strategies can be employed towards evolving musical structures out of relatively little, and therefore coherent, musical material. Its release as open-source, object-oriented Common Lisp code encourages further development and extensions on the part of the user.

5. REFERENCES


ABSTRACT

ManuScore is a music notation-based, interactive music composition application, backed by a cognitively-inspired music learning and generation system. In this paper we outline its various functions, describe an applied composition study using the software, and give results from a study of listener evaluation of the music composed during the composition study. The listener study was conducted at a chamber music concert featuring a mixed programme of human-composed, machine-composed, and computer-assisted works.

1. INTRODUCTION

Otto Laske’s notion of “composition theory” [6] focused on three fundamental principles: 1) competence: knowledge of the materials and syntax of music, required for the conception of musical ideas; 2) performance: the practical application of accumulated musical knowledge (competence) to create musical forms; and 3) the task environment: the field of action in which performance draws on competence for the invention of musical works. In the context of Computer-Assisted Composition (CAC), the task environment is embodied by a computer and its hardware/software. When this role is assigned to something as pliable as computer software, composers are suddenly given the capacity to tailor the task environment to their particular needs, in a manner not previously possible. Laske felt that, in a computer-based task environment, composers could access the virtual music of their imaginations in a manner unbounded by musical traditions. He identified the process of conception, design, implementation, and production of the task environment, and its iterative development throughout the compositional process, as the “compositional life cycle” [9]. It was Laske’s feeling that software developed through a compositional life cycle could gradually begin to embody the musical knowledge of the composer in an explicit, analyzable, and extensible way.

Early CAC tools like Koenig’s PROJECT systems [8], or Truax’s POD systems [19], took a top-down approach to CAC, in which high-level concepts were expressed parametrically, or graphically, and the software was responsible for generating numerical representations, or electronically synthesized performances, of musical output. Two important observations can be made about such systems: 1) They are not corpus-based, and thus will not generally maintain an explicit connection with the user’s musical past, and 2) They deal with musical concepts at a high level of abstraction, and thus introduce significant non-linearities into the compositional process—i.e., by substituting numerical representations for sounds, they separate composition from the act of listening (an idea that Laske very much supported, believing that such a division could lead to “unbounded” musical invention). The vast majority of commercial CAC packages (conventional Digital-Audio Workstations (DAWs) and MIDI sequencers) are essentially bottom-up systems, which fulfill the basic tasks of recording and manipulating musical performances, or transcoding and electronically ‘performing’ musical scores. Although applications of this type are often equipped with extensive feature-sets, directed toward simplifying and streamlining the workflow for such tasks, their fundamental purpose is to record.

Making up the middle-ground, there are an increasing variety of CAC tools which propose different (and often quite novel) forms of musical representation, and introduce varying degrees of interactivity into the compositional process [23, 20, 13] etc.). Among this class one could also include the increasing variety of music programming languages, graphical or otherwise ([1], [17, 21], etc.), which offer a potentially infinite variety of CAC tools-to-be, and propose potentially infinite mixtures of top-down/bottom-up control.

For the bottom-up tools, competence and performance are essentially unchanged from the traditional requirements of music-theoretical knowledge, instrumental performance ability, skill in instrumental music transcription, and so on. With the top-down tools, the demand placed on competence is shifted (and potentially increased) by the emphasis on abstraction, while performance becomes focused on the interpretation of numerical representations of musical materials [7], and/or on the comprehension of metaphorized descriptions of musical concepts: “density”, “timbral trajectory”, and so on [19].

2. MOTIVATIONS BEHIND MANUSCORE

Our initial goal in designing ManuScore was to create a music notation-based CAC tool for music-literate com-
posers, who might already possess a developed musical language and bottom-up compositional practice, but were interested in exploring a top-down interaction with their musical ideas. In contrast to Laske’s goal of freeing com- posers from musical tradition, we wanted the system to acknowledge the user’s existing musical practice, so that working in ManuScore need not impose any dramatic change in a composer’s musical language or compositional output. The intention was to create a task environment to augment a composer’s practice, not necessarily to dramat- ically alter it, and certainly not to completely automate it. In this sense, the system could be aligned with Cope’s CUE software [5], which draws from a music recombi- nance database to offer “continuations” and developments of musical ideas introduced by the user.

