

likely music

Probabilistische Musiknotation

Lukas Epple
post@lukasepple.de
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Zusammenfassung

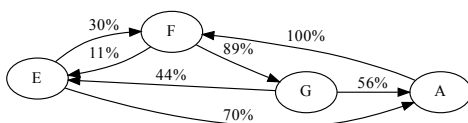
likely music ist eine Software, um probabilistische Musik zu notieren und abzuspielen. Probabilistische Musik bedeutet in diesem Falle, dass die Interpretation der vorliegenden Notation deutlich freier ist als bei herkömmlicher Musik und auch die Reihenfolge der Noten betrifft. Um dies zu erreichen, 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 Übergänge 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 dieses Jahres entschied ich mich, dieses – eine Demo [1] – abzubauen, 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 und speist 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.

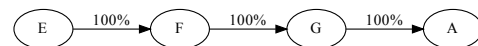
Das Modell, das ich aus Angst es zu vergessen, mehrmals aufschrieb, sieht Musik als gerichteten Graphen, wobei die Knoten Musiknoten einer bestimmten Länge und die Kanten zwischen ihnen die Wahrscheinlichkeit des Wechsel von der einen Note zu anderen sind. Vorstellen kann man sich es in etwa wie in der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



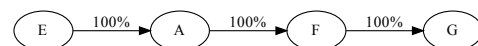
In diesem konkreten Graphen sind die Noten E, F, G und A als Knoten vertreten (der Einfachheit halber sind die Notenlängen weggelassen). Beispielsweise vom E führen zwei Kanten

weg, eine zum F mit dreißigprozentiger Wahrscheinlichkeit und eine zum A mit siebenzigprozentiger 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 ausdrucksstärkere und mächtigere Notation dar, da sie beliebig viele klassische fassen kann.

Zu beachten ist bei den beiden Beispielininterpretationen 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 fokussieren und zur Tonerzeugung eine geeignete Abstraktion zu verwenden, um diese zu vereinfachen. Ich habe hierfür MIDI gewählt, eine Technologie, die schon lang 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 Euterpea¹ [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 gerichteten 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 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 linear!). 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 Möglichkeiten für den weiteren Verlauf:

¹Ich 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.

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.

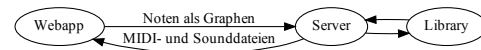
Da die meisten Graphen vermutlich vollständig untereinander verbunden sein werden, wie zum Beispiel der Beispielgraph im ersten Abschnitt, entstehen unendlich lange Interpretationen. Diese zu erstellen benötigt naturgemäß auch unendlich viel Zeit – der Interpretationsalgorithmus terminiert also nicht. 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 Betriebs-

systemen. 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. Der Server bietet folgende Funktionalität an:

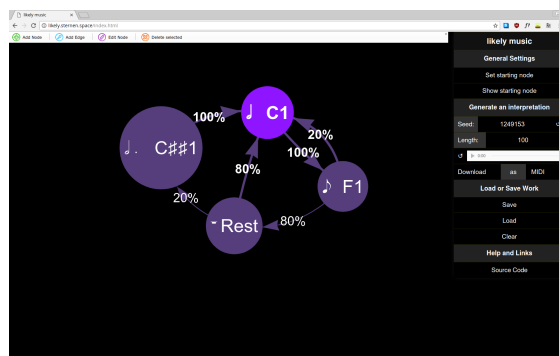
- `/interpretation/mid` An diesen Endpunkt schickt die Webapplikation einen Graphen plus einiger Parameter in Form von JSON [20] und erhält eine Interpretation auf Basis des Algorithmus als MIDI-Datei zurück.
- `/interpretation/wav` Gleich wie der obige Endpunkt, allerdings wird vorher noch das MIDI 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 nur 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:



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.

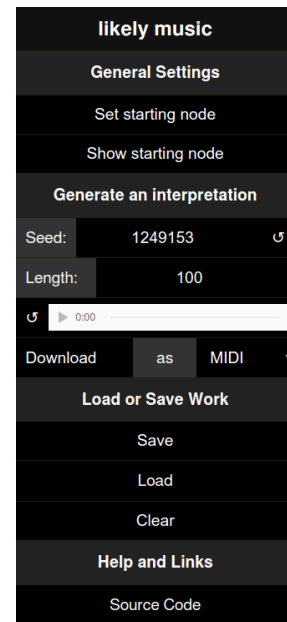
Das Speichern und Öffnen von Notationen basiert auf JSON-Dateien [20] in bestimmtem Format, die als `<dateiname>.score.json` abgespeichert werden. Eine solche enthält eine Liste aller Knoten plus Zusatzinformationen und eine Liste aller Kanten plus Zusatzinformationen. Wie eine solche aussehen kann, 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 [27] den Graphen mitsamt der Parameter an den bereits erwähnten Endpunkt `/interpretation/wav`. Nach diesem Vorgang, der merklich Zeit benötigt, da `fluidsynth` [23] erst das WAV generieren 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“.



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

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 [28] 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 [30], 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 Wettbewerbsteilnehmer*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 ge-

worden, 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.

Zukünftige Weiterentwicklung

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 interessante Möglichkeit zu sein, Mehrstimmig für *likely music* umzusetzen.
- **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 <https://github.com/sternenseemann/likely-music>
- Eine laufende Instanz³ von *likely music*

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.

<https://likely.sternen.space>

Danksagung

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- Christine S. für ihr Korrekturlesen.
- kohlrabi dafür, dass er sich mit mir über Musikprogrammierung und -theorie unterhielt und Ideen zu meinem Projekt beisteuerte.
- all dafür, dass er mich in Richtung Musikprogrammierung stieß.

