

# CS280r Spring 2017 - Final Project Report

## *Ἀρμονία* (Harmonia): A System for Collaborative Music Composition

Mark Goldstein, David Wihl  
{markgoldstein,davidwihl}@g.harvard.edu

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### Abstract

Increasing productivity of music composition has many positive benefits. Listeners would appreciate individually tailored music to their emotional needs and context. Composers would be facilitated by greater and more diverse cooperation yielding more innovative music. Composition agents could assist in the generation of repetitive or experimental musical forms. Therapists can use music as part of a treatment plan for autism and many other disorders. The system we propose attempts to address these myriad needs by offering two key innovations: a SharedPlan with collaborative versioning to mediate the workflow of a composition, an algorithmic evaluation of a composition against the intention of the SharedPlan to provide guidance to both human and agent composers.

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### 1. Introduction

It is my design to render it manifest that no one point in its composition is referrible either to accident or intuition – that the work proceeded, step by step, to its completion with the precision and rigid consequence of a mathematical problem.

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*Edgar Allen Poe*  
*The Philosophy of Composition*

Music composition has historically been an individual endeavor, which is counterintuitive when music is mostly played and experienced in a group. Part of this is due to the singular nature of creative expression, but a large part is also due to a dearth of viable tools to enable collaborative efforts between composers. Most modern composition is performed using digital workstation tools, yet composers do not generally have access to the collaborative tools and evaluation processes available to an analogous entry level software engineer.

Deep Learning networks are being used for creation of new visual[ref], narrative[ref] and now musical works[ref]. These more sophisticated tools can assist human composers both in terms of

idea exploration as well as objective evaluation against intent of the composition and expression of originality.

We propose a system for music composition that addresses collaborative music composition inspired by tools used for software teamwork, course-sourced ideation, and mathematical evaluation of the work in progress, while integrating original contributions by Deep Learning networks. We will first examine related work for intentionality, collaboration and mathematical evaluation of music. We will then provide a specification for music composition workflow. This will be followed by a specification of algorithmic evaluation of the work in order to validate against intentionality. We will present three use cases for the entire system including possible failure modes. We will then conclude with a discussion of the proposal including limitations we have identified and potential future work.

#### RESEARCH TODO

- Mark: talk to composers and incorporate their feedback and UI suggestions
- David: speak to David Greenberg to incorporate feedback and UI

## 2. Related Work

Our work builds on several areas of research related to music, computer science, and creative cognition. First we discuss related work in collaborative ideation, both in general and specifically in music. Next we discuss intelligent music systems that facilitate human composition and improvisation, and related work in Music Information Retrieval (MIR). Finally we describe previous work that applies information theory to the analysis of musical structure.

### 2.1. Shared Plans

TODO: [David]

### 2.2. Collaborative Ideation

Collaborative Ideation (CI) seeks to improve the productivity of individuals and groups in generating ideas through collaboration. The people involved are interested in creating related objects (e.g., we all want to brainstorm solutions to social problems) and seek either feedback or examples of others' work to enhance their individual process. Collaboration is centered around a shared workspace, physical or virtual, that allows for communication and sharing of ideas. The ideas produced may be for individual use, or ideators may work on shared artifacts such as an essay or piece of art. The dynamics of collaboration may be real-time or not, though increasingly, today's settings are real-time and virtual. A simple CI setting is one where each ideator brainstorms solutions to a

problem common to all participants, and each participant can see all other’s ideas. While such approaches have been used naturally in human culture for millennia, the design of intelligent computer systems today aims to facilitate these activities to allow for increased creativity and productivity.