Adding to this general conception of a non-interfering, interactive CAC tool with corpus-based generation, we were also interested in the notion of ‘object-oriented’ com- position [15]. Our conception of object-orientation fo- cuses on the notational aspects of musical ideas. That is, we are interested in what can be captured in a musi- cal score, what the various structures on the score’s sur- face represent to the composer (i.e., what is their musical ‘objecthood’), and how these structures might ‘inherit’ from one another in the developing composition. In this sense, an object in ManuScore is somewhat analogous to a “gestalt” in the music perception and cognition litera- ture [18], i.e., it is an identifiable, holistic item, or con- cept. To whatever degree possible, we wanted to help composers explore musical ideas as gestalts, and to rep- resent them accordingly in their compositional task en- vironment. This approach connects ManuScore to pro- grams like PatchWork (or PWGL [10]) and OpenMusic [1], which also help composers interact directly with mu- sical concepts, though our focus on notational elements (i.e., leaving aside numerical operations) in the user inter- face clearly sets ManuScore apart.

The generative capabilities of ManuScore, in its cur- rent version, are focused on the notion of ‘continuation’ (i.e., of extending musical fragments introduced by the user). Generation is also currently monophonic. However, our goal with ManuScore is to implement real-time, interac- tive generation, so that musical ideas may also be explored through listening and improvisation, not just through ma- nipulation of scored musical objects.

3. MANUSCORE DESIGN & FEATURES

In designing the Graphical User Interface (GUI) for Manu- Score we wanted to emulate a ‘pencil and paper’ work- flow, while maintaining a balance between power and flex- ibility. Wherever possible, we choose to utilize the stan- dard ARROW UP/DOWN/LEFT and RIGHT keys for moving objects, selectingaccidentals, toggling articulation mark- ings, and so on, permitting the user to remember only a limited set of possible interactions when learning the soft- ware.

3.1. An ‘Open’ Musical Space

At launch, the ManuScore GUI presents the user with an empty space—a ‘blank canvas’, so to speak. The back- ground displays faint vertical guides, which act as a tem- poral grid for entering musical events. The grid does not strictly follow the conventions of musical time signatures. Rather, it acts as a visual guide to subdivide the musi- cal space, providing a similar function to the grid sys- tems found in graphics and drawing software packages, and provides “snapping” functionality to assist the user in entering rhythmically precise material. Objects can be moved independently of the grid, so that events can be placed at any location in musical time.

At the top of the score window, “Metric Markers” can be inserted, allowing the temporal grid to be subdivided in arbitrary ways. It is worth noting that this division is strictly graphical, and imposes no formal restrictions on the music itself. The numbers in each marker indicate a grouping/subdivision of time. The top two numbers are conceptually analogous to a conventional time signature, while the bottom number indicates the number of “beat divisions” used for object snapping (and thus can create any n-tuplet subdivision). Figure 1 shows a sample score with two Metric Markers added. It will be noted that the markers only alter the grid for the rhythmic space following the marker’s position. This can be seen in Figure 1, where what appears to be a signature is cut short by a signature, inserted part-way through the first mea- sure. In conventional notation software, replicating the musical meaning of this structure would require the user to completely redefine the metrical notation of the music (and in most cases, to delete and re-enter the musical pas- sage). However, because the temporal grid in ManuScore is essentially independent from the contents of the staves, this sort of structure can be created at any time, without al- tering the existing musical material. In this sense, Manu- Score’s rhythmic representation offers a ‘sandbox’ space for composition, as opposed to the highly structured met- rical space of conventional notation software.

3.2. Note Entry in ManuScore

Once a staff has been created, single notes can be entered in three ways: 1) Typing n and clicking on a staff, 2) Using the Step-Entry Cursor (e key), and 3) Using a MIDI key- board. It may have already been noted that ManuScore at- taches accidentals to all notes, following the practice used by composers like Witold Lutoslawski. In ManuScore, this is a direct result of the inherent lack of conventional bar lines, which traditionally serve to nullify previously written accidentals. Once a note is created, the accidental can be toggled, by holding the CDRMAID key and using the ARROW UP/DOWN keys.

