css" href="custom.css">
        <link rel="stylesheet" type="text/css" href="vis.min.css">
        <script src="main.js"></script>
    </head>
    <body>
        <div id="network"></div>
        <div id="sidebar">
            <h1>likely music</h1>
            <h2>General Settings</h2>
            <button id="set-starting-node">Set starting node</button>
            <button id="show-starting-node">Show starting node</button>
            <h2>Generate an interpretation</h2>
            <div class="multi-inputs">
                <label for="seed">Seed:</label>
                <input type="number" id="seed">
                <button id="random-seed">&#8634;</button>
            </div>
            <div class="multi-inputs">
                <label for="hop-count">Length:</label>
                <input type="number" min="0" id="hop-count" placeholder="Max. note
                    count">
            </div>
            <div id="player-container">
                <button id="reload-player">&#8634;</button>
                <audio id="player" controls></audio>
            </div>
            <div class="multi-inputs">
                <button id="download-audio">Download</button>
                <label for="format">
                    as
                </label>
                <select id="format">
                    <option value="mid">MIDI</option>
                    <option value="wav">WAV</option>
                </select>
            </div>
            <h2>Load or Save Work</h2>
            <button id="gen-score" class="save">Save</button>
            <label for="upload-score" class="custom-file">
                <input type="file" id="upload-score" >
                <span>Load</span>
            </label>
            <button id="clear-score" class="cancel">Clear</button>
            <h2>Help and Links</h2>
            <a href="https://github.com/sternenseemann/likely-music">Source Code</a>
        </div>
        <div id="edge-overlay" class="hidden dialog">
            <h2><span id="edge-operation"></span> edge</h2>
            <div class="multi-inputs">
```

```
                <label for="prob">Probability:</label>
                <input id="prob" type="number" min="0.0" max="100">
                <span>%</span>
            </div>
            <div class="multi-inputs">
                <button class="save" id="edge-save">Save</button>
                <button class="cancel" id="edge-cancel">Cancel</button>
            </div>
        </div>
        <div id="node-overlay" class="hidden␣dialog">
            <h2><span id="node-operation"></span> node</h2>
            <div class="multi-inputs">
                <label for="pitch">Pitch:</label>
                <select id="pitch"></select>
            </div>
            <div class="multi-inputs">
                <label for="octave">Octave:</label>
                <input id="octave" type="number" step="1">
            </div>
            <div class="multi-inputs">
                <label>Duration:</label>
                <input min="0" id="numerator" type="number" step="1">
                <span>/</span>
                <input min="0" id="denominator" type="number" step="1">
            </div>
            <div class="multi-inputs">
                <button class="save" id="node-save">Save</button>
                <button class="cancel" id="node-cancel">Cancel</button>
            </div>
        </div>
    </body>
</html>
```

web/source/custom.css

```
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*/

body {
    font-size:1em;
    font-family: sans-serif;
    margin: 0px;
    background-color: black;
}

#network {
    width: 79%;
    float:left;
    height: 100vh;
}

#sidebar {
    width: 20%;
    float:right;
    color: white;
    background-color: black;
    box-shadow: 0px 0px 20px #111;
    font-size: 1.2rem;
}

#sidebar > * {
    width: 100%;
    border-top: 1px solid #232200;
    color: white;
    padding-left: 0px;
    padding-right: 0px;
    margin: 0;
}

#sidebar button:hover, #sidebar input:hover,
#sidebar .custom-file:hover, #sidebar select:hover, #sidebar a:hover {
    background-color: #563d7c;
}

#sidebar button, #sidebar input, #sidebar .custom-file, #sidebar select, #sidebar a {
  background-color: #000;
}

#sidebar h1 {
    font-size: 1.5rem;
    padding-top: 0.75rem;
    padding-bottom: 0.75rem;
    text-align: center;
    background-color: #111;
}

#sidebar h2 {
    font-size: 1.2rem;
    padding-top: 0.9rem;
    padding-bottom: 0.9rem;
    text-align: center;
    background-color: #222;
}

#sidebar select {
  color: white;
  border: none;
  padding: 0.75rem;
```

```
  font-size: 1.2rem;
  width: auto;
}

#sidebar a {
  padding-bottom: 0.75rem;
  padding-top: 0.75rem;
  display: inline-block;
  text-decoration: none;
  color: white;
  text-align: center;
}

button {
    border: none;
    color: white;
    background-color:black;
    font-size: 1.2rem;
    margin:0;
    padding:0.75rem;
}

input[type="number"] {
    background-color: #333;
    color: white;
    border: none;
    text-align: center;
    font-size: 1.2rem;
    padding:0.75rem;
}

