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The Genesis of GENDY3
The Creative Process that Led to Xenakis' *Opus Summum*

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Abstract**:** *Gendy 3 (1991) by Iannis Xenakis is the culmination of his lifelong quest for an automated (i.e. algorithmic) music. About 20 minutes of digital sound are computed direct-to-disk and presented more or less as such to the public. Therefore, Gendy 3 demonstrates the machine computability of a work of art. Officially, there is only one Gendy 3 in Xenakis' catalogue of works. However, before the world premiere of Gendy 3 on 11/17/1991 in Metz, France, Xenakis presented a proto version called GENDY301 at ICMC Montreal on 10/18/1991, which is a similar but completely different piece. Moreover, an uncut "raw" version (I call it "GENDY3") can be obtained by re-executing Xenakis' own algorithm. It contains 75 seconds more music than Gendy 3. And finally, Xenakis' algorithm also allows creating a 16-track version by generating all of its 16 layers of sound separately. These 4 versions (2 by Xenakis, 2 by the author), taken together, help to retrace the creative process that led to one of the most remarkable pieces of electroacoustic music to date.*

Keywords*: Xenakis, electroacoustic music, computer music, algorithmic composition, sound synthesis.*

1. Preface

Not much is known about the creative process that led to Xenakis' masterwork Gendy 3. We know its date of premiere (11/17/1991) but we do not know exactly when the music was computed at CEMAMu[2]. We do not know when exactly the program version that computed the music of Gendy 3 was finalized by the composer. Neither do we know exactly when the development of this computer program was started by Xenakis in the first place. What we do know is when it

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[2] It might have been two days before. See discussion below. CEMAMu = Centre d'Etude de Mathématique et Automatique Musicales or in English "Center for Mathematical and Automated Music". We might today say "Center for the Study of Mathematics and Computation in Music".

ended. Xenakis abandoned work on his program shortly after the premiere of S709 in 1994[3]. When I came to Paris in 1995, I was granted access to his working space in CEMAMu exactly because of the fact that Xenakis would not work there anymore.

If one is interested in how Gendy 3 came into being, one is left with the artifacts that survived Xenakis' death and the closing of CEMAMu in 2001. Gendy 3 is available on DAT tape from Xenakis' publishing house Salabert and on CD[4]. What is less known is that there is a proto version of Gendy 3 called GENDY301 which was produced to accompany Xenakis' paper on "More Thorough Stochastic Synthesis" at ICMC 1991, a month before, as a sort of demo (that is at least the way I see it)[5]. Fortunately, this music has survived through the organizers of ICMC 1991[6]. So we have two artifacts: a proto "demo" version, called GENDY301, and, one month later, a released work of art that found its way into the composer's catalogue of works, called Gendy 3[7]. If we compare the two, maybe we can find out how the composer worked on the last meters towards his opus summum.[8]

In addition to the music, we have printed documentation by Xenakis which is mainly the text of the computer program(s) written by him that created the music. And we have this only because in 1991, Xenakis, as an old-school programmer, printed them out on fanfold paper, annotated them in a way clearly referring to Gendy 3, and stored them on a shelf in CEMAMu[9]. I was allowed in 1995 by CEMAMu staff to photocopy these documents, along with some other printouts that I found interesting. I used this material for the preparation of my PhD ([Hoffmann2009]) and then more or less forgot about it. Only recently it occurred to me that these sheets, taken together, shed some more light onto the way Xenakis worked towards the creation of Gendy 3.

We will see that these documents help to understand how Xenakis' Automated Music was conceived, how it was operationalized, and how it evolved between Montreal and Metz. What I do not describe here is the afterlife of Xenakis'

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[3] 12/02/1994, Paris, Journées UPIC à Radio France.

[4] [Xenakis1991].

[5] GENDY301, premiered at ICMC 1991, Concert 7, Salle Pollack - Pavillon Strathcona - Université McGill, Montréal (Québec), October 18, 1991.

[6] I owe a copy of GENDY301 to James Harley. Without his donation this paper would never have been written.

[7] GENDY3, premiered at Rencontres Internationales de Musique Contemporaine, Metz, November 17, 1991.

[8] I regard Gendy 3 as Xenakis' opus summum because it is the sounding proof of his life-long research towards a computable music ("automated music" in Xenakis' words), much in analogy to computable mathematics, if I dare say so, that led to the postulation in 1936 and later to the construction of the computer in 1941/1944. See [Hoffmann2019] for a discussion.

[9] The digital program was already lost. I do not know if the original printouts still exist.

program since 1991, how he altered and extended it to compose his last[10] electroacoustic composition S709 in 1994, because it ended up being a different program producing a completely different music.

