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ABSTRACT

We conducted three studies with contemporary music composers at IRCAM. We found that even highly computer-literate composers use an iterative process that begins with expressing musical ideas on paper, followed by active parallel exploration on paper and in software, prior to final execution of their ideas as an original score. We conducted a participatory design study that focused on the creative exploration phase, to design tools that help composers better integrate their paper-based and electronic activities. We then developed *InkSplorer* as a technology probe that connects users' hand-written gestures on paper to *Max/MSP* and *OpenMusic*. Composers appropriated *InkSplorer* according to their preferred composition styles, emphasizing its ability to help them quickly explore musical ideas on paper as they interact with the computer. We conclude with recommendations for designing interactive paper tools that support the creative process, letting users explore musical ideas both on paper and electronically.

Keywords

Composer, Creativity, Design Exploration, InkSplorer, Interactive Paper, OpenMusic, Technology Probes.

1. INTRODUCTION

Composing music is a highly creative process, requiring both musical and technical skills. Within the past few decades, composers have been drawn to computers that offer powerful tools for specific tasks, such as *Finale* and *Sibelius* for editing scores, as well as full-scale programming environments, such as *OpenMusic* and *Max/MSP*. Composers use these tools to explore new musical ideas, generate novel sounds, and evaluate elements of a piece via real-time processing.

Composers are well-served with technology that helps them execute previously generated ideas. These tools can serve as a testbed, providing inspiration and the ability to test and assess different musical alternatives [2]. However, computer software is less effective for the earliest stages of the creative process, when the composer first struggles to represent a musical idea. Many composers still rely on pencil and paper for sketching partially formed ideas [12]. Coughlan [5] argues that, when expressing ideas, paper requires a lower cognitive load than software. A sketch can represent a complex, but as-yet incomplete idea: the details can be worked out later. Some sketches are rough and unfinished, others are carefully executed, such as curves that represent amplitude or other real-time processes [10]. Hand-drawn sketches are useful for working out a composition's structure, hand-written notes and annotations help the composer remember specific ideas. In fact, many composers design their own personal notations to represent and explore their musical ideas [12].

This paper describes our work with contemporary music composers to understand and provide technology that better supports the creative phases of the design process. We describe an initial study of how contemporary music composers at IRCAM use both paper and software tools. We present a framework for understanding their creative process, including activities on paper and in software. We then describe two design-exploration studies: a participatory-design study in which we worked with a composer on tools for paper expression and exploration, followed by the exploratory design of *InkSplorer*, an interactive paper application that links hand-written gestures to *OpenMusic* and *Max/MSP*. We used *InkSplorer* as a technology probe [11] to better understand the creative composition process and to explore how linking paper and software can better support innovation. We conclude with recommendations for the design of such tools and directions for future research.

2. RELATED WORK

We are interested in developing interactive systems that actively support the creative aspect of the composition process. Resnick et al. [16] propose a set of principles to guide the design of creativity-support tools. They emphasize the need for simple tools that encourage exploration of multiple alternatives and advocate using multiple tools, rather than just one. They argue that designers should begin with real-world observation and use participatory design for their development.

Composition software has a mixed record for supporting the creative process. In one in-depth study, Eaglestone and Ford [6] noted that an electroacoustic music composer had difficulty keeping track of electronic objects and navigating the various user interfaces. However, they also remarked on the experimental nature of his creative process and found that errors "often produce the most artistically interesting results". Amitani and Hori [3] explored how providing spatial music representations to the composer can improve creativity and Gelineck & Serafin [9] argued that computer tools that introduce some level of uncertainty may stimulate creativity.

A number of systems, including Xenakis' UPIC [13], Hyperscore[1], Qsketcher [1], Sonic Sketchpad [5], HighC[2] and Music Sketcher [20] were designed to take advantage of the power of sketching ideas, by linking drawings to music composition. These systems all use a mouse, graphics tablet or an electronic surface to draw musical forms on a computer screen. An alter-

NIME'11, 30 May–1 June 2011, Oslo, Norway.

[1] *http://www.hyperscore.com/*
[2] *http://highc.org*

native approach is *interactive paper* [14], which enables users to capture hand-written gestures on paper and transmit them to the computer. As with other tangible interfaces, interaction on paper is *space-multiplexed* [7] rather than *time-multiplexed*, as with a graphics tablet or a mouse. Users must view everything through a single window on a screen or tablet, rather than flipping through or spreading out different, potentially very large, sheets of paper. The physical representation of gestures on paper also affords exploration and offers both visual and computational reminders that can be quickly revisited, evaluated, and refined. The direct visual trace that the pen leaves on paper reinforces reflection on the task [17] and aids creativity.