.custom-file {
    top:0;
    right:0;
    position: relative;
    display: inline-block;
    height: 3rem;
}

.custom-file input[type="file"] {
    position: relative;
    top:0;
    left:0;
    right:0;
    z-index:0;
    opacity: 0;
    width: 100%;
    height: 100% !important;
    margin:0;
    padding:0;
}

.custom-file span {
    text-align: center;
    position: absolute;
    top: 0;
    left: 0;
    right: 0;
    z-index: 1;
    width: 100%;
    height: 3rem;
    pointer-events: none;
    background-color: transparent !important;
    font-size: 1.2rem;
    line-height: 1.5rem;
    padding-top: 0.75rem;
    padding-bottom: 0.75rem;
}

.dialog {
    position: absolute;
    top: 10%;
    left: 25%;
    width: 30%;
    min-width:500px;
    padding: 10px;
    background-color: black;
    color: white;
    box-shadow: 0px 0px 10px #111;
```

```
}

.dialog select {
  padding: 0.75rem;
  font-size: 1.5rem;
  color: white;
  background-color: #111;
  border: none;
}

.hidden {
    visibility:hidden;
}

.dialog > div {
  width: 100%;
}

.dialog button {
    padding: 0.75rem;
    font-size: 1.5rem;
}

.dialog input {
  font-size: 1.5rem;
}

button.cancel {
    background-color: #a23a30;
}

button.save {
    background-color: #0ea92f;
}

.dialog .multi-inputs {
  font-size: 1.5rem;
}

.multi-inputs {
  display: inline-flex;
  flex-direction: row;
  flex-wrap: nowrap;
  justify-content: flex-start;
  align-items: baseline;
  width: 100%;
}

.multi-inputs > * {
  flex-grow: 1;
  flex-basis: auto;
  transition: width 0.7s ease-out;
  max-height: 100%;
  text-align: center;
}

.multi-inputs :nth-child(1) {
  text-align: left;
}

.multi-inputs label {
  display: inline-block;
  background-color: #333;
  padding: 0.75rem;
}

.multi-inputs input {
  display: inline-block;
  color: white;
  background-color: #111;
  padding: 0.75rem;
  border: none;
  min-width: 0px;
}

.multi-inputs span {
  display: inline-block;
  padding: 0.75rem;
  background-color: #222;
```

```
}

.multi-inputs button {
    padding: 0.75rem;
}

#player-container {
  display: inline-flex;
  align-items: center;
}

#player-container > * {
  flex: auto;
}
```

web/source/main.js

```
//  Copyright 2017 Lukas Epple
//
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import vis from 'vis';
import { Map } from 'immutable';
// types / internals

const valid_pitches = [
    'Rest',
    'Cf', 'C', 'Cs',
    'Df', 'D', 'Ds',
    'Ef', 'E', 'Es',
    'Ff', 'F', 'Fs',
    'Gf', 'G', 'Gs',
    'Af', 'A', 'As',
    'Bf','B', 'Bs'
];

const display_pitches = [
    'Rest',
    ' C', 'C', ' C',
    ' D', 'D', ' D',
    ' E', 'E', ' E',
    ' F', 'F', ' F',
    ' G', 'G', ' G',
    ' A', 'A', ' A',
    ' B', 'B', ' B'
];

function displayPitch(pitch) {
    var i = valid_pitches.indexOf(pitch);
    if(i === -1) {
        throw 'Invalid pitch';
    } else {
        return display_pitches[i];
    }
}

function standard_rests(dur) {
    if(dur.numerator === 1) {
        switch(dur.denominator) {
            case 1:
                return  ' ';
                break;
            case 2:
                return  ' ';
                break;
            case 4:
                return  ' ';
                break;
            case 8:
                return  ' ';
                break;
            case 16:
                return  ' ';
                break;
            case 32:
                return  ' ';
                break;
            case 64:
                return  ' '
                break;
            case 128:
                return  ' '
```