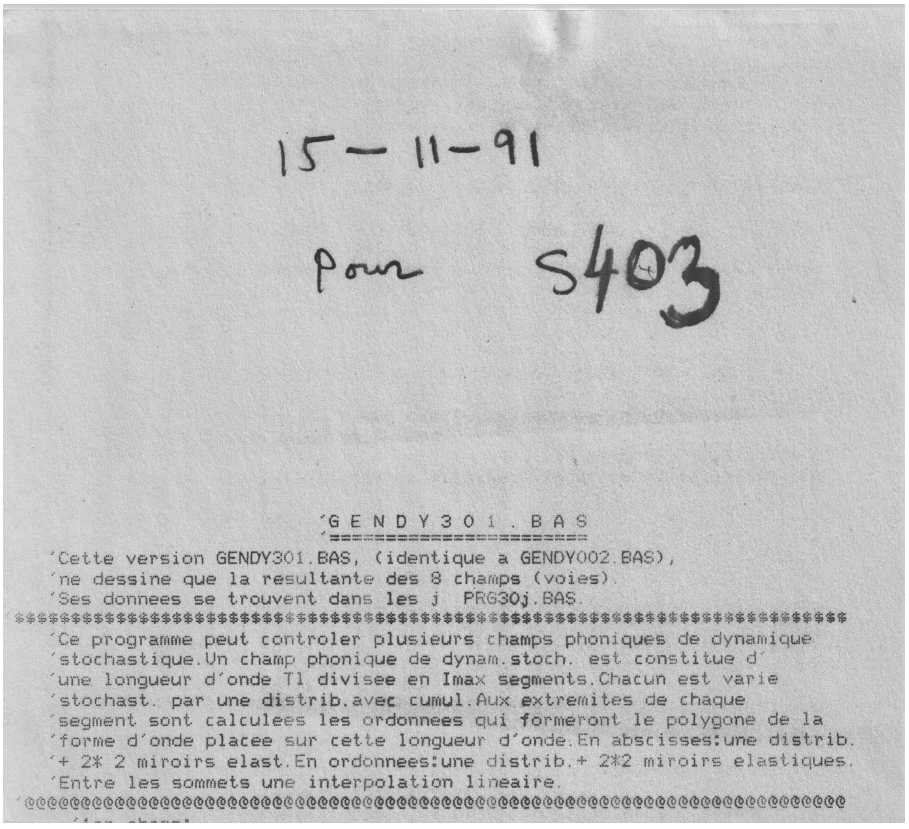

Fig. 1. *The first sheet of Xenakis' synthesis program GENDY301.BAS, in the version that created Gendy 3, with his annotation of date and output sound file name.*

2. The Programs that Computed Gendy 3

There are 12 programs that contributed to the creation of Gendy 3[11]. One program computed the two sound file(s) of the piece. This program is called GENDY301.BAS

[10] There was a commission of the Bath Festival, Erod, premiered in 1997, but it was withdrawn by Xenakis soon afterwards.

[11] For a discussion of the spelling Gendy 3 vs. GENDY3, see [Hoffmann22]. One can define GENDY3 as the raw, uncut version of Gendy 3, featuring 75 seconds of sound that Xenakis did not want us to hear.

(see figure 1). Xenakis annotated his printout by hand “15-11-91 / pour S403”. And there are 11 programs defining the 11 sections (called “sequences” by Xenakis) of Gendy 3. Each of these programs defines the onset and duration of every sound in that section (the “architecture” in Xenakis’ words). For each of up to 16 parallel sound tracks, it also defines a set of parameters that govern its stochastic dynamics, i.e. its sonic character during that section. These programs are called PARAG3i, i going from 1 to the number of sections of the piece (8 in case of GENDY301, and 11 in case of Gendy 3). Xenakis wrote on top of his PARAG printout “5-11-91 / S402 / faire la partition” (see figure 2).

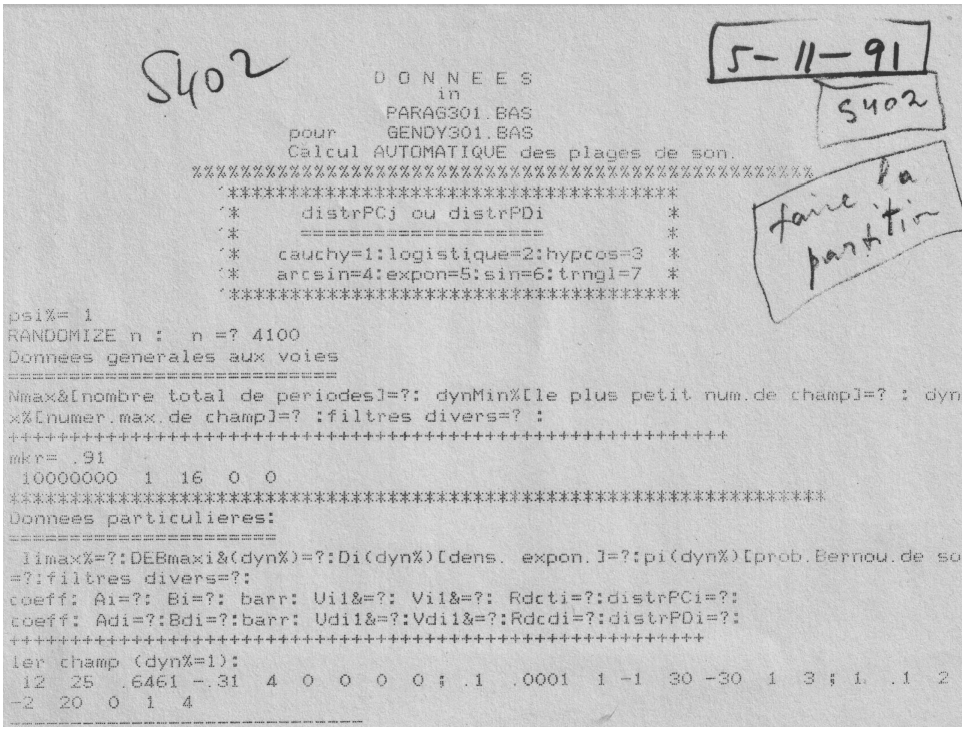

Fig. 2. *The first sheet of a printout of the 11 parameter programs PARAG301 to PARAG311, with Xenakis’ handwriting. The notated date (11/05/91) is ten days prior to the notated date of figure 1, and the sound file name is different too.*

With these programs PARAG3i, Xenakis would hard-code the parameter values of each section into program text (around 1000 lines of code each) and from there write a plethora of small binary files to disk from where they would be read by his synthesis program GENDY301.BAS. Xenakis could also, with the help of the PARAG3i.BAS programs, create a picture of the architecture of each section in a

kind of piano roll notation (only durations, no pitch[12]) on his computer screen (see figures 3 and 4). Xenakis printed the screenshots of the whole architecture of Gendy 3 on paper ("faire la partition") and on this printout, he annotated by hand "données du 5-11-91 pour GENDY3 de METZ / S403 (idem S402)"[13]. Therefore, comparing his annotations on the printouts, Xenakis prepared the parameters of GENDY3 10 days prior to synthesis.

