Searching for lost data: outlines of aesthesic–poietic analysis*

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Fifty years down the line, the analysis of computer music is still a very complex issue, highly dependent on the identity of computer music itself: the variety of software, the lack of a common musical notation for scores, the absence or presence of computer data. This has led to the emergence of a multitude of analytical methods, including *aesthesical* analysis, which approaches music from the point of view of perception, and *poietical* analysis, which pays attention to the creative process.

This study aims to combine these two methods of analysis in order to understand the relationship between technology and the actual piece of music. The article presents a methodological approach – focused on six pieces produced at IRCAM in Paris and at CSC in Padua, between 1975 and 1985 – via an in-depth consideration of Mauro Graziani's *Winter leaves*, a work conceived in 1980 at the CSC using Music360. The method used consists of comparing data collected using a diversity of practices: repeated listening, the tracing of graphical schematics, sonogram and spectrogram analysis, data listing analysis. An algorithm has also been created in order to calculate the degree to which the software is exploited and to enable a comparison between the different analyses. It is hoped that this procedure will combine traditional musicological methods with new approaches suited to the medium and grounded in a thorough knowledge of computer technology and musical environments.

1. INTRODUCTION

The most interesting aspect in the development of digital musical instruments is not the fact that new instruments have been created alongside acoustic instruments, but the fact that an instrument has been created which is able to define its own instruments (Vidolin 1988: 54). The computer is a 'limitless' instrument; its programs enable several possible approaches to be taken. A composer can, for example, be attracted by the palette of sounds and concept tools, or by the possibility of considering them as an alternative to the player, their technical principles being reduced to an aesthetical value (acoustics, instrumental multiplication to demonstrate the capacities of language). A composer can also be drawn to the computer's ability to formalise the compositional processes. This limitlessness, combined with the complete freedom involved in artistic creation, tends to be canalised rather precisely by the composer who, from the conception of a work, has to know the principal characteristics of all the instruments he wants to use. Concerning this matter, Max Mathews writes that sounds 'produced by conventional instruments are so well known that composers can proceed with the intuitions they have developed from long experience. However, such intuitions exist for new sounds' (Mathews 1969: 173). As such, the assimilation of the computer's possibilities is a fundamental phase. First of all, the composer must understand the relation between the physical sound produced and its perceived effect. Marie-Elisabeth Duchez describes this conceptual revolution by saying that 'the control of electronic computer material, a new relation between men and the world of sounds, requires from the composer, a new ear, a new way of thinking to enable this new relation to be assimilated, as well as a new language and new concepts of analysis. All objectified by new categories and even legitimised by a new notation' (Duchez 1991: 54).

Since the late 1950s, the revolution in computer music has drastically changed the main poles around which a musical work is developed. Those poles are: sonic matter, notation – that is, the use of symbolic and operational means having no longer anything to do with either intuitive musical representations – and form, that is developed in strict relation with new timbres.[1] It can be noted then, that the musicological study of computer music coincides with the study of this hybrid world – where technology and art work alongside each other. The analysis of the effects of this

*This article presents some reflections taken from the doctoral thesis, *Science and Technology as Sources of Inspiration at the CSC in Padova and IRCAM in Paris*, in joint guardianship with Sciences of Music (University of Trento, Italy: Prof. Rossana Dalmonte) and Musicology of the XX century (University of the Sorbonne, Paris IV: Prof. Marc Battier), presented in public on 12 November 2003.

[1]As the synthesis programs demand that the attention of the composer has to be completely devoted to the dimension of sound generation, in digital historical works the formal aspect often has a second dimension. That is why several works are built on a sound object that forms its genetic code. In this case, the shape of the work is the organic dilatation of this code. However, the repertory also shows works based on traditional formal conceptions derived from serialism, the golden section, etc.

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union must examine the relations that exist between machine and music, as well as between the program, which is used to produce the sounds or structures, and the work itself. Both the sonic result and its method of production must be studied whilst also taking into consideration the constellation of musical computer works. This process is determined by compositional choices, the work environment, the choice of computer programs, the study of its possibilities and the compilation of the instructions. As Marc Battier explains, 'the environment of a work is [. . .] not just a subsection of a network of tools, gathered together for a unique occasion: it cannot be reduced to the juxtaposition or the assembly of tools. It's born of a voluntary and active action that groups, re-cuts and condenses various poles, concepts, materials or software; the environment is a condensation of these poles in one network' (Battier 1992: 217).

2. THE CSC IN PADOVA AND THE IRCAM IN PARIS

In terms of computer composition, art and technology interact in order to achieve an equilibrium between computer language and musical language. In order to investigate this relation, some samples have been chosen from the universe of digital artistic production for which common elements can be compared. Musical productions by the CSC (Centro di Sonologia Computazionale dell'Università di Padova) and by the IRCAM (Institut de recherche et coordination acoustique/musique) in Paris between 1975 and 1985 have been studied.

Having initiated their respective research in the same period (early 1970s), these two centres have become two of the principal references for the international computer music community. As for research and musical production, they were both interested at this time by the idea of digital synthesis, the employment of software originating from university centres in the United States (such as the program MUSIC), research into the voice and instrumental sounds (spectral analysis) and, more generally, inter-disciplinarity. In other words, they were both looking to attach similar importance to research and to production, as well as to developing an enriching exchange between these two domains. From an administrative point of view, the centre in Padova is part of a university structure (Durante and Zattra 2002). As such, it is similar in many ways to US computer music centres. Nearly all of its researchers are part of the teaching staff and their first results are published thanks to the presence, in the team, of an established professor (Giovanni Battista Debiasi). Initially, however, unlike the US centres, the Italian centre was not officially recognised as being part of the university structure. This status was not delivered until 1979, and influenced greatly the development of the first projects. In reality, research is made possible thanks to the administrative centre of the University (CCA – Centro di Calcolo di Ateneo), which provides researchers with machine time and space. However, the computers remain, first and foremost, the property of the university and have to be used for administrative activities. Even if musical research relies on temporal and memory limits, the initial non-formalisation offered great freedom to researchers who were able to devote time to their personal interests. IRCAM, on the other hand, was created as part of a cultural structure (Centre Pompidou) and has nothing in common with a university structure. It was constructed around its director, Pierre Boulez, who as a composer-theorist imposed a different way of working.