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_\(computer_programming\)](https://en.wikipedia.org/wiki/Callback_(computer_programming))
- [27] https://developer.mozilla.org/en-US/docs/Web/API/Fetch_API
- [28] https://developer.mozilla.org/en-US/docs/Web/API/Web_Storage_API
- [29] <https://www.gnu.org/licenses/agpl-3.0.html>
- [30] <https://www.gnu.org/philosophy/free-sw.de.html>

Anhang

Screenshots

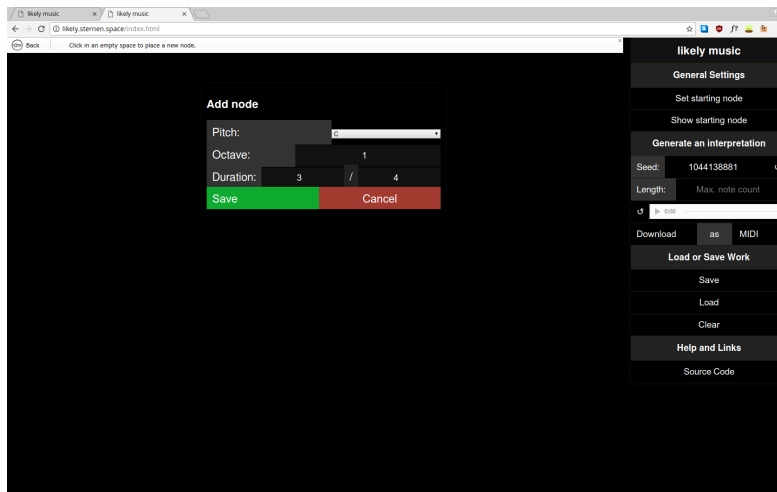


Abbildung 1: Hinzufügen eines Knotens

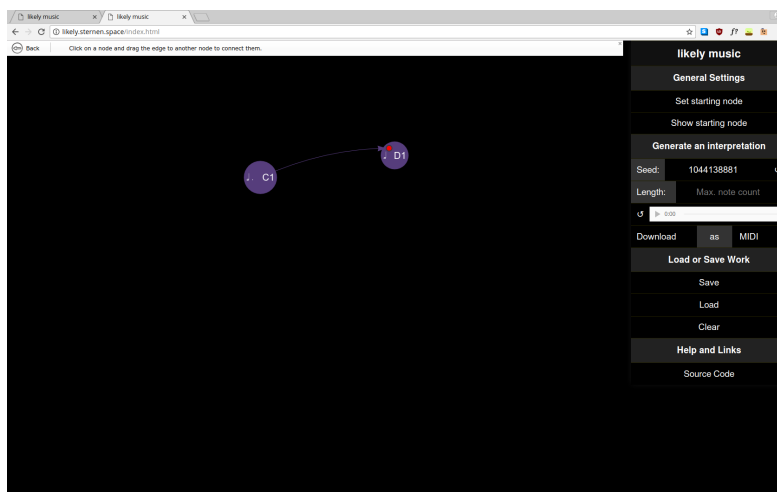


Abbildung 2: Verbinden zweier Knoten mit einer Kante

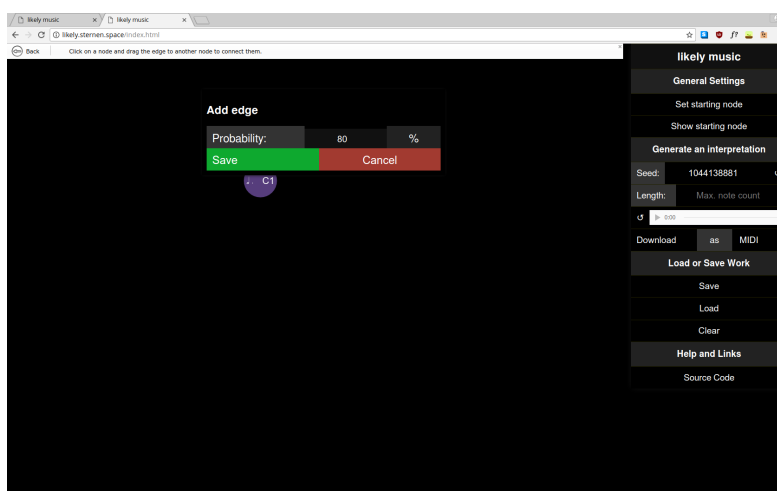


Abbildung 3: Setzen der Kanteneigenschaften

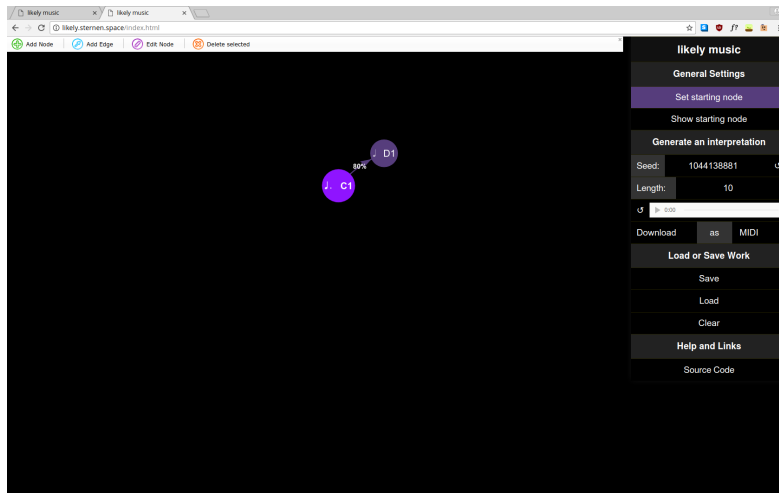


Abbildung 4: Setzen des Startknotens durch Auswählen des Knotens

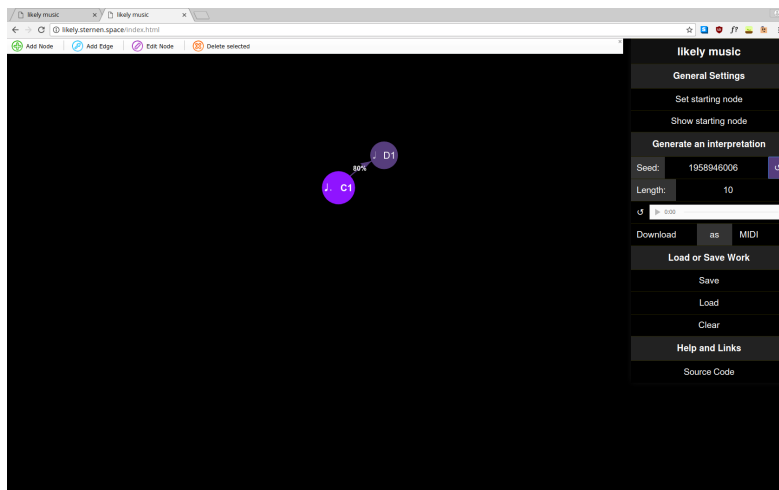


Abbildung 5: Auswürfeln eines neuen Startwerts per Knopfdruck

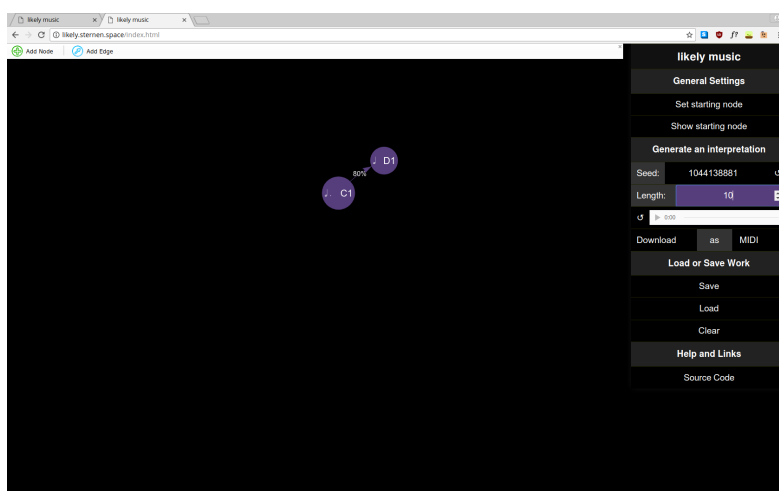


Abbildung 6: Setzen der maximalen Interpretationslänge

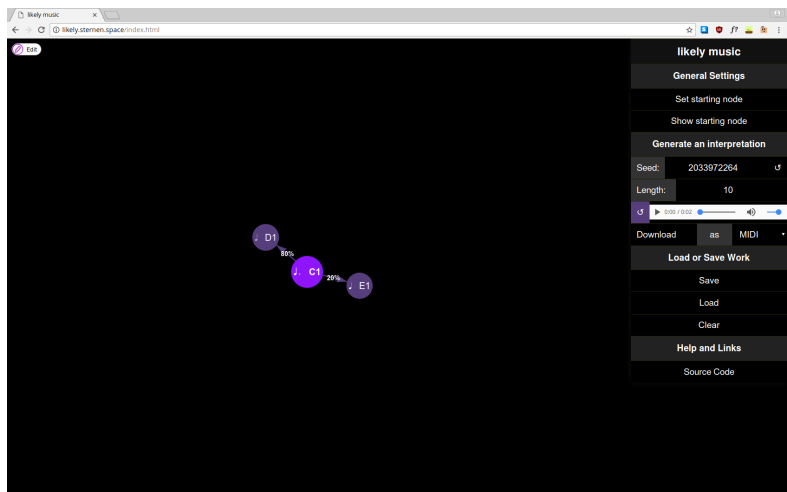


Abbildung 7: Laden der Interpretation in den Player

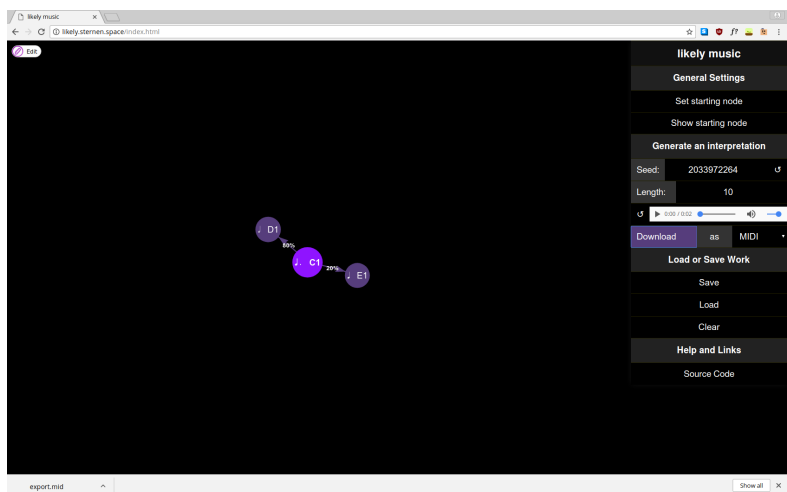


Abbildung 8: Download der Interpretation als MIDI-Datei

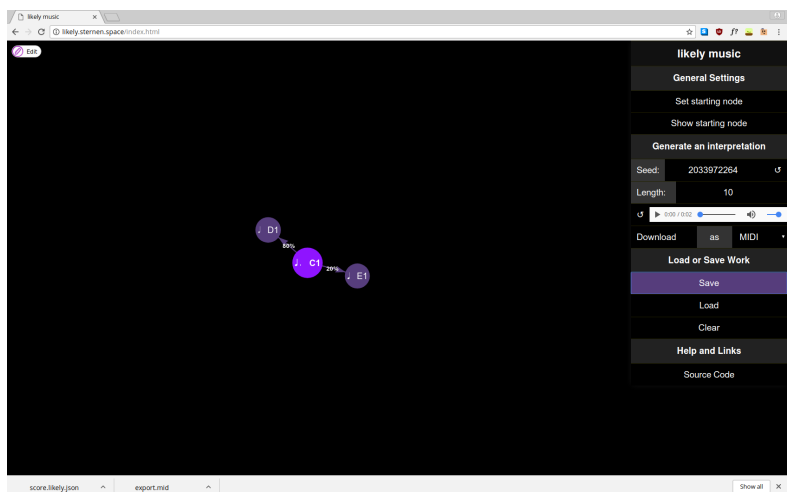


Abbildung 9: Speichern der Notation

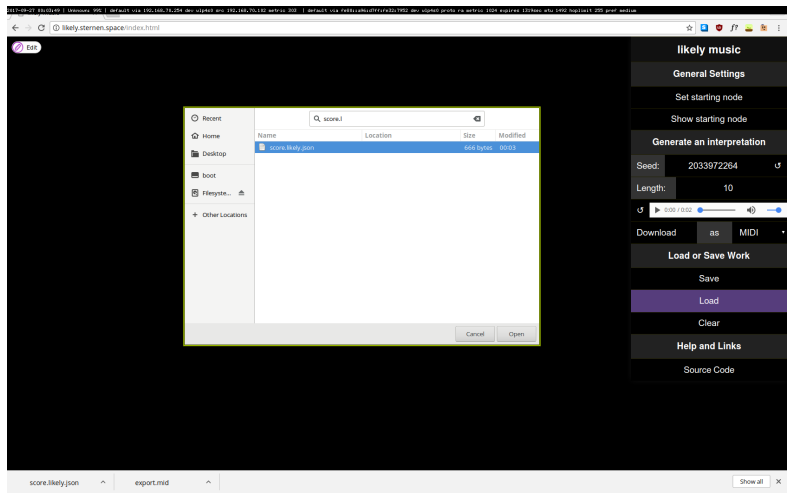


Abbildung 10: Laden einer Notation

Quelltext

Library

lib/Sound/Likely.hs

```
1  -- Copyright 2017 Lukas Eppe
2  --
