Structured Observation with Polyphony: a Multifaceted Tool for Studying Music Composition

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ABSTRACT
Contemporary music composition is a highly creative and disciplined activity that requires free expression of ideas and sophisticated computer programming. This paper presents a technique for structured observation of expert creative behavior, as well as *Polyphony*, a novel interface for systematically studying all phases of computer-aided composition. *Polyphony* is a unified user interface that integrates interactive paper and electronic user interfaces for composing music. It supports fluid transitions between informal sketches and formal computer-based representations. We asked 12 composers to use *Polyphony* to compose an electronic accompaniment to a 20-second instrumental composition by Anton Webern. All successfully created a complete, original composition in an hour and found the task challenging but fun. The resulting dozen comparable snapshots of the composition process reveal how composers both adapt and appropriate tools in their own way.

Author Keywords
Interactive paper; music composition; creativity

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces – Graphical User Interfaces; H.5.5 [Sound and Music Computing]: Methodologies and Techniques.

INTRODUCTION
Contemporary music composers express, explore and evaluate musical ideas by using a range of physical and computer tools [13]. They express ideas with sketches on paper [16], improvise with instruments, write notes with music editors, and define mathematical models, functions and musical parameters with music composition software [14]. Music development software is highly specialized and each focuses on a specific aspect of the composition process. For example, programming environments such as *Max* are used to develop and elaborate computational models that control computerized instruments and sound controllers. On the other hand, music notation editors such as *Finale* and *Sibelius* let composers write music with standardized musical notation. Yet notations change and take new forms as each piece evolves over time, influenced by both the stage in the process and the format of the tool. Previous studies have shown the power of paper as an open-ended tool for representing musical ideas [16], supporting everything from early sketches to the final score [18]. Composers create their own individual ad hoc strategies for expressing ideas, and often move back and forth between multiple representations on paper and on the computer.

Designing novel interactive systems to support this messy and highly creative process requires a deeper understanding of just how such tools, whether physical or digital, support the creative task. This also requires, in our view, a correspondingly creative approach to research methodology. We must explore diverse strategies not only to understand the process but also to design innovative tools that support it. Composition is normally studied via field studies [9], interviews [4] and informal exploratory studies [13] but rarely, if ever, observed in a controlled setting.

This paper uses a structured observation method [20] that combines elements of a controlled experiment, to facilitate comparison, with a realistic composition task, to enhance external validity. Rather than test hypotheses, per se, we observe behavior in a systematic way, which helps us identify and better understand the similarities and differences that obtain among professional music composers, and thus better inform the design of music composition tools. We describe our collaboration with a professional composer to create an hour-long composition task for expert composers. We then describe *Polyphony,* a unified interface to interactive paper and professional music composition software that supports all phases of the composition process.

We then describe a structured observation study in which 12 professional composers and musicians use *Polyphony* to create a complete electronic accompaniment to a well-known composition. We present our results, both on the composition process and the *Polyphony* user interface, and discuss how the structured observation method helps us understand real-world, expert-level creative processes. We conclude with a discussion of directions for future research.

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RELATED WORK

In order to understand the music composition process, we draw upon research at the intersection of studies of creativity and of the design of interactive composition tools, especially pen-based interfaces for musical creation. We also examine methods for evaluating creativity support tools.

Studying the Music Composition Process

Music composition is less well studied than other musical creation fields, such as performance [6]. For example, the NIME (New Interfaces for Musical Expression) community emphasizes the design of novel instruments, interactive installations and sound controllers [21] over user interfaces for composition per se. However, the few existing studies of the composition process highlight its iterative nature, requiring multiple steps between an ill-formed idea, usually sketched on paper, to more formal software representations or final scores [13]. Bennett [4] interviewed eight classical composers and found that they usually start by sketching a germinal idea, then iteratively refine the draft, until they create the final score. Healey & Thiebaut's [16] study of the early stage of music composition concludes that sketches provide a *"suitably underspecified representation"* that helps composers avoid premature commitment to the details of the musical piece.

Eaglestone [10] notes that musicologists conduct most of the studies of composers, and interpret them from an educational or music-theoretical perspective rather than on technology, software or user interface design. For example, Donin et al. [9] studied the entire composition of a piece through interviews and video logs. Although composition involved the use of several computer-aided composition tools, the study focused on long-term cognition rather than how the actual tools supported the creative process.

Composers are well served by digital tools designed to support distinct aspects of their work, e.g., libraries of sounds, programming environments such as *Max* for creating new sounds and controlling their effects, and score editors such as *Finale* for writing final scores. All of these tools focus on a single, specific stage of the creative process; however, none support the transitions between the composition stages identified by Bennett [4].

Pen-Based Interfaces and Creative Work

Contemporary music composers often use paper to invent and work with personal representations of arbitrarily complex musical structures and models. Oviatt et al. [22] suggest that using paper stimulates ideation, and is particularly effective in supporting nonlinguistic or spatial representations that are poorly supported by traditional interfaces. Contemporary composers use paper not only to express musical ideas but also to explore and complete the detailed implementation of their final musical score [13, 26].