The most productive way of studying the fruit born of technology and art's interaction within these two centres (in other words an investigation into the reconciliation of musical aspiration and software potential/limitation whilst retaining a sonically organic result) is via a musicological analysis of six works, chosen from the repertory produced in Padova and Paris.[2] The scientific and musical community considers the 1970s and the first half of the 1980s to be two periods characterised by intense activity in terms of the investigation, the discovery and the exploitation of increasingly solid synthesis techniques. As such, the works considered can be seen as representing the arrival of this pioneering period, before the era of real-time technology.

However, difficulties have always arisen in the analysis of computer music due to the difficultly of judging computer data, which is hard for non-specialists to understand. Consider Jean Molino's famous semiologic tripartite, reinterpreted by Jean-Jacques Nattiez, which looks at the work of humans, in accordance with the three modes of existence of the object: its neutral level, its reception capacities (aesthesic level) and its production controls (poietic level) (Nattiez 1989, Molino 1991). The last two categories include the vast domain of difficulties in perception and in the analysis of productive processes. If it is difficult to indicate the neutral level of computer music, it is nevertheless possible to analyse the methods of listening to, and the production processes

[2]Six works have been chosen to be analysed (from among fifty-seven created at the CSC and seventy-eight at IRCAM between 1976 and 1985) which used MUSIC software in different versions. For Padova we studied the works of Mauro Graziani, *Winter leaves*, 1980 (Music360), Wolfgang Motz, *Sotto pressione* for two oboes and tape, 1982 (Music5), and Fausto Razzi, *Progetto secondo*, 1980 (Music5); for Paris we analysed the pieces of Jonathan Harvey, *Mortuos plango, vivos voco*, 1980 (Music5, Chant), York Höller, *Résonance* for ensemble and tape, 1980 (Music10), and Jean-Claude Risset, *Inharmonique* for voice and tape, 1977 (Music5). In addition to the synthesis MUSIC programs, differed time is the second characteristic that relates the works (except for a small part of the work of Höller created during a concert with the help of a 4A processor).

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of a work. This is why we have chosen to define an analytical approach, taking into account both the aesthesic and poietic approaches. Despite both approaches being incomplete in themselves, their association can enrich the personal vision that the analyst builds when listening to computer music thanks to the objectivity of sonogram representations and, above all, to the profound knowledge of computer data used for the creation of sound objects.

3. AESTHESIC–POIETIC ANALYSIS

Since the *Traité des objets musicaux* (Schaeffer 1963), several studies have been published emphasising the difficulties of analysing electroacoustic music, the causes and the consequent choice to approach this music from the point of view of the auditor. Among those works, approaches can be found which try to categorise objectively sound objects (Smalley 1986, 1991) or their relations (Emmerson 1986a), as well as those which favour individual/subjective listening (Delalande 1972, 1986, 2001; Imberty 1995, 2001) by looking for structural connections based on the results of the auditor. A small number of studies tried to analyse this music based on its representation in the time/frequency domain (Cogan 1984), but the results are still at a primitive stage because of the difficulty of locating sound objects in this type of representation.[3]

This type of approach – so-called aesthesic – affirms that electroacoustic music does not have, and probably never will have, a neutral level, a musical text with a strict connection between its graphical representation and its sound text. So, the auditor becomes the only element of the musical electroacoustic phenomenon that it is possible to study. It is no coincidence that several musicologists who have founded their analysis strategy on listening are composers themselves. Having direct experience, they neglect the creation phase of the work and deny the possibility of starting an analysis from computer data, saying that the object of analysis is music without a score. Maybe this is justified by their conviction of the superiority of timbre, the sound *material*, which does not exist before the creative act and, as an object which is deliberately projected, dematerialises itself and has simply to be perceived (Duchez 1991).

As well as its advantages, such an aesthesic approach also has its downfalls. That is why lately some musicologists have considered poietic analysis (Di Scipio 1995a), constructing their study of the compositional process on an examination of digital data, on the composer's rough sketches, on preparatory schemas and various other documents related to the compositional phase. It is a method which points towards the development of a link with the sound image. This differs from the analysis of a traditional score, in which symbolic data is more important than the sonic result.

After such reflections, we contemplated the fact that in computer music there is incontestably a text, which exists: the score of computer data. Consequently, 'it's not possible to avoid the understanding of instruments, which makes it possible for an artist to mediate between his interior and exterior world' (Di Scipio 1995a: 34). Di Scipio has defined the negation of these aspects as a lack of an ethno-musicological conscience (Di Scipio 1995b). The conviction that both the aesthesic and poietic approaches can each offer important and complementary knowledge has led to the need to think of them equally, and to use them in an analytical method, defined here as aesthesic–poietic analysis. Using this method we would like to enrich the personal analytical vision received when listening to computer music with an objectivity (depending on criteria of visualisation) of time/amplitude representation and sonograms and through a profound knowledge of the computer data used for the creation of sound objects. It is a method which takes us from a subjective approach to an objective study (remembering that interpretations are all inherently subjective) of effect-producing tools.

The analysis of a work will adhere to the schema given in figure 1. Once completed, the analysis does not provide us with any definitive analytical conclusions about the work, but acts as a learning process which improves our understanding of the work as the analysis progresses. It is the development of knowledge *in progress* which starts with a naïve listening and ends with the analysis of digital data. It is a process made of sound suggestions, of fragmented sound objects, of research into specific characteristics, of confirmed reflections concerning the composition or decomposition of a work, which eventually lead to the confirmation or denial of the results obtained throughout the different stages of the study.

3.1. Analytical obstacles: lost data

It is obvious that different degrees of expansion are possible regarding this method, depending on the analyst's competences and, above all, on the quantity of the available documentation. Given the importance of the two centres considered in this study, we were initially confident that extensive archives would be available and that both computer scores and other

[3]This direction of research could benefit from the current and future results of *auditory scene analysis*, i.e. a number of works that, over fifty years (since the first research on the voice) of study have tried to formalise for the computer what the perceptive human system does automatically: perceptive separation, identification of sound sources, interpretation.