GENDY301.BAS, on synthesis, would read the parameter files of all sections (called "sequences" by Xenakis) defined by the PARAG3i set of programs. But it would not do so in a linear way from 1 to 11. Xenakis defined a subroutine called ARCSEQ1 (probably shorthand for "architecture des sequences") with which he would determine (again hardcoded into the program) the temporal order of the sections in the piece to be synthesized[14]. By changing this temporal order, it was easy for Xenakis to re-assemble the succession of the sections in a collage-like manner[15]. Xenakis changed the succession of sections between the two pieces GENDY301 and Gendy 3, and that is the reason these two pieces are so different and at the same time sound so similar. While the ARCSEQ of Gendy 3 is documented in the printout, the ARCSEQ of GENDY301 can only be inferred by comparative listening to the recordings.

Xenakis' program GENDY301.BAS which synthesized GENDY3 in 1991 was 6064 lines of code of BASIC, a programming language usually preinstalled on a IBM compatible desktop computer since the 80s[16]. BASIC was presumable chosen by Xenakis (or suggested to him by CEMAMu staff) because it supported GOTOS and labeled statements, so that Xenakis could continue the programming style he was acquainted to since his FORTRAN programming experience of the 60s and 70s[17].

At the same time, BASIC was an interpreted language, executable line by line and easy to debug[18].

[12] For a complete graphic rendition of GENDY3 including pitch, see [Hoffmann 2009].

[13] See figure 1 in [Hoffmann2022], p 107. The raw uncut version GENDY3 can be resynthesized by executing the (reconstructed) GENDY301 program. It is a kind of re-enactment comparable to playing a pianola role of a Busoni interpretation.

[14] For GENDY301, the ARCSEQ goes 1, 2, 3, 7, 4, 5, 8, 6. For GENDY3, it goes 10, 1, 2, 9, 3, 8, 4, 5, 7, 11, 6.

[15] I have stated elsewhere [Hoffmann2019] that the function ARCSEQ is the computer implementation of Xenakis' in-time mapping of outside-time structure (i.e. the PARAG3i.BAS architectures).

[16] For Gendy 3 and S709 Xenakis used Quick BASIC Professional 4.5 because the regular BASIC would not support his need for large memory allocation.

[17] See [Grintsch2009] for a very informed discussion of programming under the condition of early computers.

[18] In his program, there are a number of STOP statements, i.e. execution breakpoints, most of them commented out which show that Xenakis would, from time to time, meticulously inspect control flow and variable values while developing and executing his program.

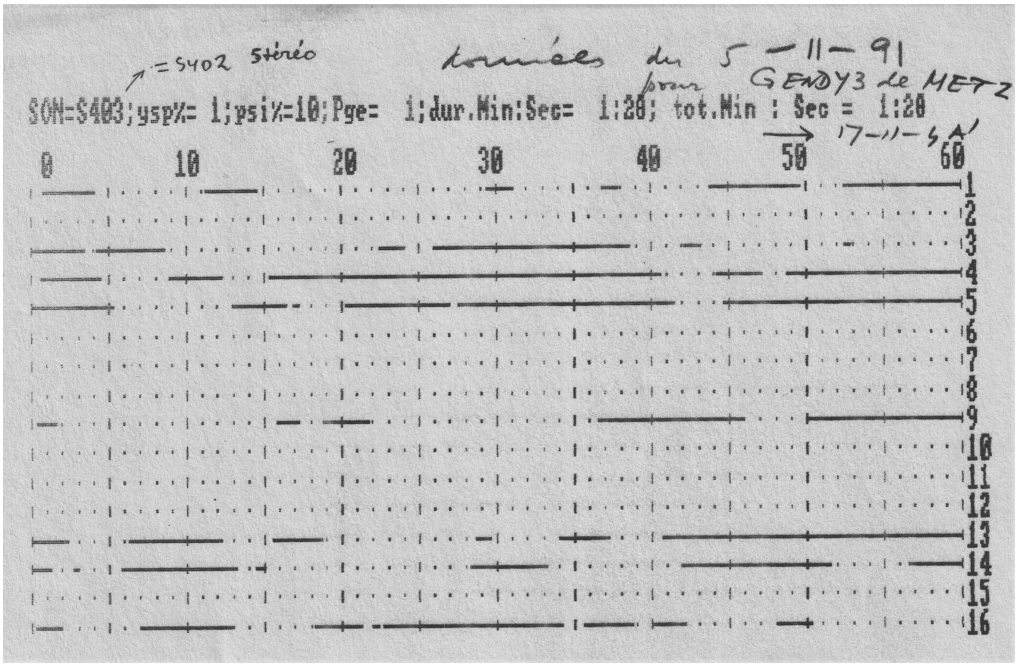

Fig. 3. *The first sheet of the full timing "score" of GENDY3 (the first 60 seconds) with Xenakis' handwritten annotation of title, date (same as in figure 2) and sound file name(s), and the date of the Metz premiere 11/17/91, the number 91 being written in Ancient Greek spelling.*

With this BASIC program, in a version that finally suited the demands of Xenakis, one month before the Metz version, he prepared his "demo" composition GENDY301 for the ICMC 1991 in Montreal. This composition bears exactly the same name as the program which computed it (which underlines, to my taste, its demo character). The composition consists of 8 sections and lasts 14'25" (i.e. only three quarters of the duration of the Metz version). In the accompanying paper to ICMC 1991, Xenakis described his oeuvre as: "an unpredictable live [...] music, being able to vary […] from the pure 'sine wave' (sic!) sound to noise"[19].

One month later, Xenakis computed with the same[20] program(s) the Metz version, called GENDY3[21].

[19] Xenakis, Iannis: "More Thorough Stochastic Music", Proc. ICMC, 1991 p. 517. Interestingly, only with the Metz version, Xenakis would compose a section of pure noise, that is, 5 parallel tracks of relentless noises lasting over several minutes.

