Algorithmic art and music composition

Ch 8.4
Generative and algorithmic art

Generative art refers to art that has been
- generated, composed, or constructed in an algorithmic manner
- through the use of
  - systems defined by computer software algorithms,
  - or similar mathematical or mechanical or randomized autonomous processes

Algorithmic art:
- the creative design is the result of an algorithmic process
- It is usually digital art

The artist's self-made algorithms are:
- an integral part of the authorship,
- a medium through which their ideas are conveyed.
The role of the algorithm

- Creation must include a process based on an algorithm devised by the artist.
  - detailed recipe for the design and possibly execution of an artwork

- Input may be mathematical, computational, or generative in nature
  - some random factor is usually introduced
  - some artists also work with gestural input which is then modified by an algorithm.
Creativity is the ability to come up with ideas or artifacts that are new, surprising, and valuable.

- Psychological creativity: P-creativity
  - it is new to the person who generated it.
- Historical creativity: H-creativity
  - is P-creative and has never occurred in history before.

Types of creativity:
- combinational creativity
  - produces unfamiliar combinations of familiar ideas
- exploratory creativity
  - rests on some culturally accepted style of thinking,
- transformational creativity
  - the space or style itself is transformed by altering (or dropping) one or more of its defining dimensions.

Boden, AI Magazine 2009
Types of creativity

- **Combinational** creativity
  - produces unfamiliar combinations of familiar ideas,
  - works by making associations between ideas that were previously only indirectly linked.
  - eg.: collage in visual art
  - analogy, exploits shared conceptual structure.
  - *Computer*:
    - easy: generate novel combinations
    - very difficult: prune uninteresting combinations

- **Exploratory** creativity
  - rests on some culturally accepted style of thinking.
  - space defined (and constrained) by a set of generative rules.
  - rules are largely, or even wholly, implicit.
  - *Computer*: requires deep knowledge of the domain

Boden, AI Magazine 2009
Types of creativity

- **Transformational** creativity
  - the space or style itself is transformed by altering (or dropping) one or more of its defining dimensions.
  - ideas can now be generated that simply *could not* have been generated before the change.
  - The more stylistically fundamental the altered constraint, the more surprising—even shocking— the new ideas will be.
    - e.g. van Gogh sold only one painting in his lifetime

- **Computer**
  - The rules and instructions specified in the program determine its possible performance.
  - program may include rules for changing itself
    - e.g. genetic algorithms

Boden, AI Magazine 2009
Algorithms for music composition

- Modeling traditional, non-algorithmic compositional procedures.
- Modeling new, original compositional procedures, different from those known before.
- Selecting algorithms from extra-musical disciplines.
Taxonomy of generated art

- **G-art** works are generated, at least in part, by some process that is not under the artist’s direct control.

- **CG-art** is produced by leaving a computer program to run by itself, with minimal or zero interference from a human being.

- **Evo-art** is evolved by processes of random variation and selective reproduction that affect the art-generating program itself.

- **R-art** is the construction of robots for artistic purposes, where robots are physical machines capable of autonomous movement and/or communication.

- In **VR-art**, the observer is immersed in a computer-generated virtual world, experiencing it and responding to it as if it were real.

- In **CI-art**, the form/content of some CG-artwork is significantly affected by the behaviour of the audience.
Approaches

- Mathematical models
  - Markov processes
  - Stochastic processes
  - Fractals
- Knowledge based systems
- Generative grammars
- Evolutionary methods: e.g. genetic algorithms
- Learning systems
- Extramusical approaches: e.g. cellular automata
- Interactive Music Installations
Algorithms
Algorithmic processes

**Algorithm** GenerateAndTest

while composition is not terminated
    generate raw materials
    modify according to various functions
    select the best results according to rules

**Algorithm** RandomWalk

Get events distribution by analysing a music repertoire

while composition is not terminated
    sample a random event from the distribution of events
    add to the piece
Statistical distributions have been used which can be thought of as a means of constraining random processes.

For an even distribution function, probability $P$ of event $E$ occurring is the ratio between no of events in $E$ and no of all possible events $S$.

E.g. for a dice:
- $S = \{1, 2, 3, 4, 5, 6\}$
- If $E$ is 'get a number higher than 3', then $E = \{4,5,6\}$
- So $P(e) = 3 / 6 = 0.5$

Distribution functions can be defined to make certain events more or less likely

![Linear distribution](image)
![Exponential distribution](image)
![Concave distribution](image)
Journal des Lumières und der Mode.

Februar 1787.