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Figure 1. Aesthesic–poietic analysis.[4]

diverse material around the works would be at hand. Unfortunately, this was not exactly the case. In Padova, it was possible to find an assortment of material on paper and tape, but the archives were not kept methodically nor catalogued, but rather left to chance. It is the composers and founders who have kept hold of the copies of the computer scores, which enable the complete analysis and the creation of a methodology. At IRCAM, on the other hand, documentation of past works is extremely heterogeneous and incomplete. Completed analyses, such as *Inharmonique* by Jean-Claude Risset (Lorrain 1980) and *Mortuos plango vivos voco* by Jonathan Harvey (Bossis 2001, 2003) can be found, but outside this detailed documentation of research activity in *Rapports d'activité*, there was very little documentation concerning the processes of musical production. Even the computer scores have been lost.

Thus, what seems fundamental to the study of this type of music is the recuperation of the different material used during the creation of a work: most importantly, computer scores, but also rough sketches, different recordings, published articles, etc. The international community is starting to pay attention to this type of activity, but it is still at a very primitive stage. An excellent example of the preservation and complete distribution of material used for the creation of an electroacoustic work – which could become a model for editorial publications of this type of music – is *Perseo e Andromeda* by Salvatore Sciarrino, a lyrical piece for four voices and real-time sound synthesis, produced in 1989 at the CSC in Padova. The edition, under the auspices of Ricordi (Sciarrino 1992), includes the traditional score for four voices along with tape, as well as the complete computer score made using Music5. It should be pointed out that the synthetic sounds have been written in traditional notation by indicating the approximate intonation possible for objects made with white filtered noise.

Publishing of such kind ensures the conservation of data which is not only finalised for possible analytical work but also for future performances of the work using new software (transcriptions). One cannot deny here that *Perseo e Andromeda*'s case is rare. A commission, which involves months of work within a centre, performances and the publication of a score 214 pages long, is the exception rather than the rule. Still, the conservation of a complete file for each work performed, as well as the recuperation of past work's material is an indispensable part of the work computer music centres should be doing.

[4] After the presentation of a general framework which includes work and composer and which is necessary to create the context and an inventory of available material, analysis through listening starts the trajectory of knowledge. It is divided in two phases. During familiarisation listening (term taken from Imberty 2001: 527), the work is heard in its entirety without stopping the recording. We note successively the impressions we receive (description of the sound objects, which are the most meaningful, dynamic, timbre, annotations on shape, etc.) knowing that musical perception of this type of music follows the gestaltic criterion 'figure-background'. After this phase we define categorisation criteria of objects and parameters to identify changes of the sound flux. In the next step we create the graphical score. At this stage a reiterated listening is allowed. The program CoolEdit Pro 1.2 is used for the analysis of time/amplitude and time/frequency representations in order to study the objective representation of the acoustic flux. At this stage it is possible to make a comparison between the results that were obtained with the aesthesic analysis. The poietic approach aims to understand the process of computer creation. It envisages the apprenticeship of the software used in the manual at that time, the study of instructions, and the reconstruction, if possible, of the instruments used with Csound software. The translation of the instruments by using a current program, conceived according to the same logic as the music software which was used at CSC and IRCAM during the relevant period, offers a profound knowledge of the instrument timbre. If reading of the computer score does not allow a full understanding of the creation of the work, one can read the articles about the creation of the work or ask the composer himself ('voice of the composer').

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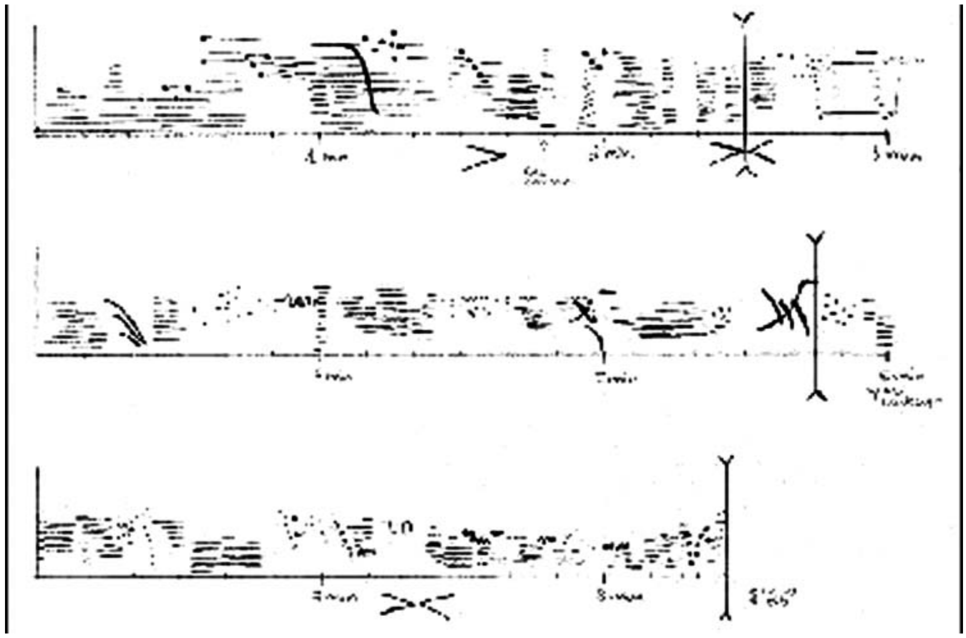

Figure 2. *Winter leaves*: graphical score.

3.2. Example of method application: *Winter leaves* by Mauro Graziani

Winter leaves (EDIPAN PRC S20-16, 1984) is a piece for tape, created in 1980 by Mauro Graziani at the CSC in Padova using Music360 software.[5] Thanks to the richness of available documentation, we were able to analyse the piece, respecting all the steps of the method.[6] When listening to *Winter leaves*, we have the impression of hearing a flux of sound objects (layers, beats, glissando) which change slowly and transform themselves into one another. This causes problems when one wants to make a graphical score. The piece can be divided into three parts: a first part in which « chords » are slowly transforming themselves, a second more complex part, which is made up of short sound objects, and a last part in which the chords seem to reappear, enriched by short objects. The following objects and criteria are considered to be important: (i) sound quality, based on the presence of noise or purified sound (noise is rare; one can hear more often harmonic or enharmonic sounds); (ii) the attack of the objects: soft or percussive (no object is ‘natural’); (iii) the continuity of sound layers which change slowly; (iv) the approximate pitch (sharp, medium, low); and (v) silence.