IdeaHound [Siangliulue 2016] addresses at-scale collaboration in this setting. Siangliulue’s work claims that only a small subset of the idea pool may be relevant and inspiring to a single ideator, that it is overwhelming for each ideator to view all participant’s ideas. The system creates a semantic map of all generated ideas that allows each ideator to easily view their work in the context of the entire solution space. The map is automatically generated. Each user is prompted to interact with a personal “whiteboard” where they can cluster their ideas and separate them by semantic distance, and the global map is computed from the collection of whiteboards. This approach bypasses the need for external workers to power semantic analysis of ideas. Using this map, IdeaHound recommends diverse suggestions to each ideator, eliminating the cognitive load of idea search. Our work is largely influenced by IdeaHound, but several challenges specific to collaborative music composition require new interventions. First, the generated objects are structured rather than unordered collections of ideas. Second, ideators need to build over each other’s ideas rather than only seek inspiration.

CI has surfaced in a setting closer to ours, in the space of online blogs and services designed to share visual art and music. Ideas range from small, unfinished efforts seeking directions to finished pieces seeking critique. Artists improve upon their ideas using the large-scale feedback. SoundCloud is an example of a hybrid music streaming service and CI platform. Though much of the hosted music is presented in finished form, people also post incomplete projects. Artists sometimes share “stems” to their music, which are individual sound files that feature isolated instrumental tracks, with the intention that others seeking inspiration remix their pieces into new work. A newer platform, Blend, makes the sharing of source files explicit. By default, artists share their works in progress in the format of music production software source files, which allows others to quickly pick up on their work and take it in new directions. This setting is closer to our area of application and supports building on one another’s ideas. What changes when several ideators intend to create a single shared piece? With SoundCloud and Blend, one may take another’s piece in a totally different direction. In our work, a collaborative composition has a goal associated with it through the duration of its existence. It is up to the composers and the system to keep a piece of music close to its shared plan.

### *2.3. Computer Facilitated Composition and Improvisation*

Computer agents with the ability to facilitate and take part in music composition and improvisation are of great interest to music theorists and artificial intelligence researchers. These systems have in common a requirement to “understand” music at multiple levels, including low-level acoustic signal, mid-level theoretical constructs such as harmony and rhythm, and high-level level aspects

such as mood, genre, and style. For example, music recommendation system such as Spotify seek to analyze music and extract a measure of relevance for a function such as "study music". These issues constitute the research area of Music Information Retrieval.

In systems that create music, the interest is to assist human composers, rather than replace them. Perhaps a composer has good "seeds" ideas, but the system may recommend variations of ideas, or re-orderings of ideas, to make them more conveying. Such system knowledge often comes from large-scale corpus analysis that mines patterns common to a collection of music. ChordRipple [Huang 2016] is a recent system that takes as input a progression of musical chords from a composer, and suggests substitutions of intermediate chords that preserve the original semantics of the input while serving to replace conventional choices with more interesting ones. If the composer agrees to make one of the recommended changes, the system assists the composer in interpolating between original and substituted material before and after the initial substitution, resulting in further mixing of human and system generated music.

While our current work seeks primarily to assist teams of human composers to enrich and organize their work, we intend to design the system such that intelligent computer agent composers may be further in the loop. The Google Brain team has recently launched the Magenta Project for exploring machine intelligence in music. Magenta is an integrated environment of software tools and music-related datasets. Recently, Magenta released AI Duet, a computer system that reacts to human improvised gestures. Improvisation is an important part of composition. Even in steps where a human is composing, it may be beneficial to have an agent for the human to go back-and-forth on ideas with, much like two friends would iteratively vary and refine their ideas. In settings where a piece is defined by a specific enough set of guidelines, such as in a therapy use case where a listener may need music at a certain tempo and with a simple beat [See section INSERT SECTION] , powerful information retrieval systems make effective machine composition agents possible. Human composers may be placed at later steps of collaboration to ensure that the piece meets requirements in a humanly perceptible way.