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7  -- the Free Software Foundation, either version 3 of the License, or
8  -- (at your option) any later version.
9  --
10 -- likely music is distributed in the hope that it will be useful,
11 -- but WITHOUT ANY WARRANTY; without even the implied warranty of
12 -- MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
13 -- GNU Affero General Public License for more details.
14 --
15 -- You should have received a copy of the GNU Affero General Public License
16 -- along with likely music. If not, see <http://www.gnu.org/licenses/>.
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           if S.null edges
```

```

75         then emptyMusic
76         else interpretation gen' graph
77             . eTo . edgeForRoll prob $ edges
78
79 edgeForRoll :: Probability -> S.Set Edge -> Edge
80 edgeForRoll prob set =
81     let curr = S.elemAt 0 set
82     in if prob <= eProb curr
83         then curr
84         else edgeForRoll (prob - eProb curr) (S.delete curr set)
85
86 emptyMusic :: Music a
87 emptyMusic = Prim (Rest 0)
88
89 exampleGraph :: Graph
90 exampleGraph = Graph $ M.fromList
91     [ (Node "bla" (c 4 qn), S.fromList [ Edge (Node "blub" (d 4 qn)) 1 ] )
92     , (Node "blub" (d 4 qn), S.fromList [ ])
93     ]
94
95 -- / Take the first @n@ notes of a 'Music'
96 takeNotes :: Integer -> Music a -> Music a
97 takeNotes _ m@(Prim _) = m
98 takeNotes n (Modify c m) = Modify c $ takeNotes n m
99 takeNotes _ m@(_ :=: _) = m
100 takeNotes n (m1 :+: m2)