Paper has additional qualities that make it suitable for creative work [24], including its high display and input resolution, its ergonomic form (thin, flexible, and light), and its affordances for a range of natural actions, such as grasping, folding, physical positioning and navigating, and annotating [18]. These properties motivated the design of interactive paper for music composition, e.g., Musink [26] and Inksplorer [13], as well as for 3D architectural design [25] and field research [27]. Other systems such as Xenakis' UPIC [19], QSketcher [1] and Sonic Sketchpad [8] support pen-based music creation by drawing graphical music representations on a screen.

Evaluating Composition Support Tools

The creative process is open-ended, which makes precise evaluation difficult. Pennycook [23] surveyed computer music interfaces and argued that: *"Unlike text-editing environments, in which measures of productivity can be gathered empirically, in most musical settings, productivity and aesthetic value become hopelessly confused [...] A user interface that satisfies the needs of one musician in an efficient, well-ordered way may be awkward or even counter-productive for another musician."* For example, Fiebrink et al. [12] studied composers who create digital instruments. Composers said they appreciated seeing unexpected results when gestures were mapped to sounds, but they also insisted on a high level of prediction and control over these mappings. Similarly, Eaglestone & Ford [11] found that an electroacoustic music composer had difficulty keeping track of electronic objects and navigating the various user interfaces. They noted the experimental nature of his creative process, in which errors *"often produce the most artistically interesting results"*. Amitani & Hori [3] explored how providing composers with spatial music representations can enhance creativity and Gelineck & Serafin [15] argued that computer tools that introduce some level of uncertainty may stimulate creativity. Studying creativity requires seeking the unexpected in noisy, hard to control environments.

Methods for studying composition tools include collecting questionnaire data [16], talk-aloud protocols and interviews [10]. Others involve field studies with open-ended explorations of interactive tools [11, 22]. Still others propose new metrics, such as degrees of freedom for musical control or required expertise [5]. Unfortunately, the highly diverse and personal nature of each composer's work practices makes comparisons difficult. We need new methods for understanding how experts use composition tools.

GOALS AND APPROACH

We are interested in supporting real-world music composition from the earliest, most creative phase to the final musical score, particularly for experts for whom paper and music composition software are both fundamental to their work. Our challenge is to observe and evaluate the complete composition process, from early paper sketches to the final electronic score, to inform the design of composition support tools. This requires:

1. A *structured observation method* to compare composition behavior at the same stage of the process.

2. A short but realistic and complete *composition task*.
3. A *technology probe* [17] that integrates a mix of previously studied composition tools, including paper, instruments and composition software, and records their activity throughout the process.

Structured Observation Method

In order to tease apart individual differences from common composition patterns, we need to observe composers under as similar conditions as possible, as they go through a complete composition cycle. We want to know how and when they use paper, when they explore ideas by playing on instruments or with the computer, and how they transition between rough ideas on paper to formal representations on the computer. Since we are particularly interested in how composers move between expression and implementation of musical ideas, we must investigate how they combine pen-based technologies (graphics tablets or interactive paper) and computer-based composition tools.

We use a structured observation method [20], similar to a quasi-experiment [7], that seeks to balance control and external validity. We create a controlled setting in which a relatively large number of expert composers (12) perform the same constrained creative task, with the same set of composition tools, input devices, and software. Composers are free to use their own creative process. We limit the task to one hour to facilitate recruitment of professional composers.

Note that, although this method is similar in form to a controlled experiment, our goal is not to test hypotheses or determine cause and effect, but rather to create highly comparable conditions for comparing measures of qualitative and quantitative behavior. We hope to identify common patterns that emerge, despite the highly individual nature of composition strategies, so we can support fluid transitions between pen-based and existing software composition tools.

Composition Task

Creating an appropriate composition task was a major challenge, since it must be short, yet creative and meaningful to professional composers. We worked with a Ph.D. candidate in music composition (C1), who is a professional composer with in-depth knowledge of music technology. She helped design the task and tested our first prototype. We pilot tested the task with an experienced, professional composer (C2) who offered additional suggestions about its design.

Creativity Stimulus

The starting point for creating a musical piece is an idea, a theme or an internal need that drives the creative process. We replaced this phase by a *composition stimulus* around which composers develop their piece. We considered two alternatives: a short video clip or abstract graphic animation that acts as inspiration, and an existing musical piece that composers import and reuse in their work. We chose the second alternative. C1 suggested Anton Webern's *Bagatelle No. 2 for String Quartet, Op. 9*, which is remarkably short, only 20 seconds, yet still considered a complete composition and well known to most contemporary composers.

Instrumentation Constraints

A composer usually writes music for a certain combination of physical and digital instruments or a whole orchestra. Contemporary composition often includes transformation of the sounds produced by performers as well as recorded material such as samples or electronic sounds. After several iterations with C1 and C2, we created a task that uses an audio effect and a synthesizer, explained as follows:

> *Use the effect to create a variation of Webern's 20-second piece and write an accompaniment for the synthesizer.*

Although this task is not representative of all real-world composition processes, it still requires key composition skills to analyze the given material, explore possibilities offered by the tools and produce an original musical result.