Early interactive paper systems, e.g., *Digital Desk* [23], projected multi-media content onto paper or used a hand-held PDA to augment a biologist's notebook, e.g., *A-book* [15]. More recent systems [19, 22] use Anoto technology: a pen with a tiny video camera detects the precise location of each pen gesture with respect to barely visible dots printed on the paper.

Our previous research, *Musink* [21], used Anoto to help composers create and evolve personal notations on paper over time. We focused on initial expression of ideas, offering composers an extensible, gesture-based syntax with the freedom to incrementally create their own composition languages and link them to music software. Here, we focus on how users explicitly combine paper and software to explore ideas, with the goal of creating tools that support such exploration in both media.

3. OBSERVATIONAL STUDY

Before developing novel technology, we wanted to first understand the existing composition process, with particular emphasis on clarifying the early creative phases. We interviewed composers and watched them work as they expressed and explored musical ideas, either on paper or with software.

3.1 Method

Participants: We interviewed four advanced composition students from IRCAM, a center for contemporary music in Paris. All are experienced composers who have won prizes for their compositions. All have studied computer-assisted composition with software tools including *OpenMusic*, *Max/MSP*, and *Audiosculpt*. All are male, aged 30-40. We identify them by their initials: NM, AE, EM and MB.

Procedure: All participants were finalizing a composition intended for a soloist, with electronic elements. We asked them to bring this piece, plus their personal computers and any other related documents. Each interview was recorded and lasted approximately one hour. We transcribed and analyzed each interview, along with photographs or copies of their sketches and scores. We began by asking them to describe their current project and discuss how it evolved, in both paper and electronic forms. We asked Critical Incident-style questions [8] with recent concrete examples of how they addressed problems, followed by more general open-ended questions. At the end of each interview, we demonstrated a *Livescribe*[3] pen, which records sound with playback, as well as auditory and visual feedback. We asked them to brainstorm how such technology could assist their transition between paper and electronic representations or enhance their creative work in other ways.

3.2 Results

Expressing ideas on paper: Even though they are experienced users of composition software, all use paper to express their earliest musical ideas. Each has a unique way of working that varies in form and style. Some begin with blank paper and add musical scores or other graphical structures. Others develop personal notations to represent complex musical ideas or electronic processing (Figure 1). Their sketches include various graphical parameters, e.g. scale, color settings, orientation, envelopes, and thickness, which are mapped to musical parameters, often in an as-yet unspecified way.

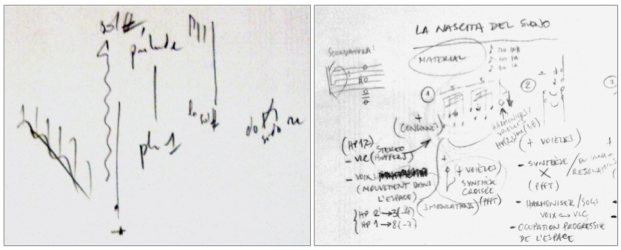

Figure 1. Left: Graphical representation of a piece (NM). Right: Hand-written scores and annotations (AE).

These composers distinguish sketches, which represent specific musical ideas, from underlying frameworks, which structure their ideas. For example, some composers redraw the musical staff; others use graph paper or specialized grids to lay out their ideas. This allows both flexibility and control when expressing concepts such as time, duration, pitch and density.

Exploring ideas on both paper and in software: After expressing their initial ideas on paper, composers move to an exploration phase, which involves both paper and the computer. NM described this as a tree: he generates and tests potential branches, successively accepting or rejecting them for the final composition. AE and EM use *OpenMusic* and *Audiosculpt*, combined with hand-written scores to experiment with ideas. NM and MB use *Finale* and *Sibelius* (music editors) to produce the final score, after first testing and printing some ideas. They also explore ideas using *OpenMusic*, exporting the results directly into a music editor or into *Max/MSP* as an event list to control electronic parts. Both NM and MB annotate printed or copied scores. AE and MB use real-time algorithms to control sound processing, AE, EM and NM use spatialization techniques and EM and MB use real-time synthesis.