Material can also be entered in complete ‘gestures’, using the Gesture Tool (g key). This tool allows the user to draw a free-hand line on the staff, which is subsequently interpreted by the underlying generative system. Manu- Score is backed by our ‘Closure-based Cueing Model’ (CSTM), which is used for gesture interpretation. The process operates by using the CSTM to infer the pitch contour of the gesture. For each transition in the inferred “Schema” pattern [11] (i.e., contour), the algorithm se- lects those pitches which best approximate the position of the gesture line. ManuScore’s interpretation of a drawn gesture is shown in Figure 3. It is worth noting that, although most of the interpreted pitches follow the line quite tightly, the low D represents a ‘best-attempt’ of the CSTM, given its training. Its failure to follow the ges- ture line indicates that, in the given musical context, the system did not have a learned transition that could better approximate the path of the line. For a detailed discussion of the CSTM, see [11].

3.3. Orchestration in ManuScore

Our general goal of ‘ openness’ can also be seen in Manu- Score’s flexible approach to orchestration. Rather than following the conventional design, in which instruments are created a priori, on “tracks” similar to those used in analog tape recorders, ManuScore uses an approach inspired by the practice of composing to “short-score.” When composers work to short-score, they often apply orchestration notes after the fact, assigning instruments to
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Material can also be entered in complete ‘gestures’, using the Gesture Tool (g key). This tool allows the user to draw a free-hand line on the staff, which is subsequently interpreted by the underlying generative system. Manu- Score is backed by our ‘Closure-based Cueing Model’ (CbCM), which is used for gesture interpretation. The process operates by using the CbCM to infer the pitch contour of the gesture. For each transition in the inferred “Schema” pattern [11] (i.e., contour), the algorithm se- lects those pitches which best approximate the position of the gesture line. ManuScore’s interpretation of a drawn gesture is shown in Figure 3. It is worth noting that, although most of the interpreted pitches follow the line quite tightly, the low D represents a ‘best-attempt’ of the CbCM, given its training. Its failure to follow the gest- ure line indicates that, in the given musical context, the system did not have a learned transition that could better approximate the path of the line. For a detailed discussion of the CbCM, see [11].

Finally, new material can also be generated directly by the CbCM, as a continuation of a given musical context. When a note on a staff is selected, the CbCM can generate a continuation from that note, and render the continuation on a separate staff. An example of a CbCM continuation is shown in Figure 4. In the example, the top staff is the user-defined “context” and the lower staff is the generated continuation. The text above the generation “P 10/18 - R 1/4” indicates that the CbCM generated 18 pitch continuations, the 10th of which has been selected, and 4 rhythmic continuations, the 1st of which has been selected. Holding the OPT100/DOWN keys and using the Arrow UP/DOWN keys will toggle through the different pitch patterns, while using the Arrow LEFT/RIGHT keys will toggle through the different rhythmic patterns.

3.3. Orchestration in ManuScore

Our general goal of ‘openness’ can also be seen in Manu- Score’s flexible approach to orchestration. Rather than following the conventional design, in which instruments are created a priori, on “tracks” similar to those used in analog tape recorders, ManuScore uses an approach inspired by the practice of composing to “short-score.” When composers work to short-score, they often apply orchestration notes after the fact, assigning instruments to...
specific musical gestures directly on the staff. Orchestration in ManuScore follows the same process, as shown in Figure 5. With a correctly configured MIDI system, the instrumental switch from Flute to Viola at F♯4 will be played back via MIDI. In this scenario, the ball is assigned to the staff under the release as the “target” staff. The source staff acts as a data source, and the target staff acts as a receiver of some aspect of the source staff’s data. An example of applying the pitch contour from a source staff to the target staff is shown in Figure 7. Link functions currently include the following operations:

