

likely music

Probabilistische Musiknotation

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Zusammenfassung

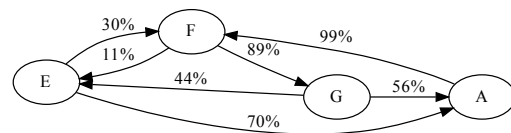
likely music ist eine Software, um probabilistische Musik zu notieren und abzuspielen. Probabilistische Musik heißt in diesem Falle, dass die Interpretation der vorliegenden Notation deutlich freier ist als bei herkömmlicher Musik und auch die Reihenfolge der Noten betrifft. Um dies zu erreichen wird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

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

Idee

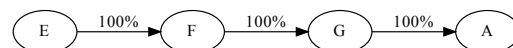
Der eigentlichen Idee ging ein mehr oder minder gescheitertes Projekt für diesen Wettbewerb voraus. Im Frühjahr dieses Jahres entschied ich mich dieses, eine Demo [1], abubrechen, einfach weil ich befürchtete, es nicht bis zur Frist fertigstellen zu können. Die Motivation für dieses Projekt speiste sich aus meiner Faszination für Demos an sich, denn ich hatte bereits im Vorfeld öfters mich mit diesen beschäftigt und beim Ansehen der Einsendung von Demo-Wettbewerben ein Bedürfnis entwickelt auch so etwas zu entwickeln. Das neue Projekt speiste sich aus einer weiteren Faszination von mir, nämlich einer für Kunst, die basierend auf Kunst entsteht. Ich erinnere mich oft besonders an Kunstinstallationen, die ihr gestaltendes Element durch Zufall oder einen undurchschaubaren oder chaotischen Prozess bezieht. Beim Nachdenken über Zwölftonmusik, die – meiner Meinung nach – ein wenig jenen Elements hat, kam mir die Grundidee – wie ich mich erinnere – auf dem Gang zwischen zwei Schulstunden für *likely music*, nämlich ein Modell, um Musik zu beschreiben, die zufällig im Vortrag ist.

Das Modell, das ich übertrieben panisch auf ein Stück Notizblock kritzelte, 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. Vorstellen kann man sich es in etwa so:



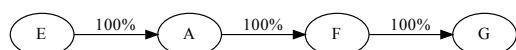
In diesem konkreten Graphen sind die Noten E, F, G und A als Knoten vertreten (der Einfachheit halber sind die Notenlängen weggelassen). Beispielsweise vom E führen zwei Kanten weg, eine zum F mit dreißigprozentiger Wahrscheinlichkeit und eine zum A mit siebenzigprozentiger Wahrscheinlichkeit, d. h. nach dem E kommt in sieben von zehn Fällen das A und in den drei übrigen das F, analog gilt 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 aufzutreten, 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 bezeichnen, auf eine lineare Notation reduziert werden kann, die mit einem Instrument oder vom Computer gespielt werden kann. Es ist sogar nicht nur eine lineare Notation, sondern – je nach vorgegebenen Graph – eine Vielzahl ihrer möglich. Beispielsweise wäre eine weitere:



Ähnlich gibt es noch viele weitere Möglichkeiten. Zu beachten ist bei den beiden Beispielinterpretationen noch: Sie sind nach vier Noten 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 mir persönlich sehr gut taugen, um mal einige zu nennen.

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 – gegeben ein Algorithmus dafür – jegliche Daten in Töne umwandeln, was interessante Möglichkeiten er-

gab, 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 macschinen-nahem 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, die diese zu vereinfachen. Ich habe hierfür MIDI gewählt, eine Technologie, die schon lang in allen Arten von Software und Hardware zur Musikproduktion verwendet wird, entschieden. 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, dass der Interpretationsalgorithmus, also das (zufällige) Ablaufen des Graphen, möglichst effizient zu machen. 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

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.

muss also möglichst effizient sein, die Kanten nachzuschlagen, die von einem Knoten *wegführen*. Mit der Datenstruktur *Map* [11] (im deutschen Sprachgebrauch typischerweise *assoziative Datenfeld* bzw. *assoziatives Array*) kann man genau das sehr leicht realisieren, indem man die Knoten als Schlüssel und eine Liste von Kanten, die vom Schlüssel weggehen, als Elemente verwendet. 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 Nachschlagen 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!), wodurch auch das Interpretieren großer Graphen ziemlich schnell bleibt. 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 und 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:

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 Ergebnis 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 natürlich 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.