Regardless of their technical expertise, all move back and forth between paper and software, sometimes drawing multiple curves on paper that they test in software, sometimes sketching an idea on paper that was inspired by a sound generated by the computer. Paper is clearly more flexible than software, demanding fewer constraints when expressing an ill-formed idea. For example, some composers use sketches to represent the structure of the whole piece or, like Marco Stroppa [12], use graph paper to draw extremely precise curves. When they move back to software, some paper-based representations get lost or must be translated into classical notation, which acts as a common language between paper and electronic representations. This runs counter to a Resnick's et al. [16] suggestion that "*creativity support tools should seamlessly interoperate with other tools*". Here, composers must shift between two methods of exploring ideas, forcing them to stay conscious of the medium and distracting them from the idea itself.

Representations evolve over time: The characteristics of drawings reflect different stages of the composition process. Figure 2 shows how MB's ideas evolve over time, as well as his use of paper and software. Figure 2a is a quick sketch, where the horizontal axis represents time, size correlates with amplitude and the orientation of the lines indicates transitions between notes. Figure 2b translates this sketch into a score, including a hand-drawn staff. MB does this to facilitate the transfer of the idea from paper to OpenMusic, which deals with curves and notes on a staff. Figure 2c is a printout of the corresponding musical object from *OpenMusic* which he has printed

[3] *http://www.livescribe.com*

on paper and added annotations, as explanations and reminders about what to try next. Figure 2d is the final score printed from *Finale*. He keeps both this score and his earlier hand-written sketches and printouts, as a record of his creative process.

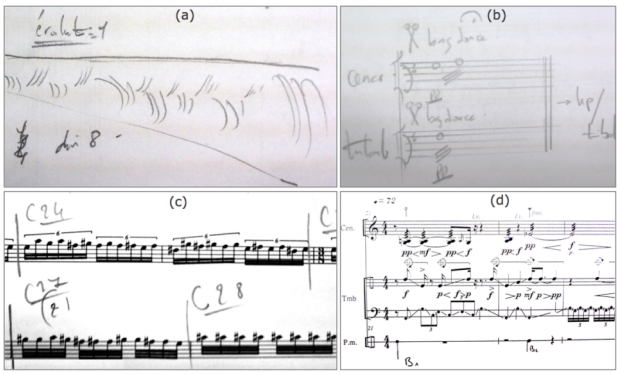

Figure 2. Evolution of musical ideas on paper (MB)

Conclusion: We found that composers engage in three main activities: *expressing* an initial idea, *exploring* it, and finally *executing* it in a composition. This cycle of expression, exploration and execution is highly iterative and occurs on both paper and in software, although paper-based activities occur earlier and end later. Figure 3 illustrates how composers use paper and software in parallel, without being able to truly integrate them.

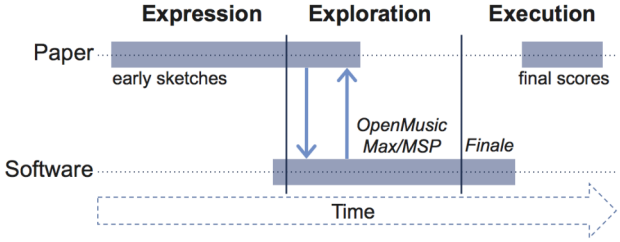

Figure 3. Composers work in parallel between paper and software, expressing, exploring and executing musical ideas

We were interested in what the composers thought about introducing a new technology, the *Livescribe* pen, into this process and asked them to reflect on how they might integrate it into their own work practices. They all wanted translations from hand-written notes into a musical editor, with the ability to modify or add details to scores printed from the software, ideally in a way that the software could then re-interpret. Although all were fascinated by the possibility of listening to parts of a score directly from the pen, they found the *Livescribe* pen itself too large and uncomfortable for daily use. All commented that they used pencils, not pens, and needed an eraser.

Based on these findings, we decided to conduct two studies to explore how interactive paper technology can aid the creative process. We wanted to offer composers the advantages of physical paper, with all its affordances, while also enabling them to benefit from the power of software tools. Our earlier *Musink* work focused on the initial 'idea expression' phase. Here, our goal is to support the middle exploration phase of Figure 3, more specifically, to help bridge the gap between paper-based and electronic composition activities.

4. PARTICIPATORY DESIGN STUDY

We used participatory design [18] to study how one composer explores musical ideas, with an emphasis on how interactive pens can enhance this process. Clearly, each composer has a unique composition process. We did not seek to find a generic solution, but rather to explore the design space and gain insights and ideas grounded in real-world composition activities.

