THE INFORMATICS PHILHARMONIC IN NEW MUSIC

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ABSTRACT

This paper describes our ideas and experience using a musical accompaniment system — the Informatics Philharmonic (Info Phil) software application — in new compositions that combine live performance on an acoustic instrument with computer-generated sound.

Using this system, we adapted three compositions of Jacob ter Veldhuis ("JacobTV") for solo instrument and tape: *Billie*, *Garden of Love*, and *Farewell Feathered Friends*. We will discuss our experience adapting these works, and analyze the adapted versions in terms of enabling the longevity of the composition, musical effect, and performance ease. Lastly, we show how the Informatics Philharmonic technology can be extended to include other programs, such as Max/MSP, to allow virtually unlimited interaction between a soloist and recorded or live-processed sound.

1. INTRODUCTION

Since the 1950s, many composers have chosen to combine acoustic and electronically-generated musical material. Early examples such as Stockhausen's *Gesang Der Junglinge* utilized a completely fixed format, meshing recorded vocal lines with processing and generated sounds [1]. For many decades composers have also incorporated live performers with pre-assembled tape tracks. For example, Steve Reich's *Different Trains* joins a live string quartet with tape composed from processed vocal material and train sounds, and Thea Musgrave's *Niobe* pairs solo oboe with tape containing high vocal-like lines and bells. Unlike completely fixed works, these *mixed* works can vary from performance to performance based on the live player's expressive input. The performer is still entirely responsible for coordinating with the tape, but such pieces need little technological infrastructure; usually only a microphone, playback device and speaker are required for a successful concert.

Another popular mixed composition paradigm combines live acoustic performance with *interactive* electronics. Works such as John Chowning's *Voices*, Pierre Boulez's *Antemes* and George Lewis's *Emergent* pair a live acoustic soloist with electronics that distort and react to their playing in real time. This type of composition allows direct interaction between players and electronics, but often requires nontrivial technological setup and execution. Unless the composer is present at a performance or the performer is especially technology-literate, these complex setups can serve as a barrier to a work's accessibility [2].

The development and maturation of real-time score following technology has brought exciting possibilities to the world of mixed composition. Introduced by Dannenberg and Vercoe in the mid 1980s [3, 4], score following allows a computer to know a player's position in a predetermined score at all times. New music compositions which incorporate score following take different approaches. For example, *Tensio* by Phillip Manoury has a "live media" approach, using the IRCAM Antescofo score following system to automatically trigger electronic events and real-time audio processing in intricate response to a live string quartet [5, 6].

Another approach, advocated by the authors, builds on top of score following by adding a model for musical timing. In the Informatics Philharmonic (Info Phil) software [7], a musical timing model translates the onset times of each soloist note into a continually-evolving prediction of future musical evolution. This model allows the system to coordinate through prediction, rather than response, representing the most important difference between our work and that of IRCAM. These predictions can be used to drive a MIDI accompaniment or to continually modify the playback speed of a pre-recorded accompaniment track. In this context performers are free to choose their tempo at all times, closely simulating the experience of playing with human collaborators.

Examples of this approach in new music include Nick Collin's *Concerto for Accompaniment* for oboe and computer-controlled piano [8]. Collins wrote this piece explicitly for the Info Phil, composing a piano part that was not "humanly performable" then using the Info Phil to synchronize MIDI-generated piano with a live player. Jan Beran also wrote a series of works for Info Phil utilizing a similar approach [9]. A hallmark of these pieces is the use of the unlimited technical virtuosity of the computer, including unplayably fast passages and highly complex rhythms such as simultaneous groups of 7 and 11.

In Fall 2019, we approached Dutch composer Jacob ter Veldhuis — "JacobTV" — about adapting his work *Garden of Love* (2002) for oboe (or soprano saxophone) and tape to work with the Info Phil. He and a longtime collaborator, saxophonist Connie Frigo, suggested we also adapt *Billie* (2003), a jazz-based piece commissioned by Frigo for alto saxophone and tape. Frigo premiered the Info Phil adaption of *Billie* at the 2020 North American Saxophone

Figure 1: Given a spectrogram of the accompaniment tape and a full score, one can use Info Phil to create a marked track with accompaniment entrances, soloist entrances, and other temporal information.

