Evolutionary Music

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Overview

- Define music and musical tasks
- Survey of EC musical systems
- In-depth example: GenJam
- Key issues for EC in musical domains

Music

- What is music?
  - Lots of opinions, styles, genres, religions…
  - Music vs. noise
    - "I may not know music, but I know what I like"
    - Usually means, "I like what I know…"
- Two defining characteristics:
  - Music is aural (heard)
  - Music is temporal (happens in real time)
- Music is ***temporally organized sound***

Aspects of Music

- Pitch (not necessarily tonality)
  - Melody: Horizontal (temporal) arrangements
  - Harmony: Vertical (simultaneous) arrangements
- Rhythm (timing, not necessarily a pulse)
  - Temporal sequences, relationships of events
  - Repetition, meter, tempo
- Timbre (any sounds are fair game)
  - Traditional instrument sounds, ambient sounds
  - Computer-generated sounds (anything possible)
- Form (maybe emergent, even random)
  - Structure, organization, conception
  - Hierarchy (multiple levels)

Musical Tasks

- Composition: Create score (abstraction)
- Performance: Realize score in sound
- Synthesis: Generate sounds electronically
- Listening: Derive abstraction from sounds
- Improvisation: Everything simultaneously

EC in Music

- Dates back to 1991
  - Horner and Goldberg: Thematic bridging
  - Gibson and Byrne: NEUROGEN
- Activity increasing rapidly
  - Reviewed over 120 articles for this tutorial
  - EC music class projects appearing on the www

Generative Systems

- Certainly evolutionary, certainly relevant
  - Cellular Automata (music apps since 1980's)
  - Swarms (emergent behavior, colonies)
  - Artificial Life
  - Sonification of data, DNA (Genetic music)
  - Fractals, chaotic systems (music since 1970's)
- Not my primary focus, due to time

Survey of EC Applied to Music

- Organized around musical tasks
  - Task analysis of the musical domain
  - Choose subtasks where EC used
- Some representative examples
  - See my Web site for references and links
  - www.it.rit.edu/~jab
- Goals
  - Recruit some new blood
  - Motivate discussion of fundamental EC issues

EC in Composition

- First application area (1991)
- Largest application area
- Agenda
  - Describe subtasks of composition
  - Cite some examples
  - Summarize themes and variations

Composition Subtasks

- Generate melodies (motives)
  - Generate melodic line (sequence of pitches)
  - Generate rhythm (sequence of durations)
- Develop (extend, enhance) melodies
  - Generate variations
  - Combine motives to create longer lines
  - Generate countermelodies

Composition Subtasks

- Harmonization
  - Generate harmony parts (hymns, chorales)
  - Generate harmonic foundation (chord changes)
- Arranging
  - Rhythm section accompaniment
  - Counterpoint
- Structure
  - Generate or adhere to form
  - Generate sections, higher level units

A Few Examples

- Horner and Goldberg (1991)
  - Thematic bridging (melody morphing)
  - Bred sequence of operations to transform one motive into another
  - Fitness - hit target, if so check bridge length
- NEUROGEN (Gibson and Byrne, 1991)
  - Rhythm - GA with NN fitness function
  - Add pitch - GA, 2 NN (interval, structure)
  - Harmony - Simple rule base

variations (Bruce Jacob, 1995)

- Three components, all GAs
  - Composer - builds phrases from user-supplied motives
  - Ear - Judges the composer's output (fitness)
  - Arranger - Orders phrases into composition, fitness by user
- Starts at motive level (above notes)
- Co-evolution of Composers and Ears
- Sample: Hegemon-Fibre, 1st movement 

GP-Music (Johanson & Poli, 97)

- GP melody generator (short, monophonic)
  - Terminals - pitches or rest
  - Functions - musical development
- No real rhythm (all notes same length)
- Fitness
  - Interactive (1-100 rating, pair-wise comparison)
  - Neural nets trained on ratings from interactive runs (1-100 version worked less badly)
- Even toy domains are tricky

GenDash (Rodney Waschka II)

- New music composer, not a techie
- GenDash - GA tool he tweaks for each piece (since mid-1990's)
- Sappho's Breath (2001): 1-act opera (arias)
  - Initial population: 26 measures of music
  - Random selection, crossover at note level
  - All children of each generation heard
  - Around five generations per aria
- Highly collaborative, artistic