4.1 Method

Participant: The composer (MB) had also participated in the first study.

Procedure: We first met with MB in a 2-hour participatory design session, followed by four shorter meetings over six months. We worked with a variety of different media including sketches on paper, a video prototype, and a Livescribe pen, used as a technology probe to capture data about his creative process and inspire ideas for new technology.

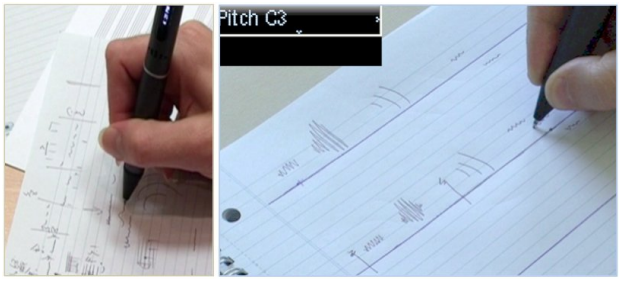

Figure 4. Left: MB explains his work process on paper. Right: Video prototype extract after a 2-hour design session

Livescribe pens run Java ME programs (*penlets*) and offer a range of functions, including auditory and visual feedback, audio recording and replay, interactive buttons and special areas printed on paper. For example, Figure 5 shows boxes with multiphonic tones for a saxophone piece that MB printed from *OpenMusic*. This let MB reflect on each sound while working on paper, using a penlet to replay sounds at will.

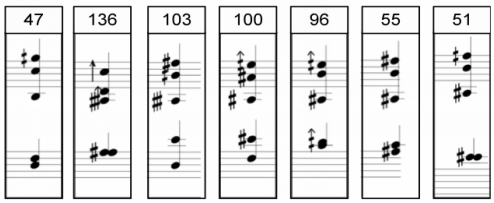

Figure 5. MB can tap on a box containing multiphonic tones and hear them from the pen

4.2 Results

MB offered a number of insights as to how he switches between expressing and exploring ideas, on paper and in software. He begins with sketches and gestures instead of classical musical notation so he can improvise and work *"at the speed of the thought"*. For him, providing live feedback from the pen would be too intrusive or distracting during the early stages of working out an idea. He is, however, interested in automatically translating paper-based gestures into classical notation that can then be interpreted by *Finale* or as an *OpenMusic* patch. This would save time and let him focus on expression rather than execution of ideas. He said the pen must capture as many data points as possible and he would find it 'unbearable' if the pen continuously notified him about what it had just recognized.

Design implications: Live interaction with the pen is not recommended for early expressive activities, but could provide the following useful functions during the exploration phase:

1. Record and play sounds by interacting with drawings or printed musical elements (as in Figure 5).
2. Evaluate and refine the result of drawings and gestures drawn on paper.
3. Define and modify rhythms and dynamics.
4. Restructure a piece by indexing different segments of the piece and exploring new structural alternatives.

We used a video prototype[4] (Figure 4) to explore how to implement some of these ideas. We created one space for the initial creation of ideas (gestures, musical symbols and drawings) and a separate "interaction space" that runs in parallel, along a common timeline. The latter was designed to be interactive and allow users to obtain information about their gestures, refine recognition and define rhythms. We explored additional interaction techniques to support this functionality including *Knotty Gestures* [22] to assign meaning, and physical transparent lenses [4] to refine the recognition of gestures.

5. TECHNOLOGY PROBE STUDY

We next investigated whether and how interactive paper could assist composers' exploration activities with *OpenMusic* and *Max/MSP*. Our goal was to enhance the computer-based exploration phase by providing additional physical space on paper for reflection, expression, evaluation and refinement of ideas. Based on our previous research [21], we also expected this technology to offer composers greater precision when defining musical parameters in a graphical form.

We developed *InkSplorer* to connect interactive paper technology to *OpenMusic* and *Max/MSP*. *InkSplorer* is a palette of tools, not a single prototype. This supports a technology probe [11] approach, in which our goal is not to validate a particular design solution, but rather to develop tools that composers can easily adapt to meet their individual needs. We hope to both gain new insights about the composition process as well as generate new ideas for designing interactive paper technology that supports the creative process.