Alliance (NASA) Biennial Conference. In Summer 2020, we adapted *Farewell Feathered Friends*, a piece composed by JacobTV during the COVID-19 pandemic for piccolo and tape. Our version was premiered at the recital of Jamey Guzman, a master's student at the Jacobs School of Music at Indiana University, Bloomington (JSoM).

2. PROCESS

2.1 Informatics Philharmonic Overview

We will start by discussing the considerations and capabilities of the Info Phil score-following and AI accompaniment software [7]. While the Info Phil can produce MIDI-generated accompaniment, the most common use case involves a prerecorded accompaniment track. Using audio time-stretching techniques, the track is resynthesized in real time to follow a soloist.

2.1.1 Requirements and Operation

The Info Phil requires two items to create its reactive accompaniment: a recording of the accompaniment alone and a full score in symbolic notation. We first generate an "index" into the accompaniment audio by performing offline polyphonic score alignment, followed by some degree of manual adjustment. When this phase is complete, each note in the score is matched to its corresponding time point in the accompaniment recording. See Figure 1 for a visual representation of this process. After this marked accompaniment information is loaded into the Info Phil application, a player simply needs to press the "play" button on the Info Phil's GUI interface to start reactive accompaniment playback.

2.1.2 Score Following and Soloist Prediction Model

During rehearsal or performance, the Info Phil uses a Hidden Markov Model(HMM)-based online score follower to analyze the soloist's movement through the score in real time. In this method, the soloist's audio is read into the Info Phil as 30 milisecond frames. The HMM model relates the sequence of "heard" frames to the sequence of notes making up the monophonic soloist part, allowing the Info Phil to continually determine the performer's position in the marked score. An additional layer — the timing model — uses this information to predict when the soloist's next notes will occur. The track's playback rate is then sped up or slowed down through phase vocoding to maintain the correct rhythmic relationship between solo and accompaniment.

A high-level example showing how the Info Phil's audio recognition and prediction systems work together in real time can be seen at this link: `http://www.music.informatics.indiana.edu/~craphael/info_phil/info_phil_2012/Maria_RC.mp4`, which shows an Info Phil-based performance of the 4th movement of Lalo's *Symphonie Espagnole*.

2.1.3 Training

The Info Phil will also learn from a player's past performances, should they choose to "train" on that data. Information about the player's past tempo tendencies allows the Info Phil to better anticipate their future interpretation by estimating free parameters of the timing model.

2.1.4 Audio Stretching and Compression

The Info Phil utilizes a generic variety of phase vocoding which does not distinguish between pitch and noise-based content. This means that when the soloist plays at a different tempo from the original accompaniment recording, the speedup or slowdown in accompaniment playback rate is the same regardless of what content is being stretched or compressed. A side effect of this phase vocoding strategy is that noise-based sounds which should take the same amount of time regardless of tempo (e.g. percussion, wind entrances, and non-traditional music elements like found sounds and birdsong) are altered to be faster or slower than their normal length. Usually this change is not noticeable to the human ear, but may sometimes sound unnatural when extreme playback rate changes are applied.

We found that training the system on previous performances was generally effective in decreasing these arti-

facts. Usually, the most extreme shifts occur when the Info Phil encounters a player's note in an unexpected location, then must quickly move through the audio track to re-align. Training allows the Info Phil to learn the player's tendencies, and thus helps protect against extreme track modifications likely to result in artifacts.

2.2 Adapting Fixed Media Works

In adapting JacobTV's music, the track marking process described in Figure 1 is complicated by his extensive use of hard-to-notate sound sources like spoken voice and birdsong. The Info Phil was constructed for traditional Western art music, thus assuming discrete pitches and "rational" rhythm. Birdsong and spoken voice have many microtonal shifts and slides, and thus are hard to notate within a traditional written music framework.

Fortunately, JacobTV's score already converted these sounds to notes and rhythms in order to help the soloist better interpret their rhythmic relationship with the accompaniment track. Since this notation was meant as a performer's guide rather than an absolute specification, the track labeling process in Figure 1 was only semi-automatic, relying heavily on manual input.