Harmonization - SATB

- Soprano Alto Tenor Bass (classic four-part)
  - Voicing individual chords and voice leading
  - Standard rule sets exist => automatic fitness
- Basically a scheduling problem (optimize)
  - Represent chord sequence or voice sequences
  - Fitness usually number of constraints violated
- Mixed success
  - Easy if chords specified (more constrained)
  - Harder if chords evolved too (more creative)

Harmonization Examples

- Horner and Ayers (1995)
  - Melody and chord symbols -> 4-part harmony
  - Broke problem into 2 parts
    - Enumerate all possible voicings for each chord
    - GA to find best sequence of voicings (voice leading)
- Phon-Amnuaisuk, et al (1999)
  - Evolved chords themselves as well
  - More creative, less tractable
  - Rule-based system worked better
- EC probably not the best approach

Rhythm - Drum Machine

- Generate single-measure or longer patterns
- 2D grid (standard drum machine interface)
  - Time on X axis
  - Instrument on Y axis
  - MIDI velocity in the cells (0-127)
- Build textures
  - Loop one measure
  - Build longer phrases from multiple patterns

Rhythm Examples

- Horowitz (1994)
  - Representation - params to generating function
  - One-measure drum textures presented visually
  - Mentor listens, selects favorites to survive/breed
- CONGA (Tokui and Iba, 2000)
  - 4 to 16 measure patterns (user specifies)
  - GA evolves half or one-measure patterns (grid)
  - GP arranges patterns into phrases (hierarchy)
  - Levels evolved separately (mentor switches)
  - Neural net to thin the GA population

SBEAT (Tatsuo Unemi, 2002)

- Currently in third version
- Representation (individuals are measures)
  - 16 events (fixed time grid) X
  - 3 chromosomes (pitch, rhythm, velocity) X
  - Up to 23 parts (13 solo, 2 chord, 8 rhythm)
- Collaborative system - User can
  - Select individuals to breed
  - Manipulate underlying chord/scale
  - Enter and protect parts
  - Arrange measures into score (piece)

Pitch/Duration Representations

- Pitch
  - Absolute pitch (scale degree, MIDI note, Hz)
  - Relative interval
    - From previous pitch
    - From beginning of phrase or composition
    - From tonic of key or root of chord
- Durations
  - Beat-oriented (multiples/divisions of beat)
  - Absolute (milliseconds)

Melody Chromosomes

- Position-based
  - Time windows on fixed temporal grid (beats/fractions)
  - Enforces beat/measure/phrase structure
  - Tilts toward beat-oriented music
- Order-based
  - Pitch/duration pairs (durations can be arbitrary)
  - Measure lines ignored, superimposed, or irrelevant
  - Facilitates non-pulse music
- Tree-based (GP)
  - Terminals usually notes (pitch, maybe duration)
  - Functions usually musical operators
  - Facilitates more complex forms (extend hierarchy)

Melody Fitness

- Explicit rules and heuristics
  - From music theory or hip pocket
  - Usually combined via weighted average
- Interactive (human mentor, critic, rater)
  - Display individuals; rater selects and rates
  - Perform in musical context (real-time)
- Learn from examples (neural networks)
  - Input either features or melodic fragments
  - Examples come from desired style

Operators - Initialization

- Random - Start from scratch
  - White noise generator
  - Fractals
  - Markov chains
- Sampled
  - User supplied motive(s) to develop
  - Licks from analyzed corpus

Operators - Selection

- Traditional fitness-based
  - Encourages convergence
  - Can be problem if diversity critical
- Musically aware
  - Look for individuals to fill a role
- Random - no fitness
  - Works if individuals all musically meritorious
  - Maximum diversity

Crossover and Mutation

- Is purpose to alter or develop?
  - Alter - more random, less guided
  - Develop - more musically aware
- Crossover point(s)
  - At bit vs. musical boundaries (note, measure)
  - Random vs. musically meaningful
- Mutations
  - Flip bits - likely to be unmusical
  - Musically meaningful - may be too "safe"

EC in Performance

- Expressive performance of score not trivial
  - Classical: alter note onsets, length, envelopes
  - Jazz: also alter notes (add, delete, change)
- Annotate jazz performance (Grachten)
  - GA to minimize cost of edit-distance operations to transform score to performance
  - Use training sets of "correct" performances