101     | n < 1    = emptyMusic
102     | n == 1   = m1
103     | otherwise = m1 :+: takeNotes (n - 1) m2
104
105 instance FromJSON Node where
106     parseJSON = withObject "Node" $ \v ->
107         Node <$> v .: "id" <*> (Prim <$> v .: "music")
108
109 lookupNode :: Text -> [Object] -> Parser Node
110 lookupNode id nodes = do
111     matches <- filterM (fmap (== id) . (.: "id")) nodes
112     case matches of
113         [node] -> parseJSON (Object node)
114         _ -> fail "Couldn't match node by id"
115
116 buildMap :: [Object] -> [Object] -> Graph -> Parser Graph
117 buildMap _ [] m = pure m
118 buildMap nodes (e:es) m = do
119     toId <- e .: "to"
120     fromId <- e .: "from"
121     edge <- Edge <$> lookupNode toId nodes <*> e .: "prob"
122     from <- lookupNode fromId nodes
123     buildMap nodes es $ insertEdge from edge m
124
125 instance FromJSON Graph where
126     parseJSON = withObject "Graph" $ \v -> do
127         edges <- v .: "edges"
128         nodes <- v .: "nodes"
129         buildMap nodes edges $ Graph mempty
130
131 instance FromJSON (Primitive Pitch) where
132     parseJSON = withObject "Primitive" $ \v -> do
133         -- TODO Ratio Integer is easy DOSable
134         -- RAM consumption
135         duration <- v .: "dur"
136         octave <- v .: "octave"
137         pitchClass <- v .: "pitch"
138         case pitchClass of
139             "Rest" -> pure $ Rest duration
140             p -> pure $ Note duration (read pitchClass, octave)