This indirect way of translating voice and birdsong into absolute rhythms also has another effect: the "true" rhythm specification is a compromise between the written score and the tape track. In JacobTV's music, live players often need to play in unison with birdsong or voice. In the preface to *Billie*'s score, Connie Frigo explains that in these cases, if a player finds slight deviations between the notated rhythm and Billie Holiday's voice samples, they should always assume the audio recording is correct and alter their rhythm to match vocal inflections. This performance practice poses a potential issue for Info Phil adaptation. Since the program bases its behavior on the score, it only seeks simultaneity between a solo event and an accompaniment event if both events are explicitly notated at the same score position. To combat this issue, we edited the score so true simultaneous sections always had equivalent rhythmic notation. As long as the birdsong or voice "notes" occur at the same rhythmic positions as soloist notes, the Info Phil tries to align these events during performance.

3. JACOBTV'S PIECES

3.1 Garden of Love

Our first adaptation was *Garden of Love*, originally for oboe and tape, though now more well-known as a piece for soprano saxophone. Based on the poem "Garden of Love" by William Blake, the piece uses spoken audio samples to create rhythmic "voice melodies." JacobTV combines these vocal samples with synthesized sixteenth notes and birdsong to create a driving, high-energy, at times mechanical piece. While rehearsing *Garden of Love* we observed that the Info Phil facilitated the performer's task by allowing pauses to enable breathing and otherwise assisting coordination. Since the original version requires almost continual playing to keep up with the tape, we found

that slight breaks between sections made playing the piece a more enjoyable experience. We also noticed that the Info Phil was able to automatically get back on track when the soloist made rhythmic or timing errors.

This sense of performance ease was reinforced by Wes Taylor, a JSoM saxophone student whom we worked with. He appreciated that similar to performing with a live accompanist, the Info Phil allowed computer and human to share the responsibility for coordinating their parts instead of the player being solely responsible. While the Info Phil makes things easier for the performer, the composer had mixed feelings about the adaptation. The majority of *Garden of Love* is characterized by a relentless, mechanical "groove" created from synthesized midi sixteenth notes or cut-up voice samples. Since mechanical precision is important for the character of the piece, the flexibility allowed by the Info Phil may be somewhat at odds with musical intent. We will return to discussing this issue in Section 4.

3.2 Billie

Billie, for alto saxophone and tape, incorporates a similar "voice-melody" approach to *Garden of Love* using samples from rare interviews with jazz singer Billie Holiday. However, since the piece is jazz-inspired and more relaxed, there was more room for tempo variation than in *Garden of Love*. We found that in *Billie*, freedom with timing led to new expressive possibilities. Frigo observed that playing with the adapted version gave her the impression of a "real-time conversation" with Billie because she could "flex the soundtrack in response to what she was saying." Frigo was also able to change the emotional impact in certain sections of the piece. She stated that choosing slightly different tempos from the original can "change the character of Billie's voice. It can create more anxiety, it can make the speech sound more laid back, or nonchalant, stressed..." JacobTV further commented that "with this technique, you could be a stage director, telling Billie to get more excited, or irritated, or angry ... this person, Billie Holiday, comes alive through the speed Connie picks for the piece."

The character shift described by JacobTV and Frigo is clear when comparing the two different ways Frigo performed measures 21-26 of *Billie* at the NASA conference. The audio at `https://drive.google.com/file/d/1SFzXUInAHG9aukAuUxovLZzcBd6M3aeF/view?usp=sharing` shows Frigo first playing this section with the fix track, then with the Info Phil. The version with the original track, constricted by a fixed tempo, is calm, steady and deliberate. In the flexible version, Frigo chose to first accelerate, creating a sense of agitation, then slow down at the end of the phrase to give a sense of release. A link to her full performance and our talk at the NASA Biennial Conference can be seen at `https://vimeo.com/407549620`. Frigo preceded her "real" performance at the conference with a rather wild interpretation, demonstrating the high degree of flexibility supported by the Info Phil, though also raising questions about how the technology should work in tandem with musical considerations.

