The Use of Markov Chains in Ex Machina

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Abstract

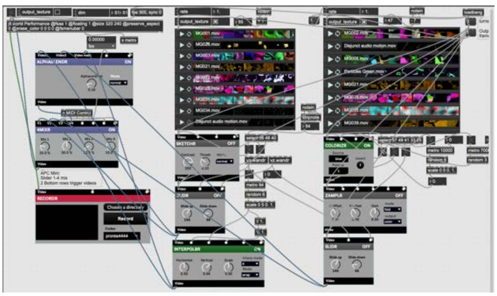
Ex Machina is a multi-disciplinary work combining composed and algorithmically generated music, processed video, and modern dance. The work is a concert-length performance, a spectacle of sound, light, and movement. Inspired by themes in novels by Philip K. Dick and William Gibson and others, ensemble performance is integrated with computer-generated music, video, and dance, generating interplay between real and virtual worlds, between grittiness/immediacy of daily life and cyber fantasy. The work is a musical, visual experience embracing technology and celebrating performance.

Several movements of *Ex Machina* are generated by Max/MSP patches generating progressions of chords or sequences of melodies using Markov chains. Markov chains generate variations of musical content, ensuring that it is similar but never the same. Video elements are mixed live by a VJ; they incorporate text from Donna Haraway's *A Cyborg Manifesto,* Baudrillard *Simulacra and Simulation,* and *The Conspiracy of Art* and videos of biomorphic shapes and lines. Time-based processing (e.g., interpolation) is used in conjunction with mixes of multiple video channels. The opening of *Ex Machina* signals possibilities suggested by Haraway: "By the late twentieth century, our time, a mythic time, we are all chimeras, theorized and fabricated hybrids of machine and organism; in short, we are cyborgs. The cyborg is our ontology; it gives us our politics." [1]

Ex Machina Structure

Ex Machina is a seven-movement multi-disciplinary work for electric guitar, drum set, fixed media, live audio and video processing, and dance. The work uses Ableton DAW for audio playback and live mixing; and Max/MSP for video playback/mixing, and for generating MIDI using the Max/MSP Markov object. The work alternates computer-generated and composed instrumental music in sections 1, 4, 6 and 2, 3, 5, and 7 respectively. MIDI information generated by the Markov object in sections 1, 4, and 6 is routed through multiple synthesizers and signal processing in the DAW. We will limit the discussion to musical material and the use of Markov Chains in the 1st and 4th sections of the work after a brief discussion of the Max/MSP video patch.

The video patch (Ex. 1) employs four channels of video information mixed using a launchpad controller. Max/MSP Vizzie objects process and mix video clips. Some patch elements may be controlled by random objects using scaled values or a r andom walk (vz.wandr). This patch is used for the entire work, with each section using a subset of the clips from the two playlists.

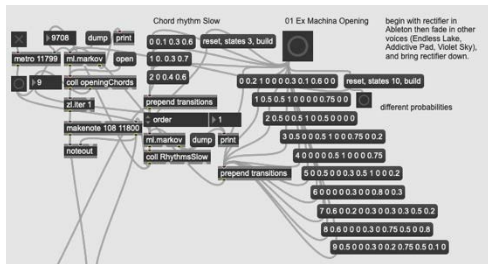


Example 1: Ex Machina Max/MSP video patch.

Ex Machina Section 1 is a pre-show running for 5-30 minutes before the ensemble performs; it is the work's preamble. The videos integrate text from Haraway's *Cyborg Manifesto*, with clips of biomorphic shapes, processed with time-based frame smearing/delay and interpolation controlled and shaped by a VJ using automated processes and a MIDI controller.

Ex Machina Section 1 M arkov Chains

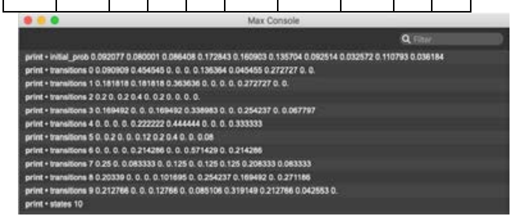
The Max/MSP patches employed for generating MIDI in Sections 1, 4, and 6 either specify the transition states (1, 6) or use the Markov Object to generate states based on training data from a MIDI file. In Section 1, transitions are determined by pre-set messages, and the Markov object triggers sonorities contained within the coll object "OpeningChords." Transition states are shown in message boxes (0-9) (center of window). Note that messages specifying transition states need not sum to 1.0 (Ex. 2). The Markov object scales transition states regardless of input values (Ex. 3), enabling the user to weight values intuitively. The duration of sonorities is generated by a s econd Markov object with three states (Ex 2-RhythmsSlow). Each of the three durations are Phi proportions X(1.618). [1] Markov objects in Section 1 use first-order chains (memoryless). [2] Comparison of weighted random, 0^{th}, 1^{st}, 2^{nd} and 3^{rd} order chains will be discussed in reference to Section 4 of the work.



Example 2: Ex Machina Max/MSP Section 1 patch.

