Teaching Computational Thinking through Musical Live Coding in Scratch

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ABSTRACT

This paper discusses our ongoing experiences in developing an interdisciplinary general education course called *Sound Thinking* that is offered jointly by our Dept. of Computer Science and Dept. of Music. It focuses on the student outcomes we are trying to achieve and the projects we are using to help students realize those outcomes. It explains why we are moving from a web-based environment using HTML and JavaScript to Scratch and discusses the potential for Scratch's "musical live coding" capability to reinforce those concepts even more strongly.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education — *computer science education, curriculum.*

General Terms

Design, Languages

Keywords

Performamatics, Scratch, computer science education, interdisciplinary courses, musical live coding, generative music, curriculum design.

1. PERFORMAMATICS BACKGROUND

Performamatics is a series of courses intended to attract students to computer science (CS) by tapping their inherent interest in performance and the arts. Toward that end, two CS professors have teamed with five Music, Theater, and Art professors to offer both introductory and advanced courses where assignments designed to reinforce CS concepts center around applications in the Arts. These courses are in the spirit of pioneering work done by Cooper, Dann, & Pausch [3], Guzdial [6], and Yanco et al. [15], and have been described in many other papers and presentations [5, 7, 8, 9, 12]. Readers are also referred to www.performamatics.com for links to online materials.

The most successful Performamatics courses to date (based on enrollment and student feedback) have clearly been the introductory ones. These are general education (GenEd) courses co-listed in two departments, allowing CS majors to earn Arts & Humanities GenEd credit while Arts majors earn Science & Technology GenEd credit. *Tangible Interaction Design* is a collaboration between CS and Art, while *Sound Thinking*, the course on which this paper focuses, is a collaboration between CS and Music.

2. SOUND THINKING

One of the hurdles in getting our first offering of *Sound Thinking* approved for dual GenEd credit was to convince the GenEd committee that Music majors would learn something about technology and CS majors would learn something about music. The committee feared that if project teams had both CS and Music majors, each group would naturally navigate to its own discipline and there might be relatively little true cross-over. We therefore established the following behavioral objectives for all students.

Upon completion of this course, students should be able to:

1. Identify properties of sound and describe the organization of sound into music.
2. Design a simple notation system and describe the differences between formal and informal notation.
3. Distinguish between analog and digital audio.
4. Discuss the basic differences between various audio file formats and sound compression techniques.
5. Create a web-based computer program that plays a music file.
6. Create a web-based computer program that plays a user-definable sequence of music files.

In the first half of the semester, students created compositions for "found" instruments, invented notations for those instruments, recorded the instruments' sounds, manipulated those sounds with audio editors, and remixed and recomposed the sounds into original compositions. In the second half, they created webpages that incorporated music, used a JavaScript Application Programmer Interface (API), and developed interactive web applications in which music played an integral part. Looking back, we see that objectives 1, 2, 5, and 6 held the most interest for students, and that's where we spent most of our class time.

Before the course was taught, there was much discussion among the Performamatics faculty about the development platform to be used for programming assignments. A CS professor said, "The Music majors will cringe if you make them code. You've got to use a visual programming environment." But a Music professor strongly disagreed, saying "One of our goals is to have them overcome any fear they have of code. We *want* them to see real code." Given that we thought students would enjoy creating webpages that they could share with their friends, we therefore chose Dreamweaver as our development platform, because it allowed viewing the page layout and its underlying code simultaneously. This helped students easily see the cause-and-effect relationship between the code and its result. We taught the basics of underlying HTML and JavaScript (with a custom API to play sounds and sound files), and only one of the 13 students had any real trouble doing the webpage development assignments.

On the contrary, most of the Music majors were very technically savvy and the post course student evaluations revealed that they wanted to know *more* about what was "under the hood." They enjoyed referring to the CS professor on the faculty team as a "magician" (because he could almost always make their pages do what they wanted when their CS partners were stumped), and they suggested that when the next the course is taught, the programming should be spread throughout the semester rather than confined to the second half.

We are now revising *Sound Thinking* for its next offering. With the help of students funded through a Research Experience for Undergraduates supplement to our NSF CPATH grant, we investigated a number of other platforms for use in the course. We have settled on Scratch [10, 11]. The remainder of this paper discusses why we feel that Scratch is an appropriate platform for teaching computational thinking through music.