Lizenzierung

Benutzung

Zukünftige Weiterentwicklung

Links

- Der gesamte Quelltext <https://github.com/sternenseemann/likely-music>
- Eine laufende Instanz 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

Anhang

Quelltext

Library

lib/Sound/Likely.hs

```
1 {-# LANGUAGE OverloadedStrings #-}
2 {-# LANGUAGE FlexibleInstances #-}
3 module Sound.Likely
4   ( Probability
5   , ID
6   , Node (..)
7   , Edge (..)
8   , Graph (..)
9   , insertNode
10  , insertEdge
11  , interpretation
12  , takeNotes
13  , emptyMusic
14  , exampleGraph
15  ) where
16
17 import Control.Monad
18 import Data.Aeson
19 import Data.Aeson.Types (Parser ())
20 import Data.Maybe
21 import Data.Text (Text ())
22 import Euterpea
23 import System.Random
24 import qualified Data.Map as M
25 import qualified Data.Set as S
26
27 type Probability = Double
28 type ID = Text
29
30 data Node
31   = Node
32   { nId :: ID
33   , nMusic :: Music Pitch
34   } deriving (Show, Eq, Ord)
35
36 data Edge
37   = Edge
38   { eTo :: Node
39   , eProb :: Probability
40   } deriving (Show, Eq, Ord)
41
42 newtype Graph = Graph { unGraph :: M.Map Node (S.Set Edge) }
43   deriving (Show, Eq, Ord)
```

```

44
45 insertNode :: Node -> Graph -> Graph
46 insertNode t = Graph . M.insertWith S.union t S.empty . unGraph
47
48 insertEdge :: Node -> Edge -> Graph -> Graph
49 insertEdge n e =
50   insertNode n . Graph . M.insertWith S.union n (S.singleton e) . unGraph
51
52 interpretation :: RandomGen g => g -> Graph -> Node -> Music Pitch
53 interpretation gen graph n = (nMusic n) :+
54   recurse (fromMaybe S.empty (M.lookup n (unGraph graph)))
55   where (prob, gen') = randomR (0.0, 1.0) gen
56   recurse edges =
57     if S.null edges
58     then emptyMusic
59     else interpretation gen' graph
60       . eTo . edgeForRoll prob $ edges
61
62 edgeForRoll :: Probability -> S.Set Edge -> Edge
63 edgeForRoll prob set =
64   let curr = S.elemAt 0 set
65   in if prob <= eProb curr
66     then curr
67     else edgeForRoll (prob - eProb curr) (S.delete curr set)
68
69 emptyMusic :: Music a
70 emptyMusic = Prim (Rest 0)
71
72 exampleGraph :: Graph
73 exampleGraph = Graph $ M.fromList
74   [ (Node "bla" (c 4 qn), S.fromList [ Edge (Node "blub" (d 4 qn)) 1 ] )
75   , (Node "blub" (d 4 qn), S.fromList [ ])
76   ]
77
78 — / Take the first @@ notes of a 'Music'
79 takeNotes :: Integer -> Music a -> Music a
80 takeNotes _ m@(Prim _) = m
81 takeNotes n (Modify c m) = Modify c $ takeNotes n m
82 takeNotes _ m@(_ :=: _) = m
83 takeNotes n (m1 :+ m2)
84   | n < 1    = emptyMusic
85   | n == 1   = m1
86   | otherwise = m1 :+ takeNotes (n - 1) m2
87
88 instance FromJSON Node where
89   parseJSON = withObject "Node" $ \v ->
90     Node <$> v .: "id" <*> (Prim <$> v .: "music")
91
92 lookupNode :: Text -> [Object] -> Parser Node
93 lookupNode id nodes = do

```

```

94 matches <- filterM (fmap (== id) . (: "id")) nodes
95 case matches of
96   [node] -> parseJSON (Object node)
97   _ -> fail "Couldn't match node by id"
98
99 buildMap :: [Object] -> [Object] -> Graph -> Parser Graph
100 buildMap _ [] m = pure m
101 buildMap nodes (e:es) m = do
102   toId <- e .: "to"
103   fromId <- e .: "from"
104   edge <- Edge <$> lookupNode toId nodes <*> e .: "prob"
105   from <- lookupNode fromId nodes
106   buildMap nodes es $ insertEdge from edge m
107
108 instance FromJSON Graph where
109   parseJSON = withObject "Graph" $ \v -> do
110     edges <- v .: "edges"
111     nodes <- v .: "nodes"
112     buildMap nodes edges $ Graph mempty
113
114 instance FromJSON (Primitive Pitch) where
115   parseJSON = withObject "Primitive" $ \v -> do
116     -- TODO Ratio Integer is easy DOSable
117     -- RAM consumption
118     duration <- v .: "dur"
119     octave <- v .: "octave"
120     pitchClass <- v .: "pitch"
121     case pitchClass of
122       "Rest" -> pure $ Rest duration
123       p -> pure $ Note duration (read pitchClass, octave)