[20] If Xenakis altered the program between the Montreal and the Metz version, it might most probably have been for the random seed number hardcoded into the program text because with the number

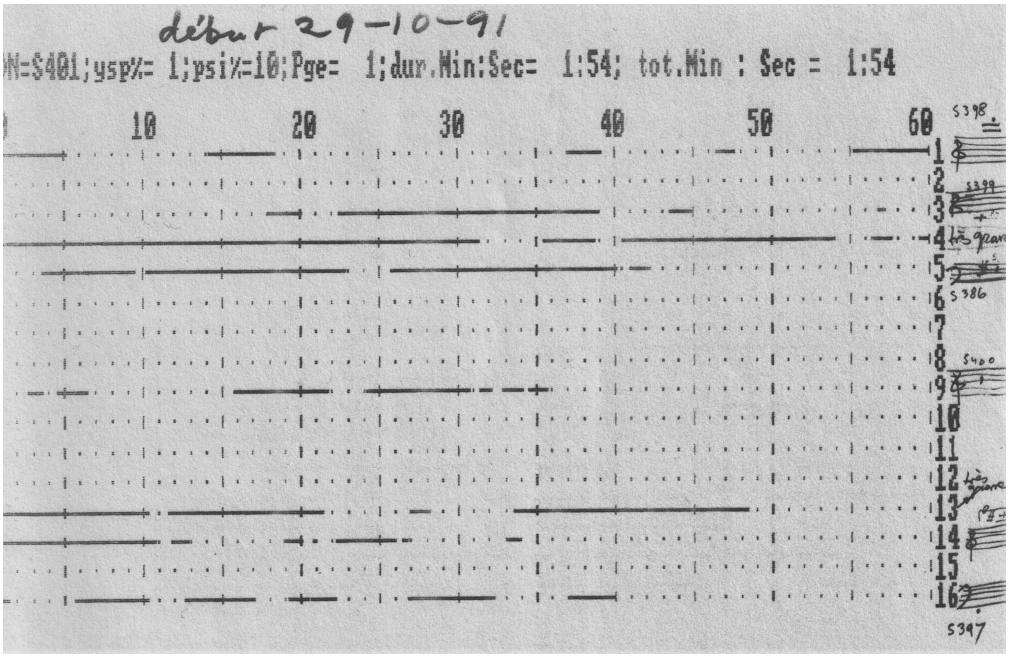

Fig. 4. *A different timing "score" of the first 60 seconds of GENDY3 in a version prior to S402, another 7 days before. Note the definition of fixed pitch on the right margin of each active track. Note the association of track 9 to sound files S400 which means that extensive pitch research immediately preceded the making of GENDY3.*

If one takes the printouts of the PARAG3i.BAS files, the GENDY301.BAS file, and the graphical architecture together, where the first two bear the annotation of "S402" and "S403" and the third "S403 (idem S402) and "pour GENDY3 de Metz" along with the date of the premiere 11/17/1991[22] (see figure 3), one is able to re-create the music of GENDY3, by just typing the program texts into a computer, execute

hardcoded into the Metz version, it is impossible to exactly recreate the music of GENDY301. Unfortunately for a computer music archaeologist like me, Xenakis liked changing this number.

[21] I use the spelling GENDY3 on Xenakis' score for the raw uncut version of Gendy 3 that I was able to reproduce using Xenakis' programs. The published version Gendy 3 is missing some 75 seconds of sound that Xenakis apparently found uninteresting or spoiling the dramaturgy of his piece.

[22] Xenakis would annotate his instrumental scores with the date of the premiere, and so he did with the computer "score" of GENDY3: "17-11-ϟA'". The glyph ϟ is no Nordic rune but the Greek minuscule letter "koppa" (from which the Latin "Q" evolved), used in the ancient Greek Milesian alphabetic number system to denote the number "90". "A" is the first (majuscule) letter of the Greek alphabet which stands for the number "1". The combination of these two stands for the year "91".

them with a QUICK BASIC Professional 4.5 interpreter running under DOS on an IBM compatible PC, and (re-) produce GENDY3 as the uncut, raw version of Gendy 3[23]. If Xenakis had documented the creation of GENDY301 the same way he documented the creation of GENDY3, one would also be able to reproduce the Montreal version GENDY301 as faithful as one is able to reproduce GENDY3[24]. However, being able to reconstruct GENDY3, one can now reconstruct a version at least very similar to GENDY301, just by reducing and re-ordering the resynthesized sections of GENDY3. Now we can see how Xenakis went from GENDY301 to GENDY3: he created three more sections and rearranged their order with the help of the ARQSEQ routine of his program. And as we see how Xenakis worked between these two pieces, we also get a feeling how he worked to get to GENDY301 in the first place.

2. Analysis of the Changes from GENDY301 to GENDY3.

GENDY301.BAS permits to synthesize the 11 sequences of GENDY3 as separate sound files (using the ARCSEQ routine). It also permits to synthesize individual sounds (Xenakis used this feature for the creation of the "solo" sound files with fixed pitch, as seen in figure 4.) So we have a clear temporal segmentation of the piece into sections which is more exact than segmentation by listening could ever be. And we have a clear horizontal separation of the up to 16 layers of sound which are more exact than any listening analysis (e. g. at the beginning of GENDY3, the attack of the starting high glissando sound is in fact the acoustic sum of three simultaneous sounds)[25].

Therefore, we can reassemble 8 out of 11 sections of GENDY3 (10, 1, 2, 9, 3, 8, 4, 5, 7, 11, 6) in a different order that corresponds to the order of GENDY301: 1, 2, 3, 7, 4, 5, 8, 6 (see figure 5).

[23] The music can be reproduced because Xenakis wrote the seed of the time random walks governing pitch into the program text of GENDY301.BAS. Otherwise, all my studies of the last 25 years would not have been possible.

[24] Maybe he did, and I was just too stupid to find it?

[25] The 16 layers of my GENDY3 resynthesis, together with a stereo mixdown and a program note, can be accessed on [Hoffmann2020]. A discussion of this project is [Hoffmann2022].