While performer and composer were both positive about

the performance at the conference, we did note some skepticism from at least one conference participant regarding the musical appropriateness of making the piece more flexible. *Bille* is well-known to the saxophone community, and the accompaniment recording released with the piece has enforced a high degree of conformity in the way it is performed since one cannot stray from the tape track's timing. We wondered if the preference by some for a more mechanical interpretation of *Billie* was simply the gravitational pull of what is familiar.

3.3 Farewell Feathered Friends

At its best, Info Phil adaptions allowed for the tight synchronization required by JacobTV's works without constricting the player to a fixed temporal interpretation. This advantage was most striking in our third adaptation, *Farewell Feathered Friends* for piccolo and tape. The tape track of *Farewell Feathered Friends* prominently features birdsong from seven species of endangered European birds. The piccolo often sounds much like another bird, in either conversation or in synchrony with the recorded birdsong, though perhaps more lyrical. The Info Phil version was performed by JSoM student Jamey Guzman, who enjoyed how the timing freedom in this version allowed her to respond to the birdsong. She commented in her recital introduction that "[the Info Phil] truly lets me lead and express the emotions in the piece without feeling locked into the same tempo every time like in a traditional fixed media piece." Guzman's performance can be viewed at `https://drive.google.com/file/d/1RbgunOAdcGy2oX9c8S0CyMQOTVh0ha5A/view?usp=sharing`.

4. OUR EXPERIENCE WITH JACOBTV'S MUSIC

Through our experience creating and working with the Info Phil adaptions for *Garden of Love*, *Farewell Feathered Friends*, and *Billie*, we have gained a deeper understanding of the advantages and questions raised by this new musical medium. Our observations coalesced into two main issues to consider when deciding among performance options for a tape piece.

4.1 Longevity

One of the biggest barriers to wide performance of live media pieces is the complexity needed to set up and perform live electronics. Often, the composer, or another individual familiar with the work's construction, must be personally involved in the performance, as expressed in Bruce Pennycook's article, "Who will turn the knobs when I die?" [2]. Using the Info Phil to control an originally fixed track offers the interactivity associated with live media with comparatively easy setup. Our work with Guzman and *Farewell Feathered Friends* is a good example. As a result of the COVID-19 pandemic, we were unable to offer Guzman in-person technical support. We only met once to give her necessary equipment: a pair of speakers and a Mac computer installed with the Info Phil software. Despite these less-than-optimal circumstances, Guzman was

able to successfully run the program by herself during both rehearsals and her performance. As one can see in video of Guzman's performance in Section 3.3 , Info Phil usage is very straightforward; once the program starts, no external input from the performer or a technician is necessary. That said, the traditional non-interactive performance strategy of mixed music with fixed tape is nearly unbeatable in terms of facilitating a composition's longevity.

4.2 Learning vs. Performance

We observed that the performer's experience with the Info Phil could be divided into two categories: the *learning* process and the *performing* process. The players we collaborated with had a range of familiarity with JacobTV's music. Some, like Frigo, had performed the fixed media version of *Billie* for more than a decade. Others, like Taylor and Guzman, had just started their experiences with *Garden of Love* and *Farewell Feathered Friends*. All these collaborators brought engaging perspectives on their experiences performing and learning these works with the Info Phil.

4.2.1 The Info Phil as a Learning Tool

Taylor first started learning *Garden of Love* with the fixed track two weeks before trying the Info Phil version. He observed that the ability to practice sections with the accompaniment at a slower-than-marked tempo was a major benefit. Specifically, a slower tempo allowed him to pay attention to technical aspects of playing like tuning and rhythmic precision. He noted that "much like putting a piece together with a piano, you always start slow so you can find alignment between both parts, tuning issues, and work on passing off melodic lines . . . Being able to take sections at slower tempi [with the Info Phil] allowed for me to work on the same things." Aside from these technical improvements, Taylor also gained new insight on *Garden of Love*'s musicality, finding "grooves in sections [he] was not previously aware of." Lastly, Taylor found that the flexible version of *Garden of Love* allowed him to gain a deeper understanding of the relationship between the solo and accompaniment parts:

> "Another advantage of being able to play through Garden of Love at a slower tempo was that it helped ingrain different parts of the track in my head. I walked out of the office that day with a much better idea of how the piece was constructed, how it was supposed to sound, and what aspects of the track were helpful to me as a performer. I definitely would say I learned more about the piece in those two hours than I did in the 2-3 week window prior in which I was learning it [with the fixed track]."