```

Backend

backend/Api.hs

```
1 {-# LANGUAGE OverloadedStrings #-}
2 {-# LANGUAGE FlexibleInstances #-}
3 {-# LANGUAGE DataKinds         #-}
4 {-# LANGUAGE TypeOperators     #-}
5 module Api where
6
7 import Data.Aeson
8 import Data.ByteString.Lazy (ByteString ())
9 import Data.Monoid ((<>))
10 import Data.Ratio
11 import Data.Text (Text ())
12 import GHC.Generics
13 import Servant.API
14 import Sound.Likely
15
16 type LikelyApi = "interpretation" :> Capture "format" OutputFormat
17                                     :> ReqBody '[JSON] GraphWithParams
18                                     :> Post '[OctetStream] ByteString
19                                     :<|> "seed" :> Get '[JSON] Int
20                                     :<|> Raw
21
22 data OutputFormat = Midi | Wav
23   deriving (Show, Eq, Ord)
24
25 instance FromHttpApiData OutputFormat where
26   parseUrlPiece "mid" = Right Midi
27   parseUrlPiece "wav" = Right Wav
28   parseUrlPiece x     = Left $ "Couldn't match" < x < " with {mid, wav}"
29
30 data GraphWithParams
31   = GraphWithParams
32   { gpParams :: Params
33   , gpGraph  :: Graph
34   } deriving (Show, Eq, Ord)
35
36 instance FromJSON GraphWithParams where
37   parseJSON = withObject "GraphWithParams" $ \v ->
38     GraphWithParams <$> v  :: "params"
39     <*> v  :: "graph"
40
41 data Params
42   = Params
43   { pMaxHops      :: Int
44   , pStartingNode :: Node
45   , pSeed         :: Int
46   } deriving (Show, Eq, Ord)
47
```



```

48 instance FromJSON Params where
49     parseJSON = withObject "Params" $ \v ->
50         Params <$> v .: "maxhops"
51         <*> v .: "starting_node"
52         <*> v .: "seed"

```

backend/Main.hs

```

1  {-# LANGUAGE OverloadedStrings #-}
2  module Main where
3
4  import Api
5
6  import Codec.Midi (buildMidi)
7  import Codec.ByteString.Builder
8  import Control.Monad.IO.Class
9  import Data.ByteString.Lazy (ByteString ())
10 import qualified Data.ByteString.Lazy as B
11 import Euterpea hiding (app)
12 import GHC.IO.Handle
13 import Network.Wai
14 import Network.Wai.Handler.Warp
15 import Servant
16 import Sound.Likely
17 import System.Directory
18 import System.Exit
19 import System.Environment
20 import System.FilePath.Posix
21 import System.IO
22 import System.Process
23 import System.Random
24
25 api :: Proxy LikelyApi
26 api = Proxy
27
28 midiString :: ToMusic1 a => Music a -> ByteString
29 midiString = toLazyByteString . buildMidi . toMidi . perform
30
31 server :: Server LikelyApi
32 server = genInterpretation :<|> randomSeed :<|> serveDirectoryWebApp "web/
    dist"
33
34 randomSeed :: Handler Int
35 randomSeed = liftIO newStdGen >>= return . fst . random
36
37 genInterpretation :: OutputFormat -> GraphWithParams -> Handler ByteString
38 genInterpretation Midi g = do
39     let params          = gpParams g
40         maxHops         = fromIntegral . pMaxHops $ params

```

```

41     randomGen      = mkStdGen $ pSeed params
42     song           = interpretation randomGen (gpGraph g) (pStartingNode
                        params)
43     return . midiString $ takeNotes maxHops song
44     genInterpretation Wav g = genInterpretation Midi g >=> synthWav
45
46     synthWav :: ByteString -> Handler ByteString
47     synthWav midi = do
48         inName <- tempFile "mid"
49         liftIO $ B.writeFile inName midi
50         outName <- tempFile "wav"
51         (_, _, _, ph) <- liftIO $
52             createProcess_ "fluidsynth"
53                 (proc "fluidsynth"
54                     [ "-a", "file"
55                       , "-F", outName
56                       , "-i"
57 —             , "/usr/share/soundfonts/FluidR3_GM.sf2"
58             , "/nix/store/59l834mz365ccwyj3ah2d66ncsqvp8w9-Fluid-3/share/
                        soundfonts/FluidR3_GM2-2.sf2"
59             , inName ])
60         { std_in = CreatePipe }
61         code <- liftIO $ waitForProcess ph
62         case code of
63             ExitFailure _ -> throwError err500 { errBody = "fluidsynth_failed" }
64             ExitSuccess -> do
65                 out <- liftIO $ B.readFile outName
66                 liftIO $ removePathForcibly outName
67                 return out
68
69     tempFile :: String -> Handler FilePath
70     tempFile ext = try 0
71         where maxtries = 100
72               try :: Integer -> Handler FilePath
73               try n
74                   | n < maxtries = do
75                       progName <- liftIO $ getProgName
76                       let path = "/tmp" </> addExtension (makeValid progName ++ "-"
77                                                         ++ show n) ext
77                       exists <- liftIO $ doesFileExist path
78                       if exists
79                           then try (n + 1)
80                           else pure path
81                   | otherwise = throwError err500
82     app :: Application
83     app = serve api server
84
85     main :: IO ()
86     main = newStdGen >> run 8081 app

