

Music and Algorithms

Week 4: Computational Approaches

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Overview

- Historical examples
 - Hiller and Isaacson
 - Xenakis
- Knowledge based systems
 - Rule based
 - Grammars
- Stochastic approaches
 - Probabilities
 - Markov chains
- Neural Networks
- Genetic algorithms
 - Automated fitness function
 - Interactive fitness function
 - Coevolution
- Extra-musical
 - Fractals
 - Cellular automata
 - Swarm models

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Historical examples

Ada Lovelace making prophetic remarks about the potential for Babbage's Analytic engine:

"Again, it [the Analytical Engine] might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine...Supposing for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent."
- from Note A



Ada Lovelace (1815 - 1852)

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Early examples

Hiller and Isaacson - Illiac suite 1957



"I observed that if we could program a computer to simulate a 'walk' through, say, ordinary space, we could also simulate a 'walk' through a grid defined to represent musical elements such as pitch, rhythmic durations, and timbre choices ..." Hiller

- Approach: generate, test, repeat
 - a) generate 'raw materials'
 - b) modify according to various functions
 - c) select the best results according to rules
- Aims: 4 movements created from 4 experiments:
 - 1st and 2nd "demonstrate that standard musical techniques could be handled by computer programming"
 - 3rd To "show that computers might be used by contemporary composers to extend present compositional techniques"
 - 4th to "show ... that computers might be used in highly unusual ways to produce radically different species of music"

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Early examples 2

Iannis Xenakis (1971) – Stochastic composition.

"a form of composition which is not the object in itself, but an idea in itself, that is to say, the beginnings of a family of compositions."



- Approach
 - Stochastic mathematical techniques, including including probability (Maxwell-Boltzmann kinetic theory of gases in *Pithoprakta*, aleatory distribution of points on a plane in *Diamorphoses*, minimal constraints in *Achorripsis*, Gaussian distribution in *ST/10* and *Atrees*, Markov chains in *Analogiques*), game theory (in *Duel* and *Strategie*), group theory (*Nomos Alpha*), Boolean algebra (in *Herma* and *Eonta*) and Brownian motion (in *N'Shima*).
- 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.

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Knowledge Based Systems 1 – Rule based

- Many early systems focused on taking existing musicological 'rules' and embedding them in computational procedures.
- Examples
 - William Schottstaedts (1989) automatic species counterpoint program
 - Based on Johan Joseph Fux *Gradus as Parnassum*
 - "The program is based around almost 75 rules, such as 'parallel fifths are not allowed'. Schottstaedt assigned a series of penalties for breaking the rules according to statements"
 - Ebiciglu (1984) CHORALE -
 - Generates four-part chorales in the style of JS Bach according to over 350 rules
 - "If the melody skips and if the notes within the scope of the skip have not already been sounded, then they must eventually be sounded before the end of the melody" Ebiciglu
 - "compares well with the average conservatory student" Ebiciglu
 - Advantages:
 - Ensures 'well formed' music within rule set
 - Disadvantages:
 - VERY difficult to define formal rule sets for music
 - Leaves little room for novelty
 - Formalisation implies reductive processes that fail to capture the informal aspects of musical phenomenon
 - formalisation of some musical domains "Limits the usefulness of reduced models to trivialisations of complex musical problems" Loy

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KBS 2 - Grammars – methods

- Other systems are 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

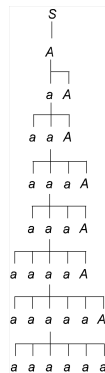
Example of simple grammar:

S → A | B
A → aA | a
B → bB | b

Where:

Hi case = non terminal node
lo case = terminal node
S = start point
| = or
-> = 'is defined as'

so possible sequence =
S => A => aA => aaA => aaaA => aaaaA => aaaaa



Tree representation of grammar

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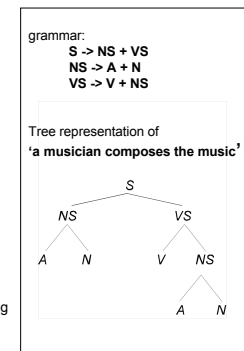
Grammars – natural language example