#### *2.4. Information Theory and Music Analysis*

Our systems relies on the ability to model musical structure in a way that supports automated feedback for collaborating composers, where feedback is in the form of suggested rearrangements of musical ideas that help a composition reach a mutually specified structural goal. In this direction, there has been a rich body of work in automated analysis of musical structure from the 1950's to present. A prominent direction is to model musical form by way of listener perception and the expected dynamics of their attention and surprise. Understanding musical structure and its impact on listeners is a cogent goal to music theorists, cognitive scientists, and machine learning researchers. Many of these approaches have drawn on probability theory and information theory. A survey of approaches historical to contemporary can be found in the Con Espressione Manifesto

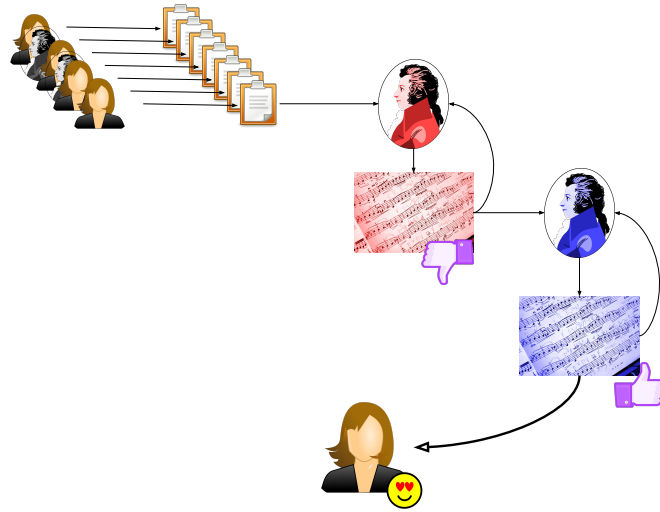


Figure 1: Overall workflow: a non-musical user or a composer define a SharedPlan. Composer 1 (red) starts iterating and commits a work-in-progress. Composer 2 (blue) continues iterating until the original user is satisfied.

[Widmer 2016], which is a strong position paper on the coming devade of research directions for music information reitaval

Our work builds on the the Information Dynamics Approach [Abdallah et al 2012]. Abdallah uses predictive information rate, a entropy/divergence based metric that measures how a listener’s mid-piece distribution over future musical events is continually revised as new information is presented, to compute a curve that summarizes aspects of surprise in redundancy in a piece of music. Our work assumes that musical structure can be effectively summarized by this criteria. We assume that pieces from a particular genre/mood are defined by characteristic balances of surprise and redundancy over time, with peaks of information content (communicated by the composer) in genre-specific locations. We leverage this metric as the foundation of our automatic analysis system, which compares a collaborative work-so-far against the characteristic curves for the genre and mood specified by the mutual plan for the piece, and suggests edits to the composers to keep them in line with their goal.

### 3. System Design

[perhaps include a workflow image and a MIDI image side-by-side here]

#### 3.1. Workflow Overview

TODO [David]

someone creates a shared plan (individual or composers)

information retrieval system gets characteristic metrics using as much of the sharedplan info as it can

composers iteratively work on the piece

Within a particular composer/system interaction, automated analysis is run on the piece as it is. suggests some actions to the composer, particularly suggesting to switch two parts of a piece. Composer can follow suggestions or do their own modifications, or do nothing and finish.

### 3.2. *GIT*

git + intention, attributing credit, version control not available in existing midi systems

TODO [David]: reference splice.com and blend.io

### 3.3. *Genre + Mood*

TODO: [Mark]

NOTE: MAYBE THIS SHOULD NOT BE A SEPARATE SECTION, BUT RATHER, A COMPONENT OF THE ANALYSIS SECTION, AND ALSO MENTIONED IN THE METADATA SECTION?

existing information retrieval systems

### 3.4. *MIDI and actions to be taken on piece of music*

TODO: [Mark]

Our system represents music in MIDI format. MIDI is a protocol for communicating discrete information about the pitch, duration, and dynamics of individual notes. A musical work is described by specifying the vertical arrangement of individual notes as chords and their horizontal arrangement over time. Most familiar software for music notation and music production build user interfaces on top of a basic MIDI file editor. Extensions to this protocol include MusicXML, which allows for the specification of additional parameters such as expression markings and articulation information. In our system, a simple MIDI editor is sufficient for now.