For the audio effect, we implemented a *harmonizer* that takes the original sound file as input and outputs a transposed version without altering its rhythmic properties. The transposition effect has two continuous parameters: a transposition factor expressed in midi-cents from -1200 to +1200, which is equivalent to minus or plus an octave, and the amplitude of the transposed audio signal from 0 to 1 in linear scale. The synthesizer is a note-controlled polyphonic sine-based synthesizer that accepts a sequence of notes and an amplitude signal from 0 to 1, again in linear scale. Notes are defined by their pitch, onset and duration.

A Technology Probe

Technology probes [17] combine three goals: collect data about use, test future technology in situ, and inspire novel design ideas. We wanted to provide a simple, easy-to-learn interface that integrates all phases of the composition process, from the earliest expression of rough ideas to the final implementation and performance of those ideas. Rather than introduce a new, generic composition interface, we created *Polyphony*, a constrained environment that provided familiar tools, but only those required for the composition task. We deliberately simplified the functionality and musical capabilities so we could concentrate on how interactive tools affect the creative process. *Polyphony* allows us to study both the composition process and the role played by an interactive system under controlled settings.

POLYPHONY

Polyphony provides a unified user interface for capturing pen-based input (on paper or on a graphics tablet), as well as musical performance on a piano keyboard, and typed or mouse-based input to control established music composition software.

Computer Interface

The *Polyphony* interface is implemented in *Max* and contains three main panels (Figure 1). The top panel displays the musical piece that serves as stimulus, with two different representations: the waveform of its sound source and its musical score with a linear time scale. We use the *bach*

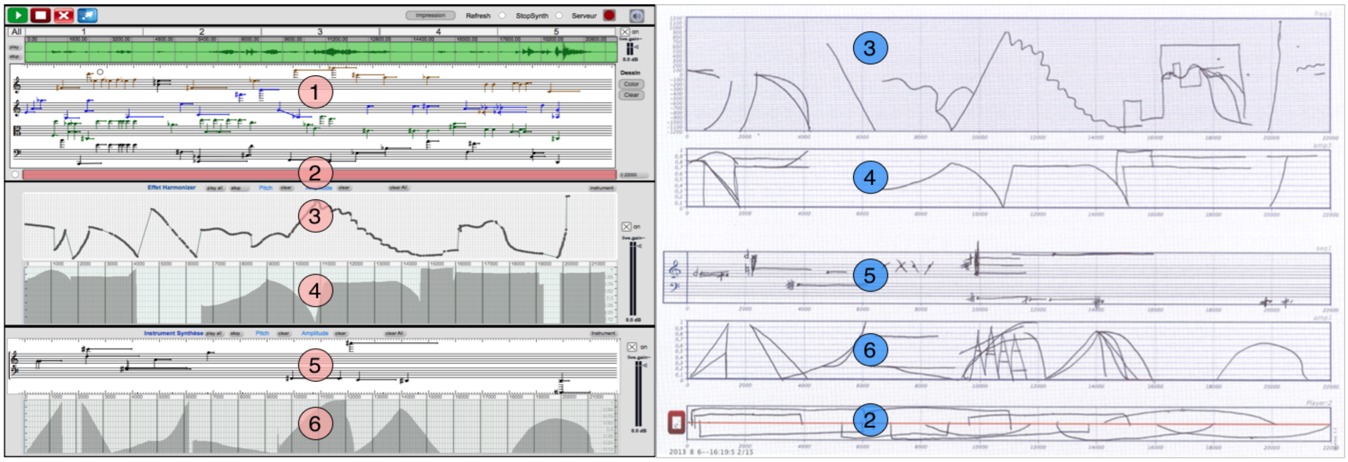

Figure 1: Final *Polyphony* score by P5. Left: *Max* interface. Right: Interactive paper interface. The top panel displays the waveform and the score transcription of Webern's piece (1), and a widget to select a time range (2). The middle panel (3, 4) controls the harmonizer effect. The bottom panel (5, 6) controls the synthesizer.

plug-in [2] score object to accommodate musical notation in *Max*. The middle panel includes interactive graphical objects for defining the two parameters of the harmonizer effect: the transposition factor and the amplitude. Finally, the bottom panel is dedicated to the synthesizer. It includes a *bach* object for entering notes and a graphical object for defining amplitude. To input curves that control the transposition factor of the harmonizer, we used a breakpoint function object, in which the user defines discrete points that are automatically interpolated. In contrast, amplitude curves of both the harmonizer and the synthesizer are continuous functions defined by the drawing. The user interface provides additional interaction mechanisms that complement the editing tools:

Free Annotation. Composers can sketch on the original score with different colors or print the current version as it appears on screen and annotate it with a pen or a pencil.

Precision Levels. Composers can work at two levels of precision: they can view the whole piece or zoom in on a small part by clicking on the corresponding button on the top panel. The score is divided into five 4-second parts, which C1 and C2 felt was the appropriate level of precision for the task. If a part is selected, each interface element's display is updated, and a green overlay shows the selection on top of the waveform. Composers can move among parts of the piece by dragging the overlay to the target position.

Audio Controls. The interface offers several controls for evaluating partial composition results: play and stop buttons, mute switches, gain sliders, and a selector tool. The latter enables the user to select a specific time range to evaluate. Finally, the user can explore the synthesizer and the harmonizer by opening a dedicated window with several live controls: a software piano, buttons and knobs.