```

Web

web/source/index.html

```
1 <!doctype html>
2 <html>
3   <head>
4     <meta charset="utf-8">
5     <meta http-equiv="x-ua-compatible" content="ie=edge" />
6     <meta name="viewport" content="width=device-width, initial-scale=1"
7       />
8     <title>likely music</title>
9     <link rel="stylesheet" type="text/css" href="custom.css">
10    <link rel="stylesheet" type="text/css" href="vis.min.css">
11    <script src="main.js"></script>
12  </head>
13  <body>
14    <div id="network"></div>
15    <div id="sidebar">
16      <h1>likely music</h1>
17      <h2>General Settings</h2>
18      <button id="set-starting-node">Set starting node</button>
19      <button id="show-starting-node">Show starting node</button>
20      <h2>Generate an interpretation</h2>
21      <div class="multi-inputs">
22        <label for="seed">Seed:</label>
23        <input type="number" id="seed">
24        <button id="random-seed">&#8634;</button>
25      </div>
26      <div class="multi-inputs">
27        <label for="hop-count">Length:</label>
28        <input type="number" min="0" id="hop-count" placeholder="
29          Max. note count">
30      </div>
31      <div id="player-container">
32        <button id="reload-player">&#8634;</button>
33        <audio id="player" controls></audio>
34      </div>
35      <div class="multi-inputs">
36        <button id="download-audio">Download</button>
37        <label for="format">
38          as
39        </label>
40        <select id="format">
41          <option value="mid">MIDI</option>
42          <option value="wav">WAV</option>
43        </select>
44      </div>
45      <h2>Load or Save Work</h2>
46      <button id="gen-score" class="save">Save</button>
47      <label for="upload-score" class="custom-file">
```

```

46         <input type="file" id="upload-score" >
47         <span>Load</span>
48     </label>
49     <button id="clear-score" class="cancel">Clear</button>
50 </div>
51 <div id="edge-overlay" class="hidden_dialog">
52     <h2><span id="edge-operation"></span> edge</h2>
53     <div class="multi-inputs">
54         <label for="prob">Probability:</label>
55         <input id="prob" type="number" min="0.0" max="100">
56         <span>%</span>
57     </div>
58     <div class="multi-inputs">
59         <button class="save" id="edge-save">Save</button>
60         <button class="cancel" id="edge-cancel">Cancel</button>
61     </div>
62 </div>
63 <div id="node-overlay" class="hidden_dialog">
64     <h2><span id="node-operation"></span> node</h2>
65     <div class="multi-inputs">
66         <label for="pitch">Pitch:</label>
67         <select id="pitch"></select>
68     </div>
69     <div class="multi-inputs">
70         <label for="octave">Octave:</label>
71         <input id="octave" type="number" step="1">
72     </div>
73     <div class="multi-inputs">
74         <label>Duration:</label>
75         <input min="0" id="numerator" type="number" step="1">
76         <span>/</span>
77         <input min="0" id="denominator" type="number" step="1">
78     </div>
79     <div class="multi-inputs">
80         <button class="save" id="node-save">Save</button>
81         <button class="cancel" id="node-cancel">Cancel</button>
82     </div>
83 </div>
84 </body>
85 </html>