Thus a big potential benefit of the accompaniment system is in *learning* the piece at hand, whether or not one chooses to perform that way.

Having premiered Billie in 2003, Frigo had a different perspective on the learning process. Her experience with

the Info Phil version involved adjusting previous expectations playing with fixed track to work with the new, flexible format. Frigo was concerned saxophonists who only used the Info Phil to learn Billie could use the flexibility as a "crutch." When playing fixed media pieces, even rehearsing the work requires one to be intimately aware of how the solo part fits within the accompaniment track. But since the Info Phil is resilient to rhythmic mistakes, one can play the piece from start to finish without a robust understanding of the accompaniment. When asked whether one should learn from the fixed track or the flexible version, Frigo stated:

> "The reason I can be so flexible, even when experimenting, is because I know the soundtrack so well. And if you don't know the soundtrack, you're not actually aware of what you're playing with. When you play with fixed [track], you get to know there's a note right here, there's a cymbal here, a bass note here ... and if you don't know that, it's just like going into a rehearsal with a pianist without doing score study in advance .... [First practicing with the fixed track] would be a requirement just to give justice to the piece and understand how to create spontaneity within it."

In summary, Taylor noted a contribution the Info Phil brings to *learning* new pieces, though Frigo expressed some skepticism that this contribution could be abused. Of course, the fixed-media approach — playing along with a recording, is a time-honored way of learning the interrelations between parts, as well as introducing young musicians to the coordination demands of ensemble playing. However, we note an important problem with learning from fixed recordings. When the live player starts to lose track of her place in the larger structure, things often fall completely apart, with the live player unable to find her way back. In contrast, the Info Phil is more tolerant, able to help the player recover from a moment of uncertainty without getting irretrievably lost, potentially leading to a more robust experience.

4.2.2 Performing with the Info Phil

We consistently observed that the Info Phil makes the process of performing a fixed media piece significantly easier. The program is an equal partner in creating a synchronous performance, rather than putting this burden entirely on the soloist. For instance, the program allows a wind player to breathe in a more natural way, and supports, rather than punishes, the temporary glitches that pervade nearly all human performance scenarios.

On a deeper level, it solves the biggest challenge of playing with fixed media: making the performance sound spontaneous and interactive instead of constricted by a predetermined set of timing requirements. Though a skilled performer can create the impression of interactivity within a fixed tape framework, considerable virtuosity and familiarity with the work is necessary to sustain that illusion [2].

Even if one successfully projects the illusion of freedom with a non-interactive accompaniment, it can still make the performer feel like a puppet, tightly controlled by external strings. By fostering the performer's feeling of immersion and flow, the Info Phil can contribute to the their overall sense of comfort.

But are all types of music suitable to this flexible format? The Info Phil was originally conceived with the Romantic solo work in mind. Here the soloist may *lead* a pianist or ensemble using flexible timing, among other means, to make the music expressive. This leader-follower model is a reasonable approximation for a lot of solo music, while the recognition of these asymmetric roles is commonly acknowledged in discussions about music performance. However, from a different perspective, the leader-follower model seems even more justifiable in a human-machine musical collaboration since only one of the two performers actually cares what happens, or is fit to judge the level of success. Of the pieces we adapted, not all made these same implicit assumptions of fluid timing and leader-follower roles. Most notably, *Garden of Love*'s driving, metronomic tone felt at odds with the flexibility afforded by the Info Phil. Since rigidity is a key musical component, the added flexibility, while making the performance easier for the human, may work against the piece's aesthetic nature.