A time/amplitude representation of the work (made using CoolEdit Pro 1.2) reveals a very rich texture in terms of musical dynamics. Signals passing from silence to 10,000 or 20,000 can be seen almost

[5] *Winter leaves* (premiere in Milan on 11 April 1980) was played, among others, in Rome (5 November 1980, *Musica Verticale*), New York (13 November 1980, *International Computer Music Conference*), Paris (19 February 1980, *Ircam ‘composer and computer’*) and Toronto (27 February 1981, *Third International Electronic Music Festival*). It was created with an IBM S7 connected to an IBM 370/158. Mauro Graziani (Vérona 1954) studied music at the Conservatory of Venice with Alvise Vidolin. In 1970 he started to work in the domain of computer music. Since 1976 he has worked at the CSC as a composer and researcher. His works are played in Italy and Europe, United States and Eastern Europe. He has received honours from the Biennale of Venice (1980, *The Silent God*) and the RAI-Radio Televisione Italiana (1983, *Trasparenza*). His works *Winter leaves*, *The silent God* and *Landing* (1982) received special honours at the IX and XI International Competition of Electroacoustic Music in Bourges. He also created *Wires* (1984), *Untitled n. 1 (4i studio)* (1984) and the works *Aquam flare in media labia tua* for trombone and 4i System (1987) and *Combinazioni approssimate di tempo indefinito* for trombone, tenor saxophone, MIDI and 4i System (1988) in collaboration with Walter Prati. He participated at the Biennale of Venice in 1980, 1982, 1986 and 1989. As an assistant technician he created the computer scores of *Parafrasi* and *Fantasia su RoBErto fABriCiAni* by Aldo Clementi, *Canzona Veneziana* by Joel Chadabe, and *Elettronico* by Franco Donatoni (for the piece *Atem*). In collaboration with A. Vidolin and Sylvianne Sapir he produced the computer part for the two first versions of *Prometeo* by Luigi Nono (Venise 1984, Milan 1985). He has also composed instrumental music (1976, *ESP* for string quartet; 1980, *Morning Trill* for ensemble and tape-loop), analogical music and made audio-visual installations. He has published several articles in specialised magazines and is intensely active as a teacher. His works are available on the records EDIPAN INSOUND 2 (PRC S20-16) and INSOUND 3 (PRC S20-18).

[6] For the analysis we had: (i) the computer score provided by Mauro Graziani; (ii) an unpublished article in a dactylographic version; and (iii) a manuscript, preserved at the CSC, of technical files of the work (at the CSC each work had to be registered according to a permanent scheme). One has to underline the complete availability of the composer. He provided us with: (i) schemes in traditional notation used for the choice of frequencies; (ii) a scheme including the digital coefficients used for the choice of the frequencies; and (iii) other unpublished documents (score in an approximate traditional notation) for the recording of the work at the SIAE, the Italian society for author rights.

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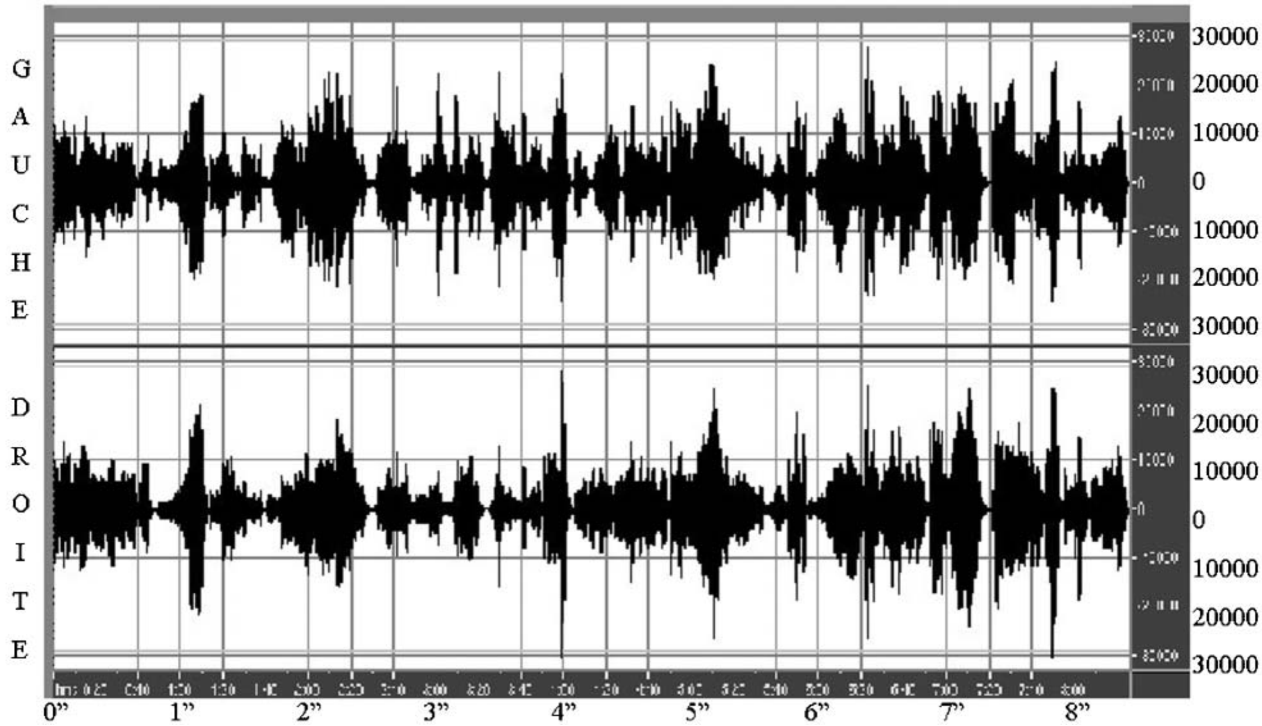

Figure 3. *Winter leaves*: time/amplitude representation.[7]