5.1 InkSplorer

InkSplorer creates interactive paper with wireless Anoto ADP-301 pens that detect position and low-precision pressure. Pen data is sent to the computer via Bluetooth. Since drivers are not yet available for Mac OS X, we redirect pen data from a Windows 7 virtual machine to *OpenMusic* and *Max/MSP*. We use the OSC [24] communication protocol (fully supported by both *Max/MSP* and *OpenMusic)*. We created a library to manage storage and efficient retrieval of data so we can support real-time interaction with strokes on paper. The library uses the SpatialIndex library[5], an implementation of R-Tree, to store strokes, and was implemented as a Java external for Max/MSP. We also implemented patches and libraries in Common LISP for *OpenMusic* and Java for *Max/MSP*, to facilitate the integration of paper tools into composers' personal workspaces. The user interface in Figure 6 is a *Max/MSP* patch that lets users launch paper-aware applications and control pen configuration. The patch uses Jitter's OpenGL rendering to display incoming pen strokes.

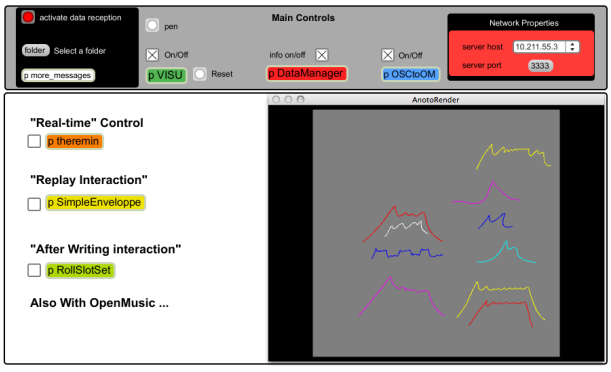

Figure 6. *Max/MSP* user interface for managing pen data

We developed a set of mini-applications of *InkSplorer* that integrate interactive paper into *Max/MSP* and *OpenMusic*:

1. A *Theremin*, controlled by moving the pen on paper.
2. A *Max/MSP* patch that maps pen strokes to sound envelopes (Figure 7, left).

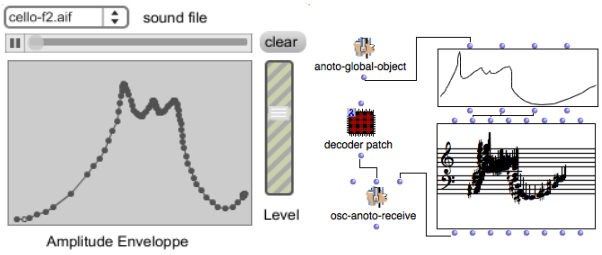

Figure 7. Mapping pen strokes to online graphical objects

3. *OpenMusic* patches that map strokes to BPF and BPC objects (Figure 7, right). Custom paper templates facilitate drawing and scaling of strokes.
4. *OpenMusic* patches that convert multi-strokes into musical objects using *maquette* [2] and custom paper templates.
5. Pen-drawing support for *bach*[6], a *Max/MSP* tool that enhances real-time processing with advanced musical notation. Duration and amplitude profiles of notes can be drawn on paper (Figure 8).

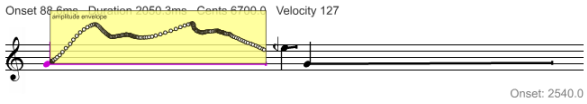

Figure 8. Defining a note's amplitude with pen data in *bach*

We created patches that detect and communicate various stroke properties: the x-and-y coordinates of each data point, data point density, pen pressure and time-stamps for each point. We can thus detect writing speed and variability throughout the duration of a stroke. From the user's perspective, *InkSplorer* provides a direct link between stokes on paper and the software.

Use Scenario: *MB is working on a piece for piano and real-time electronics. He has a clear idea for an electronic sound in his mind and captures it on paper in the form of a rough, abstract sketch with some text. He then creates an OpenMusic patch and proceeds to work out how to implement the sound. He inserts a BPF object to control the pitch range and turns to InkSplorer to explore different variations. He draws four curves on paper, singing the sound to himself as he draws. He taps on each curve and listens to the corresponding sounds produced by OpenMusic. MB likes the third best, but decides to change the final segment. He draws several slightly different curves on top of curve three and settles on the second variation. He adds an annotation to remember certain decision details, and circles the chosen curve, which stores it in OpenMusic. He also saves the original rough sketches and an OpenMusic printout in his notebook.*

5.2 Method

We conducted a series of mini-workshops with four composers at IRCAM, using *InkSplorer* as a technology probe to help them reflect on how to use interactive paper in their own work.