3. MAKING MUSIC WITH SCRATCH

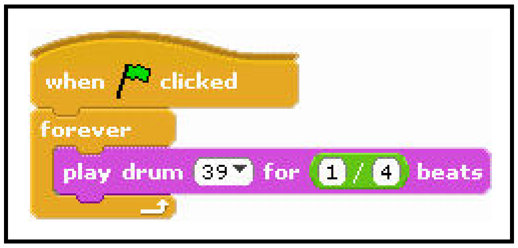
Scratch has the ability to generate and play sounds using various components in its Sound category. But if one wants to begin making *music* with more than one sound line in Scratch, one needs to address the issue of synchronization.

This issue is best addressed once students are familiar with looping, an essential concept in the implementation of many musical models. As students begin working with models where multiple voices are layered, it becomes necessary to maintain the tempo using the Scratch timer. Figure 1 shows a loop that will play a hand clap (MIDI drum instrument #39) every quarter of a beat. However, this example will not have a steady tempo, and if it was used to layer multiple voices, each would eventually fall out of synchronization.

The Scratch timer offers a way to address this problem. We first determine how many seconds our hand claps should be apart and then use the Scratch timer to control when each clap should occur. Figure 2 shows a more complex loop that will remain synchronized with the tempo regardless of the number of iterations performed. Each iteration waits until the Scratch timer reaches the value stored in variable now. This variable holds the time when a hand clap should sound. A message is then broadcast to play the hand clap. This ensures that the loop will complete and return to the "wait until" statement before the next hand clap needs to be played by delegating the actual playing to a "when I receive" event handler. The value of variable now is then changed to contain the time at which the next hand clap should be played. The Scratch timer ensures that the hand claps remain in tempo.

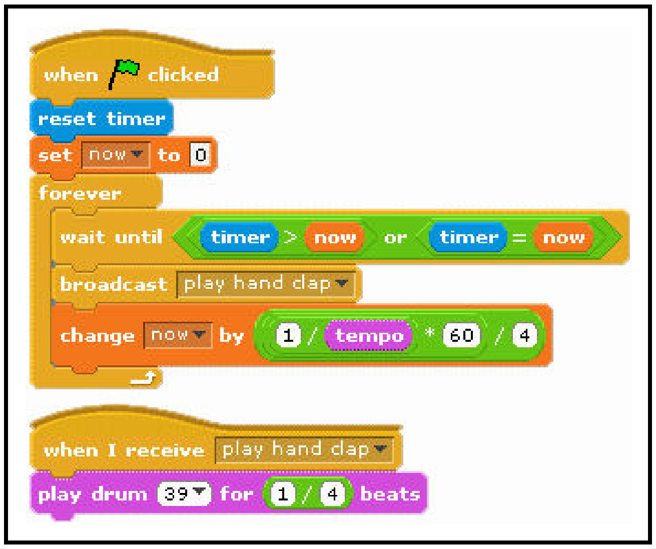
Note that in addition to synchronization, many other computational thinking concepts are touched upon by this example.

- looping
- initialization
- use of variables
- changing variables algorithmically
- modularization
- event processing



```
when [flag] clicked
forever
    play drum 39 for (1 / 4) beats
```

Figure 1. A hand clap loop.



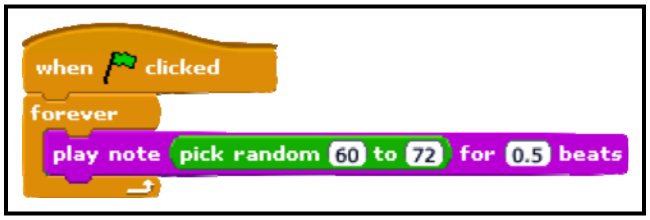
```
when [flag] clicked
reset timer
set now to 0
forever
    wait until <<(timer) > (now)> or <(timer) = (now)>>
    broadcast play hand clap
    change now by (((1 / (tempo)) * 60) / 4)

when I receive play hand clap
play drum 39 for (1 / 4) beats
```

Figure 2. Hand clap loop synchronized via the Scratch timer.

4. FROM CODE TO MUSIC

Once students understand basic note and sound generation in Scratch and can implement synchronization, more musical, generative algorithms for creating and manipulating sequences of notes can be explored.

One possible starting point is to use the "forever" loop to generate random melodies constrained by lower and upper boundaries as shown in Figure 3. In this example, random musical pitches from middle C (MIDI note #60) and the C above that (MIDI note #72) are chosen and played for half a beat. Because the "play note" function is surrounded by a "forever" loop, Scratch continues to generate notes until the Scratch stop button (●) is pressed.



```
when [flag] clicked
forever
  play note (pick random 60 to 72) for 0.5 beats
```

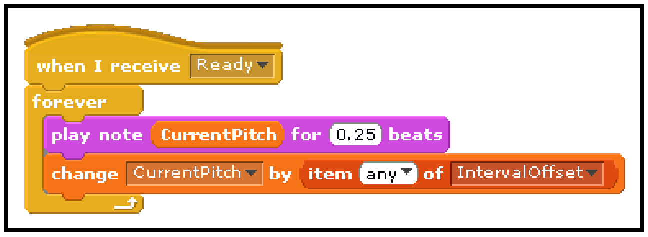
Figure 3. Code for a random melody by boundary constraints.