Physical Controller

Polyphony uses a small MIDI piano keyboard with buttons and potentiometers to control the synthesizer and audio effect. Figure 2 shows the physical representation of the synthesizer and the harmonizer, which allows composers to actually play the synthesizer and the audio effect.

Figure 2: MIDI keyboard for playing the harmonizer (in red) and the synthesizer (in blue).

Paper Interface

Polyphony uses Anoto technology with a streaming digital pen to augment rather than replace the computer interface. Composers can enter notes or control curves and interactive elements to test sounds and partial results. They can also use the available free space for sketching and annotations.

The printed interface (Figure 3) fits on six pairs of A4-size paper. One pair contains the global low-precision view of the piece and the five other pairs are dedicated to each individual part of the piece. The first page of each pair contains the transcription of the original piece and free space for writing and sketching, as well as interactive buttons for printing parts of the score and an interactive *timeline selector*. Composers can draw arcs along the length of the selector to define score ranges and play the associated segments by tapping the line traces. The second page contains a timeline selector for listening to selected segments of the piece and several components for writing music for the harmonizer and the synthesizer:

1. One component for drawing control curves for the synthesizer's amplitude;
2. Two components for drawing control curves for the harmonizer, one for pitch transposition, and one for controlling amplitude;
3. Two staves (G and F key) for entering the synthesizer's pitches and durations, using a simplified notation.

Components for entering curves support incremental drawing and refinement. Composers can edit curves and symbols, erasing with a simple mark or redrawing some or all of the gesture. Interactive staves automatically recognize most intonation symbols used by composers, e.g., flats, naturals, sharps, quarter sharps, and three-quarter sharps. All of the above actions are accompanied by audio feedback. The paper interface communicates directly with *Max*, so data entry on paper is immediately reflected in the computer interface. Composers can refine the score using the mouse and keyboard on the computer or use the digital pen to rework it on the printed page.

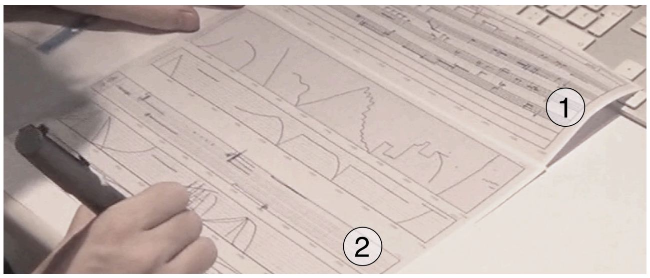

Figure 3: P5 inputs curves and notes on two pages of interactive paper, aligned along the common timeline: (1) Page with Webern's piece and print buttons. (2) Page with interactive components to work on the piece.

Polyphony includes a specialized Java tool (Figure 4) that can create and manage interactive paper components, which are easily built, reused, and connected to music applications such as *Max* via the OSC (Open Sound Control) protocol [28]. It can allocate the Anoto pattern to pages and components, exchange data through applications, and log or retrieve data from partial or whole interactive sessions.

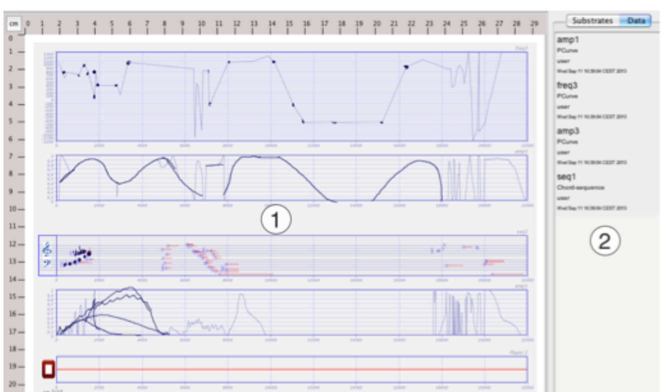

Figure 4: *Polyphony* interface with data from P3. (1) Virtual page with data from *Max* and digital pen. (2) List of available *Max* data streams.

STRUCTURED OBSERVATION STUDY

We conducted a structured observation [20] study of 12 expert composers who each composed an electronic accompaniment to Webern's well-known instrumental piece. We focused on: similarities and differences in composition practices, reflections about their own composition processes, and feedback as to the benefits of integrating interactive paper with their usual computer-based composition tools.

Participants

We recruited 12 composers (11 men and one woman), aged 25-70, all right-handed. Ten are professional composers, both composition professors and advanced graduate students. One is a Masters student in acousmatic composition; another is an electronic music controller engineer. Some are highly renowned composers and all have had their music compositions played in public.

Apparatus

Polyphony runs on a Macbook Pro 2.4 GHz Intel Core i5 with 4GB memory, running Mac OS X 10.6.8. The main *Max* interface (Figure 1) fits on a single screen.

Participants sit in front of a 24-inch Apple display with a native resolution of 1680 x 1050 pixels. The setup also includes two loudspeakers, headphones, a midi controller (Figure 2), a computer keyboard and a mouse. Sessions are recorded with a digital video camera on a tripod placed behind the participant's shoulder.

Figure 5: P9 uses the standard configuration with a screen, keyboard, mouse, and MIDI controller, plus a graphics tablet.