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}

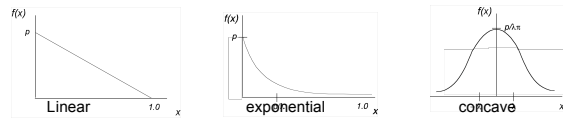
- Does not ensure semantic sense in linguistics ("the coffee hears the dog" is equally valid).
- Musical meaning is arguably more open than linguistic, but also harder to formalise...
- Example
 - Cope's Experiments in Musical Intelligence - SPEAC
 - Uses an advanced transition network = technique for writing a formal grammar
 - Grammar defines 'deep structure', pattern extraction mechanism creates 'surface structure' from example inputs.
 - See Cope *Computers and musical style* for more info



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Stochastics 1 - Probabilities

- 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.
- Eg for a dice:
 - $S = \{1, 2, 3, 4, 5, 6\}$
 - If E is 'get a no 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



- Examples
 - Xenakis used various probability distributions to derive characteristics of sound
 - Nic Collins bbcut libraries uses weighted probabilities to define drum patterns.

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Stochastics 2 - Markov Chains

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

Input notes and probability matrix for 'Mary had a little lamb'

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

Transition Probability Matrix:

Next Event	C	D	E	F	G
C		2/3	1/3		
D	3/10		4/10		
E		5/11	5/11	1/11	
F					
G		1/2			1/2

- 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

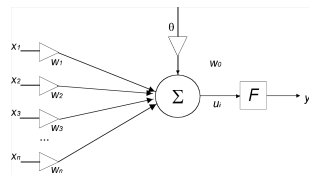
- Advantage**
- Captures note-by-note structure of input in short term

- Disadvantage**
- Lacks long term structure

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Neural networks - methods

Taking inspiration from learning in biological neurons, the idea behind using artificial neural networks (ANNS) is that musical 'rules' can be learnt rather than explicitly encoded. In general, existing musical works are presented to the network. The network can then be used to produce music bearing similar structures (in theory!).



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 (θ) models sensitivity/ resistivity

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Neural Networks – methods 2: training

- In general (there are exceptions), training involves presentation of input samples and example (desired) outputs. When training is successful, the network should be able to recognise examples similar to those used in training, and be able to generalise to similar, non-identical sets.
 - Network receives stimulus at input.
 - Input causes state changes in the network (learning rule implements weight changes).
 - Changes in parameter settings cause change in output.
- 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

Reference: Neural Networks for Pattern Recognition Christopher M. Bishop. Oxford University

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Neural networks

- **Rationale**
 - Musical structures can be 'learnt' without needing to formalise rules.
 - Networks can 'compose' based on structures learnt during training.
- **Examples**
 - Mozer, 1994 CONCERT
 - Network trained on existing corpus of work (J.S. Bach and European folk tunes)
 - Results better than 3rd order Markov but still lack global coherence.
 - Produced compositions that "only its mother could love". Mozer, 1991
 - See eg Todd and Loy 1991 for more examples
- **Advantages**
 - Capable of representing longer term and more abstract patterns than Markov processes
 - Also allow inclusion of eg psychologically motivated constraints on pitch and time representations
- **Disadvantages**
 - Little evidence for acquisition of 'deep' structure
 - 'new' compositions are novel, but not in any meaningful way

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Genetic algorithms (GA)

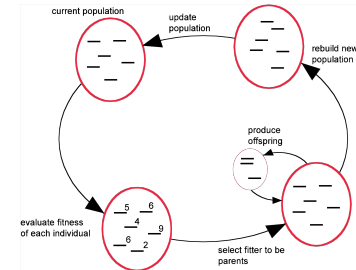
- Taking inspiration from natural evolution to guide search of problem space, the idea is that 'good' compositions, or composition systems can be evolved from an initial (often random) starting point.

Basic Scheme :

```

Initialise population
While not finished evolving {
  Calculate fitness of each individual
  Select preferred individuals to be parents
  For N = PopSize{
    Breed new individuals
    (cross over + mutation)
  }
  Build next generation
}
  
```

Render output:



- Fitness-proportionate reproduction ensures better solutions proliferate over time
- Mutation ensures new individuals are introduced into the population
- Reproduction operator (cross-over) mixes 'good' solutions of 2 parents

Reference: Holland, 1975, see also Mitchell, 1996 for a general introduction

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Genetic algorithms

Considerations

- What are we evolving ?
 - actual composition, system etc
- Representation
 - binary, real valued
- Method of initialisation
 - random, existing musical material
- Mutation, and crossover operators
 - possibilities for embedding musical constraints
- Fitness function
 - Interactive (humans), rule-based, coevolved
- We will look at different approaches to implementing the fitness function.
 - Think of the evolving population as a series of competitive composers/ compositions: our challenge is to design a critic who can judge their output.