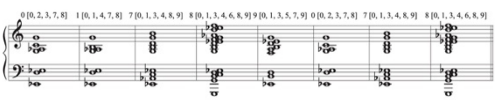
The Max Console window below shows interpolated transition probabilities. Compare Ex. 2 and Ex. 3 transition "0" (pictured).

.2	1	0	0	0	.3	0.1	.6	0	0
.09	.45	0	0	0	.14	0.05	.27	0	0



Example 3: Ex Machina Max/MSP Section 1 transition states interpolated.

Example 4 shows eight sonorities generated from the patch during a session. Compare the sample with probabilities from Ex. 3 [0-1, .45; 1-7, .27, 7-8, .21; 8-9, .04; 0-7, .27; 7-8, .21]. For this sequence, many of the highest probability sonorities were triggered. The least probable movement was 8-9, .04. The success of progressions here and in the discussion of Section 4 are influenced by pc content [8-27: 0, 1, 2, 4, 5, 7, 8, T], repeated pitch structures (e.g. [0, 1, 3] and weighted transition factors that produce progressions with viable musical results. Upon examination of the sonorities below, one finds that connections between sonorities (voice-leading) strongly influence the progression's perceived flow, as do changes in register in the bass and soprano voices. This excerpt does not demonstrate the variety of bass motions possible between the ten sonorities, though.



Example 4: Ex Machina Section 1 generated sonorities.

In Section 1, the tension generated by dissonance, rhythmic and ha rmonic expectations, and the timbral characteristics of synthesizers produce its overall mysterious or ominous effect. Section 6 uses the same Markov transitions to trigger sonorities and rhythms, but the pc content is inverted, generating a lighter or uplifting mood. This is mirrored in the colour scheme of video clips chosen for each section. The music of these Sections establishes the theme of *Deus Ex Machina* [3] but proposes no solution or resolution. In essence, arbitrary colour choices and sonorities triggered by random probability matrices engender the perceived emotional content. [4]

Ex Machina Section 4 Markov Chain Matrices

Section 4 employs Markov Chains to generate melodic variations from the guitar solo of Section 3 mm. 111-130. The pitch structure of the solo projects the following sets/intervals: *a* [0, 1, 5], *b* [0, 4, 8], and *c* [0, 1, 4, 5] and *ic 4* (Ex. 5). Measures employing *a* exhibit diverse melodic contours while *Ic 4* and *b* appear as ascending and descending figures respectively. *C* (the combination of *a* and a_i) ascends, and in the last few measures, *b* mirrors the second half of m. 124 in m. 129-30 using a broken arpeggio. Phrase relationships are A-A-At-B-Bt-Bt'-C. *A* Phrases are 2:1 proportion with *B* and *C.* [2] The solo from Section 3 uses eleven PC's, all but the pitch d, but I will focus on w hat the Markov object generates using the six PC's of mm. 111-14.

Example 5: Ex Machina Section 3 instrumental solo.

Musical material from mm. 111-14 [Phrase A] will be us ed to demonstrate what higher-order Markov chains generate with the musical material. The initial state, 1st, and 100th order transition matrices are provided as examples, and analysis of musical examples will demonstrate what happens at each stage. Phrase [A] is structured around transpositions of *a* [0, 1, 5], ic 4, and *b* [0, 4, 8], and as pitches are triggered in the Max/MSP patch, these structures emerge as musical regions resembling the original phrase more or less depending on the order of the Markov chain.

Example 6: Ex Machina Section 3 instrumental solo, mm. 111-14.

The table below shows the PC's and the number and percent occurrences of each in mm. 111-14 of the solo. Transitions are calculated from these (Ex. 8).

PC.	# of occurrences	% occurrence
G	5	17%
F#	2	7%
B	10	33%
C	2	7%
E	4	13%
D#	7	23%

Example 7: Ex Machina Section 4 mm. 1-4 pc's and weights.

The transition matrix below is calculated from pitch motions in mm. 111-14, and the weights above.

	G	F#	B	C	E	D#
G	0	2/5	0	0	0	3/5
F#	0	0	1	0	0	0
B	3/10	0	0	2/10	2/10	3/10
C	0	0	0	0	1	0
E	1/4	0	1/2	0	0	1/4
D#	0	0	1	0	0	0

Example 8: Ex Machina Section 4 1st order Transition Matrix.

This is the same 1st order matrix showing probabilities as decimals.

	G	F#	B	C	E	D#
G	0	.4	0	0	0	.6
F#	0	0	1	0	0	0
B	.3	0	0	.2	.2	.3
C	0	0	0	0	1	0
E	.25	0	.5	0	0	.25
D#	0	0	1	0	0	0

Example 9: Ex Machina Section 4 1st order Transition Matrix.

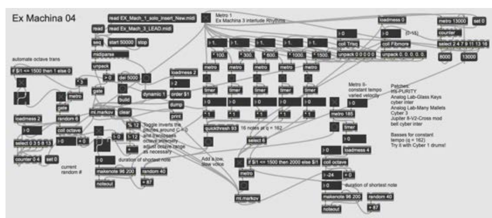
The transition matrix for this particular sample is convergent as shown below. Note that the values resemble the original weighted distribution shown in Ex. 7. The example is of the 100th order matrix.