The fact that Scratch also functions as a live interpreter/compiler makes things more interesting. This feature allows the boundaries of the random pitches as well as the duration of the sound played to be manipulated in real time through "musical live coding" [2, 13, 14] without disrupting the sounds being generated. That is, the resultant melody can be changed in real time by adjusting the upper and lower bounds of the random function and changing the duration value for the beat without stopping program execution.

The code in Figure 3 can be expanded to generate a random melody from notes provided in a pitch set as shown in Figure 4. This code implements a Scratch "list" that contains a Pentatonic (five note) pitch set. It then selects a random note from that pitch set and adds a pitch offset (MIDI note 38). In a real-time performance, the pitch could be changed by manipulating the offset to move the randomly chosen notes higher and lower through the pitch register. Additionally, through the use of the "pick random" function, the bounds of the notes chosen from the Pentatonic pitch set could be further constrained. For example, if we wanted to choose only the 2nd, 3rd, or 4th note of the set, we could change the function to "pick random 2 to 4." This technique enables live coders to create more variety in the resultant musical output.

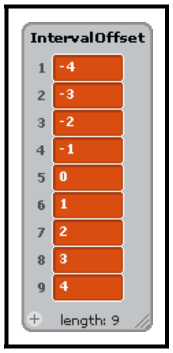
In most music, melodies do not move by random intervals. If one has a large pitch set, random intervals could result in very large leaps from one pitch to the next. A more natural sounding melody can be generated by implementing a "random walk" algorithm to change subsequent pitches as shown in Figures 5a and 5b. This results in a more musical melody by constraining the interval movement between -4 and +4 of the prior pitch. This approach also enables the melody to move freely across the MIDI pitch spectrum rather than to be constrained by the length of the pitch set as was the case in the prior examples.

Eventually, these techniques can be expanded to model the musical styles of various composers. Our initial explorations have centered on generating music in the style of Arvo Pärt and Philip Glass. Figure 6 shows a small part of a larger algorithm inspired by Arvo Pärt's *Stabat Mater* [1]. This example iterates through the AeolianPitchSet list (organized as a descending minor scale) to select pitches and then chooses random rhythm values from the RhythmSet list. The values of the RhythmSet list were derived from an aural analysis of the *Stabat Mater* and weight the probability of selecting a whole note twice that of selecting a half note. In the full algorithm, this code is duplicated twice to create three multithreaded musical parts that are triggered via keystrokes. The addition of human control to starting and stopping threads enables the performer to create dynamic variations in musical form and texture by starting and stopping sections of the overall code.



```
when I receive [Ready]
forever
  play note (CurrentPitch) for 0.25 beats
  change [CurrentPitch] by (item [any] of [IntervalOffset])
```

Figure 5a. Code for a melody via a "random walk" algorithm.

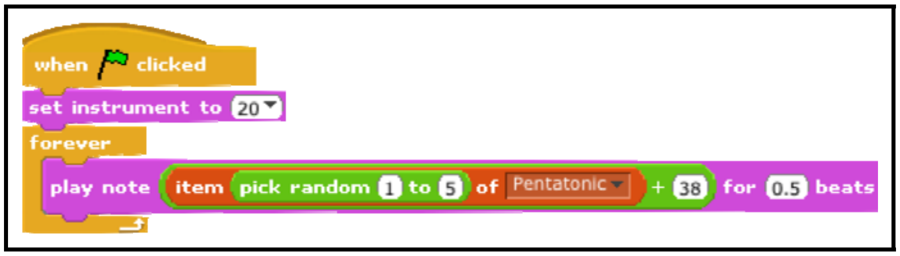


IntervalOffset	
1	-4
2	-3
3	-2
4	-1
5	0
6	1
7	2
8	3
9	4
length: 9	

Figure 5b. Interval list for use with the "random walk" algorithm.