I. Musikalisches Würfel-Spiel.

Zitate der besten französischen Musiker und Komponisten, mit der Stimmung, dass man sie hören möchte. Ein solcher Spitzel geht es vor, was für mich kein schlechter. Aber für mich hat es nicht nur einen günstigen Einfluss. In der Tat war auch ein wahrhaft guter Komposition, was mich sehr freut, dass ich die Zeilen von Kompositionen von Meistern und große Musikalität, Harmonie und das rechte Tempo haben kann. Ihrer Absicht habe ich mich noch höher geeignet, dass ich sie hören möchte. Ihre Absicht ist nicht nur eine hochgradige, sondern auch eine sehr weise. Ich hoffe, dass sie in ihnen lernen, solche Zeilen zu schreiben, die man hören möchte. Ich hoffe, dass sie in ihnen lernen, solche Zeilen zu schreiben, die man hören möchte. Ich hoffe, dass sie in ihnen lernen, solche Zeilen zu schreiben, die man hören möchte.
Early examples 2


- eg Morsima-Amorsima for 4 instruments

Approach

- Stochastic music programme “deduced” a score from a list of note densities and probabilistic weights defined by the composer.

Aims

- Development of a mathematical language for describing and manipulating music.
- First to conceive of a composing program as a utility capable of generating many pieces, rather than achieving one specific compositional goal.
Stochastic - Markov Chains

- Conditional probability system where probability of future events is defined by past events.
- Applied in music e.g. for probabilistic construction of melodic lines in tonal music
- No of events taken into consideration defines the 'order' of the chain
  - I.e. first order takes 1 previous event into consideration, n-th order considers n previous events.
- Represented by a transition probability matrix of n+1 dimensions

Example
- Miranda’s CAMUS 3D uses markov chains to control rhythm and temporal organisation of note groups
- Several of Cope’s systems are based on nth order Markov chains

Advantage
- Captures note-by-note structure of input in short term

Disadvantage
- Lacks long term structure

Input notes and probability matrix for ‘Mary had a little lamb’

<table>
<thead>
<tr>
<th>Current Event</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2/3</td>
<td>1/3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3/10</td>
<td>3/10</td>
<td>4/10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5/11</td>
<td>5/11</td>
<td></td>
<td>1/11</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td>1/2</td>
<td>1/2</td>
</tr>
</tbody>
</table>

Set of input notes: E D C D E E D D D D E D E G G E D C D E E E D D D E D C

Markov processes

- HMM as music generator

1. Choose initial state \( x(1) = S_1 \) according the initial state distribution \( \pi \).

2. Set \( t = 1 \)

3. Choose \( o(t) \) according the symbol probability distribution in state \( x(t) \) described in matrix \( \mathbf{B} \)

4. Transit to new state \( x(t+1) = S_j \) according to the state transition probability for state \( x(t) = i \), i.e. \( a_{i,j} \)

5. Set \( t = t + 1 \) and return to step 2

- Markov chain
  - Without step 3 and output \( x(t) \)
Example Markov chain

"Hymn tunes” generated by computer from an analysis of the probabilities of notes occurring in various (37) hymns. (1957)
Disadvantages of stochastic processes

- Someone needs to find the probabilities by analyzing many pieces.
  - The resulting models will only generate music of similar style to the input.
- For higher order Markov models, transition tables become unmanageably large for the average computer.
- The deviations from the norm and how they are incorporated in the music is an important aspect.
- They also provide little support for structure at higher levels
Knowledge based systems

Many early systems focused on taking existing musicological rules and embedding them in computational procedures.

- systems which are symbolic and use rules or constraints.

Advantages

- have explicit reasoning;
- can explain their choice of actions.

Disadvantages

- Knowledge elicitation is difficult and time consuming,
- depend on the ability of the "expert"
- become too complicated if we try to add all the "exceptions to the rule and their preconditions,"
Grammars

- The idea that there is a grammar of music.
- Linguistics is an attempt to identify how language functions:
  - what are the components,
  - how do the components function as a single unit,
  - how do the components function as single entities within the context of the larger unit.

- Generative grammar
  - formal system of principles or rules which describes (or ’generates’) the possible sentences of the language.

- Composition algorithms: based upon more abstract representations of musical structures.
A grammar is a collection of prescriptive and/or descriptive rules for analysing or generating sequences of symbols.

- can be applied to natural and computer languages ...
- and musical symbols
- used computationally to define valid symbol strings

Example of simple grammar:

<table>
<thead>
<tr>
<th>Production</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S -&gt; A</td>
<td>B</td>
</tr>
<tr>
<td>A -&gt; aA</td>
<td>a</td>
</tr>
<tr>
<td>B -&gt; bB</td>
<td>b</td>
</tr>
</tbody>
</table>

so possible sequence =

S => A => aA => aaA => aaaaA => aaaaa

Tree representation of grammar
If lexicon of possibilities is provided, can be used to generate syntactically correct sentences.

Simple lexicon for natural language:
- A = {the, a, an}
- V = {composes, makes, hears}
- N = {dog, computer, music, musician, coffee}

Does not ensure semantic sense in linguistics ("the coffee hears the dog" is equally valid).
Grammars: problems

- They are hierarchical structures while much music is not (i.e. improvisation).
  Therefore ambiguity might be necessary since it “can add to the representational power of a grammar”.
- Most, if not all, musical grammar implementations do not make any strong claims about the semantics of the pieces.
- Usually a grammar can generate a large number musical strings of questionable quality.
- Parsing is, in many cases, computationally expensive especially if we try to cope with ambiguity.
Evolutionary methods

Genetic algorithms (GAs)
- very efficient search methods, especially when dealing with problems with very large search spaces.
- ability to provide multiple solutions

Algorithm GeneticAlg
- Initialize population
- while not finished evolving
  ◆ Calculate fitness of each individual
  ◆ Select preferred individuals to be parents
  ◆ for N != populationSize
     ◆ Breed new individuals
     ◆ (cross over + mutation)
  ◆ Build next generation
- Render output
Evolutionary methods

- **Fitness function**
  - Use of an objective fitness function.
  - Use of a human as a fitness function. ➔ Interactive GA

- **Mutation** ensures new individuals are introduced into the population.