Participants: In addition to MB from the previous studies, three professional composers, KH, GL and MM, aged 31-52, agreed to test the *InkSplorer* prototype. KH, MB and MM had been interviewed in earlier studies [21] and were already famil-

[4] *http://vimeo.com/12853935*
[5] *http://trac.gispython.org/spatialindex/*
[6] *http://www.bachproject.net/*

iar with the basic Anoto technology. All were expert users of *Max/MSP* and *OpenMusic,* especially KH who had participated in the latter's development. GL and MM both teach computer-aided composition at IRCAM.

Procedure: We conducted a two-hour session with each composer, who brought his personal laptop and related documents, including musical scores, drafts of finished or in-progress pieces, and patches in *Max/MSP* and *OpenMusic*. All sessions were videotaped and later analyzed.

We first asked each composer about his background, professional activities, and experience and frequency of use of different music-composition tools. We then conducted a 30-40 minute semi-structured interview, focusing on how they represent and interpret curves and graphical forms, both in software and on paper. We asked for at least three specific examples and asked them to explain in detail how they worked out details, e.g. *"Describe the parameters this curve represents."* These interviews helped us to understand their work in context and identify concrete scenarios in which drawing curves on paper could be augmented with software functionality.

Next, we explained how to use *InkSplorer* and the mini-applications described above. Together with the composers, we selected examples from their work and imported their workspaces or parts of them to our laptop computer, where the pen drivers and *InkSplorer* had been installed. We successfully imported the *OpenMusic* workspace for three composers but not for KH, due to software version incompatibilities.

We asked composers to reflect upon how *InkSplorer* might change how they define, explore or refine musical parameters on paper and in *OpenMusic* or *Max/MSP*. We encouraged them to draw with the pen and use a 'think-aloud' protocol to describe its strengths and weaknesses. At the end of each session, we asked them to give us their reactions to *InkSplorer* as well as any suggestions they had for future designs.

5.3 Results

All four composers use *OpenMusic,* but only MB and MM use *Max/MSP* for composition. The other two use *Max/MS* for synthesis and interactive performance. These composers demonstrated diverse uses of curves to control various processes. For example, KH uses short curves to control an individual localized component of an algorithm or a synthesis process. Figure 9 (left) shows his use of a short curve to define a synthesis envelope or a pitch variation for granular synthesis. KH made a strong distinction between sound synthesis and music composition: For him, drawing curves to control synthesis, whether on paper or in software, is interesting, but he insisted that he is not a *"painter"* and does not use curves to compose music.

In contrast, MM uses long curves to control global properties of a piece or a section. Such curves are often more complex and more precise than short ones. Figure 9 (right) shows how MM uses long curves to control tempo variations in a 15-minute piece he composed for a short film.

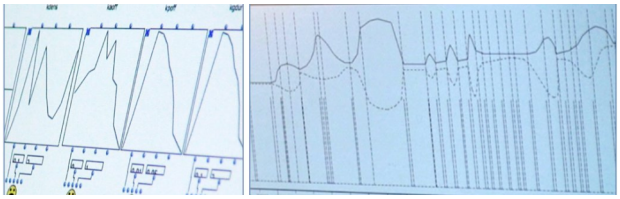

Figure 9. Hand-drawn curves control diverse processes

MM and KH use OpenMusic's maquette for spatial organizations of musical objects, controlled by temporal and graphical parameters. Reflecting on *InkSplorer*'s support for the maquette, the two composers showed examples from their work (Figure 10) that could be potentially produced by spatiotemporal mappings between paper gestures and maquette.

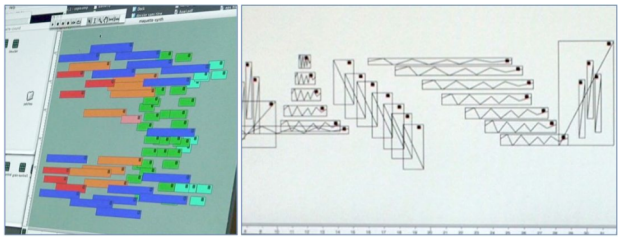

Figure 10. Spatial and temporal (x-axis) organization of musical objects (KH, MM)

The composers all chose to explore examples derived from their use of *OpenMusic*. The following issues concern both interactive paper in general and *OpenMusic* in particular.