```
                break;
            default:
                return null;
                break;
        }
    } else {
        return null;
    }
}

function standard_notes(dur) {
    if(dur.numerator === 1) {
        switch(dur.denominator) {
            case 1:
                return  ' ';
                break;
            case 2:
                return  ' ';
                break;
            case 4:
                return  ' ';
                break;
            case 8:
                return  ' ';
                break;
            case 16:
                return  ' ';
                break;
            case 32:
                return  ' ';
                break;
            case 64:
                return  ' '
                break;
            case 128:
                return  ' '
                break;
            default:
                return null;
                break;
        }
    } else if(dur.numerator === 2 && dur.denominator === 1) {
        return  ' '
    } else {
        return null;
    }
}

function compute_dot_times(dur, den) {
    let term = den * ( (2 / den) - (dur.numerator / dur.denominator));
    return [ den, -Math.log2(term) ];
}

function musical_symbol(lookup, dur) {
    // unicode characters sometimes hide from you!
    const dot = ' ';
    let isNat = n => {
        if (typeof n !== 'number')
            return false;
        return (n >= 0.0) && (Math.floor(n) === n) && n !== Infinity;
    };
    var standard_symbol = lookup(dur);
    var dots = [0, 1, 2, 3, 4, 5, 6, 7 ].map(compute_dot_times.bind(this, dur))
        .filter(([den, dots]) => isNat(dots));

    if(standard_symbol !== null) {
        return standard_symbol;
    } else if (dots.length !== 0) {
        var symbol = lookup(new Rational(1, dots[0][0])) + ' ';
        for(var i = dots[0][1]; i > 0; i--) {
            symbol = symbol + dot;
        }
        return symbol;
    } else {
        return dur.toString();
    }
}

class Music {
```

```
158     constructor(dur, pitch_class, octave) {
159         this.dur = dur;
160         if(valid_pitches.indexOf(pitch_class) !== -1) {
161             this.pitch = pitch_class;
162         } else {
163             throw `Invalid pitch class '${pitch_class}'`;
164         }
165         this.octave = octave;
166     }
167 
168     toString() {
169         if(this.pitch === 'Rest') {
170             return `${displayPitch(this.pitch)} for ${this.dur.toString()}`;
171         } else {
172             return `${displayPitch(this.pitch)}${this.octave} for ${this.dur.toString()
                    }`;
173         }
174     }
175 
176     nodeText() {
177         if(this.pitch === 'Rest') {
178             return `${musical_symbol(standard_rests, this.dur)} Rest`;
179         } else {
180             return `${musical_symbol(standard_notes, this.dur)}   ${displayPitch(this.
                    pitch)}${this.octave}`
181         }
182     }
183 
184 
185     static fromObject(obj) {
186         return new Music(Rational.fromObject(obj.dur), obj.pitch, Number(obj.octave));
187     }
188 }
189 
190 class Rational {
191     constructor(a, b) {
192         this.numerator = a;
193         this.denominator = b;
194         this.reduce();
195     }
196 
197     reduce() {
198         let gcd = (a, b) => !b ? a : gcd(b, a % b);
199         let div = function(a, b) {
200             if(b === 0) {
201                 throw 'Divide by zero';
202             } else {
203                 return Math.floor(a / b);
204             }
205         };
206 
207         var d = gcd(this.numerator, this.denominator);
208         this.numerator = div(this.numerator, d);
209         this.denominator = div(this.denominator, d);
210     }
211 
212     toString() {
213         return `${this.numerator}/${this.denominator}`;
214     }
215 
216     static fromObject(obj) {
217         return new Rational(obj.numerator, obj.denominator);
218     }
219 }
220 
221 function collectGraphData(nodeDate, edgeData) {
222     return {
223         nodes: [... nodeData.values()].map(x => ({
224             id: x.nodeData.id,
225             music: x.music
226         })),
227         edges: [... edgeData.values()].map(x => ({
228             id: x.edgeData.id,
229             from: x.edgeData.from,
230             to: x.edgeData.to,
231             prob: x.prob
232         }))
233     };
234 }
```

