

Enabling Participants to Play Rhythmic Solos Within a Group via Auctions

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Abstract. The paper presents the interactive music system SoloJam, which allows a group of participants with little or no musical training to effectively play together in a “band-like” setting. It allows the participants to take turns playing solos made up of rhythmic pattern sequences. We specify the issue at hand for allowing such participation as being the requirement of *decentralised coherent circulation* of playing solos. This is to be realised by some form of intelligence within the devices used for participation. Here we take inspiration from the Economic Sciences, and propose this intelligence to take the form of making devices possessing the capability of evaluating their *utility* of playing the next solo, the capability of holding *auctions*, and of *bidding* within them. We show that holding auctions and bidding within them enables decentralisation of co-ordinating solo circulation, and a properly designed utility function enables coherence in the musical output. The approach helps achieve decentralised coherent circulation with artificial agents simulating human participants. The effectiveness of the approach is further supported when human users participate. As a result, the approach is shown to be effective at enabling participants with little or no musical training to play together in SoloJam.

Keywords: active music, collaborative performance, conflict resolution, algorithmic auctions

1 Introduction

In many musical cultures and genres there is often a large gap between those who *perform* and those who *perceive* music. In such ecosystems, the performers (musicians) *create* the music, while the perceivers (audience) *receive* the music [11]. Even though perceivers may have some control of the music creation in a concert situation, by means of cheering, shouting, etc., this only indirectly changes the musical output. The divide between performer and perceiver is even larger in the context of recorded music, which is typically mediated through some kind of playback device (CD, MP3 file, etc.). Here the perceiver has very

limited possibilities in controlling the musical content besides starting/stopping the playback and adjusting the volume of the musical sound.

The last decades have seen a growing interest in trying to bridge the gap between the performance and the perception of music [6]. Examples of this can be seen as interactive art/museum installations, music games (e.g. Guitar Hero) [7], keyboards with built-in accompaniment functionality [1], “band-in-a-box” types of software, mash-up initiatives of popular artists [10], sonic interaction designs in everyday devices [9], mobile music instruments [2], active listening devices [4, 8], etc. An aim of all such *active music* systems is to give the end user control of the sonic/musical output to a greater or lesser extent, and to allow people with little or no training in traditional musicianship or composition to experience the sensation of “playing” music themselves [5].

There are numerous challenges involved in creating such active music experiences: everything from low-level microsonic control (timbre, texture), mid-level organisation (tones, phrases, melodies) to large-scale compositional strategies (form). In addition comes all the challenges related to how one or more participants can control all of these sonic/musical possibilities through mappings from various types of human input devices. In this paper we will mainly focus on creating a system that is flexible enough for the participants’ interaction, yet bound by an underlying compositional idea.

Our approach in SoloJam is to allow for a group of participants with little or no musical training to come together and behave as a “band” of musicians, wherein, they play their respective solos in turn. Thus, the responsibility of playing solos circulates around the band and continues to do so until an indefinite period. To solve the problem of co-ordinating the circulation of responsibility of playing these solos autonomously and effectively, we propose an approach inspired by the Economic Sciences. Specifically, we borrow the concepts of *auctions* and *utility* to address the problem. Our investigation shows that auctions do indeed help decentralised, thus autonomous, circulation of solos within the group. In addition, a careful consideration of the utility function helps participants produce coherent musical output.

We start by introducing the musical scenario that we refer to as SoloJam in Section 2, specifying the issue with participating within it. We then describe our proposed Economics inspired approach to tackling the issue, and the implementation details for the same, in Section 3. Section 4 then looks at the application of the approach within SoloJam, investigating the approach for its effectiveness in enabling participation by artificial agents (who simulate participants with little or no musical training) and human users.

2 The Musical Scenario

In our current context we are interested in creating a system that allows for a group of participants with little or no musical training to get the feeling of being involved with creating music, yet defined in such a way that a certain level of musicality is ensured in the final sounding result. The participants are

to play music using a device that assists them for the same. Such a device, together with the participant using it, is what we call a *node* in this paper. The participant may either be a human user using the device, or an artificial agent behaving in a specified manner simulating a user, and as such associated with the device. In a situation like this, we will need the devices to help co-ordinate the participants' intentions. The devices will have to resolve the conflict that arises from multiple participants wanting to control the same features of the composition. Thus, conflict resolution should be a necessary constituent part of any composition, but indeed, not necessarily the only thing.

In this paper, we focus our attention on this conflict resolution aspect of compositions. As such, we imagine a band of musicians who want to play their respective solos pertaining to the same musical feature. Only one musician ever plays their respective solo at a time. We call this musician the *leader*. However, over time, the playing of solos circulates across the band, as and when other musicians get the opportunity to play their respective solos or become the leader. The control of this circulation of solos happens in a decentralised manner.

The musical space within the system considered in this paper is made up of rhythmic patterns. A sequence of rhythmic patterns when played by one node, is viewed as a *solo* in the context of this paper, until another node commences playing rhythmic patterns. Each rhythmic pattern has a specified number of beats, which we consider as one bar. Thus the musical output is supposed to be a series of rhythmic patterns, one in each bar. Each bar in a sequence can either be a repetition of the rhythmic pattern in the previous bar or not, specifically when played by one node as a solo. And, the next solo, which would be played by another node, should start with a rhythmic pattern that is not exactly the same as, and ideally only slightly different to, the one played by the previous solo playing node in the previous bar. The composition is specified by the aforementioned elements, which also describe the boundaries or constraints to which the musical output should adhere to.