```

web/source/custom.css

```
1  body {
2      font-size: 1em;
3      font-family: sans-serif;
4      margin: 0px;
5      background-color: black;
6  }
7
8  #network {
9      width: 79%;
10     float: left;
11     height: 100vh;
12 }
13
14 #sidebar {
15     width: 20%;
16     float: right;
17     color: white;
18     background-color: black;
19     box-shadow: 0px 0px 20px #111;
20     font-size: 1.2rem;
21 }
22
23 #sidebar > * {
24     width: 100%;
25     border-top: 1px solid #232200;
26     color: white;
27     padding-left: 0px;
28     padding-right: 0px;
29     margin: 0;
30 }
31
32 #sidebar button:hover, #sidebar input:hover,
33 #sidebar .custom-file:hover, #sidebar select:hover {
34     background-color: #563d7c;
35 }
36
37 #sidebar button, #sidebar input, #sidebar .custom-file, #sidebar select {
38     background-color: #000;
39 }
40
41 #sidebar h1 {
42     font-size: 1.5rem;
43     padding-top: 0.75rem;
44     padding-bottom: 0.75rem;
45     text-align: center;
46     background-color: #111;
47 }
48
```

```
49 #sidebar h2 {
50     font-size: 1.2rem;
51     padding-top: 0.9rem;
52     padding-bottom: 0.9rem;
53     text-align: center;
54     background-color: #222;
55 }
56
57 #sidebar select {
58     color: white;
59     border: none;
60     padding: 0.75rem;
61     font-size: 1.2rem;
62     width: auto;
63 }
64
65 button {
66     border: none;
67     color: white;
68     background-color: black;
69     font-size: 1.2rem;
70     margin: 0;
71     padding: 0.75rem;
72 }
73
74 input[type="number"] {
75     background-color: #333;
76     color: white;
77     border: none;
78     text-align: center;
79     font-size: 1.2rem;
80     padding: 0.75rem;
81 }
82
83 .custom-file {
84     top: 0;
85     right: 0;
86     position: relative;
87     display: inline-block;
88     height: 3rem;
89 }
90
91 .custom-file input[type="file"] {
92     position: relative;
93     top: 0;
94     left: 0;
95     right: 0;
96     z-index: 0;
97     opacity: 0;
98     width: 100%;
```

```
99     height: 100% !important;
100     margin:0;
101     padding:0;
102 }
103
104 .custom-file span {
105     text-align: center;
106     position: absolute;
107     top: 0;
108     left: 0;
109     right: 0;
110     z-index: 1;
111     width: 100%;
112     height: 3rem;
113     pointer-events: none;
114     background-color: transparent !important;
115     font-size: 1.2rem;
116     line-height: 1.5rem;
117     padding-top: 0.75rem;
118     padding-bottom: 0.75rem;
119 }
120
121 .dialog {
122     position: absolute;
123     top: 10%;
124     left: 25%;
125     width: 30%;
126     min-width:500px;
127     padding: 10px;
128     background-color: black;
129     color: white;
130     box-shadow: 0px 0px 10px #111;
131 }
132
133 .dialog > div {
134     height: 3rem;
135 }
136
137 .hidden {
138     visibility:hidden;
139 }
140
141 .dialog > div {
142     width: 100%;
143 }
144
145 .dialog button {
146     padding: 0.75rem;
147     font-size: 1.5rem;
148 }
```

```
149
150 button.cancel {
151     background-color: #a23a30;
152 }
153
154 button.save {
155     background-color: #0ea92f;
156 }
157
158 .dialog .multi-inputs {
159     font-size: 1.5rem;
160 }
161
162 .multi-inputs {
163     display: inline-flex;
164     flex-direction: row;
165     flex-wrap: nowrap;
166     justify-content: flex-start;
167     align-items: baseline;
168     width: 100%;
169 }
170
171 .multi-inputs > * {
172     flex-grow: 1;
173     flex-basis: auto;
174     transition: width 0.7s ease-out;
175     max-height: 100%;
176     text-align: center;
177 }
178
179 .multi-inputs :nth-child(1) {
180     text-align: left;
181 }
182
183 .multi-inputs label {
184     display: inline-block;
185     background-color: #333;
186     padding: 0.75rem;
187 }
188
189 .multi-inputs input {
190     display: inline-block;
191     color: white;
192     background-color: #111;
193     padding: 0.75rem;
194     border: none;
195     min-width: 0px;
196 }
197
198 .multi-inputs span {
```



```
199     display: inline-block;
200     padding: 0.75rem;
201     background-color: #222;
202 }
203
204 .multi-inputs button {
205     padding: 0.75rem;
206 }
207
208 #player-container {
209     display: inline-flex;
210     align-items: center;
211 }
212
213 #player-container > * {
214     flex: auto;
215 }
```

web/source/main.js

```
1 import vis from 'vis';
2 import { Map } from 'immutable';
3 // types / internals
4
5 const valid_pitches = [
6   'Rest',
7   'Cff', 'Cf', 'C',
8   'Dff', 'Cs', 'Df',
9   'Css', 'D', 'Eff',
10  'Ds', 'Ef', 'Fff',
11  'Dss', 'E', 'Ff',
12  'Es', 'F', 'Gff',
13  'Ess', 'Fs', 'Gf',
14  'Fss', 'G', 'Aff',
15  'Gs', 'Af', 'Gss',
16  'A', 'Bff', 'As',
17  'Bf', 'Ass', 'B',
18  'Bs', 'Bss'
19 ];
20
21 const display_pitches = [
22   'Rest',
23   'C', 'C', 'C',
24   'D', 'C', 'D',
25   'C', 'D', 'E',
26   'D', 'E', 'F',
27   'D', 'E', 'F',
28   'E', 'F', 'Gff',
29   'E', 'F', 'G',
30   'F', 'G', 'A',
31   'G', 'A', 'G',
32   'A', 'B', 'A',
33   'B', 'A', 'B',
34   'B', 'B'
35 ];
36
37 function displayPitch(pitch) {
38   var i = valid_pitches.indexOf(pitch);
39   if(i === -1) {
40     throw 'Invalid pitch';
41   } else {
42     return display_pitches[i];
43   }
44 }
45
46 function standard_rests(dur) {
47   if(dur.numerator === 1) {
48     switch(dur.denominator) {
```

```

49         case 1:
50             return '';
51             break;
52         case 2:
53             return '';
54             break;
55         case 4:
56             return '';
57             break;
58         case 8:
59             return '';
60             break;
61         case 16:
62             return '';
63             break;
64         case 32:
65             return '';
66             break;
67         case 64:
68             return '';
69             break;
70         case 128:
71             return '';
72             break;
73         default:
74             return null;
75             break;
76     }
77     } else {
78         return null;
79     }
80 }
81
82 function standard_notes(dur) {
83     if(dur.numerator === 1) {
84         switch(dur.denominator) {
85             case 1:
86                 return '';
87                 break;
88             case 2:
89                 return '';
90                 break;
91             case 4:
92                 return '';
93                 break;
94             case 8:
95                 return '';
96                 break;
97             case 16:
98                 return '';