Audience Mediated Performance

- GenJam Populi (more later)
- Sound Gallery (Woolf and Thompson)
  - Artistic installation piece
  - Speakers in corners of room (four islands)
  - Each driven by evolving hardware distorting a source sound
  - Fitness: location of patrons (closer is better)
  - Migration to keep people moving

Performance (kind of)

- GA to enhance public speaking voice (Sato)
  - Three "genes" - pitch, volume, speed
  - Fitness - from mentors
  - Not real-time yet…
- HPDJ (Hewlett Packard Disc Jockey)
  - Select tunes, sequence them, do crossfades
  - Fitness: crowd animation level

EC in Synthesis

- Control synthesis algorithms/techniques
- Goal: Higher level (more musical) interface
  - Huge, chaotic parameter spaces
  - Provide guided search through synthesis space
- Two different subtasks
  - Match a target sound
  - Generate new (hopefully interesting) sounds

Matching a Target Sound

- Basically an optimization problem
- Fitness - [perceptual] spectral matching
- GA to evolve parameter settings (Horner)
  - Unit generator (UG) parameters (FM, modular)
  - Additive synthesis envelope breakpoints
  - Wavetable, physical modeling parameters
  - *CSound Recipes* (Horner and Ayres, 2002)
- GP to evolve UG topologies (Garcia, 2001)
- Reverb params - match room (Mrozek, 96)

Search for New Sounds

- Explore a synthesis technique's sound space
- Fitness - mentor preference
- Goal often collaborative tool for sound designers and composers
- Example - Timbre trees (Takala, 1993)
  - Evolve topology of unit generator patches (GP)
  - Sounds synchronized to animated motion

Granular Synthesis

- Sound objects made up of 1-100 ms grains
  - Each grain has waveform, pitch, envelope, …
  - Sound object (cloud) has density, shape, …
  - *Microsound* (Roads, 2001, MIT Press)
- GA to evolve parameters (Johnson, 99)
  - FOF (formant wave-function) synthesis
  - Evolves parameters for CSound function call

Emergent Granular Synthesis

- Chaosynth (Miranda, 1995-)
  - CA to control grain parameters
  - As CA self-organizes, sound emerges
- Swarm Granulator (Blackwell, 2003)
  - Swarmer - Swarm is the granular cloud
  - Interpreter - Interprets swarm for granulator
  - Granulator - Sound engine (Max/MSP)
  - Real-time interactive performance 

Synthesizer Control

- Commercial Synthesizers hard to control
- Muta-Synth (Palle Dahlstedt, 2001) 
  - Customizable S/W controller for Nord synth
  - Extended to real-time interactive performance
- Genophone (Mandelis, 2002)
  - Evolves sounds and gesture mappings
  - Data glove interface
  - Sends SysEx messages to Korg Prophecy

Breed Actual Waveforms

- Thesis (Cristyn Magnus , SDSU, 2003)
- Representation
  - Waveform (sample array)
  - Genes: segments bounded by zero crossings
- Operators
  - Crossover and mutations at gene level only
  - Eliminates clicks and pops 
- Fitness: Match waveform or amp. envelope
- Piece *is* evolution of initial to target sounds

EC in Listening

- NEXTPITCH (Francine Federman, 2000)
  - LCS to predict next pitch in melody
  - Nursery tunes and chorales (simple melodies)
- Accidental evolution of a radio (Layzell, 02)
  - Trying to evolve a hardware oscillator
  - Got a radio that received oscillations from a nearby computer

EC Listeners in Composers

- The EAR in Bruce Jacob's *variations* system
  - IGA to breed set of "data filters" for harmonies
  - Each filter passes an acceptable chord
- Co-evolved critics (Todd and Werner, 99)
  - "Male singers" (32-note song)
  - "Female critics" prefer certain intervals
  - Female selects male with best intervals
  - Best means most surprising

EC in Improvisation

- Compose and perform concurrently (Jazz)
- Spontaneous, real-time, interactive
- Has to be "right" the first time
- Jazz is an inherently evolutionary domain
  - Jam session environment highly competitive
  - Survival of fittest (cutting sessions)
  - Players "borrow" others' ideas (licks)
  - Can even trace lineage of licks and soloists

Spector and Alpern (1994-5)

- Toward general case-based artist generator
- Traded bebop fours using GP (not real-time)
  - Terminal set: four-bar phrase from human
  - Function set: 13 melody transforms
  - Evolved programs to transform human four
- Fitness
  - Five features from jazz theory literature
  - Neural net trained on Bird licks
  - Hybrid combination worked best