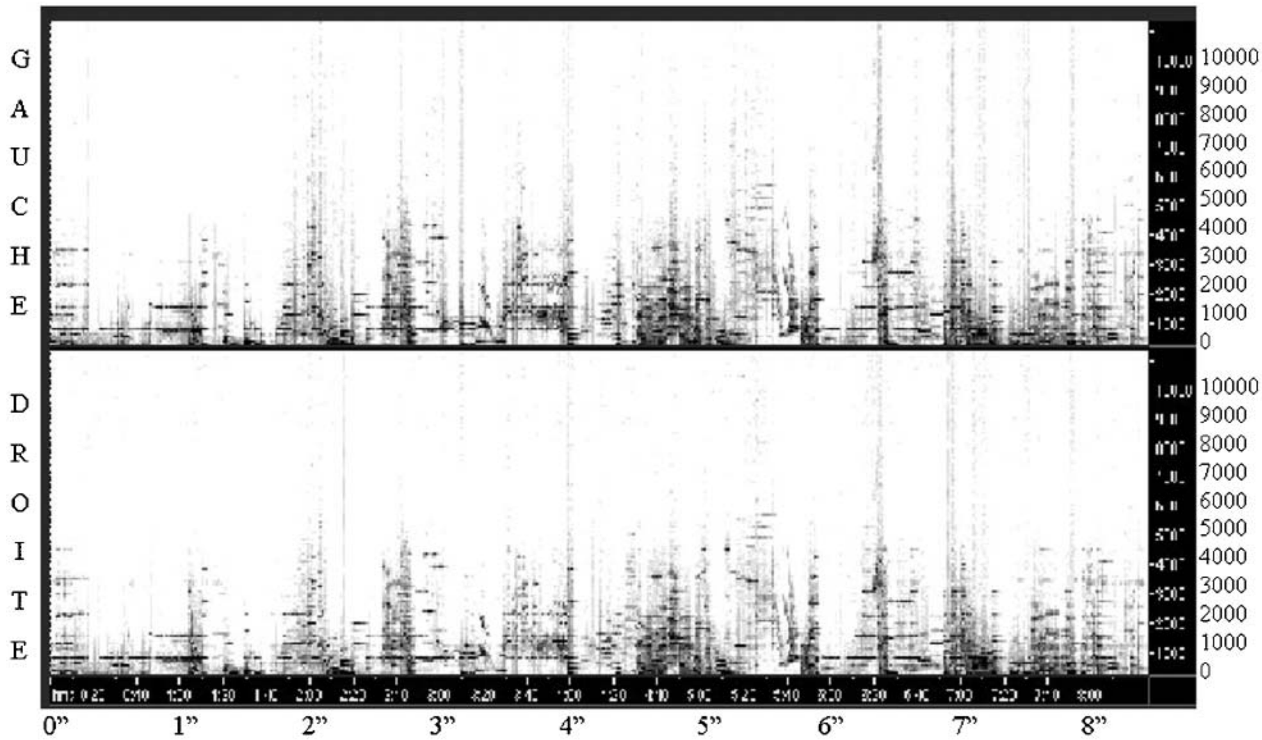

Figure 4. *Winter leaves*: sonogram.[8]

constantly. The work seems, therefore, to be highly segmented. On the contrary, a time/frequency representation (sonogram) reveals a certain 'chordal' aspect of the piece, characterised by sounds with a rich spectrum of components. However; the representation used here does not allow for a precise visualisation of the partials ('zooms' using the CoolEdit program would make this kind of exploration easier).

[7]The representation was made with a Hamming window, a *FFT size* of 8,192 tapes and a dynamic *range* of visualisation of 120 dB.

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Table 1

Instrument	Number	ZGADD (5 frequencies)	ZGDDP (ratio, spectrum)	ZGSEL (circuits)	ZGSTR (spatialisation)
A	1–6		3 frequencies	3 in parallel	X
B	7–12		4 frequencies	4 in parallel	
C	13–18		4 frequencies	4 in parallel	X
D	19–25	5 components	(P6, P7, P8)		X
E	26–28	(25 compos.)			
F	29–33		4 frequencies	4 in parallel non osc-amp	
G	34–40				
H	41–46		5 components		X
I	47–56				X
L	57–59				X
M	60–65				

In the sonogram, sound layers with rich spectrums, glissandos and very short sounds can be distinguished. Frequencies are seen to range from 0 to 5,000 or 6,000 Hz. There are also higher vertical lines, but as the recording contains *clicks* coming from the support, these lines can be attributed to faults on the vinyl. So, it can be understood that the piece is made up of sounds going from 0 to 5,000 or 6,000 Hz, which also gives us information about the sampling frequency of the work (theorem of Shannon).

The sonogram and FFT analysis do not enable either the isolation of the different objects or the understanding of their spectrogram. Only via the analysis of the computer score can the composition be explained.[9] As the score does not present other values, the sampling frequency can be seen to be 10,000 Hz, i.e. the lowest possible sampling frequency. According to Shannon theorem, the piece's sharpest frequency is 5,000 Hz.

Eleven instruments, often controlled by macros, create spectra born of 3 ratios (2, 2.24, 2.8856). As Music360 could not produce lots of 'notes' (I) from the same instrument at the same time, each instrument is used with several numbers. For example: in the event lists instrument A will be called numbers 1, 2, 3, 4, 5, 6.

The four main macros of *Winter leaves* have the following functions: (i) ZGSEL, for which the input can be an unspecified series of samplings, generates circuits that are modified by the multiplication and the addition of a sound wave in the input with another internal wave in the macro. The amplitude of the resulting signal is modelled by another oscillator. ZGSEL can generate one or more series of circuits in parallel. (ii) ZGDDP calculates frequencies of five sinusoidal components starting from fundamental frequency, ratio or spectral extension and a spectrum type (linear or exponential). It is a macro that can control additive synthesis (five frequencies) produced by another, the ZGADD. (iii) ZGSTR allows spatialisation by defining the type of change through a function or by blocking the sound.

The list of events is divided into eight sections, each of about one minute in length. The eighth section is divided into four shorter sections (8^1, 8^2, 8^3, end). A plan has been conceived for each section showing the temporal development of the instruments. This representation can only be read from a temporal point of view, one-dimensionally and not as a time/frequency relation. Therefore, the vertical organisation does not represent frequency organisation. Figure 5 shows the plan of the first part of the eighth section.