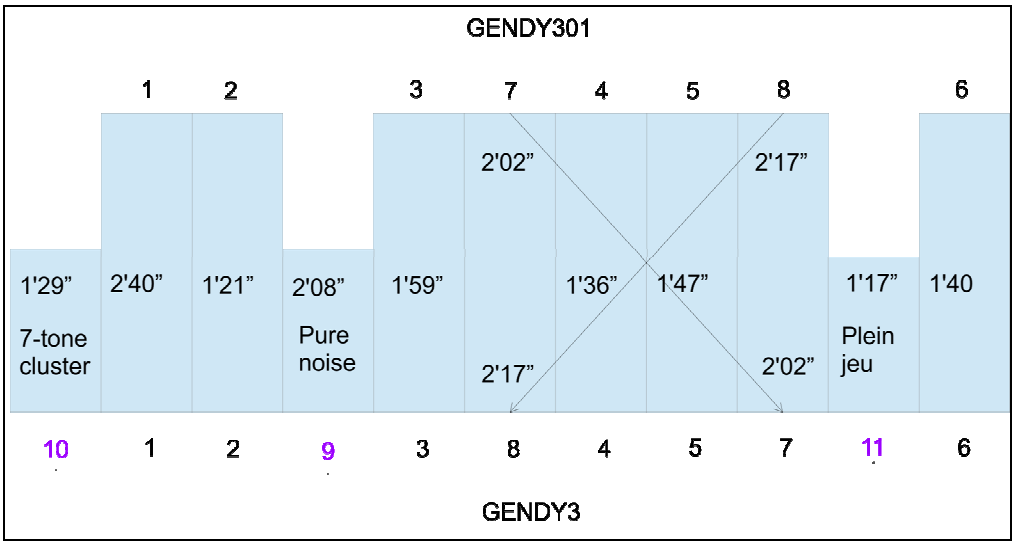

Fig. 5. *The schema of GENDY301 (upper half) and GENDY3 (lower half) and how they are derived from each other. I have added nicknames to the three new sections of GENDY3.*

If we mount the GENDY3 sections in GENDY301 order on one channel of a stereo recording, and the recording of GENDY301 on the other channel, and if we do a bit of tweaking, we can hardly tell the difference between the music on the left and the right channel. So the two pieces are more or less equal except for the number (8 vs. 11) and the order of sections. But what is the tweaking, and what does it mean "more or less?" In fact, these are the differences:

1. **The "speed".** The GENDY301 recording must be time stretched by a factor of -8.8% in order to align to the GENDY3 sections. Since -8.8% is exactly the ratio between 48kHz and 44.1 kHz sampling rate of a DAT tape recorder, I wonder if Xenakis' 44.1 kHz GENDY301 tape has by accident been transferred to 48kHz sampling rate.
2. **The timing.** Three sections of GENDY301 have a different timing than the corresponding sections of GENDY3. This means that their architecture must have been recomputed by re-executing their PARAG programs with a different random seed between the synthesis of GENDY301 and the synthesis of GENDY3 one month later. In order to equal this out, I had to insert a tiny bit of silence after the corresponding GENDY3 section in order to get both to the same length.
3. **The pitch evolution**. I have no printout of Xenakis' synthesis program GENDY301 in the version that created GENDY301. I contend that this version must be equal to the version that synthesized GENDY3 except for the seed of

the random generator governing pitch. Because everywhere where pitch is subject to randomness, it is different between GENDY3 and GENDYN301. This is only audible when pitch change is slow enough to be perceivable by the human ear (i.e. at the speed of a regular glissando). In contrast, all buzzing sounds that are created by fast pitch change are not perceived as different by the human ear even though their pitch evolution is different.

4. **Other**. In some rare cases, sounds have a different quality or are even missing either in GENDY301 or GENDY3.

To sum up, if we compare GENDY301 and GENDY3, there are three sections which sound exactly the same for the human ear (same architecture, same sounds and same pitch), two sections that sound very similar (same architecture, same sounds but diverging glissando movement) and three sections that have the same sounds but diverge in timing and pitch.

From these differences between GENDY301 and GENDY3, we can infer how Xenakis worked in the month between the premiere of GENDY301 in Montreal and the premiere of GENDY3 in Metz:

1. Xenakis created three more PARAG programs PARAG309, PARAG310 and PARAG 311. PARAG310 and PARAG 311 have the same sounds but in PARAG310 part of the sounds are muted (see figure 7). Xenakis changed the ARCHSEQ function of his program by inserting the three new sections and exchanging two of the others (see figure 5).
2. Xenakis changed the random seed number from (unfortunately) unknown to 510.
3. Xenakis computed different time architecture for three sections by re-executing PARAG304, Parag305 and PARAG308.
4. Xenakis generated about 20 sound files with solo sounds in order to study their musical properties (e.g. fixed pitch). He produced several sheets of paper with indications of correspondences between sound synthesis parameters, sound file names and notated musical pitch. He also tried to follow the genealogy between specific sound files (e.g. “S398 de S381”; “S399 de S383”; “S400 de S390”) where he might have tried to improve parameter settings (see figure 6). The change from S390 to S400 is a good example: by this change, according to his account, of his parameter “rallonge” from 4 to 6, he changed the resulting pitch from f5 to b4. But Xenakis did not only research pitch but also timbre: other sounds in figure 6 are annotated “bruit blanc aigu” and “bruit blanc coloré basse”, or “aigu oiseau”. The last sound file of these experiments is S400. Since S401 is already the sound file of a first program run for GENDY3, the experiments by Xenakis concerning the calibration of the pitch cluster of the opening section of GENDY3 are the last thing he did before the release of this piece.

5.