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GA – rule based critics

- **Rationale**
 - Artificial Evolutionary systems traditionally use computable fitness functions
- **Examples**
 - Horner and Goldberg 1991a
 - Aim: Search for thematic bridges -ie transform an initial note-set into a desired note set within a certain no of steps
 - Approach: Fitness measure based on similarity with desired set and match between no transformations and desired duration.
 - Spector and Alpern 1994
 - Aim: Automatic construction of synthetic artists that could operate in any specified aesthetic tradition.
 - Approach: Artificial critic constructed from genre specific rules – eg 'Beebop' system critic based on criteria gleaned from jazz improvisation techniques
- **Advantages**
 - Good for highly structured cases
- **Disadvantages**
 - Difficult to formalise fitness function for more general applications
 - "although the response pleases the critic it does not please us" Spector and Alpern 1994

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GA – interactive GA

- Rationale
 - Use human aesthetic preference to select individuals to create next generation
- Examples
 - Moore – 1994 GAMusic
 - Listeners evolve 32 note melodies
 - Binary representation – VAST space to search and no
 - Ralley 1995
 - GA creates variations of a starting melody
 - Reduces search space
 - Produced acceptable melodies, but difficult to direct search (natural evolution is not teleological)
 - Biles 1994 GenJam
 - Uses hierarchical representations to generate jazz solos
 - Introduces musical constraints in operators etc.
 - Won't play a 'wrong' note, but may exclude exciting possibilities

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GA – interactive GA cont

- Advantages
 - No need to 'formalise' aesthetic/ musical preferences
 - "According to some theories of art this is the best, or even only, form of assessment to judge the quality of a work.."
- Disadvantages
 - Fitness bottleneck
 - "... [but] the science of artist construction will proceed quite slowly if each iteration of each system can be assessed only by organising a public show and by waiting for critical review" Spector and Alpern 1994
 - Boredom effects
 - Because many examples may sound similar, listeners tend to forget aesthetic preferences and select those that simply sound different. This results in a population of mutants!

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GA – learning-based critics

- Rationale
 - Remove need for explicit rules and human intervention by 'training' network to act as critic.
- Examples
 - Spector and Alpern 1995
 - extended rule based critic with neural network trained to make aesthetic evaluations of a case-base of melodies based on eg bad continuations of a single measure (silence, random etc)
 - Advantages
 - New critical constraints can be added easily by training network on additional examples
 - Disadvantages
 - Cannot know what the network is learning - leaves room for evolutionary methods to exploit weaknesses in fitness criterion.
 - Fixed evaluation method means GA can converge on inappropriate solution

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Coevolution

- Rationale
 - Critic evolves WITH composer.
- Examples
 - Werner and Todd 1997
 - Males produce melodic lines, females listen.
 - Behaviour of male 'composer' and female 'critic' guided by neural networks, based on transition tables
 - Various scoring methods used – local and global expectation, and surprise
 - Produced diversity and variation, but lacked musical structure
 - "each male song sounds crappy – but each sounds crappy in a unique new way"
- Advantages
 - Removes fitness bottleneck associated with IGA
 - Reduces likelihood of GA exploiting fitness function
 - Increases synchronic (across populations) and diachronic diversity (across generations)
- Disadvantages
 - Difficult to ensure that critics aesthetic preferences matches human ones!
 - Still leaves room for GA to exploit weaknesses

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'Extramusical' approaches

Use of mathematical models to define musical parameters. This can be thought of as a more experimental, or metaphorical approach. Rather than learning directly from existing music, or attempting to formalise musicological concepts, many systems use mathematical models that exhibit musically-relevant dynamics or structures.