Through the use of additional metadata (next section), composers are able to segment MIDI files into separate segments. For example, a piece may be subdivided into several sections. Segmentation may represent intentions about musical form, for example one may segment part of a composition into an exposition and a development section.

During an interaction with the system, a composer is able to change a composition by editing the MIDI in several low-level or high-level ways. Composers can add a new block of material, edit an existing block, remove an existing block, swap the order of two blocks, merge two blocks, or split a block into two.

At each iteration of editing, the system suggests an option that may bring the work in progress closer to what is specified by the SharedPlan. This is primarily in the form of "switch blocks A and B?" (See Section on Automatic Evaluation)

### 3.5. Shared Plan + Metadata, inter-composer communication

TODO: [David]

git + intention + algorithmic eval

How do composers or users express intentions?

What sharing of information occurs between users and composers? Decoupling (be explicit)

failure mode: how to avoid revision wars? It can be expected that one composers moves the piece along in the direction that another composer does not approve of, regardless of whether the change happens make the block-box auto eval system say "this is closer to the goal".

NOTE FROM MARK: Talked to Pao about this a little. Finding out a nice way for composers to share their intentions about an added passage will help because it will distinguish between two kinds of disagreements

1. composer agrees with another composer's intention about an edit, but disagrees with the actual implementation 2. composer fundamentally disagrees with the intention

## 4. User Interface

TODO: [David]

## 5. Automated Analysis of Musical Structure

TODO: [Mark]

Harmonia facilitates collaborative composition in two ways. First, the interface as a whole, including the revision system and the shared metadata associated with each composition, helps with practical aspects of communication and coordination. Second, the analysis system lets composers know how close their work-in-progress is to their goal, as measured by similarity to characteristic pieces relevant to their goal. The analysis system also suggests structural edits such as swapping the order of existing material, or deleting material, that could further improve the piece. In this section, we describe the automated analysis of musical structure that is used by our system. Crucial to our system, our computational approach models the structure of a piece of music in relation to the expected trajectory of surprise and redundancy that a listener experiences.

### 5.1. Entropy of Musical Events and Divergence

Let  $X$  be a discrete random variable that takes on values from the set  $\mathcal{X}$ . For example,  $X$  may represent the next chord that a listener hears in a piece of music.  $X = x$  indicates that the listener heard  $X$  take on the value of a specific chord  $x$ . Let  $p_X(x) = p(x)$  denote the probability that  $X$  will take on value  $x$ , *before* the listener hears the chord, as estimated by a distribution that the listener brings with them from prior musical experiences, as well as from what they have heard in the piece so far.  $-\log p(x)$  then corresponds to the *surprise* of the event, because the more the listener expects

the event, the lower the surprise, where the log is taken for convenience (it is monotonic in the  $p(x)$ ). Since  $X$  represents the event that the listener is about to experience (e.g. the chord they are about to hear), we can represent the expected surprise of  $X$  averaged over all possible values as:

$$H(X) = - \sum_{x \in \mathcal{X}} p(x) \log p(x)$$

which corresponds to the Entropy of  $X$ ,  $H(X)$ . Intuitively, this means that the listener does not know what the next even, but from context (from their current state of listening as represented by their current distribution over future events), they expect a certain extent of surprise from the next event.

Because we choose to represent musical structure in terms of the dynamics of the surprise experienced by the listener, it is necessary to describe the way in which the listener’s distribution over future events changes as they hear each realization of whichever series of events they are following, for example the chord progression in the running example. Here it is necessary to describe the “difference” between the distribution over future events before the listener hears the realization of  $X$  at the current time-step and after the event is heard. The Kullback-Leibler Divergence of one distribution from another captures this notion of distance:

$$D_{KL}(X|event||X) = \sum_{x \in \mathcal{X}} p(X|event) \log \frac{p(X|event)}{p(X)}$$

For an accessible yet informative discussion of the significance of Entropy as a measure of information and KL Divergence, see [insert link to Colah blog here]. This divergence describes the amount of revision to a listener’s distribution over the future that happens as they hear each event. Let this be called the *predictive information* of the event  $X = x$  as the listener hears it. Note that in the running example, entropy and divergence were discussed in terms of a sequence of chords heard by the listener. In even a simple piece of music, the listener tracks multiple such parameters.