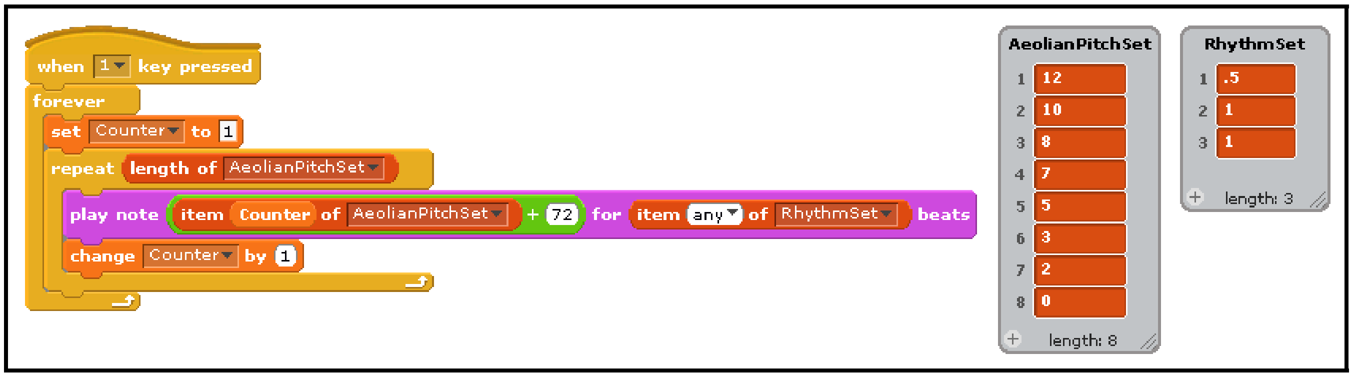
In addition to the live manipulation of lists, variables, and offsets shown in prior examples, Figure 6 also enables the selection of multiple pitch set lists, modification of the direction in which the list is iterated, and the ability to choose randomly or to isolate and repeat pitch values. Additional functions from the Scratch Sound and Numbers menus can be added, removed, and manipulated in real time to generate more musical control and expression. For example, a "change volume by x" function could be added to create changes in musical dynamics or to realize dynamic fading in or fading out of sections of the code. Additionally, a "change tempo by x" function could be inserted at various points to slow down or speed up the tempo. This could be set to a discrete value or by a mathematical function as shown in Figure 7.

Performing effective real-time manipulation of code (musical live coding) to create and shape generated music requires both musical and computational understanding. From a musical perspective, one needs to understand how the ongoing, generative music should sound. From a computational perspective, one needs to understand how the code can be adjusted and manipulated in real time to achieve the aural and musical changes and outcomes one



```
when [flag] clicked
set instrument to [20]
forever
  play note ((item (pick random 1 to 5) of [Pentatonic]) + 38) for 0.5 beats
```

Figure 4. Code for a melody from pitch and rhythm set lists.

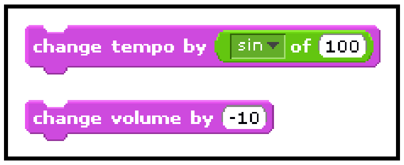


```
when 1 key pressed
forever
    set Counter to 1
    repeat length of AeolianPitchSet
        play note item Counter of AeolianPitchSet + 72 for item any of RhythmSet beats
        change Counter by 1
```

AeolianPitchSet	
1	12
2	10
3	8
4	7
5	5
6	3
7	2
8	0
	length: 8

RhythmSet	
1	.5
2	1
3	1
	length: 3

Figure 6. Melodic code inspired by Arvo Pärt's *Stabat Mater*.



```
change tempo by sin of 100

change volume by -10
```

Figure 7. Examples of built-in Scratch functions well suited to musical live coding.

desires. These are advanced skills, but they can be learned through experimentation and exploration that is both educational and fun. Scratch provides a unique, easy-to-learn platform that enables musical live coding by allowing nearly all aspects of the code to be adjusted in real time. Students can then share and showcase their work in live or pre-coded performances, which is the essence of Performamatics.

5. ADDING A TANGIBLE INTERFACE

As the course develops, we plan to integrate tangible computing using IchiBoards [4] (Figure 8). Using these devices' live sensing capabilities, we can implement gestural musical input and design new instruments to perform musical algorithms implemented in Scratch.