- **Pitch contour**: Applies the source staff’s pitch contour to the contents of the target staff. If the target staff has a greater number of events than the source, the source contour is repeated.
- **Rhythmic contour**: Renders the rhythmic values of events on the target staff to match the rhythmic contour of events on the source staff.
- **Pitch grid**: Provides ‘crisp’ locking of target pitches to source pitches.
- **Harmonic grid**: Provides ‘fuzzy’ locking of target pitches to source pitches. The locking algorithm uses a histogram of pitches used in the score up to the time of the target staff. Weighted toward the pitches in the source staff.
- **Rhythmic grid**: Imposes the rhythmic pattern of the source staff onto the contents of the target staff.
- **Trigger Staff**: Allows non-linear playback possibilities by causing the source staff to “trigger” the target staff. When playback of the source staff ends, the target staff begins, regardless of its horizontal position on the score.
- **Interrupt Staff**: If the target staff is playing back at the time when the source staff begins, the target staff is muted; i.e., the source staff “interrupts” the target staff.

4. A COMPOSITION STUDY USING MANUSCORE

In the spring of 2011, an applied composition study using ManuScore was conducted by composer James B. Maxwell, working under the supervision of composer/Professor Owen Underhill. The objective of the study was to test the functionality of the software in a one-to-one composition study context. During the study, the composer was to create two short works; one using his regular software package (with which he had been working for many years), and the other using ManuScore. Both pieces were to be approximately 5.00 minutes in duration, and both were to be scored for string quartet. As a further limitation on the process, both works would draw source material from Fredrick II’s “Royal Theme” (best known as the subject of Bach’s Musical Offering). The two works would be premixed together, in performance, in the fall of 2011, and a listener study conducted at the concert, as described in Section 5.

We do not suggest that the above limitations provide a strong enough framework for quantitative evaluation. However, we do feel that they impose enough commonality on the two compositional processes to isolate, at least to some degree, the software itself as a potential source of difference between the resulting works. Each working process was recorded using video screen capture, in order to provide detailed documentation. An excerpt of playback from the compositional process of the work composed in ManuScore can be viewed online (audio playback in the clip is directly from ManuScore, using the “Vienna Instruments” software):

http://rurate-music.com/home/Media/MS/experttest.mov

The CbCM in ManuScore was trained on three works from the composer’s catalogue: *vover*, for flute and ensemble, *limma*, for flute, piano, and percussion, and *penura*, for wind quintet. Most of ManuScore’s functionality was utilized during the composition process, though the composer reported particular use of the Gesture Line tool and the “pitch grid” Link function. The composer also noted that although he considered the final work to be human-composed, the software did have a strong influence on both the form and content of the piece. In particular, he found that continuations offered by the CbCM tended to provoke different possibilities for the melodic development of the work, even in cases where the continuations were not included in their original, unedited form. Continuations provided by the CbCM were often edited from the composer’s catalogue:

One of the above #1

SFU, and also included several machine-composed works by composer/Professor Dr. Arno Eigenfeld, and one human-composed work, “One of the above #1”, also by Dr. Eigenfeld.

Participants in the study were 46 audience members from Vancouver’s new music community. The concert featured a total of ten works, written for percussion, string quartet, Disklavier, and other hybrid combinations of these instruments. Each audience member received a concert programme, which explicitly indicated that “machine-composed and machine-assisted musical compositions” would be performed. Each audience member also received an evaluation card on which they were encouraged to provide feedback. On the front side of the evaluation card, audience members were asked to indicate, on a 5-point Likert-scale from 1 to 5, to what degree the piece felt like a “quality human-composed work,” and to indicate which instruments were thought to be human-composed, and which were thought to be machine-composed. Each audience member was also asked to indicate, on a 5-point Likert-scale from 1 to 5, the level of engagement while listening to each of the compositions. Additionally, audience members were asked to indicate which three pieces they felt were most directly human-composed. All questions on the front side of the card were to be filled out during the performance. The back side of the card contained an additional ten 5-point Likert-scales, asking audience members to indicate the memorability of each piece. This was to be filled out at the end of the concert. However, due to low response rate, this information was excluded from the analysis. Audience members were also given space to write in their own comments. A paper outlining the general findings of the study is forthcoming.