```

Backend

backend/Api.hs

```
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7  -- the Free Software Foundation, either version 3 of the License, or
8  -- (at your option) any later version.
9  --
10 -- likely music is distributed in the hope that it will be useful,
11 -- but WITHOUT ANY WARRANTY; without even the implied warranty of
12 -- MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
13 -- GNU Affero General Public License for more details.
14 --
15 -- You should have received a copy of the GNU Affero General Public License
16 -- along with likely music. If not, see <http://www.gnu.org/licenses/>.
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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2  --
3  -- This file is part of likely music.
```

```

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7  -- the Free Software Foundation, either version 3 of the License, or
8  -- (at your option) any later version.
9  --
10 -- likely music is distributed in the hope that it will be useful,
11 -- but WITHOUT ANY WARRANTY; without even the implied warranty of
12 -- MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
13 -- GNU Affero General Public License for more details.
14 --
15 -- You should have received a copy of the GNU Affero General Public License
16 -- along with likely music. If not, see <http://www.gnu.org/licenses/>.
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 Eulerpea 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/59l834mz365ccwyj3ah2d66ncsqvp8w9-Fluid-3/share/soundfonts/
76        FluidR3_GM2-2.sf2"
77      , inName ])
78   { std_in = CreatePipe }
79   code <- liftIO $ waitForProcess ph
80   case code of
81     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)
94                     ext
95                 exists <- liftIO $ doesFileExist path
96                 if exists
97                     then try (n + 1)
98                     else pure path
99                 | otherwise = throwError err500 { errBody = "no temp files" }
100 app :: Application
101 app = serve api server
102
103 main :: IO ()
104 main = newStdGen >> run 8081 app

```

Web

web/source/index.html

```
1  <!--
2
3      Copyright 2017 Lukas Epple
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5      This file is part of likely music.
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7      likely music is free software: you can redistribute it and/or modify
8      it under the terms of the GNU Affero General Public License as published by
9      the Free Software Foundation, either version 3 of the License, or
10     (at your option) any later version.
11
12     likely music is distributed in the hope that it will be useful,
13     but WITHOUT ANY WARRANTY; without even the implied warranty of
14     MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
15     GNU Affero General Public License for more details.
16
17     You should have received a copy of the GNU Affero General Public License
18     along with likely music. If not, see <http://www.gnu.org/licenses/>.
19
20 -->
21 <!doctype html>
22 <html>
23     <head>
24         <meta charset="utf-8">
25         <meta http-equiv="x-ua-compatible" content="ie=edge" />
26         <meta name="viewport" content="width=device-width, initial-scale=1" />
27         <title>likely music</title>
28         <link rel="stylesheet" type="text/css" href="custom.css">
29         <link rel="stylesheet" type="text/css" href="vis.min.css">
30         <script src="main.js"></script>
31     </head>
32     <body>
33         <div id="network"></div>
34         <div id="sidebar">
35             <h1>likely music</h1>
36             <h2>General Settings</h2>
37             <button id="set-starting-node">Set starting node</button>
38             <button id="show-starting-node">Show starting node</button>
39             <h2>Generate an interpretation</h2>
40             <div class="multi-inputs">
41                 <label for="seed">Seed:</label>
42                 <input type="number" id="seed">
43                 <button id="random-seed">Generate random seed</button>
44             </div>
45             <div class="multi-inputs">
46                 <label for="hop-count">Length:</label>
47                 <input type="number" min="0" id="hop-count" placeholder="Max. hop count">
48             </div>
49             <div id="player-container">
50                 <button id="reload-player">Reload player</button>
51                 <audio id="player" controls></audio>
52             </div>
53             <div class="multi-inputs">
54                 <button id="download-audio">Download</button>
55                 <label for="format">
56                     as
57                 </label>
58                 <select id="format">
59                     <option value="mid">MIDI</option>
60                     <option value="wav">WAV</option>
61                 </select>
62             </div>
63             <h2>Load or Save Work</h2>
64             <button id="gen-score" class="save">Save</button>
65             <label for="upload-score" class="custom-file">
66                 <input type="file" id="upload-score" >
67                 <span>Load</span>
68             </label>
69             <button id="clear-score" class="cancel">Clear</button>
70             <h2>Help and Links</h2>
71             <a href="https://github.com/sternenseemann/likely-music">Source Code</a>
72         </div>
73         <div id="edge-overlay" class="hidden dialog">
74             <h2><span id="edge-operation"></span> edge</h2>
75             <div class="multi-inputs">
```



```

76         <label for="prob">Probability:</label>
77         <input id="prob" type="number" min="0.0" max="100">
78         <span>%</span>
79     </div>
80     <div class="multi-inputs">
81         <button class="save" id="edge-save">Save</button>
82         <button class="cancel" id="edge-cancel">Cancel</button>
83     </div>
84 </div>
85 <div id="node-overlay" class="hidden_dialog">
86     <h2><span id="node-operation"></span> node</h2>
87     <div class="multi-inputs">
88         <label for="pitch">Pitch:</label>
89         <select id="pitch"></select>
90     </div>
91     <div class="multi-inputs">
92         <label for="octave">Octave:</label>
93         <input id="octave" type="number" step="1">
94     </div>
95     <div class="multi-inputs">
96         <label>Duration:</label>
97         <input min="0" id="numerator" type="number" step="1">
98         <span>/</span>
99         <input min="0" id="denominator" type="number" step="1">
100     </div>
101     <div class="multi-inputs">
102         <button class="save" id="node-save">Save</button>
103         <button class="cancel" id="node-cancel">Cancel</button>
104     </div>
105 </div>
106 </body>
107 </html>