From the fifth section the look of the *score* changes completely. We can no longer find the instructions I adhered to, using numbers from 1 to 65, but rather we find very small numbers going up to 10. It is obvious that the composer has implemented a change of programming, perhaps due to the extreme complexity of the digitalisation of the instruments numbered from 1 to 65. The explanation of this new use of codes (almost always clear) can be found at the end of each section, for example at the end of the sixth section. Here, the composer writes in his notes: 'Instruments numbered from B1'. A sub-routine converts the numbers of the *opcode* by numbering instruments A to M from 0 to 10 and not from 1 to 11. This is a characteristic of programming language C, which counts positions starting from 0. Instrument A will become number 0, B becomes 1, C becomes 2 etc. The instructions for section six say:

B01 6 6 6 7 3 5 7 6 10 3 6

[9] The computer score, printed on 24 January 1980, is divided into three parts: in the first (29 pages) we find the score of the orchestra. In the second we find STRSET SRCSET sub-routines (3 pages) written in the FORTRAN language; in the third we can see the event lists of the score (68 pages). The score does not include instructions on the *job* itself (generally presented on the first pages), in other words the class of priority of the work to which Graziani had access in the centre. In the score we cannot find instructions for the final mix of the work, or the sub-routines (Macro) created by Graziani, which in *Winter leaves* are indicated by ZGx, even if we can understand them from the expansions that appear in the orchestra score (instructions beginning with the symbol +).

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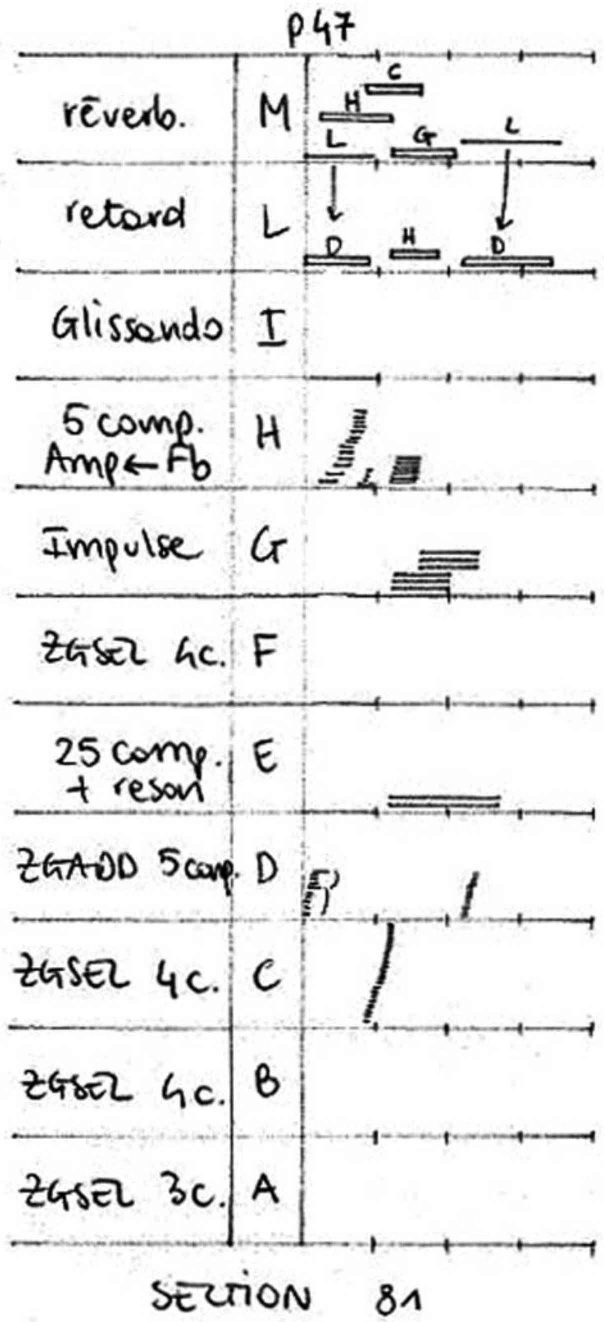

Figure 5. *Winter leaves*: plan of initialisation time of instructions in section 8-1.

This means that instrument B (by reading the line from left to right) is made up of (in the original Music360) six numbers, in other words six possibilities of producing sounds at the same time (in the original programming, B was indeed going from 7 to 12). Instruments C and D can have six numbers, Instrument E seven, etc. (table 2 shows B01 conversion sub-routines of sections 6 and 7).

To sum up, the description of instruments allows us to understand that in *Winter leaves* the composer uses two synthesis systems via macros. The first system (ZGADD + ZGDDP) performs the additive synthesis, the second (ZGSEL) modifies the base frequency, according to different parameters indicated in the event list. Other module-instruments create the glissandos (I) and impulsions (G). L and M are the instruments that modify sound with delay lines and reverb. Consequently, if we only take into account the instruments that produce sound, we can conclude that the piece has glissandos, impulsions and rich spectra created by additive synthesis.

The use of the macros (ZGx) itself is also an important clue to understanding the compositional logic of this piece. The composer chooses the program (Music360) which allows a very high level of programming. Synthesis is not applied to each list of events but at a superior level, allowing the computer to generate data lists automatically, starting from a given piece of input in the *score*. On the one hand, this allows the composer to have access to a great variety of different spectra but demands, on the other, a profound knowledge of the possible results. It is true that using automatic generation entails the risk of producing unexpected results and spectra, which explode.

In terms of the length of each section (and not the total length of the piece, seeing as such representation does not consider temporal proportions), the instruments are used this way (see also figure 6):

> M 68.18%, H 63.63%, D 43.18%, G 34.09%, L 31.81%, I 22.72% E 20.45%, F 18.18%, B 11.36%, C 2.27%.