```

```

99         break;
100     case 32:
101         return '';
102         break;
103     case 64:
104         return '';
105         break;
106     case 128:
107         return '';
108         break;
109     default:
110         return null;
111         break;
112     }
113 } else if (dur.numerator === 2 && dur.denominator === 1) {
114     return '';
115 } else {
116     return null;
117 }
118 }
119
120 function compute_dot_times(dur, denominator) {
121     let baseLog = (b, x) => Math.log(x) / Math.log(b);
122     let term = (dur.numerator * Math.pow(2, denominator)) / dur.denominator
123     ;
124     return baseLog(1.5, term);
125 }
126
127 function musical_symbol(lookup, dur) {
128     const dot = '.';
129     let isNat = n => {
130         if (typeof n !== 'number')
131             return false;
132         return (n >= 0.0) && (Math.floor(n) === n) && n !== Infinity;
133     };
134     var standard_symbol = lookup(dur);
135     var dots = [0, 1, 2, 3, 4, 5, 6, 7].map(compute_dot_times.bind(dur)).
136         filter(isNat);
137     if (standard_symbol !== null) {
138         return standard_symbol;
139     } else if (dots.length !== 0) {
140         for (var i = dots[0]; i > 0; i--) {
141             }
142         } else {
143             return dur.toString();
144         }
145     }
146
147 class Music {

```

```

147     constructor(dur, pitch_class, octave) {
148         this.dur = dur;
149         if (valid_pitches.indexOf(pitch_class) !== -1) {
150             this.pitch = pitch_class;
151         } else {
152             throw 'Invalid pitch class '${pitch_class}'';
153         }
154         this.octave = octave;
155     }
156
157     toString() {
158         if (this.pitch === 'Rest') {
159             return '${displayPitch(this.pitch)} for ${this.dur.toString()}';
160         } else {
161             return '${displayPitch(this.pitch)}${this.octave} for ${this.dur.toString()}';
162         }
163     }
164
165     nodeText() {
166         if (this.pitch === 'Rest') {
167             // alignment using a space! #justvisjsthings
168             return ' ${musical_symbol(standard_rests, this.dur)}';
169         } else {
170             return '${musical_symbol(standard_notes, this.dur)} ${displayPitch(this.pitch)}${this.octave}';
171         }
172     }
173
174
175     static fromObject(obj) {
176         return new Music(Rational.fromObject(obj.dur), obj.pitch, Number(obj.octave));
177     }
178 }
179
180 class Rational {
181     constructor(a, b) {
182         this.numerator = a;
183         this.denominator = b;
184         this.reduce();
185     }
186
187     reduce() {
188         let gcd = (a, b) => !b ? a : gcd(b, a % b);
189         let div = function(a, b) {
190             if (b === 0) {
191                 throw 'Divide by zero';
192             } else {

```

```

193         return Math.floor(a / b);
194     }
195 };
196
197     var d = gcd(this.numerator, this.denominator);
198     this.numerator = div(this.numerator, d);
199     this.denominator = div(this.denominator, d);
200 }
201
202 toString() {
203     return `${this.numerator}/${this.denominator}`;
204 }
205
206 static fromObject(obj) {
207     return new Rational(obj.numerator, obj.denominator);
208 }
209 }
210
211 function collectGraphData(nodeData, edgeData) {
212     return {
213         nodes: [... nodeData.values()].map(x => ({
214             id: x.nodeData.id,
215             music: x.music
216         })),
217         edges: [... edgeData.values()].map(x => ({
218             id: x.edgeData.id,
219             from: x.edgeData.from,
220             to: x.edgeData.to,
221             prob: x.prob
222         })))
223     };
224 }
225
226 function importGraphData(g) {
227     nodeData = new Map();
228     edgeData = new Map();
229     var nodeSet = new vis.DataSet({});
230     var edgeSet = new vis.DataSet({});
231     for(let node of g.nodes) {
232         var music = Music.fromObject(node.music);
233         var data = { id: node.id, label: music.nodeText() };
234         nodeData = nodeData.set(node.id, { nodeData: data, music: node.
            music });
235         nodeSet.add(data);
236     }
237
238     for(let edge of g.edges) {
239         var data = {
240             id: edge.id,
241             from: edge.from,

```

```

242         to: edge.to,
243         label: '${edge.prob * 100}%'
244     };
245     edgeData = edgeData.set(edge.id, { edgeData: data, prob: edge.prob
246     });
247     edgeSet.add(data);
248 }
249 network.setData({ nodes: nodeSet, edges: edgeSet });
250 }
251
252 // helper
253
254 function download(url, filename) {
255     var link = document.createElement('a');
256     link.setAttribute('href', url);
257     link.setAttribute('download', filename);
258     link.style.display = 'none';
259     document.body.appendChild(link);
260     link.click();
261     document.body.removeChild(link);
262 }
263
264 function downloadFile(content_type, filename, content) {
265     var data = 'data:${content_type},${encodeURIComponent(content)}';
266     download(data, filename);
267 }
268
269
270 // graph code
271
272 var nodeData = Map();
273 var edgeData = Map();
274 var network = null;
275 var starting_node_id = null;
276
277
278 function showOverlay(id) {
279     document.getElementById(id).classList.remove('hidden');
280 }
281
282 function genericEditNode(data, callback) {
283     function clearOverlay() {
284         document.getElementById('node-save').onclick = null;
285         document.getElementById('node-cancel').onclick = null;
286         hideOverlay('node-overlay');
287     }
288
289     function saveNode(data, callback) {
290         var duration = new Rational(document.getElementById('numerator').