```

web/source/custom.css

```
1  /* Copyright 2017 Lukas Epple
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5  likely music is free software: you can redistribute it and/or modify
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11 but WITHOUT ANY WARRANTY; without even the implied warranty of
12 MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
13 GNU Affero General Public License for more details.
14
15 You should have received a copy of the GNU Affero General Public License
16 along with likely music. If not, see <http://www.gnu.org/licenses/>.
17 */
18
19 body {
20     font-size: 1em;
21     font-family: sans-serif;
22     margin: 0px;
23     background-color: black;
24 }
25
26 #network {
27     width: 79%;
28     float: left;
29     height: 100vh;
30 }
31
32 #sidebar {
33     width: 20%;
34     float: right;
35     color: white;
36     background-color: black;
37     box-shadow: 0px 0px 20px #111;
38     font-size: 1.2rem;
39 }
40
41 #sidebar > * {
42     width: 100%;
43     border-top: 1px solid #232200;
44     color: white;
45     padding-left: 0px;
46     padding-right: 0px;
47     margin: 0;
48 }
49
50 #sidebar button:hover, #sidebar input:hover,
51 #sidebar .custom-file:hover, #sidebar select:hover, #sidebar a:hover {
52     background-color: #563d7c;
53 }
54
55 #sidebar button, #sidebar input, #sidebar .custom-file, #sidebar select, #sidebar a {
56     background-color: #000;
57 }
58
59 #sidebar h1 {
60     font-size: 1.5rem;
61     padding-top: 0.75rem;
62     padding-bottom: 0.75rem;
63     text-align: center;
64     background-color: #111;
65 }
66
67 #sidebar h2 {
68     font-size: 1.2rem;
69     padding-top: 0.9rem;
70     padding-bottom: 0.9rem;
71     text-align: center;
72     background-color: #222;
73 }
74
75 #sidebar select {
76     color: white;
77     border: none;
78     padding: 0.75rem;
```

```

79     font-size: 1.2rem;
80     width: auto;
81 }
82
83 #sidebar a {
84     padding-bottom: 0.75rem;
85     padding-top: 0.75rem;
86     display: inline-block;
87     text-decoration: none;
88     color: white;
89     text-align: center;
90 }
91
92 button {
93     border: none;
94     color: white;
95     background-color: black;
96     font-size: 1.2rem;
97     margin: 0;
98     padding: 0.75rem;
99 }
100
101 input[type="number"] {
102     background-color: #333;
103     color: white;
104     border: none;
105     text-align: center;
106     font-size: 1.2rem;
107     padding: 0.75rem;
108 }
109
110 .custom-file {
111     top: 0;
112     right: 0;
113     position: relative;
114     display: inline-block;
115     height: 3rem;
116 }
117
118 .custom-file input[type="file"] {
119     position: relative;
120     top: 0;
121     left: 0;
122     right: 0;
123     z-index: 0;
124     opacity: 0;
125     width: 100%;
126     height: 100% !important;
127     margin: 0;
128     padding: 0;
129 }
130
131 .custom-file span {
132     text-align: center;
133     position: absolute;
134     top: 0;
135     left: 0;
136     right: 0;
137     z-index: 1;
138     width: 100%;
139     height: 3rem;
140     pointer-events: none;
141     background-color: transparent !important;
142     font-size: 1.2rem;
143     line-height: 1.5rem;
144     padding-top: 0.75rem;
145     padding-bottom: 0.75rem;
146 }
147
148 .dialog {
149     position: absolute;
150     top: 10%;
151     left: 25%;
152     width: 30%;
153     min-width: 500px;
154     padding: 10px;
155     background-color: black;
156     color: white;
157     box-shadow: 0px 0px 10px #111;

```

```
158 }
159
160 .dialog select {
161     padding: 0.75rem;
162     font-size: 1.5rem;
163     color: white;
164     background-color: #111;
165     border: none;
166 }
167
168 .hidden {
169     visibility: hidden;
170 }
171
172 .dialog > div {
173     width: 100%;
174 }
175
176 .dialog button {
177     padding: 0.75rem;
178     font-size: 1.5rem;
179 }
180
181 .dialog input {
182     font-size: 1.5rem;
183 }
184
185 button.cancel {
186     background-color: #a23a30;
187 }
188
189 button.save {
190     background-color: #0ea92f;
191 }
192
193 .dialog .multi-inputs {
194     font-size: 1.5rem;
195 }
196
197 .multi-inputs {
198     display: inline-flex;
199     flex-direction: row;
200     flex-wrap: nowrap;
201     justify-content: flex-start;
202     align-items: baseline;
203     width: 100%;
204 }
205
206 .multi-inputs > * {
207     flex-grow: 1;
208     flex-basis: auto;
209     transition: width 0.7s ease-out;
210     max-height: 100%;
211     text-align: center;
212 }
213
214 .multi-inputs :nth-child(1) {
215     text-align: left;
216 }
217
218 .multi-inputs label {
219     display: inline-block;
220     background-color: #333;
221     padding: 0.75rem;
222 }
223
224 .multi-inputs input {
225     display: inline-block;
226     color: white;
227     background-color: #111;
228     padding: 0.75rem;
229     border: none;
230     min-width: 0px;
231 }
232
233 .multi-inputs span {
234     display: inline-block;
235     padding: 0.75rem;
236     background-color: #222;
```

```
237 }
238
239 .multi-inputs button {
240     padding: 0.75rem;
241 }
242
243 #player-container {
244     display: inline-flex;
245     align-items: center;
246 }
247
248 #player-container > * {
249     flex: auto;
250 }
```