'A' is never used but, according to the orchestral analysis, it can be understood that instruments A, B and C are very similar in syntax. L and M are instruments of sound transformation, in other words they do not synthesise any sound but require input from another instrument. They are especially present from the fifth section onwards, which is also the section where the new programming begins using the sub-routine B01. This could be a clue to explaining the change in the compositional process: the evolution of an easier part, to one that is much richer in terms of timbre. Reverberation and delay multiply the

Table 2

Conversion table of sections 6 and 7

Number of notes	6	6	6	7	3	5	7	6	10	3	6
	1–6	7–12	13–18	19–25	26–28	29–33	34–40	41–46	47–56	57–59	60–65
NAME	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**L**	**M**
New sub-routine number	0	1	2	3	4	5	6	7	8	9	10

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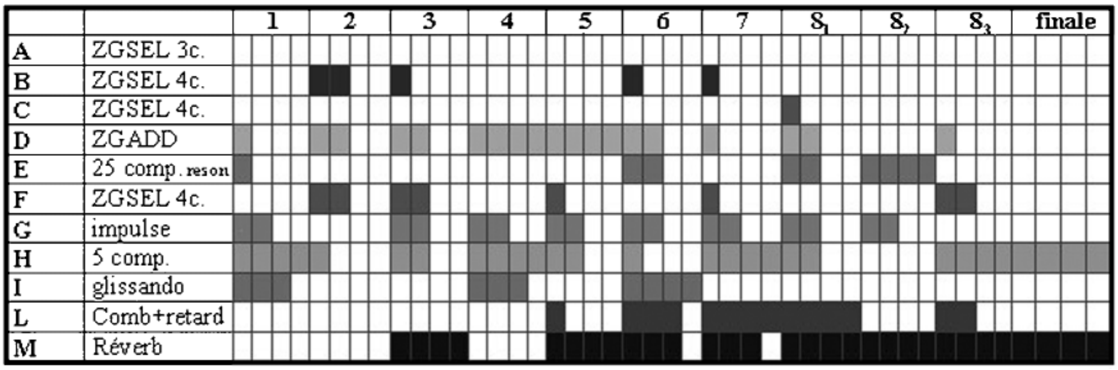

Figure 6. *Winter leaves*: distribution of instruments.[10]

sound and produce a more complex sonority. All this considered, H becomes, in reality, the synthesis instrument most commonly used. It uses macro ZGDDP to create rich spectra using three ratios: 2 (octave), 2.24 (none augmented) and 2.8856 (enharmonic). It creates sound layers but also small short elements which could be defined as sound 'drops'; it starts and ends the piece *Winter leaves*. D is mainly involved in producing layers, particularly in sections 3, 4 and 5. It also creates sound 'drops' like instrument H. G (impulsions) and I (glissando) are the two instruments most detectable in terms of perspective and in the sonogram. E is characterised by the resonance filter which modifies the spectrum in time. It appears at the beginning of the piece and in the last sections. F is similar to the instruments using ZGSEL and has four circuits. B uses the macro ZGDDP and the ZGSEL and creates layers and 'drops'. C is only used once, in section 8-1.

When considering the instrumental and temporal development schemas of the sections, it is also noticeable that *Winter leaves* starts with slow sounds, this slowness being equally related to very long sounds as to the expanded attack time between one instrument and the next. The choice of this type of sound creates a dense and calm sound flux. From the third section, G becomes more present and generates rhythmical situations. But it is in sections 6, 7 and 8 that instruments G and I really begin to generate complex and varying sound moments.

3.3. Philological problems: some examples

The success of the method, applied to the six works, depends on the presence of the computer score, which for MUSIC programs consists of the orchestra and the list of events. Reading this data allows an understanding, on the one hand, of the structure and the sonority of the instruments, and on the other, their development. Each *Pfield* controls an instrument parameter: its initialisation time, length, pitch, amplitude, sound timbre, transformations, and sound movement in space. Sometimes reading problems occur when the copy of the computer score is not the final version of the piece. In one of the analyses, this was the case. The signification of data controlling a sub-routine was changing: at a moment when the sub-routine called a frequency, the stocked data showed amplitude (*Sotto pressione*, Wolfgang Motz).

This leads us to consider problems outside the analytical sphere. A composer can approach computer music from a sonologic direction, using the computer as a sound producer which he mixes in during the final phase of the piece's creation. He can also enter data little by little, throughout the progression of the piece. This could explain deviations in the signification of data. On the other hand, the composer can set off in a more formal direction in which the computer is just a timbre-producing tool within a compositional structure. The old dualism of 'shape and sound' (Dufourt 1995: 30) is not so radical in the compositional process of the piece; the two poles are often mixed, but analysis helps to understand the general approach.

The results of the study of the works carried out at the CSC and the IRCAM also show that sometimes the digital orchestra is not fully used or that certain *Pfields* are not often or even never used. This indicates that the composer can create a hypothetical orchestra when starting his work, which he then uses according to his needs (*Sotto pressione*, W. Motz; *Winter leaves*, M.Graziani). When only a computer orchestra is available to the analysis, it is possible to deduce the general sonority of the piece, but not in detail and, of course, without a temporal appreciation of the instruments (*Résonance*, York Höller).

It is also important to evaluate the value of each instrument's *Pfields*. Data does exist to control and calculate internal data, to transform timbre and control spatial movement. When considering the complexity of an instrument one has to take into account these differences.

[10]In this representation we did not take into account the length of the sections (which makes section 8 and the end have the same size as the others). We considered each section, divided in four parts corresponding to 25%, 50%, 75% and 100%. We filled in the spaces according to the quantity (length) and the presence in the foreground of an instrument inside of each section.

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Following these observations, we can try to define a set of objective criteria which would enable an estimation of the degree to which the computer program is exploited. After the analysis of the six works an algorithm was created, based on the theory of information, allowing us to calculate the economy of use of the program's possibilities. In other words: to calculate the rigor and austerity of data compilation. Knowing that Music programs are all similar versions derived from the same software, and that in those programs the different instrumental parameters can be changed using the data defined in the *Pfields*, we created the following formula:

$$E = \frac{1}{N°instr.}\left\{\left(\frac{Pfields(NOT_n)}{1} + \frac{Pfields(NOT_n)}{1} + etc.\right) + \left(Pfields(sub\text{-}routines_n)\right)\right\}$$

It is obvious that a high E value (economy) corresponds to a piece where the use of the computer's possibilities is very developed. The results indicate the general trend in the use of software, taking into account the complete choice of instruments and the variable palette which the composer decides to use. However, it is possible that the result fails to reflect an obvious complexity if, for example, the composer only uses one of the instruments created. Indeed, the composer creates the instrument's structure and the number of fields according to the maximum quantity of new information that he wants to insert onto each line of the event list. However, he can set the values of several fields as constant (by not filling in the *Pfield*) for an undetermined number of instructions, or he can even use just one of the instrumental properties by defining the other fields as zero. The algorithm therefore defines the software's highest possible value for the analysis of the work which is, however, seldom reached. In reality, a composer (or an assistant) conceives the internal structure of the instruments in anticipation of all the changes he wants to have in the piece.