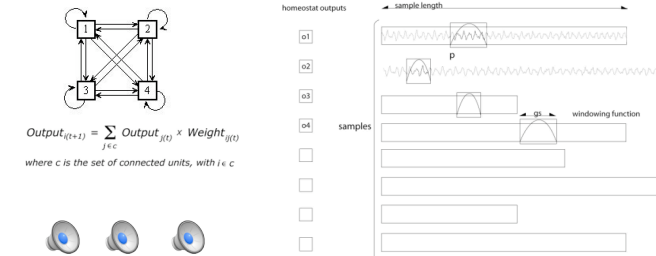
Examples (there are many many more)

- Fractals
 - Fractmus
 - What? : Selection of iterative equations used to define musical parameters (pitch, note length etc)
 - Why? : Many musical structures are self-similar
- Cellular automata
 - ChaosSynth (Miranda)
 - What? : State of 2D oscillating CA used to control parameters of granular synthesis
 - Why? : Structural dynamics of CA as oscillations form from initial randomised state mirror spectral evolution of each voice, wind instruments etc.
- Swarm models
 - Blackwell, Swarm Music
 - What? Reynolds 'boids' algorithm extended in musical space to control parameters of note events
 - Why? : models self-organising structure of free improvisation group.

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Extramusical - examples

- Self Karaoke Machine (Eldridge)
 - What? : states of homeostatic network used to 'remix' samples taken live
 - Why? : Network produces a good variety of exploratory and repetitive rhythmic patterns which can be perturbed to create new textures



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Extramusical

- Rationale
 - Structures in certain mathematical systems seen to mimic musical structures or model 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)

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Overview

- Historical examples
 - Hiller and Isaacson
 - Xenakis
- Knowledge based systems
 - Rule based
 - Grammars
- Stochastic
 - Probabilities
 - Markov
- Neural Networks
 - Supervised
 - self-organising
- Genetic algorithms
 - Automated fitness function
 - Interactive fitness function
 - Coevolution
- Extra-musical
 - Fractals
 - Cellular automata
 - Swarm models

"The Analytical Engine has no pretensions whatever to originate any thing. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths.

... Its province is to assist us in making available what we are already acquainted with. ...it is likely to exert an indirect and reciprocal influence on science itself in another manner. For in so distributing and combining the truths and formulas of analysis...the relations and the nature of many subjects in that science are necessarily thrown into new lights, and more profoundly investigated."
- Ada Lovelace from Note G

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References

- Ames, C. 1987 Automated composition in retrospect: 1956-1986. *Leonardo*, 20 (2), 169-185
- Ebicicloglu, K. 1984 An expert system for Schenkerian synthesis of chorales in the style of J.S. Bach. In *Proceedings of the 1984 International computer music conference*. (pp.135-142). San-Fransisco: ICMC
- Hiller, L. and Isaacson, L. 1959 *Experimental Music*. New York: McGraw-Hill
- Holland, J.H. 1975 *Adaptation in Natural and Artificial Systems*. Ann Arbor: University of Michigan Press. (Second edition: MIT Press, 1992)
- Horner and Goldberg 1991a Genetic Algorithms and computer assisted composition. In *Proceedings of the 1994 International Computer Music Conference* (pp.452-455) San Francisco: ICMC
- Loy, D.G. 1989 Composing with computers – A survey of some formalisms and music programming languages. In M.V. Mathews and J.R. Pierce (Eds) *Current Directions in Computer Music Research* (pp.291-396). Cambridge, MA: MIT Press
- Mitchell, M. 1996 *An Introduction to Genetic Algorithms*. Cambridge, MA: MIT Press/ Bradford books
- Mozar, M.C 1991 Connectionist music composition based on melodic, stylistic and psychophysical constraints. In P.M. Todd and D.G. Loy (Eds), *Music and Connectionism* (pp. 195-211). Cambridge, MA: MIT Press
- P.M. Todd and D.G. Loy (Eds), *Music and Connectionism* (pp. 195-211). Cambridge, MA: MIT Press
- Spector, L. and Alpern, A., 1994 – Criticism, culture, and the automatic generation of artworks. In *Proceedings of the 12th National Conference on Artificial Intelligence (AAAI94)* (pp.3-8) Menlo-Park, CA: AAAI Press/MIT Press
- Spector, L. and Alpern, A., 1995 Induction and recapitulation of deep musical structure. In *Working Notes on the IJCAI-95 Workshop on Artificial Intelligence and Music* (pp.41-48)
- Xenakis, I. 1971 *Formalized Music Bloomington, Indiana: Indiana University Press*