Because several composers already use graphics tablets for pen-based input [18], we tested two configurations of *Polyphony*: *graphics tablet* and *interactive paper*. Six composers were assigned a Wacom Intuos A5 tablet (Figure 5) in which three physical buttons at the top-left corner were labelled with frequent editing functions: *play and stop*, *add a note*, and *delete a note.* The remaining six composers were assigned an interactive paper interface with an Anoto ADP301 digital pen. All other aspects of the task and the suite of composition tools were identical and all participants could sketch on ordinary blank paper, using an assortment of pens, colored pencils and a ruler.

Study Design

Participants P1 to P6 used the standard configuration plus interactive paper for pen input. Participants P7 to P12 used the standard configuration plus the graphics tablet. Participants were matched according to age and experience between the two groups.

Procedure

Each session lasted 100 to 120 minutes, in four parts:

Introduction. We described the goals and motivations of the study. Participants then answered a short questionnaire about the tools and interfaces that they normally use to compose music. We then described the composition task.

Training. We first introduced the *Max* application, the harmonizer and the synthesizer. We explained how to use the tangible controllers to play with the audio effect and the synthesizer and how to interact with the main computer interface. We then presented a tutorial on how to incorporate pen-based input using the graphics tablet (15 minutes) or the interactive paper (20-30 minutes). We showed how to write musical notes and draw curves, as well as the erase and editing functions, and showed how to print the results on paper and iteratively modify their scores. Participants had three minutes to test the pen-input technology, and then we presented the composition task.

Composition. Participants were asked to spend at most 60 minutes to compose their piece. The experimenter acted as a technical assistant and answered questions that arose about the interface. Participants could practice on the tutorial sheet and print their score at any time. We encouraged them to try the pen-based interfaces but did not enforce their use: Participants were free to use whichever tools best supported their composition process.

Debriefing. After the piece was completed, we videotaped a five-minute interview. We asked participants to comment on their piece and summarize the steps the took to compose their piece. We asked them to focus on their creative process and how they moved from ideation, to exploration, to execution of their musical ideas. Finally, they completed a questionnaire about the musical interest of the composition task, their opinion of the musical result, their opinion of the user interface, and their suggestions for improvements.

RESULTS

All 12 composers successfully produced a unique musical piece[1] within the 60-minute time limit, except for P11, who managed to finish about 70% of the piece. Below, we examine the tools and the input devices that participants used, analyze their compositional process, and report on their experience and feedback.

Use of Input Devices, Interfaces and Controllers

Participants expressed mixed opinions about the different forms of input we provided. Figure 6 shows the time each composer spent on each interface. We measure time only for the interface of the composer's primary focus or the one controlled with their dominant hand. Several participants used different hands for different inputs, e.g., writing with the digital pen on paper while playing back the result by pressing the spacebar on the keyboard.

[1] We provide their scores and audio files as supplementary material.

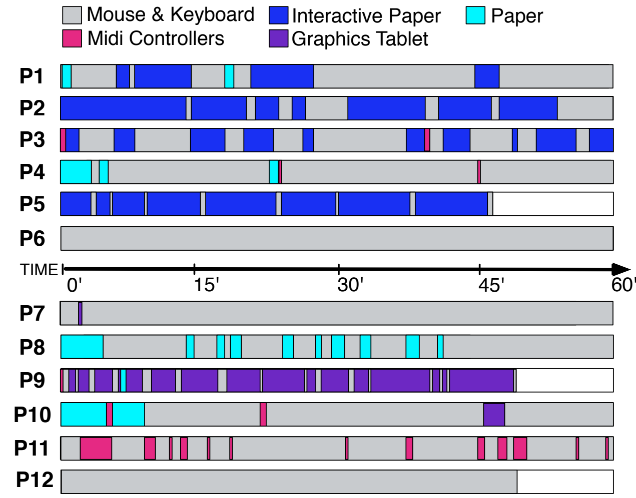

Figure 6: Participants' use of available inputs and interfaces

Graphics Tablet

P9 was the only composer who completed the piece with the graphics tablet. Although it was his first time using this form of input, he appreciated the *gestural* control of the pen, especially for drawing the profile of control curves. He commented that he could "*focus on morphologies and profiles directly related to performing gestures that I made with the tablet"*. Figure 7 compares the curves that he created with the curves produced by other composers using the mouse or interactive paper. His curves show quick dynamic gestures, a distinctive pattern that cannot be easily reproduced with the other two input devices.

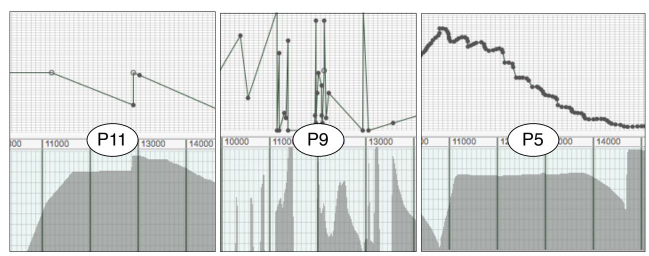

Figure 7: Control curves created for the harmonizer with the mouse (P11), the tablet (P9), and the paper interface (P5)

P7, P10 and P11 experimented with the tablet but abandoned it quickly after they made a few mistakes. P7 explained that he was already *"too trained"* working with a mouse. The rest of the composers preferred to use the mouse from the beginning.