```
235
236 function importGraphData(g) {
237     nodeData = new Map();
238     edgeData = new Map();
239     var nodeSet = new vis.DataSet({});
240     var edgeSet = new vis.DataSet({});
241     for(let node of g.nodes) {
242         var music = Music.fromObject(node.music);
243         var data = { id: node.id, label: music.nodeText() };
244         nodeData = nodeData.set(node.id, { nodeData: data, music: node.music });
245         nodeSet.add(data);
246     }
247
248     for(let edge of g.edges) {
249         var data = {
250             id: edge.id,
251             from: edge.from,
252             to: edge.to,
253             label: `${edge.prob * 100}%`
254         };
255         edgeData = edgeData.set(edge.id, { edgeData: data, prob: edge.prob });
256         edgeSet.add(data);
257     }
258
259     network.setData({ nodes: nodeSet, edges: edgeSet });
260 }
261
262 // helper
263
264 function download(url, filename) {
265     var link = document.createElement('a');
266     link.setAttribute('href', url);
267     link.setAttribute('download', filename);
268     link.style.display = 'none';
269     document.body.appendChild(link);
270     link.click();
271     document.body.removeChild(link);
272 }
273
274 function downloadFile(content_type, filename, content) {
275     var data = `data:${content_type},${encodeURIComponent(content)}`;
276     download(data, filename);
277 }
278
279
280 // graph code
281
282 var nodeData = Map();
283 var edgeData = Map();
284 var network = null;
285 var starting_node_id = null;
286
287
288 function showOverlay(id) {
289     document.getElementById(id).classList.remove('hidden');
290 }
291
292 function genericEditNode(data, callback) {
293     function clearOverlay() {
294         document.getElementById('node-save').onclick = null;
295         document.getElementById('node-cancel').onclick = null;
296         hideOverlay('node-overlay');
297     }
298
299     function saveNode(data, callback) {
300         var duration = new Rational(document.getElementById('numerator').value,
301             document.getElementById('denominator').value);
302         var music = new Music(duration, document.getElementById('pitch').value,
303             Number(document.getElementById('octave').value));
304         data.label = music.nodeText();
305         clearOverlay();
306         callback(data);
307         nodeData = nodeData.set(data.id, { music: music, nodeData: data });
308     }
309
310     function discardNode(callback) {
311         clearOverlay();
312         callback(null);
313     }
```

```
314
315     showOverlay('node-overlay');
316     var node = nodeData.get(data.id);
317     if(node !== undefined) {
318         var music = node.music;
319         document.getElementById('pitch').value = music.pitch;
320         document.getElementById('octave').value = music.octave;
321         document.getElementById('numerator').value = music.dur.numerator;
322         document.getElementById('denominator').value = music.dur.denominator;
323     }
324     document.getElementById('node-save').onclick = saveNode.bind(this, data, callback);
325     document.getElementById('node-cancel').onclick = discardNode.bind(this, callback);
326 }
327
328 function genericEditEdge(data, callback) {
329     function clearOverlay() {
330         document.getElementById('edge-save').onclick = saveEdge.bind(this, data,
                callback);
331         document.getElementById('edge-cancel').onclick = discardEdge.bind(this,
                callback);
332         hideOverlay('edge-overlay');
333     }
334
335     function saveEdge(data, callback) {
336         // for some reason, editWithoutDrag
337         // sets from & to to the node respective
338         // node objects, which results in the edge
339         // disappearing.
340         if (typeof data.to === 'object')
341             data.to = data.to.id
342         if (typeof data.from === 'object')
343             data.from = data.from.id
344
345         var prob = document.getElementById('prob').value / 100;
346         data.label = `${prob * 100}%`;
347         clearOverlay();
348         callback(data);
349         edgeData = edgeData.set(data.id, { prob: prob, edgeData: data } );
350     }
351
352     function discardEdge(callback) {
353         clearOverlay();
354         callback(null);
355     }
356
357     showOverlay('edge-overlay');
358     var edge = edgeData.get(data.id);
359     if(edge !== undefined) {
360         document.getElementById('prob').value = edge.prob * 100;
361     }
362     document.getElementById('edge-save').onclick = saveEdge.bind(this, data, callback);
363     document.getElementById('edge-cancel').onclick = discardEdge.bind(this, callback);
364 }
365
366 function deleteFromMap(data, callback) {
367     for(let node of data.nodes) {
368         nodeData = nodeData.delete(node);
369     }
370
371     for(let edge of data.edges) {
372         edgeData = edgeData.delete(edge);
373     }
374
375     callback(data);
376 }
377
378
379 function hideOverlay(id) {
380     document.getElementById(id).classList.add('hidden');
381 }
382
383 function handleImport() {
384     var files = document.getElementById('upload-score').files;
385     if(files.length === 0) {
386         alert('Select a file first!');
387     } else {
388         var file = files[0];
389         var reader = new FileReader();
390         reader.addEventListener('loadend', function() {
```