- **Reproduction operator (cross-over)** mixes 'good' solutions of 2 parents.

**Drawback**
- Subjectivity
- Efficiency, the "fitness bottleneck, boredom effects"

- This approach tells us little about the mental processes.
- Often: very simple representations.
Learning systems

- Learning systems,
  - do not have a priori knowledge (e.g. production rules, constraints) of the domain,
  - but instead learn its features by examples.
- Stored information
  - subsymbolic/distributive (Artificial Neural Networks, ANN)
  - symbolic (Machine Learning, ML).

Schematic of a simple artificial neuron

- Inputs ($x$) are weighted ($w$) (+ve or -ve)
  - Weighted inputs are summed
    $$ u_i = \sum w_{in} x_n $$
  - And passed through an activation function
    $$ y_i = F(u_i) $$
- Bias term ($\theta$) models sensitivity/ resistivity
Artificial Neural Networks – training

Three basic types:

- Supervised learning
  - Requires training data of input-output sets.
  - Error correction mechanism used. Weights altered to minimise discrepancy between actual and desired output.

- Reinforcement learning
  - Requires training data of input-output sets.
  - Binary (right-wrong) feedback given.

- Unsupervised learning
  - Input-output sets not required.
  - Network self-organises.
Learning systems: Subsymbolic

- Composition as compared with cognition is a much more highly intellectual process (more "symbolic").
  - successfully capture the surface structure of a melodic passage
  - they mostly fail to pick up the higher-level features of music
- The representation of time can not be dealt efficiently even with ANNs which have feedback.
- Usually they solve toy problems, with many simplifications,
- Need to avoid training set examples which conflict.
- Learn from examples things which can’t be represented symbolically using rules (i.e. the "exceptions")
Deep Learning

- Neural networks can incorporate memory structures when learning sequential data.

- Recurrent Neural Networks
  - family of ANN for representing sequences

- Long Short-Term Recurrent Neural Network (LSTM)

- Recurrent Temporal Restrictive Boltzmann Machine (RT-RBM)-based models
‘Extramusical’ approaches

- Models that exhibit musically-relevant dynamics or structures
  - a more experimental, or metaphorical approach.
  - Rather than learning directly from existing music, or attempting to formalise musicological concepts,
- E.g. Cellular automata

- **Chaotic**
  - Visual: Essentially random distribution of binary cell states.
  - Statistical: Low variance, small variation between iterations.
  - Harmonic: Close intervals, minimal changes each iteration.

- **Ordered**
  - Visual: Repeating patterns.
  - Statistical: Nonspecific variance, fixed variation.
  - Harmonic: Nonspecific intervals, repetitive chord pattern.

- **Complex**
  - Visual: Mixtures of regular, random and complex patterns.
  - Statistical: High variance, larger variation between iterations.
  - Harmonic: Wide intervals, larger changes each iteration.

Rhythmic mappings
Extramusical

Rationale
- Structures in certain mathematical systems seen to model musical structures/compositional or performance processes.

Advantages
- No need for explicit formalisation of musical ‘rules’
- Encourages exploration of ‘new’ music rather than attempts to recreate existing music

Disadvantages
- Arguably difficult for listeners to engage with as no cultural reference.
- Relies heavily on selecting good mappings (ie defining which musical parameters are controlled)
Recent Developments

- **Deep Learning**
  - Markov chains are conceptually simple, but cannot easily generalize
  - Deep Neural Networks can fit a wider variety of models, but require a lot of examples for training

- LSTM (Long-Short Term Memory) networks are recurrent, and can capture temporal sequences and dependencies, making them fit for the generation of melodies

- GAN (Generative Adversarial Networks) use two nets: one trying to imitate as closely as possible the input examples, the other trying to distinguish the originals from the copies. This makes them fit for generative art and music
Recent Developments

The Unfinished Symphony (Schubert + Huawei)

- Schubert’s Symphony No. 8 in B minor has only two movements (while symphonies usually have 4) because the author never finished it.
- Huawei’s AI team, in collaboration with a composer, used a LSTM network trained on Shubert’s works to finish the remaining two movements of the symphony.

https://consumer.huawei.com/uk/campaign/unfinishedsymphony/

- Huawei’s promotional article, with the link to the MP3 file of the completed symphony.
References

www.doc.gold.ac.uk/~mas02gw/papers/AISB99b.pdf

http://arxiv.org/abs/1709.01620
The Unfinished Symphony (Schubert + Huawei)