Interactive Paper

The most senior (P4) and most experienced (P6) composers decided to work directly on the computer and did not use the interactive paper interface. They explained that it would be too complex for them to master and produce a satisfying result. In contrast, P5 used the paper interface almost exclusively (Figure 3), while P1, P2, and P3 alternated between interactive paper, mouse and keyboard. To finalize the score, all the composers used the mouse.

P1, P2 and P5 used pen and paper to input pitches for the synthesizer by writing notes on the interactive staves. P2 explained that he found this input method extremely quick. P5, on the other hand, complained that the printed staves were too narrow so it was difficult for him to precisely draw a note at the correct time position. Automatic recognition of intonation symbols did not always work, so some composers used the mouse and keyboard to refine them on the computer. Interestingly, P1 used pencil to sketch input rhythms using conventional notation before transcribing them to the proportional notation supported by the interactive paper interface (Figure 8).

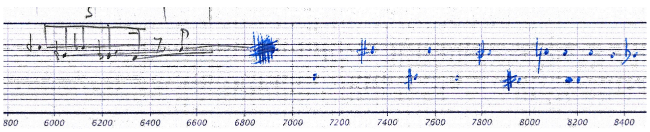

Figure 8: P1 wrote pitches and rhythm before using the proportional notation on the interactive paper.

Composers also used the digital pen to draw control curves. For example, P1 liked the pen because of its gestural control, but used the mouse to fix constant parameters values. P2 used a physical ruler with the digital pen to draw precise control lines (Figure 9).

Figure 9: P2 uses the ruler to draw a line with the digital pen

Several participants (P1, P2, P3) faced an overload problem when editing hand-written content on interactive paper. For example, after drawing several alternate amplitude curves, P1 used a non-interactive pencil to cross out the old curves and highlight the correct curve, without printing a new version. He asked for a "non-interactive" mode for the digital pen that would allow him to accomplish the same result without having to switch between pens.

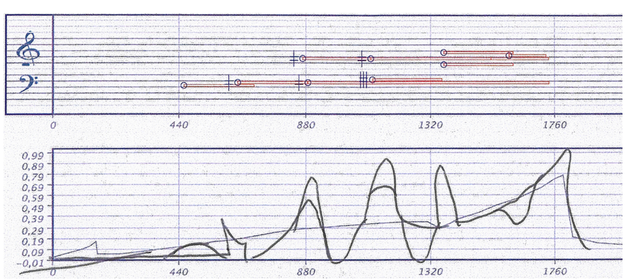

Figure 10: P3's edits over a printed amplitude curve (bottom) associated with a sequence of notes (top)

P2 and P3 followed a different strategy: each printed new interactive paper pages with their current work states and edited them for more precise results. P3 refined his amplitude curve by drawing more precise curves with the pen, using older traces to guide new refinements (Figure 10). P1, P2, P3, and P5 all used this strategy, which is particularly effective, and corresponds to other research findings [13].

Tangible Controllers

Several participants took advantage of the physical representation of the synthesizer and the harmonizer effect. Before P7 started composing, he explored the pitch controller effect from the harmonizer while playing Webern's original piece. This allowed him to think about the graphical form of the effect before drawing a first, rough version of its curve in the *Max* interface.

P10, P4 and P5 played the MIDI keyboard to try a chord or listen to a particular pitch. P8, P3 and P9 used the harmonizer's buttons to understand its possibilities. Interestingly, P8 could identify the harmonizer's transposition algorithm by playing with its controllers. P11, who had no classical music training, was the only one to play the keyboard along with the audio and then input what he had just played. This composer usually records as he plays piano and edits later.

Summary

Each composer discovered multiple strengths and limitations of each tool. P1, P2, P3, P5 and P10 appreciated the ability to draw "living" curves that inspired them in the early ideation phase. However, when composers wanted to set specific values, e.g., precise transposition values, they preferred using the mouse to control the computer interface. Similarly, while some composers (P1, P2 and P5) used the digital pen to write pitches on paper, they switched to the mouse to define precise onsets. They also used the mouse to copy and paste notes, an operation not supported by physical ink. Instead of identifying an optimal tool, composers choose the one best suited the task and composition phase.

Observations about the Composition Process

Exploring the Original Piece

All composers began by listening to the complete Webern piece; several listened a second time while reading the score. P6 and P12, who each have extensive composition experience, preferred to focus on the sound of the piece rather that its score representation. P12 explained that reading the score would negatively influence his composition.

Early Analysis and Ideation

All participants said they quickly decided how to segment Webern's piece and came up with the musical concept early in the process. However, several composers said that the task constraints limited their creativity. For example, P2 and P4 realized that their initial idea was impossible to implement. To preserve the aesthetics of the original piece, they would have to calculate several musical elements, which was not feasible given the available time and tools. They thus decided to adopt a more spontaneous compositional approach, focusing on the sound itself instead of the score. P2 and P7 said they would probably need a full week to compose something they were truly satisfied with.