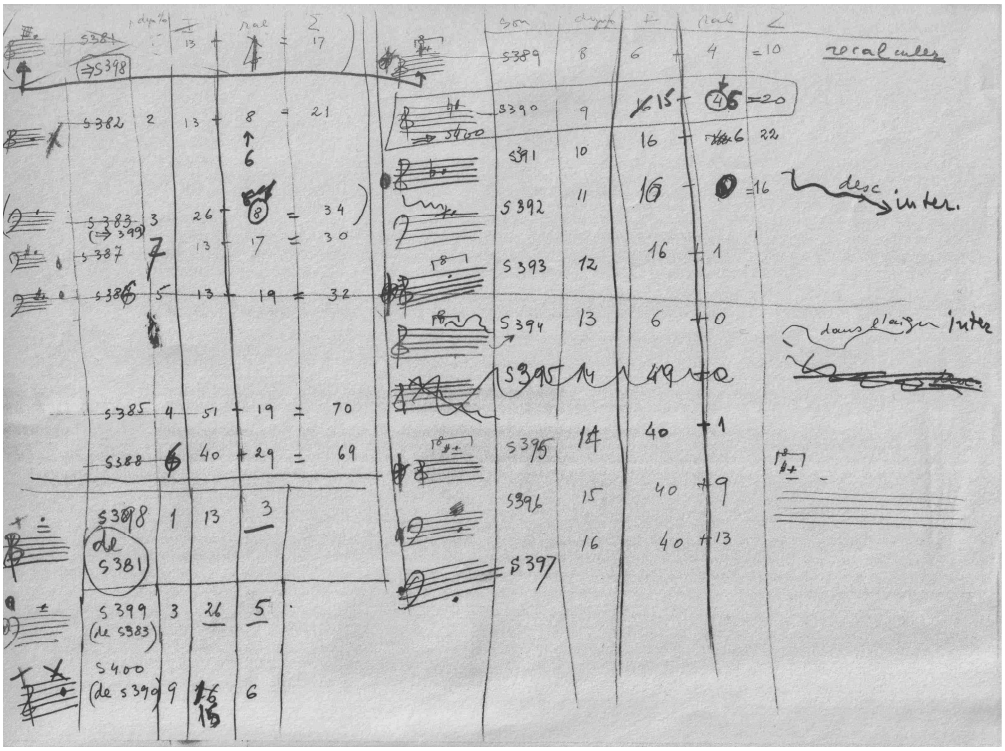

Fig. 6. *Another sheet with Xenakis' pitch studies for the opening section of GENDY3. Note the indications of sound genealogy (e.g. "S400 (de S390)") which indicate that Xenakis repeatedly changed parameters and re-listened to the resulting sound file.*

6. Finally, Xenakis created a first version of GENDY3 with sound file S401 (see figure 4), then he changed at least the time architecture of the opening section PARAG310 and then, with this new and final architecture, he created sound files S402 and S403. We see this by comparing the two "score" sheets of the first minute of GENDY3 (figures 3 and 4), one with indication S401 (figure 4) and one with indication S403=S402 (figure 3). The time structure is very different between these two. Only the latter has been realized in the published version of GENDY3.

From these observations we can infer how Xenakis approached a GENDY composition in general.

3. The Procedure Leading to Gendy 3

For Gendy 3, GENDY301.BAS produced a musical piece of around 20 minutes in one go, writing over 100 MB of mono 16-bit samples into a sound file. called “S402”. Then, Xenakis started the program again, creating a second sound file “S403”[26]. Xenakis listened to the result with the help of a huge D/A converter box sitting in his working place at CEMAMu, a custom hardware that had been built by CNET, the institution that housed CEMAMu from 1972[27], because Xenakis’ computer had no sound card[28].

The two sound files S402 and S403 were then combined to a stereo sound file with a pseudo stereo effect of a 100 ms delay. There was no other post-processing except some cuts.[29] I do not know when and where and with whom these cuts were made[30]. The existence of these cuts become obvious when one combines one channel of GENDY3 and one channel of Gendy 3 in an audio editor and tries to align the two by listening to the stereo result.

To resume, the stages of the creative process leading to Gendy 3 are:

1. Xenakis first created a number of parameter-generating programs PARAG that would define the number of sound tracks, the number of sonic patches and from a given density, the distribution of these sonic patches across the sound tracks, much in the same logic as with the ST-program 30 years before.
2. Xenakis created a version of his synthesis program that would satisfy his aesthetic needs, i.e. produce sonic output which was structurally rich enough to fulfill his requirement of being “interesting”.

[26] This is because Xenakis noted “S402” and “S403” on his printouts and it is because with the printout versions of his programs, one can reproduce these two sound files and see that the Gendy 3 recording is a combination of these two files, with 75” missing.

[27] CNET=Centre national d'études des télécommunications. The D/A converter box was about double the size of Xenakis' desktop PC.

[28] Xenakis' computer at CEMAMu was a DX-2-486 66MHz IBM compatible tower. He had no other computing machinery except his programmable pocket calculator (see [Varga1996], p.), so he could only listen to his music at his working place in CEMAMu.

[29] I described the cuts in [Hoffman2022] as some short cuts where the musical texture thins out towards the end of sections, some cuts I cannot explain the reason for, and a big cut of approx. 40 seconds in the noise section.

[30] Cuts in the later piece S709 were made with the help of Gérard Pape in the computer music studio “Les Ateliers UPIC” in Alfortville near Paris. Here, following the oral testimonial of Gérard Pape in 1997, Xenakis only demanded the suppression of general pauses, i.e. where pauses would coincide in all 8 tracks.