Expressing ideas: Composers varied in how well paper helped them to express musical ideas. For GL, musical ideas reside in computerized patches and *InkSplorer* is only potentially useful for exploring these ideas faster. In contrast, MM feels that paper is simpler and more intuitive. For him, paper forms an *"analog"* space that provides more possibilities for expression than the computer, which he finds *"digital"* and constrained. MB finds the expressive power of both media to be similar, although he enjoys working with the pen more. He treats it as a musical instrument that involves physical movement of the body, a tangible sensation as the curve is drawn on paper: *"[I] use this pen just as I do an instrument. Here, I play the pen."*

Exploring ideas: MB and GL stated that *speed* is a major strength of interactive paper: it enables them to register multiple ideas and quickly assess their potential. MB feels that the pen saves time and helps him focus on the musical outcome rather than how to implement it. His hand-drawn gestures act as *memories* of sounds that can be returned to and replayed, even though the actual implementation resides on the computer. He also notes that computer screens have limited screen real estate whereas paper offers almost infinite space for exploring and "*The work is not lost in the computer"*.

Composers discovered interesting strategies for exploring ideas with *InkSplorer*. For example, MM drew several long curves on top of each other to evaluate different alternatives in the afore-mentioned composition, each providing incremental corrections (Figure 11, left). He used layers of curves to guide each refinement, explaining, *"It's a kind of guide that lets you correct it next time"*. In Figure 11 (right), MB draws variations of a short curve to control a 2-second sound synthesis.

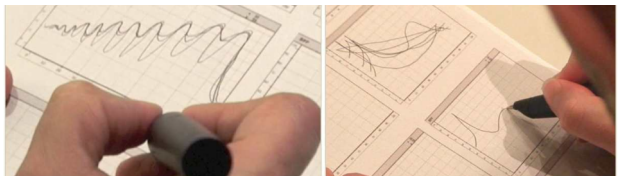

Figure 11. Reusing or refining curves (MM, MB)

Precision: Composers have different views about the relative amount of precision offered by paper and computers. MM feels that the computer is more precise because it lets him enter exact values, whereas data entry on paper is rougher. In contrast, GL finds that drawing on paper is more precise and lets him produce "more complex results". Finally, MB argues that although paper affords higher precision when drawing curves, it is not necessary for his compositions.

Design issues: The composers agree that integrating paper directly into existing tools, rather than creating a new interface, is the correct approach. However, they also want richer forms

of interaction. For example, MM finds it difficult to draw long curves without lifting the pen for a pause. He suggests that we let users easily connect segments together. Interestingly, only MM feels that capturing pen pressure or drawing characteristics such as pen angle are important, because these are essential in calligraphy. MB suspects that pressure might be useful, but would require practice to be controlled effectively. MM, GL and KH are particularly interested in using special pre-printed paper templates, particularly graph paper and musical sheets. In contrast, MB wants to create his own paper interface. The composers offered various suggestions for improving the pen design, including making them thinner, offering color, and supporting pencils or at least some form of erasure.

6. DISCUSSION AND CONCLUSIONS

Our goal is to design interactive systems that actively support the creative, exploratory phase of music composition. We conducted three studies to examine how professional composers combine paper and software tools. Study 1, based on interviews and observations of four composers, offers a framework for understanding the composition process, from early expression of ideas, to their systematic exploration and final execution. We found that composers explore both on paper and with software, as parallel, inter-related activities that they would like to better integrate.

Study 2 is a six-month participatory design study with one composer that explored how 'interactive paper' could better support his iterative testing of musical ideas. He argued that initial expression on paper is a 'delicate' phase and he does not want to be distracted by technology, i.e. live feedback that communicates state transitions and recognition errors. *Musink* [21], our first system, was designed explicitly to support the early creative phase, avoiding the interruption problem because data interpretation on first generation pens was delayed until it was uploaded to the computer. Although newer wireless pens offer real-time feedback, we recommend limiting this to later exploratory phases, when it is less disruptive.

Study 3 created *InkSplorer*, a pen-based composition tool that links paper-based and software-based to facilitate exploration of ideas. *InkSplorer* is actually a palette of mini-tools, which maximizes flexibility and supports both paper-to-computer and computer-to-paper testing and refinement of ideas. We tested *InkSplorer* with four professional composers. Their gestures on paper served as visual and computational elements that could be quickly revisited, replayed and evaluated, as well as layered and refined with new variations.

In future, we plan to more fully incorporate interactive paper into composition software such as *OpenMusic*. This will require tools that enable composers to define custom paper-based interfaces and richer, more powerful interactions with paper. We are particularly interested in gesture-based techniques such as our *Knotty Gestures* [22] and the use of portable electronic assistants [15] to aid the transition from symbols and gestures on paper to digital objects. Finally, we believe that *Musink* and *InkSplorer* are complementary and plan to integrate them in our future work.