Another important aspect is the presence of sub-routines in Music programs. Sub-routines allow the generation and/or transformation of several events. They help avoid the compilation of long lists of instructions changing by just one parameter. This is why, instead of calculating the *Pfields* of the NOT, one can take into account those of the sub-routines, if they in turn are generating a NOT.

The analysis of computer scores (if they exist) becomes useful when one wants to define the parameters of the algorithm. An evaluation of data lists allows an understanding of the ways the computer is used in the compositional process. Its value can only be defined whilst taking into consideration the different tasks performed by the *P-fields*: initialisation, local variables, timbre transformation, etc.

The results of the six analyses gave the following values: *Winter leaves* (Mauro Graziani): 17.81; *Sotto pressione* (Wolfgang Motz): 21.62; *Progetto secondo* (Fausto Razzi): 10; *Résonance* (York Höller): 13; *Inharmonique* (Jean-Claude Risset): 7.05.[11] The highest values were found in the works by Graziani and Motz. Such values represent an extensive exploitation of the computer program's potential. These composers chose a vast palette of possibilities, which suggests they wanted to take full advantage of the program's synthesis and programming possibilities (its sub-routines). Höller (economy = 13) and Razzi's (economy = 10) approach to programming is much less extreme. There are several reasons for this: In Höller's work there is an interaction between the program and acoustical instruments, which means that the programming of the computer instruments had to be very precise. It also means that the program's possibilities had to be fixed to very precise goals and not influenced by its limitless potential. In the case of Fausto Razzi, only one beat- producing instrument was used. Here, the economic value depends on the *Pfields,* which are high because they must all be determined by the same instruction: NOT. The work of Jean-Claude Risset has the lowest economic value. This is because, even when he uses several instruments in his programming, the variables of each instrument are very limited. Thus, programming focuses on the variety of instruments rather than each instrument's timbric variables.

It was stated previously that these values indicate the general trend in the use of computers. However, they also require further interpretation. It is possible for a composer to define a vast orchestra in which similar instruments are ascribed the same tasks. In this case they would be considered as just one instrument. This important characteristic can only be evaluated through careful analysis of the computer score. In this respect, consider instrument A from the *Winter leaves* score by Mauro Graziani. This instrument was never used. Moreover, its syntax is the same as that of instruments B and C. Consequently, in this work the value representing the program's economy of use is not as high as the algorithm would suggest.

[11]For the work of Jonathan Harvey, calculation was impossible as no computer documents exist. With regard to the work of York Höller, we only took into account the principal instruments and not their transformations. Moreover, we did not consider instruments for which we did not have the configuration. For the works that had sub-routines, calculation of economy of use of the program was carried out by only taking into account the *Pfields* of the NOT, except for the work of Risset (NOT + sub-routines) where he used a version of Music 5 with sub-routine modifications, or directly generated NOT. Moreover, in the case of Risset, we did not consider the sampling of the voice as an instrument as the analysis of Denis Lorrain did not present the entire instrument (Lorrain 1980). In the calculation, all *Pfields* of twin instruments were doubled.

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Such complications demonstrate immediately the relativity inherent in the strict application of such mathematical algorithms. Even if it allows a sort of scientific evaluation of the compositional process, this information is only useful in relation to its context.

4. CONCLUSIONS

In the light of these reflections one can begin to understand the extent to which a computer composition is imbibed in a universe juxtaposing man and machine. To study this constellation, this 'tree-like reality' (Dufourt 1995: 30) made up of different organisational levels, scales and properties, an analysis that could be described as 'funnel-shaped' was necessary. The positioning of the analysis of computer scores as a counterpart to listening and sonogram analysis grows from the observation that it is possible to check the results of our own perception when listening to a computer piece by reading the calculation data. However, it must be emphasised that although an understanding of the computer data is essential to an understanding of a work's compositional process, it does not enable a full assimilation of the work's general timbre. Even if an increasingly comprehensive knowledge of the different instrumental timbres allows the analyst to imagine the instruments' sonorities, it is difficult, near impossible for the analyst to have a mental image of the entire work in his/her head. This differs from traditional scores where it is possible to read the whole score whilst 'hearing' the result in ones head. In the Music software, the orchestra produces the instrument. When analysing the presence of different module generators (oscillator modules, envelope modules, random generators, modules that read files outside of the sound) and of processing (reverb and interpolation), the analyst can imagine the sonority of an instrument: if it is more or less 'pure' (sinusoids or noise), with a relatively hard transitory, etc. However, each instrument's notes are defined in the event list. As such, the analyst must link the orchestra to the event list in order to understand each instrument's pitch, intensity and evolution, and to appreciate their combinations. Moreover, the 'vertical' assembly of different sound 'lines' is written from top to bottom and often the different sound sections calculated are incorporated only at the end of the score. Therefore, it could be said that computer score notation is at the same stage that tablature notation was at in the sixteenth and seventeenth centuries.

The analysis of computer music forms part of the vast domain of the musicological study of electroacoustic music, made up of various aspects related to organ logic research (inventory and classification of electroacoustic instruments), to historiographic research, to the renovation of machines and sound documents. Even if notable progress has been made over the last few years concerning the restoration of disks and tapes and the publication of works, explaining how the technology functions as well as the possible artistic results, the situation of documented computer archives remains disastrous. Unfortunately, the myth of music 'for listening and by listening' (Delalande 1986) has made even composers complacent to the need to save files and copies of computer calculations. At the start of this study, we were confident in the level of importance of the two centres considered, especially in Paris' case, given that the organisation of archives at the centre in Padova had never been considered. However, even if the documentation of research was very precise, musical documentation was frequently left to the musicologist's initiative.

Growing out of an analytical study, attention has focused mainly on more general, but extremely important reflections, which pose urgent problems. This urgency has more serious repercussions for those interested in the analysis of computer data as a way of finding a balance between subjective and non-subjective aspects of analysis. It must be stressed that all analysis is inherently 'subjective and duplicate (conclusions go beyond the data studied). So analysis remains as related to the author and to the context of analysis as to the work in question' (Lévy 2002: 285–6).

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