Papadopoulos and Wiggins (98)

- Generate blues chorus, not real-time
- Chromosome - 12-bar blues of 1/16th notes
- Initialization - Random
- Crossover - single and two-point, note level
- Mutation - musically meaningful
- Fitness - 8 features in fixed weighted sum
- Goal: Eliminate subjectivity (EC-neat)
- Best sounding result was human-edited

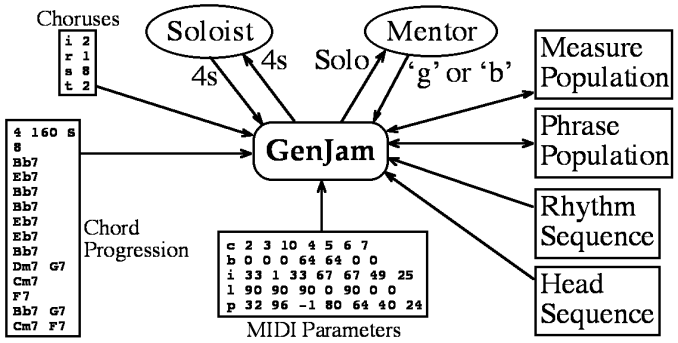
Swarm Music

- Tim Blackwell, 2003
- Swarm-based collective improvisation
- Basically Swarm Granulator operating at note level instead of grain level
- Self-organization
- Stigmergy - interact by modifying environs
- "Follow me" from CD *Swarm Music*

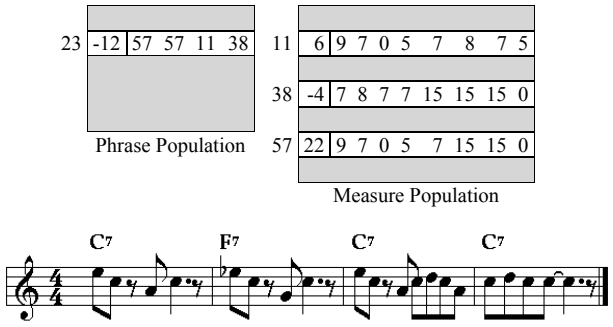
GenJam: An In-Depth Example

- *GenJam* = ***Gen***etic ***Jam***mer (1994 - present)
- Models a jazz improviser (agent of sorts)
- Real-time interactive performance (MIDI)
- Lets a trumpet player work as a single
- Versions for 4/4, 3/4, 5/4, 7/4, 12/8, 16/8
- About 250 tunes in repertoire
- Swing, bebop, cool, Latin, funk, new age
- Performed for last night's Reception

Interactive GenJam Architecture



Representation of a Phrase (GenJam Normal Form)



Chord Scale Mappings

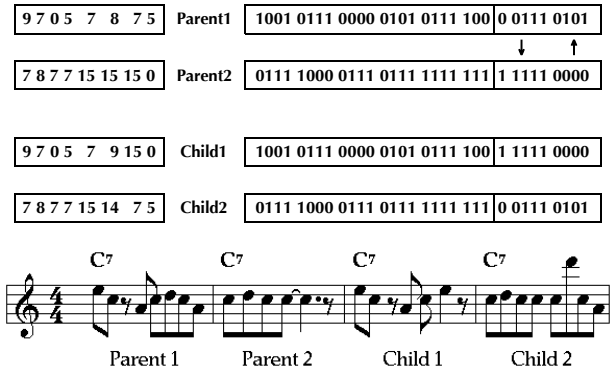
Chord	*Scale*	*Notes*
Cmaj7	Major (avoid 4th)	C D E G A B
C7	Mixolydian (avoid 4th)	C D E G A Bb
Cm7	Minor (avoid 6th)	C D Eb F G Bb
Cm7b5	Locrian (avoid 2nd)	C Eb F Gb Ab Bb
Cdim	W/H Diminished	C D Eb F Gb G# A B
C+	Lydian Augmented	C D E F# G# A B
C7+	Whole Tone	C D E F# G# Bb
C7#11	Lydian Dominant	C D E F# G A Bb
C7alt	Altered Scale	C Db D# E Gb G# Bb
C7#9	Mix. #2 (avoid 4th)	C D# E G A Bb
C7b9	Harm Minor V (no 6th)	C Db E F G Bb
CmMaj7	Melodic Minor	C D Eb F G A B
Cm6	Dorian (avoid 7th)	C D Eb F G A
Cm7b9	Melodic Minor II	C Db Eb F G A Bb
Cmaj7#11	Lydian	C D E F# G A B
C7sus	Mixolydian	C D E F G A Bb
Cmaj7sus	Major	C D E F G A B
C7Bl	Blues	C Eb F Gb G Bb