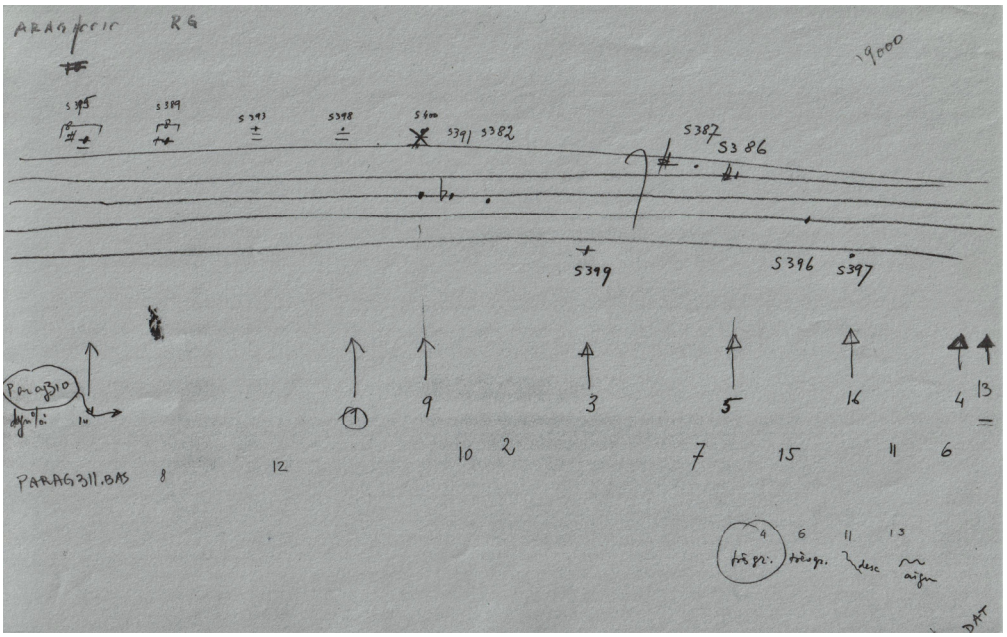

Fig. 7. *Yet another sheet by the hands of Xenakis showing the 7-pitch cluster of the opening section of GENDY3 (PARAG310, with arrows) and its completion to a 14-pitch cluster in the before-last section of GENDY3 (PARAG311). Tracks 11 and 13 have glissando pitch, as noted in the lower right corner of the sheet.*

3. After creating a suitable number of PARAG programs and turning them into sound with the help of his synthesis program, Xenakis decided upon the temporal order of these sections by defining a mapping from (outside time) section number to (temporal) index.
4. Xenakis tried to find the best synthesis parameters to obtain sounds and sound combinations that he would deem desirable. This might pertain to configurations of stable pitch, different qualities of noise (coloré, blanc, aigu…, see e.g. figure 8), dynamics of glissando movement (e.g. stepwise or smooth), etc.

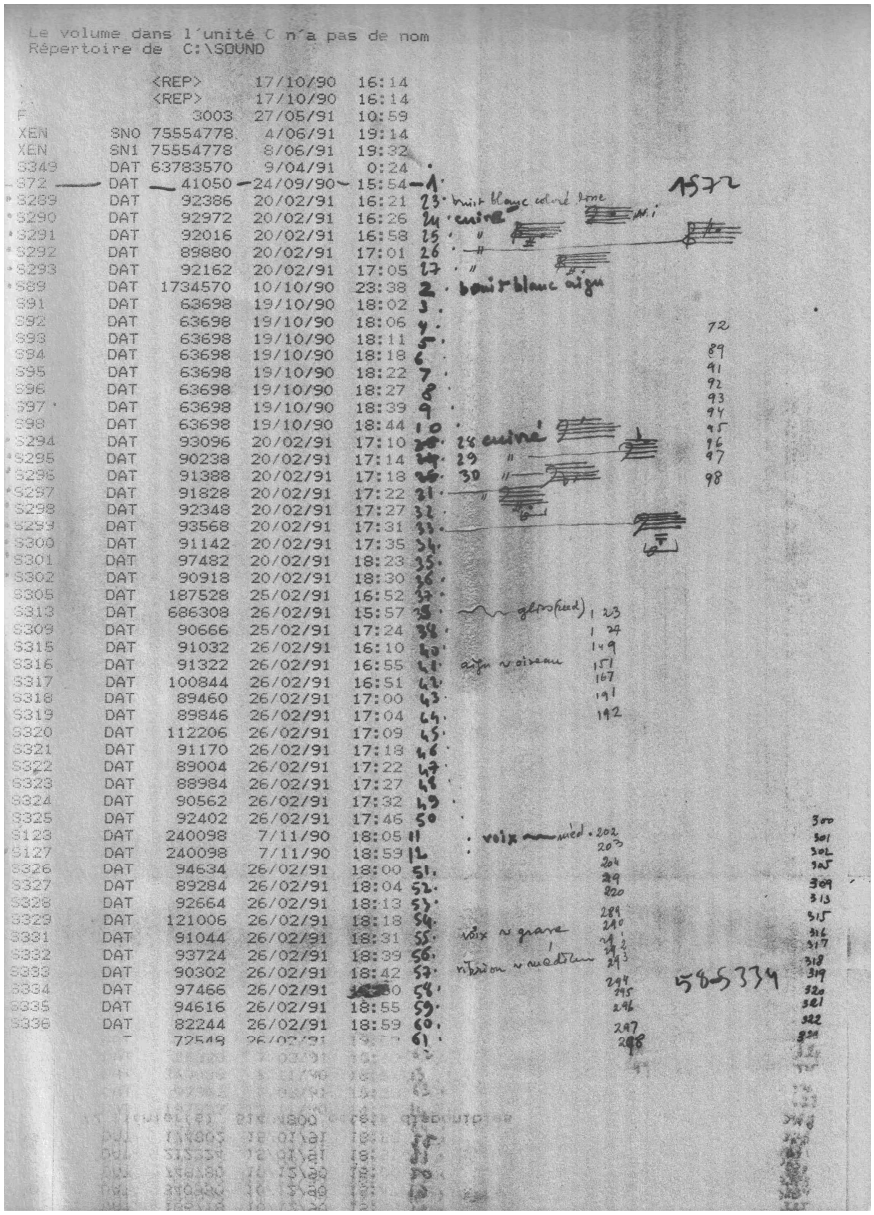

Fig. 8. *A screenshot by Xenakis of a DOS file listing of sound files produced by GENDY301.BAS on his PC computer. Note the different file sizes (entire pieces or just short sound takes). Also note Xenakis' endeavor to systematize order, pitch and timbral properties ("oiseau", "cuivré", "bruit blanc aigu", "bruit blanc coloré lisse").*

5. Xenakis changed the random number seed hardcoded into his synthesis program. We see seed numbers like 401[31] or 510 (this is the seed used for GENDY3). These are only the documented seed numbers; we may assume that Xenakis used many more. In the flow chart of his Stochastic Synthesis algorithm, he mentions the change of random numbers as an important step of composition.[32] Interestingly, the random seed numbers in the PARAG programs are chosen in a systematic way that suggests they were probably never changed because they are incremented in steps of 100: PARAG301 had 4100, PARAG301 4200 up to PARAG311 which had 5100.
6. Finally, Xenakis combined two sound files of two subsequent program runs into a stereo file and applied minor edits to it (pseudo stereo delay and minor cuts).