For the purposes of this paper we will focus on the two works composed during the composition study described in Section 4. Since the primary design goal of ManuScore is to be implicit “human” than the strictly human-composed work, fundamento.

6. STUDY RESULTS

In order to avoid the alpha inflation that arises from multiple comparisons, statistical tests were made using post-
specific musical gestures directly on the staff. Orchestra-


tation in ManuScore follows the same process, as shown in Figure 5. With a correctly configured MIDI system, the instrumental switch from Flute to Viola at F4 will be played back. In Figure 5, the instrument name is assigned to the message icon. 

Figure 5. Assigning Instruments in ManuScore.

Users can define a custom library of instruments in the MIDI Setup window. The window has four panels: 1) MIDI Setup, 2) Instrument Library, 3) Articulation Li-


library, and 4) Instrument Builder. The MIDI Setup panel allows users to select input/output ports for their MIDI system. In the Instrument Library panel, users can create named Instruments, each with a specific MIDI port and channel assignment. The Articulation Library is used to define named articulation settings—"legato", "trill mi-


notes by typing "Vienna Instruments" software): back in the clip is directly from ManuScore, using the the composer reported particular use of the Gesture Line tool, for wind quintet. Most of ManuScore’s functional-


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ing for many years), and the other using ManuScore. Both pieces were to be approximately 5:00 minutes in duration, and both were to be scored for string quartet. As a further limitation on the process, both works would draw source material from Fredrick II’s "Royal Theme" (best known as the subject of Bach’s Musical Offering). The two works would be premièred together, in performance, in the fall of 2011, and a listener study conducted at the concert, as described in Section 4.5.

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4.4. Sharing Staff Data with Links

A further application of this notion of ‘objecthood’ comes in the form of Links. A Link is a graphical connection be-


between two staves that allows one staff to become a source of information for another—a form of inheritance. Typ-


ing 1 and clicking on a staff will start the linking process by setting the clicked staff as the “source” of the Link. Dragging over another staff and releasing the Link will set the staff under the release as the “target” staff. The source staff acts as a data source, and the target staff acts as a receiver of some aspect of the source staff’s data. An ex-


ample of applying the pitch contour from a source staff to the target staff is shown in Figure 7. Link functions currently include the following operations:

- **Pitch contour**: Applies the source staff’s pitch con-


tour to the contents of the target staff. If the target staff has a greater number of events than the source, the source contour is repeated.

- **Rhythmic contour**: Recorders the rhythmic values of events on the target staff to match the rhythmic con-


tour of events on the source staff.

- **Pitch grid**: Provides ‘cresc’ locking of target pitches to source pitches.

- **Harmonic grid**: Provides ‘fuzzy’ locking of target pitches to source pitches. The locking algorithm uses a histogram of pitches used in the score up to the time of the target staff, weighted toward the pitches in the source staff.

- **Rhythmic grid**: Imposes the rhythmic pattern of the source staff onto the contents of the target staff.

- **Trigger Staff**: Allows non-linear playback possibil-


ities by causing the source staff to “trigger” the tar-


get staff. When playback of the source staff ends, the target staff begins, regardless of its horizontal position on the score.

- **Interrupt Staff**: If the target staff is playing back at the time when the source staff begins, the target staff is muted; i.e., the source staff “interrupts” the target staff.

4.5. A LISTENER STUDY

The two works composed during the composition study outlined in Section 4 were premiered in a concert held at Simon Fraser University’s School for the Contemporary Arts, Woodward’s campus, in December 2011. The con-


cert was presented by the Musical Metacreations project at SFU, and also included several machine-composed works by composer/Professor Dr. Arno Eigenfeld, and one other human-composed work, “One of the above #1”, also by Dr. Eigenfeld.

Participants in the study were 46 audience members from Vancouver’s new music community. The concert featured a total of ten works, written for percussion, string quartet, Disklavier, and other hybrid combinations of these instruments. Each audience member received a concert programme, which explicitly indicated that “machine-


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vide feedback. On the front side of the evaluation card, audience members were asked to indicate, on a 5-point Likert-scale from 1 to 5, their level of familiarity with con-


temporary music. This question was followed by ten sim-


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tionally, audience members were asked to indicate which three pieces they felt were most directly human-composed.