```
            var parsed = JSON.parse(this.result);
            if(parsed === undefined) {
                alert('Could not parse likely score');
            } else {
                var confirmation = window.confirm('Proceeding will overwrite the
                    current graph. Are you sure?');
                if(confirmation) {
                    try {
                        importGraphData(parsed);
                    } catch(e) {
                        alert(`Could not import likely score, probably the file was
                            malformed. Error: ${e}`);
                    }
                }
            }
        });
        reader.readAsText(file);
    }
}

function saveDataToLocalStorage() {
    const json = JSON.stringify(collectGraphData(nodeData, edgeData));
    const params = JSON.stringify(gatherParams());
    localStorage.setItem("score", json)
    localStorage.setItem("params", params)
}

function showStartingNode() {
    if(typeof starting_node_id === 'string') {
        network.selectNodes([starting_node_id], false);
    } else {
        alert('No starting node selected yet!');
    }
}

function setStartingNode() {
    var selected = network.getSelectedNodes();
    if(selected.length > 1) {
        alert('Only select one node!');
    } else if(selected.length === 0) {
        alert('Select a node first!');
    } else {
        starting_node_id = selected[0];
    }
}

function fetchInterpretation(params, format) {
    var jsonRequest = JSON.stringify({
        graph: collectGraphData(nodeData, edgeData),
        params: params
    });

    var myHeaders = new Headers();
    myHeaders.set('Content-Type', 'application/json');

    var myInit = {
        method: 'POST',
        headers: myHeaders,
        mode: 'cors',
        body: jsonRequest
    };

    var myRequest = new Request(`/interpretation/${format}`, myInit);

    return fetch(myRequest).then(res => res.blob());
}

function gatherParams() {
    var starting_node_entry = nodeData.get(starting_node_id);
    if(starting_node_entry !== undefined && starting_node_entry !== null) {
        var starting_node = {
            id: starting_node_entry.nodeData.id,
            music: starting_node_entry.music
        };
    } else {
        var starting_node = null
    }

    var maxhops = document.getElementById('hop-count').value;
```

```
468     if(maxhops === "" || Number(maxhops) === NaN) {
469         maxhops = null;
470     } else {
471         maxhops = Number(maxhops);
472     }
473
474     var seed = document.getElementById('seed').value;
475     if(seed === "" || Number(seed) === NaN) {
476         seed = null;
477     } else {
478         seed = Number(seed);
479     }
480
481     return {
482         maxhops:  maxhops,
483         starting_node: starting_node,
484         seed: seed
485     };
486 }
487
488 function completeGatherParams() {
489     var p = gatherParams();
490     if(p.starting_node === null) {
491         alert('Set a starting node first!');
492         return null;
493     }
494
495     if(p.maxhops === null) {
496         alert('Set the maximum amount of hops to a valid number');
497         return null;
498     }
499
500     if(p.seed === null) {
501         // TODO auto generate a random one, let the user confirm before
502         alert('Set the seed to a valid number!');
503         return null;
504     }
505
506     return p;
507 }
508
509 function importParams(p) {
510     if(p.starting_node !== null) {
511         starting_node_id = p.starting_node.id;
512     }
513     if(p.seed !== null) {
514         document.getElementById('seed').value = p.seed;
515     }
516     if(p.maxhops !== null) {
517         document.getElementById('hop-count').value = p.maxhops;
518     }
519 }
520
521 function randomSeed() {
522     if(window.crypto) {
523         var array = new Int32Array(1);
524         window.crypto.getRandomValues(array);
525         document.getElementById('seed').value = array[0];
526     }
527 }
528
529 function downloadInterpretation(format) {
530     var params = completeGatherParams();
531     if(params != null) {
532         try {
533             fetchInterpretation(params, format).then(file => {
534                 var url = URL.createObjectURL(file);
535                 download(url, `export.${format}`);
536                 URL.revokeObjectURL(url);
537             });
538         } catch(e) {
539             alert('An error occured while contacting the API: ' + e);
540         }
541     }
542 }
543
544 function reloadPlayer() {
545     var params = completeGatherParams();
546     if(params !== null) {
```

```
        if(document.getElementById('player').src) {
            URL.revokeObjectURL(document.getElementById('player').src);
        }

        document.getElementById('player').src = null;

        try {
            fetchInterpretation(params, 'wav').then(file => {
                var url = URL.createObjectURL(file);
                document.getElementById('player').src = url;
            });
        } catch(e) {
            alert('An error occured while contacting the API: ' + e);
        }
    }
}

function init() {
    var container = document.getElementById('network');