4. Final remarks

From the three sections composed between GENDY301 and GENDY3, I have so far discussed PARAG310 ("7-tone-cluster") and PARAG11 ("plein jeu"), sharing the same subset of pitches, but not yet PARAG309 ("pure noise"). This last one has the least number of active sonic tracks (only 5) of all GENDY3 sections, but since these are given maximum stochastic freedom (no pitch fixation, far-spreading "logistic" distribution) they all yield brutal noises. Xenakis must have composed this section in the 2nd half of October 1991, because, on the one hand, its ordinal number 9 precedes section number 10 (marked "debut 29-10-91)", and on the other hand, if he had composed PARAG309 before mid-October, he would certainly have included it in his demo GENDY301. I find it interesting that after the realization of this "pure noise", which for Xenakis was the richest sound[33], and which is somehow the sonic climax of GENDY3, he concentrated more or less on the study of pure pitch, which is musically and physically the exact opposite to noise.

How did Xenakis decide upon the pitches of his stable sounds? It would have been easy just to apply the simple formula "sampling rate divided by wavelength" (in Xenakis' case 44100 / Imax * rall, see table below) and then to lookup the

[31] see [Solomos2022], p. 289. Facsimile of a former program version of GENDY301.BAS called GENDY1, which was used by Xenakis to create the pitch contour of the solo violin in his concerto composition Dokh Orkh.

[32] "For many-channel stereo (sic!) music: a. compute from the start the same main programme as many times as there are channels b. use separate random-generator for each channel for the amplitudes and/or the abscissa." [Xenakis1992], p. 298.

[33] "A noise […] is too rich for the ear, we can't perceive it as repetition, so, because our ear is nothing but a periodicity-counter, we put it in the noise domain." [Varga1996], p.91.

resulting musical pitch in the internet, or write a small program to convert Hertz to musical pitch (like I did in [Hoffmann2009]). If we do this, we get for the 7-tone cluster, from high to low, the following non-temperated pitches (a4=440Hz assumed, see Table 1):

No. of track	No. of breakpoint segments ("Imax")	Segment length ("rall.")	Frequency (44100/ Imax*rall.)	Internet lookup[34] or formula	Xenakis' notation
12	16	1	2.756,25	F7 -23 cents	E6 (sic!)
8	6	4	1.837,500	A#6 -25 cents	A+6
1	13	3	1.130,769	C#6 +34 cents	D6
14	40	1	1.102,500	C#6 -10 cents	C#7 (sic!)
9	15	6	490,000	B4 -14 cents	B4
10	16	6	459,375	A#4 -25 cents	A#4
2	13	8	424,038	G#4 +36 cents	A4
3	26	5	339,231	E4 +50 cents	C4 (sic!)
7	13	17	199,548	G3 +31 cents	G#3
5	13	19	178,543	F3 +39 cents	F#3
15	40	9	122,500	B2 -14 cents	B2
16	40	13	84,808	E2 +50 cents	F2
4	51	19	45,510	F#1 -28 cents	"très grave"
6	40	29	38,017	D#1 -39 cents	"très grave"

Table 1. *An overview of the 14 fixed pitches of sequence 11 (before-last section of GENDY3). 7 of these form the opening cluster of sequence 10 (first section of GENDY3).*

If we compare the pitches calculated by formula and Xenakis' pitches (see the two rightmost columns of the table), we get the impression that Xenakis did not derive his pitches by using a formula at all. For example, he does not give a note for the two low pitches. That would have been as easy as for any other note when using a formula. Also, he indicates wrong octaves for some of the high notes. As for the pitch names, his notation is between 10 and 70 cents higher than the calculated pitch (i.e. up to a bit more than a quarter tone deviation), except for the two highest notes where his estimation is lower than the calculated pitch. In any case, these deviations are not consistent, so I am led to the conclusion that Xenakis' pitches are the result of simply listening to the sound files generated for that purpose (and maybe comparison to a reference pitch, e.g. with the help of a pitch

[34] e.g. https://www.flutopedia.com/pitch_to_frequency.htm

fork). It is curious that Xenakis, as a mathematically inclined composer, did not seem to use even a simple formula but preferred to guess the pitches instead. It is even more astonishing that he came quite near to the mathematically exact pitch. Only for track no. 3, his guess is wrong by a major third.

An explanation for this fact might be that Xenakis, in another sketch (figure 6), computed the sum of Imax and rall. instead of the product. This misconception might explain the name "rall." ("rallonge") which is the French word for "extension". That means that Xenakis failed to understand (at least in the sketch) the wavelength as a product of the number of its breakpoints (=Imax) and their spacings (=rall.) and therefore had no concept for the correct formula. At the same time, this is hard to believe because Xenakis does describe the wavelength as the product of breakpoints and their spacings in Formalized Music[35]. Maybe Xenakis, in his programming, had originally used his parameter "rallonge" as an extension of breakpoint spacings, later changed his programming using "rallonge" for the spacings proper but kept on theorizing on "rallonge" as an extension?

5. Conclusion

We have seen that with the help of a re-enactment of Xenakis' fully computerized compositional procedure that led to GENDY3, one is able to infer the pathway of the composer that led from the first essays (a postulated sound file "S001") up to the release of his masterwork Gendy 3 in 1991 (a combination of sound files "S402" and "S403"). If Xenakis had not printed on paper the program versions of his 12 computer programs used for Gendy 3, only the music would have survived from his lifetime project of an Automated Art, without any chance for posteriority to appreciate its creative process.

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[35] See [Xenakis1992], p. 289, where he implicitly gives the formula 44100 / 12 *1 for Imax=12 and rall=1.

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