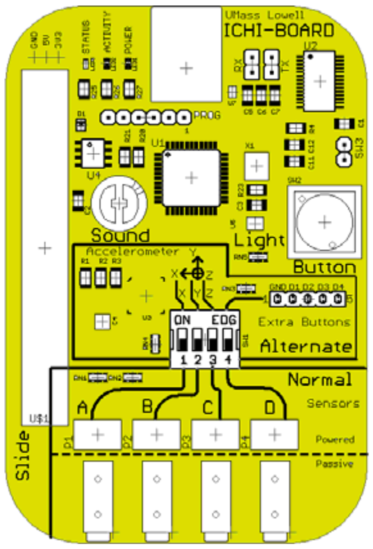
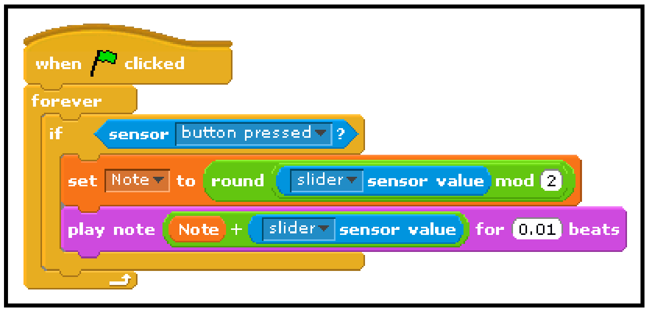


Figure 8. IchiBoard [4].

Figure 9 shows a simple program that converts an IchiBoard into a musical instrument. A "forever" loop is used to enable continuous live sensing of the board's button and slider sensors. When the button is pressed, the slider value is read and a note is played whose pitch corresponds to that value. Computational thinking comes into play because the IchiBoard's slider returns values between 0 and 100. To convert those values to a 7-note whole tone musical scale in which each interval is two equal half-steps apart, the value returned by the slider is combined with a copy of itself on which a modulus 2 operation has been applied. This ensures that when the slider is moved, the pitch of the note being played always jumps by a whole step rather than a half step. With the beat value set to 0.01, a continuous stream of pitches sounds when the button is pressed. The result is a surprisingly expressive instrument with which the user can establish a rhythm through interaction with the button and play gestural pitch sweeps through manipulation of the slider.



```
when clicked
forever
    if sensor button pressed ?
        set Note to round slider sensor value mod 2
        play note Note + slider sensor value for 0.01 beats
```

Figure 9. Code for a simple IchiBoard musical instrument.

The previous example only takes advantage of two of the eight possible sensor inputs on the IchiBoard. More complex interface configurations and Scratch code are currently in development that will enable more interesting musical performances and live coding demonstrations of computational thinking.

The integration of IchiBoards as an interface for tangible computing enables discussion of CS hardware concepts such as:

- What is a device?
- What is a sensor?
- What is a signal, and how is it detected in software?
- What is an event, and how is it detected in software?
- What different types of events are triggered by various devices (real and virtual)?

Integrating physical computing with Scratch's graphical coding environment provides a unique platform for expressive computing in real time. Programs can not only be written to create music, but they can be written to model musical environments that are performed through musical live coding or the design and interfacing of tangible computing devices such as the IchiBoard.

6. INTERDISCIPLINARY BENEFITS

After taking *Sound Thinking* in the Spring 2009 semester, Music major Charles Saulters developed a strong interest in using computational thinking as a means of developing more expressive gestural music controllers. He pursued a Research Experience for Undergraduates with us over the summer, exploring ways to apply these Performamatics concepts in even more exciting ways. He describes his work as follows.

> I am interested in enabling others to achieve more than they ever thought possible through the use of computational thinking in real world situations that are relevant and interesting to students. One "hook" that I found particularly interesting is the manipulation of virtual instruments, composing for and performing using nontraditional devices such as the iPod Touch. Now more than ever, we musicians find ourselves in an age where technologically almost anything is possible. It is therefore crucial that we understand what makes computers function and acquire a strong working knowledge of programs and the coding behind them.
>
> Interdisciplinary collaboration helps cultivate new and exciting innovations that can bring about the revitalization of CS education for which Performamatics was conceived. Using music as a hook, we can create innovative live performances and interesting visuals in conjunction with "musical live coding" to tap the imagination of people who might never have considered CS as a possible major. People (like myself) tend to be intimidated by the mystifying technical jargon. However, with more exposure to interesting multi-disciplinary projects, students can start thinking computationally and actively using that new way of thinking in a hands-on way without even realizing they are doing so. At that point, the fear is gone.
>
> Devices such as the iPod Touch and iPhone are ideal tools for exploring computational thinking. They are easy to use, have simple, intuitive user interfaces, and have a wide range of functionality: file transfer, web browsing, MIDI control through accelerometers, light sensors, microphones, and touch sensors.

While no Scratch interface to iPhones or iPods yet exists, these sensor-rich input devices have tremendous potential as expressive interfaces to musical live coding and performance. We see our work in integrating IchiBoards into *Sound Thinking* Version 2 as an initial step in providing these benefits.

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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