P8 and P10 started by sketching on regular paper to note the base series, i.e. the sequence of pitches used to create their piece. P7 and P9 decided to directly annotate the transcribed score in *Max*. P7 used the mouse to annotate while P9 used the graphics tablet and then printed the annotated score on paper (Figure 11) for later use. Interestingly, he did not print until the very end, to check if the result was consistent with his initial ideas.

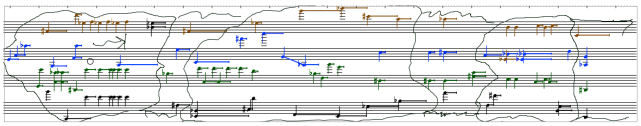

Figure 11: Annotations made by P9 with the graphics tablet

P4 wrote a short text that described the *"story"* or *"path"* of the electronics for the four parts that he identified in his piece. All other participants immediately began using the pen-based tool (graphics tablet or interactive paper) or the mouse to implement their ideas without sketching.

Iterative Process

All participants completed the composition in several iterations. P7 first added small elements in the whole piece and then iteratively refined each part to improve the result:

> *"I wanted to be sure that pivot notes are added first to guarantee the musical sense. [...] I iterate in order to respect the composition time and the length of the score".*

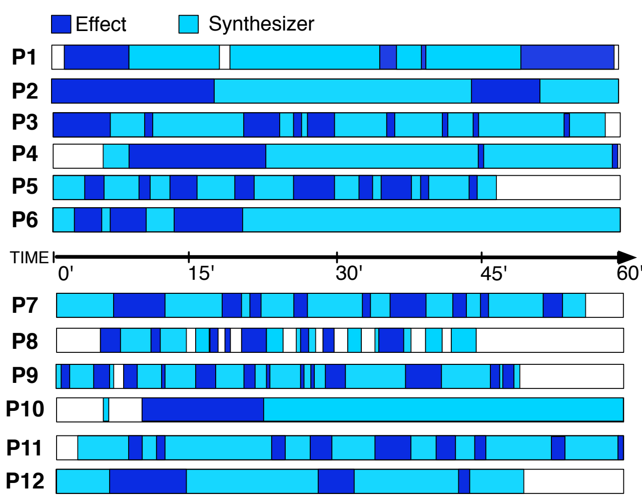

Figure 12: Composers' composition strategies. Rectangles represent each participant's activity with the synthesizer and the harmonizer effect.

Figure 12 illustrates how composers split their time between the harmonizer effect and the synthesizer. P4 said that he carefully organized his task to finish on time. He spent 10 minutes defining his goals and calibrating the tool. He tried different extreme possibilities to adjust the amplitude of the harmonizer and the synthesizer. He then spent 15 minutes composing for the harmonizer effect and 30 minutes for the synthesizer. He reserved five minutes for final edits and improvements. He divided his work into layers, one for the effect and one for the synthesizer, and for each layer, he progressed linearly along the length of the score. He made a few edits on the effect, after working on the synthesizer to improve the musical result.

P9 followed a completely different process. He worked on both the synthesizer and the effect in parallel for the whole composition task. He started by working on the last part because he was interested in the end of the piece. He then returned to the beginning of the piece and progressed to the next parts in several steps. He finished by working on the global low-precision view of the whole score to adjust the amplitude and modify some final notes.

Most participants focused on a particular musical sentence or sound object at any moment in time. Once finished, they would zoom out to the global view of the piece and listen to the result before switching to the next element. Most participants listened frequently to all the elements of the composition (original piece, effect, and synthesizer), sometimes switching one of them off. In contrast, P6 isolated and listened to individual elements without the rest of the music.

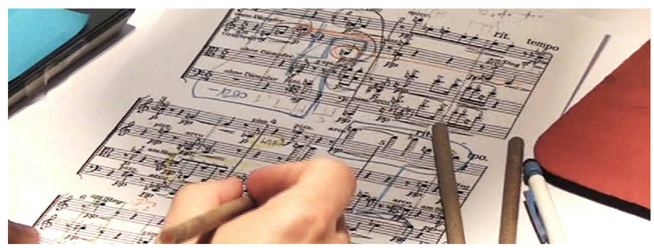

Figure 13: P8 annotates the original score with colored pencils to express ideas and keeps track of his work on the computer

P8 had an interesting approach involving the use of regular paper and colored pencils. Figure 13 shows his annotations directly on the original score. He explained that he started the task by exploring solutions on the computer. He then annotated the score to reflect on his work. After some time, he started by expressing ideas directly on paper and then implemented them on the computer. He iterated about ten times to complete the task.

Task Evaluation

Figure 14 shows how participants evaluated their familiarity with Webern's piece, the time allocated to the task, the interest of the task, and their final composition. All said they found the task to be interesting and amusing. P1 said that this kind of task "*really helps you think about the impact of electronics on the aesthetics of a piece."* Several others considered the task to be a nice composition exercise that they enjoyed. Regarding the one-hour time limit, most found it reasonable although they would need much more time for a real composition. P6, the most senior composer, felt tired at the end of the experiment and argued that she would require a break if the task were longer. All participants except P6 and P5 were generally satisfied with the result of their compositions. P6 would have liked to think more about the musical interest of her piece, but would have required more advanced tools. P5 was disappointed by the sound of the synthesizer. In contrast, P2, P7 and P12 stated that they were satisfied with the result.