GenJam's Genetic Algorithm

- Fairly standard GA process for both populations
  - Random *initialization*
  - Tournament *selection* - 4 individuals in a family
  - 2 fittest family members become parents
  - Single-point *crossover* creates 2 kids
  - Musically meaningful *mutation* until kids are unique
  - 2 kids *replace* 2 least fit family members
- Replace 50% of each population in breed mode
- Replace worst 4 measures, 3 phrases in tweak

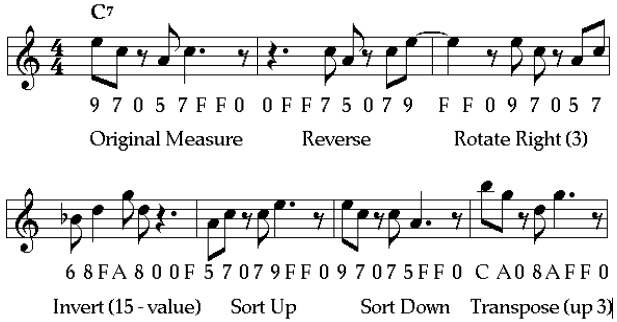
Example Measure Crossover

Random, bit-level crossover point



Musically Meaningful Mutations on Measures

Standard melodic development techniques



Musically Meaningful Mutations on Phrases

Operate at measure-pointer level, not bit level

Mutation Operator	*Mutated Phrase*	*Explanation*
None	57 57 11 38	Original Phrase
Rotate Right Random	57 11 38 57	3 positions in this case
Reverse	38 11 57 57	Play measures in reverse order
True Retrograde	38 11 57 57	Play measures backward too
Sequence Phrase	57 57 ***38*** 38	Repeat a measure
Genetic Repair	57 57 11 ***23***	Replace worst measure
Super Phrase	55 13 21 34	Winners of fitness tournaments
Lick Thinner	***31*** 57 11 38	Replace most common measure
Orphan Phrase	43 37 53 19	Losers of frequency tournaments

Intelligent Genetic Operators

- GA's usually have dumb operators, smart fitness
  - Rely on fitness to guide search
  - Leads to fitness bottleneck in IGAs, especially temporal
- GenJam currently uses smart operators
  - Intelligent mutation - Already seen
  - Intelligent initialization - Fractals & Markov chains
  - Intelligent crossover - Preserve horizontal intervals
- Good parents tend to have good children
- Reduces volume through the fitness bottleneck

GenJam Generations Demo

- Old GenJam version - improvise 4 choruses
- Tune is Tadd Dameron's *Lady Bird*
- 16-bar form, straight up rhythm
- Each chorus uses a more mature generation
  - 1st - Generation 0, white noise generator
  - 2nd - Gen 1
  - 3rd - Gen 2
  - 4th - Gen 3

Real-Time Interaction

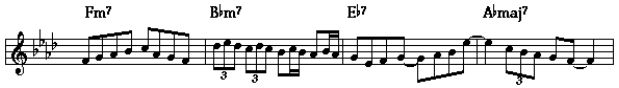
- When GenJam trades fours with human
  - Listen to human's four (Roland GI-10)
  - Map human phrase to GJNF chromosomes
  - Mutate the phrase and 4 measures
  - Play mutated result as its response
- Use mutation as melodic development
- Results in true conversation
- Highly robust and formidable opponent

Fault Tolerant Pitch Tracking

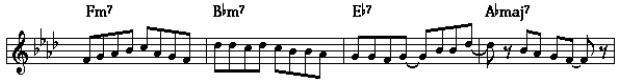
- Pitch tracker makes lots of mistakes
  - Wrong pitch
  - Extra note-on events
  - Extra note-off events
- Not a problem
  - Map to GJNF, which is highly robust
  - Errors not mistakes, they're "development"
  - Will mutate anyway before playing