```

```

    value ,
291     document.getElementById( 'denominator' ).value);
292     var music = new Music(duration , document.getElementById( 'pitch' ).
        value ,
293     Number(document.getElementById( 'octave' ).value));
294     data.label = music.nodeText();
295     clearOverlay();
296     callback(data);
297     nodeData = nodeData.set(data.id , { music: music , nodeData: data });
298 }
299
300 function discardNode(callback) {
301     clearOverlay();
302     callback(null);
303 }
304
305 showOverlay( 'node-overlay' );
306 var node = nodeData.get(data.id);
307 if(node !== undefined) {
308     var music = node.music;
309     document.getElementById( 'pitch' ).value = music.pitch;
310     document.getElementById( 'octave' ).value = music.octave;
311     document.getElementById( 'numerator' ).value = music.dur.numerator;
312     document.getElementById( 'denominator' ).value = music.dur.
        denominator;
313 }
314 document.getElementById( 'node-save' ).onclick = saveNode.bind(this , data
    , callback);
315 document.getElementById( 'node-cancel' ).onclick = discardNode.bind(this ,
    callback);
316 }
317
318 function genericEditEdge(data , callback) {
319     function clearOverlay() {
320         document.getElementById( 'edge-save' ).onclick = saveEdge.bind(this ,
            data , callback);
321         document.getElementById( 'edge-cancel' ).onclick = discardEdge.bind(
            this , callback);
322         hideOverlay( 'edge-overlay' );
323     }
324
325     function saveEdge(data , callback) {
326         // for some reason , editWithoutDrag
327         // sets from & to to the node respective
328         // node objects , which results in the edge
329         // disappearing.
330         if (typeof data.to === 'object')
331             data.to = data.to.id
332         if (typeof data.from === 'object')
333             data.from = data.from.id

```



```

334
335     var prob = document.getElementById('prob').value / 100;
336     data.label = '${prob * 100}%';
337     clearOverlay();
338     callback(data);
339     edgeData = edgeData.set(data.id, { prob: prob, edgeData: data });
340 }
341
342 function discardEdge(callback) {
343     clearOverlay();
344     callback(null);
345 }
346
347 showOverlay('edge-overlay');
348 var edge = edgeData.get(data.id);
349 if(edge !== undefined) {
350     document.getElementById('prob').value = edge.prob * 100;
351 }
352 document.getElementById('edge-save').onclick = saveEdge.bind(this, data
, callback);
353 document.getElementById('edge-cancel').onclick = discardEdge.bind(this,
callback);
354 }
355
356 function deleteFromMap(data, callback) {
357     for(let node of data.nodes) {
358         nodeData = nodeData.delete(node);
359     }
360
361     for(let edge of data.edges) {
362         edgeData = edgeData.delete(edge);
363     }
364
365     callback(data);
366 }
367
368
369 function hideOverlay(id) {
370     document.getElementById(id).classList.add('hidden');
371 }
372
373 function handleImport() {
374     var files = document.getElementById('upload-score').files;
375     if(files.length === 0) {
376         alert('Select a file first!');
377     } else {
378         var file = files[0];
379         var reader = new FileReader();
380         reader.addEventListener('loadend', function() {
381             var parsed = JSON.parse(this.result);

```

```

382         if(parsed === undefined) {
383             alert('Could not parse likely score');
384         } else {
385             var confirmation = window.confirm('Proceeding will
              overwrite the current graph. Are you sure?');
386             if(confirmation) {
387                 try {
388                     importGraphData(parsed);
389                 } catch(e) {
390                     alert('Could not import likely score, probably the
              file was malformed. Error: ${e}');
391                 }
392             }
393         }
394     });
395     reader.readAsText(file);
396 }
397 }
398
399 function saveDataToLocalStorage() {
400     const json = JSON.stringify(collectGraphData(nodeData, edgeData));
401     const params = JSON.stringify(gatherParams());
402     localStorage.setItem("score", json)
403     localStorage.setItem("params", params)
404 }
405
406 function showStartingNode() {
407     if(typeof starting_node_id === 'string') {
408         network.selectNodes([starting_node_id], false);
409     } else {
410         alert('No starting node selected yet!');
411     }
412 }
413
414 function setStartingNode() {
415     var selected = network.getSelectedNodes();
416     if(selected.length > 1) {
417         alert('Only select one node!');
418     } else if(selected.length === 0) {
419         alert('Select a node first!');
420     } else {
421         starting_node_id = selected[0];
422     }
423 }
424
425 function fetchInterpretation(params, format) {
426     var jsonRequest = JSON.stringify({
427         graph: collectGraphData(nodeData, edgeData),
428         params: params
429     });

