Dynamic visualisation of fugue analysis, demonstrated in a live concert by the Danish String Quartet

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In music, a fugue is a contrapuntal compositional technique in two or more voices, built on a *subject* (a musical theme) that is introduced at the beginning in imitation (repetition, with possible variations) and which recurs frequently in the course of the composition. We present a new type of dynamic visualisation strategy aimed at guiding a large audience throughout the listening of a fugue, so that listeners could follow the internal logic of the piece, and thus enjoy the richness of the composition. We present a technological framework that generates this visualisation in real-time during a live concert. We also present our ongoing work to automate the whole analytic process, inferring the elaborate fugue structure, so that it can be shown in the form of the dynamic visualisation. We also present a refinement of the visualisation for monophonic instruments for which each note is played with subtle fluctuation of pitch over time. This is the case in particular for string quartets, where the evolution of vibrato over time for each single note played by each instrument plays a core role in the appreciation of the performance. The rich fluctuation of pitch shaped by each musician is depicted in the form of undulating pitch curves. This visualisation technology has been demonstrated during an actual concert of the Danish String Quartet, playing the final *Contrapunctus* in J.S. Bach's *Art of Fugue*. The visualisation was shown on a screen next to the musicians.

The traditional way to show the structure of a fugue is to display the score and indicate, with for instance lines or rectangles, the different repetitions of the subject. A dynamic representation of this visualisation, folding over time while the music is playing, could simply consist of a progressive focus on the successive parts of the score aligned to the music being played. This could be a sufficient representation if only the repeated subjects are shown. But actually in a fugue, this is much more subtle, because once the first instrument finishes playing the first occurrence of the subject, when the second instrument starts playing that subject, the first instrument still plays something of importance, called the *counter-subject*, which will also be played by the second instrument (when the third instrument starts playing). It could be possible to show those counter-subjects in the same way, but the representation starts to get a bit more difficult to read.
One particularly of *Contrapunctus 14* is that the lines played by each instrument after playing the subject are quite different from each other, so they are not exact repetitions of a same counter-subject. But at the same time, all those different developments of the counter-subject, although quite varied, use a same reservoir of motivic material. Showing this using lines or rectangles would become quite impossible. Besides, *Contrapunctus 14* features three different subjects, corresponding to the three successive parts of the fugue. In addition, those subjects can appear together: during the second part, the first subject appears from time to time; during the last part, the first and second subject also appear, and in the very "end" (just before the piece is left unfinished by the composer), the three subjects are superposed.

To address those challenges, we propose a visual representation inspired by a technique, often called *paradigmatic analysis*, originating from anthropology and music semiology, highlighting the motivic repetition forming the quintessence of the fugue form. Claude Lévi-Strauss proposed a "logical model" to "study the function of myth", by dividing it into its "gross constituent units" and "bundle" them "so as to produce a meaning" (Lévi-Strauss 1955). The sequential data under analysis — in his case, the story of a myth — is written down in the form of a particularly formatted text, vertically aligning each successive part of the text with a previous part that belongs to the same "bundle." This leads to a representation where the myth, or any other text, can be read, diachronically, from left to right, from top to bottom, but where columns relate to those synchronic, signifying bundles. This has been further developed by the linguist Nicolas Ruwet in an attempt to formalise and systematise music analysis and in particular motivic analysis (Ruwet 1987), and has been used extensively afterwards, under the name "paradigmatic analysis" (Nattiez 1990).
In a fugue, the voices playing together generally play each a different moment of the subjects and countersubjects. In other words, synchronous voices are not "synchronic". For that reason, each voice needs to be analysed in isolation. Paradigmatic analysis does not seem very suitable for the analysis of fugues, due to the superposition, on a same position in the diachronic axis, of voices related to different moments in the synchronic axis. The proposed solution is to visualise the

analysis progressively, following the progressive evolution of the music along time. For each successive instant along the diachronic time, the corresponding synchronic time positions — one for each currently playing instrument — are highlighted in the score. To avoid spreading extensively the vertical dimension, we propose instead to display pitch curves and to superimpose them, so that the vertical axis is simply used to represent pitch height. To avoid making the visualisation overcharged and unreadable, the curves progressively fade away as time goes by. Only the pitch curve related to the first instance of a given motif (i.e., of a syntagmatic bundle) remains constantly visible. We thus obtain an apparently polyphonic representation of pitch curves. Except that, here, synchronous instruments are not superposed vertically, but instead are each located according to their synchronic position. Spectators might be unsettled by such unusual visualisation at first, but provided that they comprehend the principles, the resulting visualisation provides a richer representation of the music.
To make the visualisation as clear as possible, the display initially focuses on the temporal and pitch region related to the initial subject. Then the virtual camera progressively zooms out so as to show the other occurrences of the subject and countersubject. But the initial region remains highlighted with a more vivid background colour in order to emphasise its importance. Since the pitch curves are not drawn simply from left to right anymore but may appear at any place in the screen, the part of the curve being extended at a given time should be clearly highlighted. For that purpose, the last drawn point of the pitch curve corresponding to the current instant is highlighted with a clearly visible pointer, with the colour related to the instrument. Each of the three subjects of *Contrapunctus 14* has a visual identity in the form of a distinct background colour.
To draw pitch curves in real time, the audio of each individual instrument is captured using a close-up microphone installed on the instrument and the pitch tracking was performed on each isolated audio channel separately. During the real-time visualisation, at each moment, the detected pitch heights of the four instruments need to be added to the pitch curves at the appropriate horizontal positions. This requires to know exactly at which position in the music score we are at any given time. We integrated an automated score follower, but we also developed an interface to manually tap the beats while the music is being played. Since *Contrapunctus 14* has a clear and rather steady beat, it was possible to tap every beat during the live concert. This manual score follower leads to a visualisation that looks much more precise, so this method has been used. The whole software featuring the pitch tracking, the score follower and the visualiser, is integrated into a single Mac app developed in Swift.
For that experiment, the fugue analysis was made by hand. But we have been working on the development of a technology for automated detection of repeated motifs from score. We show how we are currently extending further that technology to allow the automation of the fugue analysis.

The Danish String Quartet played Bach's *Contrapunctus 14* during a concert of their DSQ festival, on October 26, 2021 in Copenhagen. Participants filled a questionnaire after the piece was performed and reported about, among other, their understanding and appreciation of the visualisation. It appeared that, due to some challenges in the integration of the visualisation to the concert, and because the audience were there to enjoy the music performance itself, they did not take much attention to, nor any interest in, the visualisation.
To evaluate more thoroughly the potentials of the visualisation, participants of various musical expertise and taste were invited in a follow-up experiment to listen to the recording and watch the visualisation on their own computer. A large majority could understand the visualisation, around half of them could see the benefit with respect to music understanding, and a small group found that it helped them better appreciate the music.
We will finally discuss our plans to add interactivity in the dynamic visualisation framework.

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