	G	F#	B	C	E	D#
G	.14	.06	.36	.07	.14	.23
F#	.14	.06	.36	.07	.14	.23
B	.14	.06	.36	.07	.14	.23
C	.14	.06	.36	.07	.14	.23
E	.14	.06	.36	.07	.14	.23
D#	.14	.06	.36	.07	.14	.23

Example 10: Ex Machina Section 4 Convergent matrix 100th order.

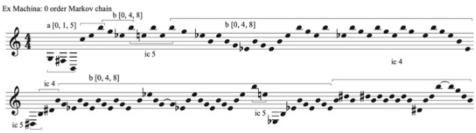
Ex Machina Section 4 Markov Chain Examples

The following musical examples were generated during a session with the Section 4 patch. Transitions for each Markov Chain are calculated by the Markov object after processing MIDI file input. Rhythms are generated by the RH side of the patch. Generated rhythms maintain a constant flow of pitches with a gradual rallentando over the course the Section 4 (ca: 4:30).



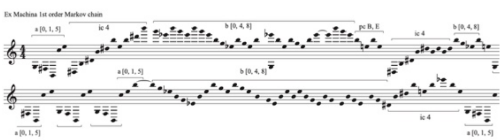
Example 11: Ex Machina Section 4 Max/MSP patch.

The 0th order Markov chain behaves as a weighted random sample of PC's from phrase A. Pc's B, D#, G, and E mirroring percent weights in the original (Ex. 7), and both *b* [0, 4, 8], and *ic* 4 occur frequently. *A* [0, 1, 5] appears only at the beginning of the example, with [F#, G, B; C, E, B] occurring once each. *Ic* 5 [B, E], a subset of *a,* occurs in the first system and as [F#, B; B, E] in the second. In these instances, neither G nor C are present to complete *a* [0, 1, 5]; the pattern in phrase A. Melodic contours in this example do not closely resemble the original.



Example 12: Ex Machina Section 4 0^{th} order Markov chain.

Example 13 shows the result of using a 1^{st} order Markov chain. *Ic* 4 and *b* [0, 4, 8] still dominate the texture, but statements of *a* [0, 1, 5] happen more frequently; at the beginning of the first and second systems and at the end of the example roughly in the same order as phrase A. Melodic contours in this example are beginning to resemble the original phrase.



Example 13: Ex Machina Section 4 1^{th} order Markov chain.

The 2^{nd} order Markov Chain mirrors the original more closely than the others. Compare Ex. 14 with Ex. 6 and *a* [0, 1, 5], *ic* 4, and *b* [0, 4, 8] all appear in their original order, and contour with few exceptions. As the 2^{nd} order chain is triggered over the course of Section 4, it maintains a close relationship with the original with distributions of *a* [0, 1, 5] occupying about 40% of the output while, *b* [0, 4, 8], and *ic* 4 occupy approximately 60%. These percentages approximate their distribution in the original solo.

Example 14: Ex Machina Section 4 2^{nd} order Markov chain.

Based on the congruence of the 2^{nd} order chain, one might assume that the 3^{rd} order chain would resemble the original even more closely, but this is not the case. In example 15, which uses a 3^{rd}-order Markov chain, more PCs are repeated, and the clear contours of the 2^{nd}-order sequence are fragmented and unrecognizable when compared to the original phrase. 3^{rd} and higher-order Markov chains will approach the probabilities of the matrix from Ex. 10, which mirrors the weighted distribution of the 0^{th}-order chain over time. In Ex Machina Section 4, the 2^{nd}-order chain was used because it generates pitch content closely resembling the original solo from Section 3.

Example 15: Ex Machina Section 4 3^{rd} order Markov chain.

Conclusions

In much of my earlier electronic music employing algorithmic processes in Max/MSP I have used varying degrees of randomness shaped by range limits, pc content, rhythmic limits, random walks, etc. In *Ex Machina*, I created a musical context in which musical events triggered by Max/MSP patches more closely mirrored the music of composed sections. The previous examples demonstrate that Markov object in Max/MSP is one way to achieve musical unity by defining content, probabilities, and the order of the Markov chain.

Notes

1. For Section 1 Rhythmic durations are: 6000 ms, 9708, ms, 15707 ms; Section 6: 5000 ms, 8090 ms, 1390 ms.
2. Nomenclature: A-phrase, At-transposed, At'-transposed and varied.

References

1. Haraway, Donna: A Cyborg Manifesto, 1985.
2. https://math.uchicago.edu/~may/REU2017/REUPapers/Freedman.pdf (p. 1, accessed 11/02/2022)
3. Unexpected solutions arising from the introduction of an out side influence. https://www.britannica.com/art/deus-ex-machina (accessed 11/2/2022)
4. http://algocomp.blogspot.com/2008/08/some-initial-thoughts-on-algorithmic.html (accessed 11/3/2022)