Anatomy of a Four

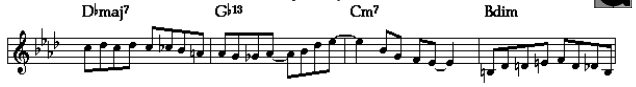
I played quote from Prince Albert



GenJam "heard" this from pitch tracker



GenJam mutated and played this back



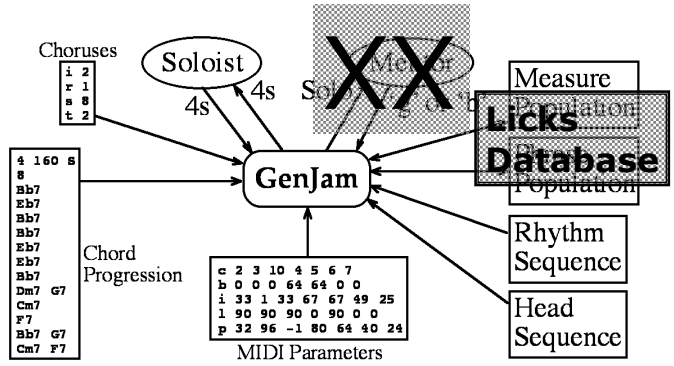
Collective Improvisation

- GenJam and human solo simultaneously
- GenJam listens to human while it's soloing
- Maps to GJNF
- Plays what human did earlier (delay line)
  - Delay of 1 bar, or n events, 4 bars (smart echo)
  - No mutation - Replay as close as possible
- Human can trade 1's, play harmony, counterpoint
- Challenge for the human!

Making GenJam Autonomous

- GenJam more fun when interactive
  - Fitness not necessary or even possible
  - Good human four -> good GenJam four
  - Initialization is very smart
- GenJam's full-chorus solos not as good
  - Ideas competent but seldom compelling
  - Initialization not smart enough
  - Move to an autonomous GenJam

Autonomous GJ Architecture



Initialize from Stored Licks

- Licks Databases (several styles)
  - 4-bar licks come from *1001 Jazz Licks*
  - Map to GJNF by hand
- Initialization algorithm
  - Select 16 4-bar licks from database
  - Seed measure pop with those 64 measures
  - First 16 phrases are the 16 original licks
  - Remaining 32 phrases are smart crossovers

Evolve Soloist Interactively

- As human solos, map measures to GJNF
- If a human measure is "good enough"
  - Select measure that best matches end points
  - Do intelligent crossover with new measure
  - Pick child that best matches endpoints
  - Replace the parent measure with that child
- Evolves soloist toward human's solo

What happened to Fitness?

- Fitness considered necessary for a GA
- View EC as generate-and-test strategy
  - Generate: Initialize, recombine, mutate
  - Test: Fitness
- Usually generators dumb, fitness smart
- GenJam's generators are smart
  - Intelligence distributed over generators
  - Nothing left for fitness to do, so eliminate it!
- If generators are good, no need to test

GenJam in Lake Wobegon

Where the old licks are strong,
the new licks sound good,
and all the children are above average!

Is GenJam Still an [I]GA?

- If a GA falls in the forest, and there's nobody there to provide fitness, is it still Evolutionary Computation?

No, it's not!

- No more Mentor (there goes the "I" part)
- No longer any explicit fitness at all
- No generational search
- No real search at all
- It's just a fancy melodic transducer!

Yes, it is!

- Employs the evolutionary paradigm
- Uses chromosome (string) representations
- Does genotype -> phenotype mapping
- Uses selection, recombination, mutation
- Generates offspring
- Fitness in deciding whether to breed human and soloist measures, which measures
- I got invited to GECCO…

Big Picture Issues

- What to consider in applying EC to music
- How does music domain bend EC
- Advice to those making music with EC
- Summarize with sweeping generalities

Traditional vs. Musical Domains

- Solve a problem vs. Generate content
- Best vs. Better (maybe just different)
- No such thing as “the best” piece
- Fitness absolute vs. relative
- Fitness objective vs. subjective
- Individuals compete vs. Connect
- Convergence vs. Diversity

Optimization vs. Exploration

- Noticed by many (Todd and Werner, 1999)
- Lewis and Clark analogy
  - Searched for (non-existent) northwest passage
  - Ended up exploring the west (more valuable)
- Usually want to explore a musical space, not optimize it

What are you trying to do?