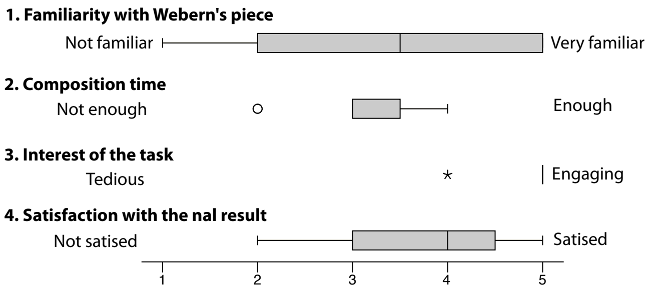

Figure 14: Box plot summarizing subjective task evaluation. Thick vertical lines are median values, dots show outliers, and asterisks represent extreme values.

Participants appreciated the live feedback provided by the *Polyphony* interface, particularly the ability to play results directly as they composed. Overall, they liked the harmonizer effect that we provided, but several requested an improved version with several voices, control for independent instruments in the audio file and more extreme transposition values. Many complained about the sinusoidal synthesis that we used for the synthesizer. P4 and P12 said that sinusoidal synthesis is "*tiring after several minutes*" and P3 added that the synthesis "*is not interesting when it is static*". Even those who complained about the simplicity of the effect and the synthesizer found it easy to understand the musical possibilities.

Finally, participants provided feedback about the functionality and usability of the *Polyphony* tools. Some requested more precise temporal alignment of notes. Others wanted copy-and-paste functionality for curves. Finally, P12 wanted more precise drawing capabilities and would have preferred to enter exact numeric parameters for amplitudes and transposition curves with the keyboard.

DISCUSSION

The combination of structured observation and an hour-long task resulted in 12 unique musical compositions, each with a comparable snapshot of the composition process. As expected, these expert composers exhibited different musical strategies and choices of composition tools as they moved from initial ideation to the final score, yet *Polyphony* successfully supported all of their creative processes.

Professional composers must spend months or years learning how to use music composition tools and integrate the capabilities into their composition process. Although none can be considered to have 'mastered' *Polyphony* in the short session time, all managed to successfully produce a composition with tools they had never previously used. These composers each appropriated different aspects of *Polyphony* to support their unique ways of thinking and many were able to incorporate pen-based input to control the computer-based composition tool *Max*.

Although we expected to see diverse composition strategies and results, we were particularly interested in shared patterns across most or all of the composers. For example, we noted that all composers focused on enhancing only some segments of Webern's piece: they referred to these as 'relaxing' parts or those with 'less content'. This implies that these professional composers have internalized composition rules that suggest where to add (or not add) to Webern's piece.

We identified two main strategies for completing the task: P1, P5, P6, P9, P11 and P12 improvised, refining their ideas and adapting them to the capabilities of the tool, whereas P2, P3, P4, P7, P8 and P10 first defined their ideas and then moved to implementation. In the debriefing, P1 and P11 said they decided to improvise because they were unfamiliar with the audio effect (P1) or not confident with instrumental music (P11). They found it difficult to plan their compositions without sufficient knowledge of the musical possibilities. P4 also started by drawing extreme curves and exploring low and high pitches to quickly test the available elements before focusing on the composition.

P1, P4, P8 and P10 all used pencils and paper to sketch or annotate content. Even so, they sketched less on paper than expected, based on previous work [16, 18, 26]. The key reasons given by P4, P7 and P12 were that the piece and the allowed time were short enough to remember their ideas. P1, P2, P3 and P11 argued that they did not need to develop a complex esthetic context, which often requires significant sketching activity, as the original score already provides it.

SUMMARY AND CONCLUSION

We used a structured observation method that produced 12 comparable snapshots of the composition process. We identified how composers both adapt and appropriate paper, pen-based interfaces and computer tools. We worked with a contemporary music composer to create and assess an hour-long composition task: to compose an electronic piece with an audio effect and a synthesizer, based on a recording of a 20-second musical piece by Webern. 12 expert composers successfully composed 12 pieces with *Polyphony*, our interface to a variety of existing music composition tools, including pen-based input with a graphics tablet or interactive paper, as well as a keyboard, mouse, and audio controllers.

Polyphony offers a novel approach for integrating all phases of the composition process, from early expression of ideas on paper to final implementation on a computer. Given the extreme time constraints, some composers limited their input to they devices they already knew. However, others switched among familiar and non-familiar interfaces, exploring their potential. Participants each appropriated *Polyphony* in their own way. Although initially designed solely for the basic composition task, *Polyphony* proved capable of supporting these expert composers' highly diverse composition strategies. All successfully expressed and implemented their compositions and especially appreciated *Polyphony's* live feedback and ability to synchronize across input devices.

This paper offers a novel composition task that enables us to compare the messy, ill-defined process of music composition across composers. We illustrate how structured observation can help us understand the creative process, as composers appropriate novel interactive systems. We plan to extend *Polyphony* to support a wider range of computer-based composition software and will implement several of the composers' suggestions, including copy-and-paste mechanisms for handwritten curves and multiple pens to better mix interactive and non-interactive modes.

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