    var options = {
        manipulation: {
            addNode: function(nodeData, callback) {
                document.getElementById('node-operation').innerHTML = 'Add';
                genericEditNode(nodeData, callback);
            },
            addEdge: function(edgeData, callback) {
                document.getElementById('edge-operation').innerHTML = 'Add';
                genericEditEdge(edgeData, callback);
            },
            editNode: function(nodeData, callback) {
                document.getElementById('node-operation').innerHTML = 'Edit';
                genericEditNode(nodeData, callback);
            },
            editEdge: {
                editWithoutDrag: function(edgeData, callback) {
                    document.getElementById('edge-operation').innerHTML = 'Edit';
                    genericEditEdge(edgeData, callback);
                }
            },
            deleteNode: deleteFromMap,
            deleteEdge: deleteFromMap,
            controlNodeStyle: {
            }
        },
        nodes: {
            borderWidth: 0,
            color: {
                background: '#563d7c',
                hover: {
                    background: '#8f14ff'
                },
                highlight: {
                    background: '#8f14ff'
                }
            },
            chosen: true,
            font: {
                color: 'white',
                size: 20,
                align: 'center'
            },
            shape: 'circle',
        },
        edges: {
            arrows: {
                to: { enabled: true }
            },
            color: {
                color: '#563d7c',
                hover: '#563d7c',
                highlight: '#563d7c',
            },
            font: {
                color: '#ffffff',
                strokeWidth: 0
            }
        }
    };
```

```
626
627     network = new vis.Network(container, {}, options);
628
629     try {
630         const score = localStorage.getItem('score');
631         if(score !== null) {
632             importGraphData(JSON.parse(score));
633         }
634     } catch(e) {
635         localStorage.removeItem('score');
636     }
637
638     try {
639         const params = localStorage.getItem('params')
640         if(params !== null) {
641             importParams(JSON.parse(params));
642         }
643     } catch(e) {
644         localStorage.removeItem('params');
645     }
646
647     const pitch_selector = valid_pitches.map((p, i) =>
648         `<option value="${p}">${display_pitches[i]}</option>`)
649         .reduce((acc, v) =>
650             acc + v, '');
651     document.getElementById('pitch').innerHTML = pitch_selector;
652
653     /* event handling, order as in sidebar */
654     document.getElementById('set-starting-node').onclick = setStartingNode;
655     document.getElementById('show-starting-node').onclick = showStartingNode;
656
657     document.getElementById('random-seed').onclick = randomSeed;
658
659     document.getElementById('reload-player').onclick = reloadPlayer;
660     document.getElementById('download-audio').onclick = () => {
661         var format = document.getElementById('format').value;
662         downloadInterpretation(format);
663     };
664
665     document.getElementById('gen-score').onclick = () =>
666         downloadFile('application/json', 'score.likely.json',
667             JSON.stringify(collectGraphData(nodeData, edgeData)));
668     document.getElementById('upload-score').addEventListener('change',handleImport);
669     document.getElementById('clear-score').onclick = () =>
670         importGraphData({ nodes: [], edges: []});
671
672     window.setInterval(saveDataToLocalStorage, 5000);
673 }
674
675 document.addEventListener('DOMContentLoaded', () => init());
```

Graph im JSON Format der Webapplikation


```
{
  "nodes": [
    {
      "id": "8639d9e3-570d-47e1-b18b-0389cfd36693",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "C",
        "octave": 1
      }
    },
    {
      "id": "0073dfd0-1d9c-49ac-b59c-db8282fd7fe2",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "D",
        "octave": 1
      }
    },
    {
      "id": "67f468d4-6d6a-4e78-b003-9dd9ebc21558",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "E",
        "octave": 1
      }
    },
    {
      "id": "569ed8c7-f6d1-427a-bf32-e2378f1fc56d",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "F",
        "octave": 1
      }
    },
    {
      "id": "e9b032b8-a7bf-4b6b-aab8-f87c03651a1c",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "G",
        "octave": 1
      }
    },
    {
      "id": "3558118c-0872-49dd-ac60-72c12603e1bd",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "A",
        "octave": 1
      }
    },
    {
      "id": "6a58ff77-d7f5-439a-b220-a68ae8f70e8a",
      "music": {
        "dur": {
          "numerator": 1,
          "denominator": 4
        },
        "pitch": "B",
        "octave": 1
      }
```

```
    }
  ],
  "edges": [
    {
      "id": "dbc6dc78-f0b9-47eb-bae1-ab4936c3839c",
      "from": "3558118c-0872-49dd-ac60-72c12603e1bd",
      "to": "8639d9e3-570d-47e1-b18b-0389cfd36693",
      "prob": 0.3
    },
    {
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