We do not have all of these questions on the front side of the card were to be filled out during the performance. The back side of the card contained an additional ten 5-point Likert-scales, asking audience members to indicate the memorability of each piece. This was to be filled out at the end of the concert. However, due to low response rate, this information was excluded from the analysis. Audience members were also given space to write in their own comments. A paper out-


lining the general findings of the study is forthcoming.

For the purposes of this paper we will focus on the two works composed during the composition study described in Section 4. Since the primary design goal of ManuScore is introduce CAC into the compositional process without disrupting the development of a composer’s musical lan-


guage, we hypothesize that audience members will not judge the computer-assisted work experiri to be implicitly more “human” than the strictly human-composed work, fundatio.

6. STUDY RESULTS

In order to avoid the alpha inflation that arises from mul-


tiple comparisons, statistical tests were made using post-
appears that the system did not dramatically alter the familiarity with contemporary music. This can be attributed to the fact that a highly significant difference between the averaged engagement ratings for all string quartet pieces ($M = 4.36, SD = 0.73$) and the “One of the Above” series of solo percussion pieces ($M = 3.36, SD = 1.06$) was found, $t(133) = 8.71$, $p < 0.001$. Similarly, a comparison between the string quartet pieces and the “hybrid” string/percussion pieces Dead Slow / Look Left and Gradual ($M = 3.69, SD = 1.09$) was also highly significant, $t(89) = 4.79$, $p < 0.001$, suggesting that audience members were more engaged by pieces containing strings than by those containing percussion. A comparison between the percussion and hybrid pieces failed to be significant, $t(89) = 1.41$, $p = 0.16$.

It is worth noting that comparisons between the expert listener engagement ratings for the two works from the composition study, fundamento ($M = 4.29, SD = 0.81$) and espectro ($M = 4.47, SD = 0.61$) were also significant, $t(18) = 1.00$, $p = 0.33$ ns. Notice ratings for fundamento ($M = 4.24, SD = 0.83$) and espectro ($M = 4.36, SD = 0.86$) were similarly non-significant, $t(24) = 0.29$, $p = 0.77$ ms.

In Table 2 we give the results for the “directly human-composed” ratings, where it is clear that both fundamento and espectro were rated significantly higher in “engagement” and it is impossible to attribute this preference to the influence of ManuScore.

The process of composing in ManuScore introduced some important changes into the compositional process, which would be worth discussing further. Specifically, the manner in which time is represented, combined with the necessity to transcribe ManuScore documents into standard music notation should be considered more closely. During the transcription process it was noted that the original rhythmic representation of espectro did not always follow an easily interpretable metrical structure. More specifically, it was found that the rhythmic representation in ManuScore did not always follow the implied metrical structure, as perceived through listening. An example occurs at the opening of the work, and is shown in Figure 8. Looking carefully at the example, we see that the original ManuScore phrase is written using a “beat division” of 5, suggesting a quintuplet pattern. However, it was decided during the transcription process that the aural impression of the phrase was more appropriately represented using a “+4/3” grouping of sixteenth-notes and triplets, rather than the original “5+2” grouping. This change effectively increased the tempo, and shifted the entire metrical structure accordingly.

A similar effect was noticed at measure 12 of the transcription, shown in Figure 9. Here we see a passage which was created as a quintuplet pattern in ManuScore (bottom), but transcribed as a grouping of six eighth-notes, under a 3/4 metre, in standard notation.