web/source/main.js

```
1  // Copyright 2017 Lukas Epple
2  //
3  // This file is part of likely music.
4  //
5  // likely music is free software: you can redistribute it and/or modify
6  // it under the terms of the GNU Affero General Public License as published by
7  // the Free Software Foundation, either version 3 of the License, or
8  // (at your option) any later version.
9  //
10 // likely music is distributed in the hope that it will be useful,
11 // but WITHOUT ANY WARRANTY; without even the implied warranty of
12 // MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the
13 // GNU Affero General Public License for more details.
14 //
15 // You should have received a copy of the GNU Affero General Public License
16 // along with likely music. If not, see <http://www.gnu.org/licenses/>.
17
18 import vis from 'vis';
19 import { Map } from 'immutable';
20 // types / internals
21
22 const valid_pitches = [
23   'Rest',
24   'Cff', 'Cf', 'C',
25   'Dff', 'Cs', 'Df',
26   'Css', 'D', 'Eff',
27   'Ds', 'Ef', 'Fff',
28   'Dss', 'E', 'Ff',
29   'Es', 'F', 'Gff',
30   'Ess', 'Fs', 'Gf',
31   'Fss', 'G', 'Aff',
32   'Gs', 'Af', 'Gss',
33   'A', 'Bff', 'As',
34   'Bf', 'Ass', 'B',
35   'Bs', 'Bss'
36 ];
37
38 const display_pitches = [
39   'Rest',
40   'C', 'C', 'C',
41   'D', 'C', 'D',
42   'C', 'D', 'E',
43   'D', 'E', 'F',
44   'D', 'E', 'F',
45   'E', 'F', 'Gff',
46   'E', 'F', 'G',
47   'F', 'G', 'A',
48   'G', 'A', 'G',
49   'A', 'B', 'A',
50   'B', 'A', 'B',
51   'B', 'B'
52 ];
53
54 function displayPitch(pitch) {
55   var i = valid_pitches.indexOf(pitch);
56   if(i === -1) {
57     throw 'Invalid pitch';
58   } else {
59     return display_pitches[i];
60   }
61 }
62
63 function standard_rests(dur) {
64   if(dur.numerator === 1) {
65     switch(dur.denominator) {
66       case 1:
67         return ' ';
68         break;
69       case 2:
70         return ' ';
71         break;
72       case 4:
73         return ' ';
74         break;
75       case 8:
76         return ' ';
77         break;
78       case 16:
```

```

79         return ' ';
80         break;
81     case 32:
82         return ' ';
83         break;
84     case 64:
85         return ' ';
86         break;
87     case 128:
88         return ' ';
89         break;
90     default:
91         return null;
92         break;
93     }
94 } else {
95     return null;
96 }
97 }
98
99 function standard_notes(dur) {
100     if(dur.numerator === 1) {
101         switch(dur.denominator) {
102             case 1:
103                 return ' ';
104                 break;
105             case 2:
106                 return ' ';
107                 break;
108             case 4:
109                 return ' ';
110                 break;
111             case 8:
112                 return ' ';
113                 break;
114             case 16:
115                 return ' ';
116                 break;
117             case 32:
118                 return ' ';
119                 break;
120             case 64:
121                 return ' ';
122                 break;
123             case 128:
124                 return ' ';
125                 break;
126             default:
127                 return null;
128                 break;
129         }
130     } else if(dur.numerator === 2 && dur.denominator === 1) {
131         return ' ';
132     } else {
133         return null;
134     }
135 }
136
137 function compute_dot_times(dur, den) {
138     let term = den * ( (2 / den) - (dur.numerator / dur.denominator));
139     return [ den, -Math.log2(term) ];
140 }
141
142 function musical_symbol(lookup, dur) {
143     // unicode characters sometimes hide from you!
144     const dot = ' ';
145     let isNat = n => {
146         if (typeof n !== 'number')
147             return false;
148         return (n >= 0.0) && (Math.floor(n) === n) && n !== Infinity;
149     };
150     var standard_symbol = lookup(dur);
151     var dots = [0, 1, 2, 3, 4, 5, 6, 7 ].map(compute_dot_times.bind(this, dur))
152         .filter(([den, dots]) => isNat(dots));
153
154     if(standard_symbol !== null) {
155         return standard_symbol;
156     } else if (dots.length !== 0) {
157         var symbol = lookup(new Rational(1, dots[0][0])) + ' ';

```

```

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

```



```

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

```

```

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

```

```

391 }
392
393 function handleImport() {
394     var files = document.getElementById('upload-score').files;
395     if(files.length === 0) {
396         alert('Select a file first!');
397     } else {
398         var file = files[0];
399         var reader = new FileReader();
400         reader.addEventListener('loadend', function() {
401             var parsed = JSON.parse(this.result);
402             if(parsed === undefined) {
403                 alert('Could not parse likely score');
404             } else {
405                 var confirmation = window.confirm('Proceeding will overwrite the
406                     current graph. Are you sure?');
407                 if(confirmation) {
408                     try {
409                         importGraphData(parsed);
410                     } catch(e) {
411                         alert(`Could not import likely score, probably the file was
412                             malformed. Error: ${e}`);
413                     }
414                 }
415             }
416         });
417         reader.readAsText(file);
418     }
419 }
420
421 function saveDataToLocalStorage() {
422     const json = JSON.stringify(collectGraphData(nodeData, edgeData));
423     const params = JSON.stringify(gatherParams());
424     localStorage.setItem("score", json)
425     localStorage.setItem("params", params)
426 }
427
428 function showStartingNode() {
429     if(typeof starting_node_id === 'string') {
430         network.selectNodes([starting_node_id], false);
431     } else {
432         alert('No starting node selected yet!');
433     }
434 }
435
436 function setStartingNode() {
437     var selected = network.getSelectedNodes();
438     if(selected.length > 1) {
439         alert('Only select one node!');
440     } else if(selected.length === 0) {
441         alert('Select a node first!');
442     } else {
443         starting_node_id = selected[0];
444     }
445 }
446
447 function fetchInterpretation(params, format) {
448     var jsonRequest = JSON.stringify({
449         graph: collectGraphData(nodeData, edgeData),
450         params: params
451     });
452
453     var myHeaders = new Headers();
454     myHeaders.set('Content-Type', 'application/json');
455
456     var myInit = {
457         method: 'POST',
458         headers: myHeaders,
459         mode: 'cors',
460         body: jsonRequest
461     };
462
463     var myRequest = new Request(`/interpretation/${format}`, myInit);
464
465     return fetch(myRequest).then(res => res.blob());
466 }
467
468 function gatherParams() {
469     var starting_node_entry = nodeData.get(starting_node_id);