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8. REFERENCES

[1] Abrams, S., Bellofatto, R., Fuhrer, R., Oppenheim, D., Wright, J., Boulanger, R., Leonard, N., Mash, D., Rendish, M. and Smith, J. QSketcher: an environment for composing music for film. In Proc. *C&C'02* (2002), 157–164.

[2] Agon, C., Bresson, J. and Assayag, G. *The OM composers's book Vol.1 & Vol.2*. (2006). Collection Musique/Sciences. Ircam Delatour France.

[3] Amitani, S. and Hori, K. Supporting musical composition by externalizing the composer's mental space. In Proc. *C&C '02* (2002), 165–172.

[4] Bier, E.A., Stone, M.C., Pier, K., Buxton, W. and DeRose, T.D. Toolglass and magic lenses: the see-through interface. In Proc. *SIGGRAPH '93* (1993), 73–80.

[5] Coughlan, T. and Johnson, P. Interaction in creative tasks. In Proc. *CHI '06* (2006), 531–540.

[6] Eaglestone, B. and Ford, N. Computer support for creativity: help or hindrance. In *ARiADA*. (Vol.2, 2002).

[7] Fitzmaurice, G.W., Ishii, H. and Buxton, W.A.S. Bricks: laying the foundations for graspable user interfaces. In Proc. *CHI '95* (1995), 442–449.

[8] Flanagan, J.C. The critical incident technique. In *Psychological Bulletin*. (Vol.51, 4, 1954).

[9] Gelineck, S. and Serafin, S. From Idea to Realization - Understanding the Compositional Processes of Electronic Musicians. In Proc. *Audio Mostly* (2009).

[10] Healey, P.G.T. and Thiebaut, J.B.T. Sketching Musical Compositions. In Proc. *CogSci '07* (2007), 1079–1084.

[11] Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B.B., Druin, A., Plaisant, C., Beaudouin-Lafon, M., Conversy, S., Evans, H., Hansen, H., Roussel, N. and Eiderbäck, B. Technology probes: inspiring design for and with families. In Proc. *CHI '03* (2003), 17–24.

[12] Letondal, C., Mackay, W.E. and Donin, N. Paperoles et musique. In Proc. *IHM '07* (2007), 167–174.

[13] Lohner, H. The UPIC system: A user's report. In *Computer Music Journal 10*. (1986).

[14] Mackay, W.E. and Fayard, A.-L. Designing interactive paper: lessons from three augmented reality projects. In Proc. *IWAR '98* (1999), 81–90.

[15] Mackay, W.E., Pothier, G., Letondal, C., Böegh, K. and Sörensen, H.E. The missing link: augmenting biology laboratory notebooks. In Proc. *UIST '02* (2002), 41–50.

[16] Resnick, M., Myers, B., Nakakoji, K., Schneiderman, B., Pausch, R., Selker, T. and Eisenberg, M. Design Principles for Tools to Support Creative Thinking. In *International Journal of Human-Computer Interaction*. (Vol.20, 2, 2006).

[17] Schön, D.A. *The reflective practitioner*. (1983). Basic books New York.

[18] Schuler, D. and Namioka, A. *Participatory design: Principles and practices*. (1993). CRC.

[19] Song, H., Guimbretiere, F., Grossman, T. and Fitzmaurice, G. MouseLight: bimanual interactions on digital paper using a pen and a spatially-aware mobile projector. In Proc. *CHI '10* (2010), 2451–2460.

[20] Thiebaut, J.-B., Healey, P.G.T. and Kinns, N.B. Drawing Electroacoustic Music. In Proc. *ICMC '08* (2008).

[21] Tsandilas, T., Letondal, C. and Mackay, W.E. Musink: composing music through augmented drawing. In Proc. *CHI '09* (2009), 819–828.

[22] Tsandilas, T. and Mackay, W.E. Knotty gestures: subtle traces to support interactive use of paper. In Proc. *AVI '10* (2010), 147–154.

[23] Wellner, P. Interacting with paper on the DigitalDesk. In *Commun. ACM*. (Vol.36, 7, 1993), 87–96.

[24] Wright, M. and Freed, A. Open Sound Control: A New Protocol for Communicating with Sound Synthesizers. In Proc. *ICMC '97* (1997), 101-104.