It was felt that such discrepancies were primarily arising as the result of the purely graphical nature of ManuScore’s temporal grid. Since the grid does not impose a specific metrical structure on the music, the cyclical process of writing and listening tends to emphasize aural rather than theoretical principles in the developing compositional process. With a temporal grid of 5 beat divisions in place, pitch was easily entered into ManuScore in quintuplet patterns. However, through the iterative process of listening, entering material, editing, and listening, the musical form naturally began to unfold according to perceived cognitive principles, driven by the musical material themselves. The phrasing of ideas in the musical foreground gave rise to certain types of groupings, and these naturally gave rise to accompaniments that supported those groupings. And because the temporal grid was easy to adjust to virtually any beat division value, it was simply not a priority to alter the metrical structure of the work in the process of moving from in-progress. In a sense, quintuplets became “the new sixteenths” for the work.

8. FUTURE WORK

A new version of Manuscore is currently under development. This version is based on a modular cognitive architecture for music, called MusiCog, which replaces the CbCM as the generative back-end for the system. An overview of this model, which is a development and extension of the CbCM, can be found in [Maxwell et al., 2012]. All of the features described in this paper have been included in the new version.

In response to the composer’s experience of frequently altering the pitch content of CbCM continuations to match local key features, we planned to add a function that would help the user to “quantize” the pitch content of generated material before it is rendered. Since the CbCM often generates continuations based on interval patterns, rather than pitch patterns, deviations from the local key/scale were somewhat expected. However, a pitch quantization mechanism would help reduce the cognitive load on users, and could be implemented using the existing algorithms from Manuscore’s “harmonic grid” Link function.

A useful future development, which came to our minds during the present study, might involve the inclusion of methods for beat induction and metrical inference. Such methods would be useful for MusiCog’s underlying music perception and cognition functions, and could also be used to periodically re-interpret the temporal grid of the score during creation. Such metrical interpretation could help the user avoid difficult transcription decisions after completing a score, and would also support the composer’s understanding of the structure of the work in progress. An extension of this functionality could allow Manuscore to transcribe standard music notation versions of showcases, for export and printing, thus streamlining the process of moving from Manuscore to concert performance.
ManuScore, and the work composed through the composer's normal process. In a sense, quintuplets became "the new sixteens" in the temporal grid. Since the grid does not impose a specific metrical structure on the music, the cyclical process of writing and listening tends to emphasize aural rather than theoretical principles in the developing composition. With a temporal grid of 5 beat divisions in place, pitches were easily entered into ManuScore in quintuplet patterns. However, through the iterative process of listening, entering material, editing, and listening, the musical phrases began to unfold according to perceptual/cognitive principles, driven by the musical materials themselves. The phrasing of ideas in the musical foreground gave rise to certain types of groupings, and these naturally gave rise to accompaniments that supported those groupings. And because the temporal grid was easy to adjust to virtually any beat division value, it was simply not a priority to alter the metrical structure of the work in progress. In a sense, quintuplets became "the new sixteens" for the work.

It was felt that such discrepancies were primarily arising as an effect of the purely graphical nature of ManuScore's temporal grid. Since the grid does not impose a specific metrical structure on the music, the cyclical process of writing and listening tends to emphasize aural rather than theoretical principles in the developing composition. With a temporal grid of 5 beat divisions in place, pitches were easily entered into ManuScore in quintuplet patterns. However, through the iterative process of listening, entering material, editing, and listening, the musical phrases began to unfold according to perceptual/cognitive principles, driven by the musical materials themselves. The phrasing of ideas in the musical foreground gave rise to certain types of groupings, and these naturally gave rise to accompaniments that supported those groupings. And because the temporal grid was easy to adjust to virtually any beat division value, it was simply not a priority to alter the metrical structure of the work in progress. In a sense, quintuplets became “the new sixteens” for the work.

8. FUTURE WORK

A new version of ManuScore is currently under development. This version is backed by a modular cognitive architecture for music, called MusiCOG, which replaces the CbCM as the generative back-end for the system. An overview of this model, which is a development and extension of the CbCM, can be found in Maxwell et al. [12]. All of the features described in this paper have been included in the new version.

In response to the composer’s experience of frequently altering the pitch content of CbCM continuations to match local key features, we plan to add a functionality for “quantizing” the pitch content of generated material before it is rendered. Since the CbCM often generates continuations based on interval patterns, rather than pitch patterns, deviations from the local key/scale were somewhat expected. However, a pitch quantization method would help reduce the cognitive load on users, and could be implemented using the existing algorithms from ManuScore’s “harmonic grid” link function.