Of course there are a great many pieces of music that seem to require an unrelenting steadiness on the part of the performers, such as marches and perpetual motion pieces. Even if one accepts that inflexible timing is indeed the musical objective, there is still some subtlety in understanding the appropriateness of a flexible accompaniment system like the Info Phil. The accompaniment system does not keep the player from performing with robotic precision, so one can still pursue this inflexible musical agenda if desired. On the positive side in such a case: since the player, being human, will not succeed in being perfectly accurate, the accompaniment system will accommodate the small and inevitable inconsistencies. On the negative side, there will always be small inaccuracies in the system's identification of note onset times played by human musicians, thus drawing the accompaniment away from metronomic performance. The tension between these two issues creates a subtle tradeoff that, ultimately, must be decided by personal preference.

One of our subjects, Taylor, had played *Garden of Love* with both fixed and flexible tracks, thus was poised to make comparisons. He mentioned that while practicing with the fixed track, certain entrances were very stressful because an initial alignment misjudgement on his end could compromise the rest of the section. When playing with Info Phil, he was able to start sections without worrying about alignment issues. Energy not spent anticipating a tricky entrance can be instead focused on expressive or stylistic playing; Taylor commented that "this security allowed me to focus on playing my part at a higher level".

Even when tight synchrony between soloist and accompaniment is a decidedly good thing, as we believe to be the case in the overwhelming majority of Western solo music,

the issue still has its subtle side. While synchrony may be a desirable objective, it is not the only objective. A good accompanist seeks to preserve the internal consistency in her part, while, at the same time, staying with the soloist. These objectives often come into tension and cannot be resolved in any obvious way, though good musicians seem to successfully navigate this challenge all the time. We do not have a ready answer to this issue, except to observe that the Info Phil is among the first generation of accompaniment systems. We cannot resist recommending this problem as an unsolved challenge for the future development of accompaniment systems, since we certainly hope that the Info Phil will not be the last word on the subject.

5. GENERALIZING BEYOND FIXED-MEDIA COMPOSITIONS

Though the examples we investigated in this paper all involve adapting fixed-media works, e.g. recordings of "accompaniment," Info Phil technology can be extended to form a more general-purpose framework for new compositions using acoustic instruments and computer-generated sound. Here our presumption is that the live player would *lead* the performance, introducing an element of spontaneity and musicality sometimes missing from computer-only music. However, we still leave open limitless possibilities for both computer-generated sound and live processing/modification of the soloist's audio. In this way we hope to allow both human and computer to do what they do best. Ideas along these lines have been pursued at IRCAM, as with Manoury's works such as *Tensio* [6], though we seek to establish a portable implementation that would allow anyone to write or play such a piece without requiring a detailed knowledge of our system's inner workings.

The score to such a composition would be similar to a traditional Western score in some fundamental ways. The solo part would be notated with traditional rhythm and pitch, with a best approximation given for extended techniques like multiphonics, flutter-tonguing, quarter tones, etc. that do not fit neatly into traditional pitched notation. Notation whose timing might be represented in seconds could easily be translated into a traditional rhythmic scheme as well. We grant that there may be some musical elements in the solo part that are awkward to represent in traditional notation. However, the Info Phil understands its flexible timing as the warping of traditional rhythm through a time-varying tempo process, so we are bound to this rhythmic representation. Furthermore, we expect that the downside of using traditional notation for the solo part is just that it over-specifies musical notions that are not so precisely conceived, e.g. music without pulse naturally expressed in seconds.

Like the soloist's part, the computer's part is also represented in terms of traditional rhythm. As described in Section 2.2, it must clearly show all points of coincidence with the soloist as well as any other intricate rhythmic interrelationships . However, the important issue of what the computer will *do* at each rhythmic location is left open – what happens at these points will be "filled in" by the composer. Every rhythmic event in the computer part could be

assigned to one or several actions, where potential actions include triggering playback of pre-recorded audio; recording soloist audio; processing soloist audio via filtering, harmonizing etc.; or terminating any of these processes. Ultimately, the computer's part is simply a list of actions that must be run when the associated musical times occur.