## 5.2. Current Design

describe the curve over a piece to summarize structure, retrieval  
blahblahblah

## 6. Use Cases

### 6.1. Individual User, Individual Composer

TODO: [David]

Our first use case considers the following scenario: a listener who may be a non-musician would like a new piece of music, perhaps to use for a function such as study music. We consider the case that the listener specifies a new project defined by a mood and genre. At this point, multiple composers could collaborate on the music specification, but we first consider the case that a single composer iterates over the piece with assistance from our system until the requester is happy.



### 6.2. *Multiple Composers*

TODO: [Mark]

Our second use case considers the case where multiple composers create a music specification together, and then collaboratively compose music that stays on track with the original specification.

TODO: include failure modes

### 6.3. *Therapist with Agent - Human Composition Team*

TODO: [David]

Our third case considers the situation where a music therapist would like music to use with their patients. These pieces may have a more highly-refined specification than music for casual listening. The specification may follow a treatment plan and may require a specific tempo or special therapeutic timbres (sound qualities).

high volume necessity

given the detailed specification, an artificially intelligent agent may do a large amount of work, which is then checked by a human composer

## 7. **Evaluation Methodology**

this will probably be a small study on trained musicians rather than a large-scale crowdsourced study

## 8. **Discussion**

TODO: [David + Mark]

### 8.1. *Enhancing or Stifling Creativity*

Notes: evaluation is optional. Can be ignored by committer.

### 8.2. *Limitations*

TODO: [David] Collaboration is offline, not real-time

Current music representation is discrete MIDI, not audio. Limits for vocals, ocean sounds

Presume that reliable corpus-based genre and mood classification solutions exist, particularly information retrieval procedures

## 9. **Conclusion**

Two Novel Contributions:

- Collaborative music composition system Intentionality, SharedPlan and Agents
- Algorithmic evaluation of composition against intention

## 10. Future work

TODO: [David]

- MusicXML for additional expression of musical ideas
- Improved agent composition
- Intelligent ad hoc composition
- Facilitator of scalable music composition
- improved evaluator, possibly RNN based

## 11. References

- Meyer, L.B., 1956. *Emotion and Meaning in Music*. Chicago University Press, Chicago, IL.
- Narmour, E.. 1992. *The Analysis and Cognition of Melodic Complexity: The Implication-Realization Model*.
- D. Huron. 2006. *Sweet Anticipation: Music and the Psychology of Expectation*. MIT Press, Cambridge, MA.
- Abdallah, Cognitive Music Modelling: An Information Dynamics Approach. 2012 3rd International Workshop on Cognitive Information Processing (CIP)
- Widmer, Gerhard. 2016. Getting closer to the essence of music: The Con Espressione manifesto. *ACM Transactions on Intelligent Systems and Technology*
- Engel et al., Neural Audio Synthesis of Musical Notes with WaveNet Autoencoders, 2017
- Wiggins, Auditory Expectation: The Information Dynamics of Music Perception and Cognition. 2012 *Topics in Cognitive Science*
- Moles, A.. 1966. *Information Theory and Aesthetic Perception*. University of Illinois Press, Urbana, IL
- Two Multivariate generalizations of Pointwise Mutual Information Tim Van de Cruys, Association for Computational Linguistics 2011
- Cohen, Joel E., *Information Theory and Music* , *Behavioral Science*, 7:2 (1962:Apr.) p.137
- Schillinger, Joseph *The mathematical basis of the arts* 1948
- Pierce, *Electronics, waves, and messages*. 1956
- Pierce, *Letter Scientific American* 1956
- Youngblood, *Style as information* 1958 *Journal of Music Theory*
- The mathematical theory of communication*. Shannon, Claude Elwood 1948. Bell Tel Labs Monograph