```

```

430
431     var myHeaders = new Headers();
432     myHeaders.set('Content-Type', 'application/json');
433
434     var myInit = {
435         method: 'POST',
436         headers: myHeaders,
437         mode: 'cors',
438         body: jsonRequest
439     };
440
441     var myRequest = new Request('/interpretation/${format}', myInit);
442
443     return fetch(myRequest).then(res => res.blob());
444 }
445
446 function gatherParams() {
447     var starting_node_entry = nodeData.get(starting_node_id);
448     if(starting_node_entry !== undefined && starting_node_entry !== null) {
449         var starting_node = {
450             id: starting_node_entry.nodeData.id,
451             music: starting_node_entry.music
452         };
453     } else {
454         var starting_node = null
455     }
456
457     var maxhops = document.getElementById('hop-count').value;
458     if(maxhops === "" || Number(maxhops) === NaN) {
459         maxhops = null;
460     } else {
461         maxhops = Number(maxhops);
462     }
463
464     var seed = document.getElementById('seed').value;
465     if(seed === "" || Number(seed) === NaN) {
466         seed = null;
467     } else {
468         seed = Number(seed);
469     }
470
471     return {
472         maxhops: maxhops,
473         starting_node: starting_node,
474         seed: seed
475     };
476 }
477
478 function completeGatherParams() {
479     var p = gatherParams();

```

```

480     if(p.starting_node === null) {
481         alert('Set a starting node first!');
482         return null;
483     }
484
485     if(p.maxhops === null) {
486         alert('Set the maximum amount of hops to a valid number');
487         return null;
488     }
489
490     if(p.seed === null) {
491         // TODO auto generate a random one, let the user confirm before
492         alert('Set the seed to a valid number!');
493         return null;
494     }
495
496     return p;
497 }
498
499 function importParams(p) {
500     if(p.starting_node !== null) {
501         starting_node_id = p.starting_node.id;
502     }
503     if(p.seed !== null) {
504         document.getElementById('seed').value = p.seed;
505     }
506     if(p.maxhops !== null) {
507         document.getElementById('hop-count').value = p.maxhops;
508     }
509 }
510
511 function randomSeed() {
512     if(window.crypto) {
513         var array = new Int32Array(1);
514         window.crypto.getRandomValues(array);
515         document.getElementById('seed').value = array[0];
516     }
517 }
518
519 function downloadInterpretation(format) {
520     var params = completeGatherParams();
521     if(params !== null) {
522         try {
523             fetchInterpretation(params, format).then(file => {
524                 var url = URL.createObjectURL(file);
525                 download(url, 'export.${format}');
526             });
527         } catch(e) {
528             alert('An error occured while contacting the API: ' + e);
529         }
530     }
531 }

```

```

530     }
531 }
532
533 function reloadPlayer() {
534     var params = completeGatherParams();
535     if(params !== null) {
536         document.getElementById('player').src = null;
537         try {
538             fetchInterpretation(params, 'wav').then(file => {
539                 var url = URL.createObjectURL(file);
540                 document.getElementById('player').src = url;
541             });
542         } catch(e) {
543             alert('An error occurred while contacting the API: ' + e);
544         }
545     }
546 }
547
548 function init() {
549     var container = document.getElementById('network');
550
551     var options = {
552         manipulation: {
553             addNode: function(nodeData, callback) {
554                 document.getElementById('node-operation').innerHTML = 'Add
555                     ';
556                 genericEditNode(nodeData, callback);
557             },
558             addEdge: function(edgeData, callback) {
559                 document.getElementById('edge-operation').innerHTML = 'Add
560                     ';
561                 genericEditEdge(edgeData, callback);
562             },
563             editNode: function(nodeData, callback) {
564                 document.getElementById('node-operation').innerHTML = 'Edit
565                     ';
566                 genericEditNode(nodeData, callback);
567             },
568             editEdge: {
569                 editWithoutDrag: function(edgeData, callback) {
570                     document.getElementById('edge-operation').innerHTML = '
571                         Edit ';
572                     genericEditEdge(edgeData, callback);
573                 }
574             },
575             deleteNode: deleteFromMap,
576             deleteEdge: deleteFromMap,
577             controlNodeStyle: {

```

```

576     nodes: {
577         borderWidth: 0,
578         color: {
579             background: '#563d7c',
580             hover: {
581                 background: '#8f14ff'
582             },
583             highlight: {
584                 background: '#8f14ff'
585             }
586         },
587         chosen: true,
588         font: {
589             color: 'white',
590             size: 20,
591             align: 'center'
592         },
593         shape: 'circle',
594     },
595     edges: {
596         arrows: {
597             to: { enabled: true }
598         },
599         color: {
600             color: '#563d7c',
601             hover: '#563d7c',
602             highlight: '#563d7c',
603         },
604         font: {
605             color: 'ffffff',
606             strokeWidth: 0
607         }
608     }
609 };
610
611 network = new vis.Network(container, {}, options);
612
613 try {
614     const score = localStorage.getItem('score');
615     if(score !== null) {
616         importGraphData(JSON.parse(score));
617     }
618 } catch(e) {
619     localStorage.removeItem('score');
620 }
621
622 try {
623     const params = localStorage.getItem('params')
624     if(params !== null) {
625         importParams(JSON.parse(params));

```

```

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

```

Lizenz

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