How is this list of musical actions executed? Just like performing a fixed accompaniment, the Info Phil listens to the traditionally-represented solo part, predicting solo note onset times as the performance evolves. Using these predictions, Info Phil creates a "scheduler" which continually updates the predicted times of future accompaniment events. Specifically, at any point during the performance the Info Phil focuses on the *currently pending* computer event — the first as-of-yet unperformed computer action. As solo note information is accumulated, this pending event will be scheduled and rescheduled, making use of all currently available information. To see the scheduling process in action, see the Lalo video referenced in Section 2. In this example and JacobTV's fixed media pieces, these predicted events are used to determine the amount of time stretching necessary to stay aligned with the soloist. However, in the context of the proposed live media system, the predicted time of each pending event will be used to directly trigger musical actions in the computer part. In practice, the program that implements the computer's part simply receives the scheduled and rescheduled event times from the Info Phil, acting when the currently-scheduled time finally arrives. A visual representation of how this scheduling mechanism could work in tandem with live media processing can be seen in Figure 2.

It is worth contrasting this paradigm for acoustic-computer compositions with the frequently encountered one in which an operator — often the composer themselves — must perform an intricate, and sometimes terrifying, sequence of button presses, slider movements, etc. in a virtuosic dance with the live performer. We seek to simplify the performance of such a piece to a more generic and less human-dependent model, thus making a composition more portable and potentially longer-lasting. We have not yet implemented this scheme, but envision that we could create an integrated Max patch encapsulating the listening and scheduling functionality of the Info Phil. This would eliminate potential communication lag between the Info Phil and Max/MSP, as well as simplifying inter-process communication.

Besides live composition, this general workflow can also apply to other domains where events are scheduled based on a pre-determined score. Possibilities include opera supertitles, or automatically controlling stage lighting and projected backgrounds for performances with audio and visual components.

We were able to prototype this live media triggering pipeline by adapting the music video for *Billie* to work with the Info Phil. During *Billie* performances with the original tape track, players have the option of simultaneously projecting a video where visual changes align with specific beats. Since our flexible renditions of *Billie* deviate from the tape's pre-determined tempos
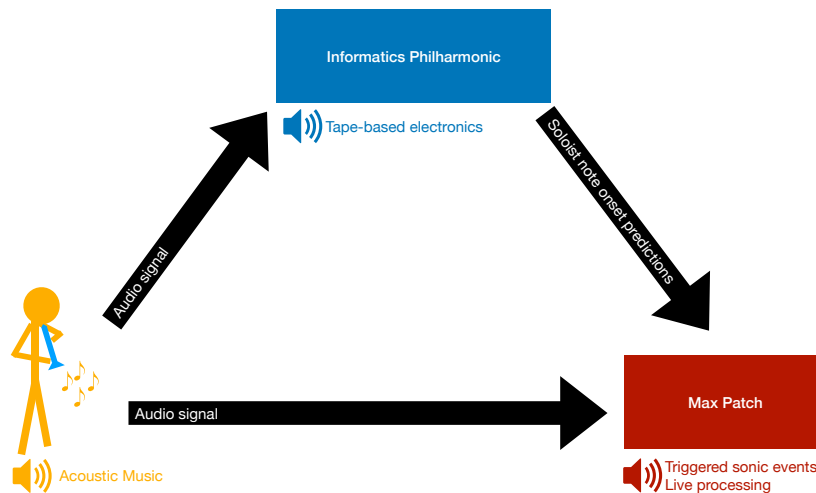
Figure 2: Schematic of information flow in pieces combining acoustic soloist, flexible tape, and live processing. Audio data from the soloist is first processed by the Info Phil to produce flexible, tape-based electronics. The Info Phil then sends times of projected accompaniment events to an external Max patch. The Max patch can serve the dual purpose of both directly processing soloist audio and triggering changes based on the player's position in the score.

and rhythms, the original video could no longer be used during performance. A new way of displaying video was needed to match the player's real-time decisions. We created a responsive video by linking the video's playback rate to scheduling information from the Info Phil. That is, the Info Phil sends messages in the form "player will reach score position *x* at time *y*" to a Max patch. When the Max patch receives such a message it resets its video playback rate so that the musical position (beats) will be reached at the desired time (seconds). A demo can be seen at `https://drive.google.com/file/d/1fq_XTW6pg-ywjt8NWTIG1cDetNCu2irH/view?usp=sharing.`

Our last word is a call to composers to write the kind of piece that can be implemented in the manner we describe. We invite such collaborations and look forward to seeing them take shape in the future.

Acknowledgments

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