A useful future development, which came to our minds during the present study, might involve the inclusion of methods for beat induction and metrical inference. Such methods would be useful for MusiCOG’s underlying music perception and cognition functions, and could also be used to periodically re-interpret the temporal grid of the score during creation. Such metrical interpretation could help the user avoid difficult transcription decisions after completing a score, and would also support the composer’s understanding of the structure of the work in progress. An extension of this functionality could allow ManuScore to transcribe standard music notation versions of the novice compositions, for export and printing, thus streamlining the process of moving from ManuScore to concert performance.
9. CONCLUSIONS
It is difficult to evaluate the role that CAC tools play in the compositional process; indeed, the influence of even the most ‘inert’ music notation software on compositional thinking is difficult to deny [2, 3, 4, 22]. ManuScore expands the field of CAC tools by augmenting common notation-based approaches with a more open conceptual design, and with the inclusion of corpus-based, generative capabilities. Although further validation of ManuScore is required, the user and listener studies outlined in this paper suggest that our goal of providing an interactive CAC tool, which enhances the compositional process, without disrupting the composer’s musical language, has been at least provisionally achieved.

10. ACKNOWLEDGEMENTS
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11. REFERENCES

THE SMUSE: AN EMBODIED COGNITION APPROACH TO INTERACTIVE MUSIC COMPOSITION

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ABSTRACT
The evolution of computer-based music systems has gone from computer-aided composition, which transposed the traditional paradigms of music composition to the digital realm, to complex feedback systems that allow for rich multimodal interactions. Yet, a lot of interactive music systems still rely on outdated principles in the light of modern situated cognitive systems design. Moreover, the role of human emotional feedback, arguably an important feature of musical experience, is rarely taken into account into the interaction loop. We propose to address these limitations by introducing a novel situated synthetic interactive composition system called the SMuSe (for Situated Music Server). The SMuSe is based on the principles of parallelism, situatedness, emergence and emotional feedback and is built on a cognitively plausible architecture. It allows to address questions at the intersection of music perception and cognition while being used as a creative tool for interactive music composition.

1. BACKGROUND
Interactive music has now become a standard feature of many multimedia systems and plays a fundamental role in contemporary art practice. Specifically, real-time human/machine interactive music systems are now omnipresent as both composition and live performance tools. Yet, the term “interactive music system” is often misused. The interaction that takes place between a human and a system is a process that includes both control and feedback, where the real-world actions are interpreted into the virtual domain of the system [4]. If some parts of the interaction loop are missing (for instance the cognitive level in Figure 1), the system becomes only a reactive (vs. interactive) system. As a matter of fact, in most of current human-computer musical systems, the human agent interacts whereas the machine due to a lack of cognitive modeling only reacts. Although the term interactivity is widely used in the new media arts, most systems are simply reactive systems [4]. Furthermore, the cognitive modeling of interactive multimedia systems, when it exists, often relies on a classical cognitive science approach to artificial systems where the different modules (e.g. perception, memory, action) are studied separately. This approach has since been challenged by modern cognitive science, which emphasizes the crucial role of the perception-action loop, the building of cognitive artifacts, as well as the interaction of the system with its environment [37]. In this paper we propose a novel approach to interactive music system design informed by modern cognitive science and present an implementation of such a system called the SMuSe.

2. FROM EMBODIED COGNITIVE SCIENCE TO MUSIC SYSTEMS DESIGN

2.1. Classical View
A look at the evolution of our understanding of cognitive systems put in parallel with the evolution of music composition practices, gives a particularly interesting perspective on some limitations of actual interactive music systems.

The classical approach to cognitive science assumes that external behavior is mediated by internal representations [6] and that cognition is basically the manipulation of these mental representations by sets of rules. It mainly relies on the sense-think-act framework [27], where future actions are planned according to perceptual information.

Interestingly enough, a parallel can be drawn between classical cognitive science and the development of classical music which also heavily relies on the use of formal structures. It puts the emphasis on the conductor.)