```

```

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

```

```

547     });
548     } catch(e) {
549         alert('An error occured while contacting the API: ' + e);
550     }
551 }
552 }
553
554 function reloadPlayer() {
555     var params = completeGatherParams();
556     if(params !== null) {
557         if(document.getElementById('player').src) {
558             URL.revokeObjectURL(document.getElementById('player').src);
559         }
560
561         document.getElementById('player').src = null;
562
563         try {
564             fetchInterpretation(params, 'wav').then(file => {
565                 var url = URL.createObjectURL(file);
566                 document.getElementById('player').src = url;
567             });
568         } catch(e) {
569             alert('An error occured while contacting the API: ' + e);
570         }
571     }
572 }
573
574 function init() {
575     var container = document.getElementById('network');
576
577     var options = {
578         manipulation: {
579             addNode: function(nodeData, callback) {
580                 document.getElementById('node-operation').innerHTML = 'Add';
581                 genericEditNode(nodeData, callback);
582             },
583             addEdge: function(edgeData, callback) {
584                 document.getElementById('edge-operation').innerHTML = 'Add';
585                 genericEditEdge(edgeData, callback);
586             },
587             editNode: function(nodeData, callback) {
588                 document.getElementById('node-operation').innerHTML = 'Edit';
589                 genericEditNode(nodeData, callback);
590             },
591             editEdge: {
592                 editWithoutDrag: function(edgeData, callback) {
593                     document.getElementById('edge-operation').innerHTML = 'Edit';
594                     genericEditEdge(edgeData, callback);
595                 }
596             },
597             deleteNode: deleteFromMap,
598             deleteEdge: deleteFromMap,
599             controlNodeStyle: {
600             }
601         },
602         nodes: {
603             borderWidth: 0,
604             color: {
605                 background: '#563d7c',
606                 hover: {
607                     background: '#8f14ff'
608                 },
609                 highlight: {
610                     background: '#8f14ff'
611                 }
612             },
613             chosen: true,
614             font: {
615                 color: 'white',
616                 size: 20,
617                 align: 'center'
618             },
619             shape: 'circle',
620         },
621         edges: {
622             arrows: {
623                 to: { enabled: true }
624             },
625             color: {

```

```

626         color: '#563d7c',
627         hover: '#563d7c',
628         highlight: '#563d7c',
629     },
630     font: {
631         color: '#ffffff',
632         strokeWidth: 0
633     }
634 }
635 };
636
637 network = new vis.Network(container, {}, options);
638
639 try {
640     const score = localStorage.getItem('score');
641     if(score !== null) {
642         importGraphData(JSON.parse(score));
643     }
644 } catch(e) {
645     localStorage.removeItem('score');
646 }
647
648 try {
649     const params = localStorage.getItem('params')
650     if(params !== null) {
651         importParams(JSON.parse(params));
652     }
653 } catch(e) {
654     localStorage.removeItem('params');
655 }
656
657 const pitch_selector = valid_pitches.map((p, i) =>
658     `<option value="${p}">${display_pitches[i]}</option>`)
659     .reduce((acc, v) =>
660         acc + v, '');
661 document.getElementById('pitch').innerHTML = pitch_selector;
662
663 /* event handling, order as in sidebar */
664 document.getElementById('set-starting-node').onclick = setStartingNode;
665 document.getElementById('show-starting-node').onclick = showStartingNode;
666
667 document.getElementById('random-seed').onclick = randomSeed;
668
669 document.getElementById('reload-player').onclick = reloadPlayer;
670 document.getElementById('download-audio').onclick = () => {
671     var format = document.getElementById('format').value;
672     downloadInterpretation(format);
673 };
674
675 document.getElementById('gen-score').onclick = () =>
676     downloadFile('application/json', 'score.likely.json',
677         JSON.stringify(collectGraphData(nodeData, edgeData)));
678 document.getElementById('upload-score').addEventListener('change', handleImport);
679 document.getElementById('clear-score').onclick = () =>
680     importGraphData({ nodes: [], edges: []});
681
682 window.setInterval(saveDataToLocalStorage, 5000);
683 }
684
685 document.addEventListener('DOMContentLoaded', () => init());

```

Graph im JSON Format der Webapplikation

```
1  {
2    "nodes": [
3      {
4        "id": "d3c408d5-1ebb-4787-b510-22af5fe7093a",
5        "music": {
6          "dur": {
7            "numerator": 3,
8            "denominator": 4
9          },
10         "pitch": "Cf",
11         "octave": 1
12       }
13     },
14     {
15       "id": "180159e7-527b-4b8a-b9b6-315dddc154d2",
16       "music": {
17         "dur": {
18           "numerator": 2,
19           "denominator": 4
20         },
21         "pitch": "C",
22         "octave": 1
23       }
24     },
25     {
26       "id": "02e24c99-780e-45da-bd2f-ea600e4d863f",
27       "music": {
28         "dur": {
29           "numerator": 1,
30           "denominator": 1
31         },
32         "pitch": "Rest",
33         "octave": 1
34       }
35     },
36     {
37       "id": "b9cd3f9d-134c-4c51-b325-d209b2529bd6",
38       "music": {
39         "dur": {
40           "numerator": 1,
41           "denominator": 8
42         },
43         "pitch": "F",
44         "octave": 1
45       }
46     }
47   ],
48   "edges": [
49     {
50       "id": "f8d0cb23-00d1-49dd-961a-2114b8a89c1d",
51       "from": "d3c408d5-1ebb-4787-b510-22af5fe7093a",
52       "to": "180159e7-527b-4b8a-b9b6-315dddc154d2",
53       "prob": 1
54     },
55     {
56       "id": "283100d9-42ee-4001-b100-45b8c766cfc5",
57       "from": "b9cd3f9d-134c-4c51-b325-d209b2529bd6",
58       "to": "02e24c99-780e-45da-bd2f-ea600e4d863f",
59       "prob": 0.8
60     },
61     {
62       "id": "e6cceb76-40ed-49ac-8925-4534cf0854de",
63       "from": "02e24c99-780e-45da-bd2f-ea600e4d863f",
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77       "prob": 0.2
78     }
79   ]
80 }
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79     {
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82       "to": "b9cd3f9d-134c-4c51-b325-d209b2529bd6",
83       "prob": 1
84     }
85   ]
86 }
```


Lizenz

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