- Study EC vs. make good music
- Scientist/engineer vs. Artist
- Neat vs. Scruffy dimension from AI in 80's
  - Neats - Model human intelligence
    - Focus on EC purity (don't cheat)
    - Goal: Show EC can do what people do (be creative)
  - Scruffies - Solve real problems
    - Use EC as one of many tools (hybrid systems)
    - Goal: Make good music

Fitness Issues

- Easy in a few (optimization) domains
- Harder in creative domains
- Hard to code "that sounds good"
- Just because you can compute it doesn't mean it's useful as fitness
- Subjective isn't bad
- If can't code it, use human fitness function

Revisit Fitness Approaches

- Automatic
  - Rule-based (heuristics)
  - Learned
    - Neural Networks
    - Statistical
- Interactive
  - Explicit feedback from one or more mentors
  - Indirect feedback from an audience
- None

Fitness: Heuristic Features

- Dozens of features proposed/used (Towsey 01)
  - Pitch - variety, range
  - Tonality - in key, non-scale, dissonant intervals
  - Melodic contour - direction, stability, interval size
  - Rhythmic - note/rest density, variety, syncopation
  - Patterns - repeated pitch, rhythm patterns
  - Statistical adherence to Zipf's law
  - Etc.
- Difference polynomials (often brittle)

Fitness: Rule-Based

- Knowledge-based (music theory)
- "Theoretically correct" may sound lousy
  - Theory ***should*** explain ***why*** something sounds good
  - Theory should ***not*** decide ***whether*** something sounds good
- Limit creative options (style enforcement)

Fitness: Neural Nets

- Example-based (training set important)
- Input layer
  - Musical objects themselves
  - Feature vectors derived from objects
- Seldom seems to work
  - Seldom generalizes
  - Features don't capture the essence
  - Context of objects ignored

Fitness: Interactive

- Most common method in creative domains
- If it's a judgment, let the human judge
- Central problem: ***Fitness Bottleneck***
  - Mentor must experience all individuals
  - Temporal => can't experience in parallel
  - Must experience in real time
  - Hard to listen that closely, critically
  - Fatigue a big issue
- However, EC can absorb noisy fitness

Mentor's Interface

- Facilitate mentor's task
- Usability is primary issue (Takaga, this AM)
- Presentation of individuals must be musically valid (in musical context)
- Mentor should be focusing on the music, not the interface

Representation

- Only represent what you want to hear
- Don't represent music you don't want to hear
- Don't represent all possible sounds unless you want to hear all possible sounds
- Decide on genre and taylor representation to that genre

Initialization

- White noise generators - often too random
- Pink noise
- Fractal/chaos generators
- Markov process
- User-generated objects
- "Greatest hits" from a corpus
- Random ≠ Creative (most of the time)

Diversity is Essential

- Convergence can be disastrous
  - "The lick that ate my solo"
  - Can make a good individual sound bad
- Encourage diversity with
  - Operators
  - Co-evolution
  - Speciation, islands
  - No fitness

Don't use EC for everything

- EC as a solution in search of a problem
- Hybrid systems usually better
- Rules, neural nets, heuristics, procedures, user collaboration are all okay
- Only evolve what you have to

KISS

- Simple & robust trumps complex & brittle
- Always competent trumps occasionally brilliant
- Start with simple
- Only get complex if you're out of simple

Constraints are good!

- Stylistic constraints can be positive
- Sticking to a genre isn't an artistic cop-out if you like the genre
- "Freedom" means a bigger search space
- Meeting an audience's expectations isn't bad, especially if you want to get gigs…

Set the bar at the right level

- Don't set the bar too low
  - I think we've nailed nursery tunes
  - Toy domains are great for class projects, but solutions seldom scale up
- Don't set the bar too high
  - Don't try to solve the "western tonal music" problem
  - Pick a doable task to focus on

Who's your audience?

- Audience as users
  - Listeners build mental model of performance
  - Model enables expectations in performance
- Adhering to rules meets expectations
- Breaking rules is a surprise
- Must balance to engage listener
- Can engage listener with audience-mediated performance

Listen to the music!

- Just because it generated notes doesn't mean it was successful
- Listen to it with fresh ears (or have fresh ears listen to it)
- If you heard it on the radio, would you change the channel?

Greatest Hits

- *Contemporary Music Review,* 22(3), September, 2003
- Bentley and Corne, *Creative Evolutionary Systems, Morgan Kaufmann, 2001*
- Todd and Werner in *Musical Networks*, MIT Press, 1999
- Burton and Vladimirova, *CMJ*, 23(2), Summer, 1999
- Lots of links: www.it.rit.edu/~jab