As such, SoloJam can be seen as a compositional idea, or *musical scenario*, where a group of nodes acting in a decentralised fashion come together and take turns in playing a piece based on rhythmic solos. Though nodes act in a decentralised fashion, they must also be able to produce a coherent musical result.

2.1 The Issue With Participation

Given the scenario mentioned above, if a group of participants are to play music, the devices that they use for this participation cannot be traditional instruments. Instead, the devices need to possess some form of artificial intelligence which might allow the group to produce a coherent musical output, and help the participants do so via local interaction with other participants, i.e. without requiring an expert to direct their interaction. Devices helping with coherence are required due to the assumption that the participants do not possess sufficient musical knowledge to produce a satisfactory result on their own. As such, what gets played should be influenced by the devices to some extent, whilst making

sure that the participants are still able to explore the musical space themselves. Devices helping with local interaction are required in order to adhere to the vision of a “band” where members organise themselves into taking turns playing solos, without a central authority directing them. Thus, deciding who plays the solo next should be dealt with by the devices interacting intelligently with each other on behalf of the participants. Such intelligence in the devices forms the crux of the issue with making participants play together effectively within our musical scenario.

We define *decentralised coherent circulation* as giving us a yardstick against which to evaluate the effectiveness of the solution to the issue of allowing participants to effectively play together in SoloJam. *Decentralisation* means that there is no central control over the circulation of playing of solos by participants. *Coherence* in our case means for nodes to be playing slight variations of each others rhythmic patterns over time as and when they become leaders, such that the next leader plays a slight variation of the rhythmic pattern played by the current leader. Thus, our goal is to design an intelligent system that allows for both decentralised control and coherent musical output. It should enable participants to play together without them possessing much musical knowledge, and without requiring an expert to direct their interaction with other participants.

3 Economics Inspired Approach For Participation

We now propose the approach inspired by the Economic Sciences to tackle the issue described in Section 2.1. A detailed specification of this approach follows.

3.1 Specification of the Approach

One can see the problem of decentralised control of circulation of solos as a resource allocation problem, where the resource can be viewed as a metaphor for *having the responsibility of playing a solo*. This responsibility is what needs to be continuously allocated to the node who may be *most deserving* of being the leader within SoloJam at any point in time.

The concept of auctions has a long standing history in human society, where the idea is to have a mechanism in place that allows for the allocation of resources/goods/services via the exchange of these resources/goods/services with other resources/goods/services, or indeed some currency. Anything that may be exchanged has some value for the parties between which the exchange happens. This is where the concept of utility comes in. Utility [3, 12], as a concept, has a long history in the Economic Sciences as being an idea that allows for expressing the value of a choice or decision that one needs to make, for example, how much may one be willing to spend in choosing to buy a guitar is the value of the guitar for the individual. This value can, with certain assumptions about the preferences of the individual with respect to making choices, be quantified in the form of a mathematical function. Such numerical expression of value makes exchanging resources/goods/services practical.

Assuming that it may be possible to compute the deservedness of being the leader, at every time step, whilst the leader is playing its solo, we make it also hold (broadcast) an *auction*, in which all other nodes can *bid* in order to become the next leader. We thus design the node such that every node can evaluate the deservedness of it being the leader as a *utility* of its current rhythmic pattern. The utility values of their respective rhythmic patterns are what the nodes use as their respective bids. As such, at any given time, the node with the highest utility for their respective rhythmic pattern, must be the leader, provided this value is computed truthfully (or honestly). At every time step, the bidder nodes can also change their respective rhythmic pattern, in order to come up with a new rhythmic pattern with higher utility as compared to the utility of their current rhythmic pattern. The transfer of responsibility happens when a bidder node wins the auction held by the leader. This necessitates a gain for the leader, i.e. the auction can only be won if the leader gains from handing over the responsibility to the highest bidder. This implies that the utility of the rhythmic pattern that the leader is currently playing, must, at the time of the transfer, be lower than the highest bid it receives. We now detail the auction mechanism for decentralised circulation of responsibility, and the concept of utility for computing deservedness and coherence.

Auction Mechanism. The leader holds a second-price sealed-bid auction, in particular, the *Vickrey auction* [13] in every bar, to receive bids from the bidders which then are used to decide whether or not there is a winner to whom the responsibility of playing the solo would pass in the next bar. The reason for this design choice is that Vickrey auctions deem truthful bidding to be the dominate bidding strategy. In our case, this means that a bidder can do no better than bidding with the true utility value of their rhythmic pattern. The second-price nature of the auction suggests for the winner of the auction to make a payment equal to the value of the second highest bid to the leader. This second price aspect of this auction mechanism makes truthful bidding a dominate bidding strategy. However, in the current setup we do not exchange money³ (in the form of such payments by bidders to the leader). This means that, although the transfer of responsibility necessitates a gain for the leader, as mentioned above, the leader only ever compares the received bids and the current utility of its own rhythmic pattern, in order to ascertain whether or not it should hand over the responsibility to the highest bidder. Ties in bids, when the bids are higher than the leader's rhythmic pattern utility, are broken randomly. The sealed-bid nature of the auction requires that the bids are not public and only known to the bidder and leader. We leave the consideration of exchange of money and other possibilities offered by this auction mechanism to the future, when dealing with more complex variants of SoloJam.

³ The auction and bidding setup in SoloJam allow for money (or virtual money), in the form of bid values to be exchanged. But, we only consider monitoring the utilities for now.

Utility. To participate in the auction effectively, each node must have a way to evaluate and communicate a value that it considers its current rhythmic pattern to be worth. A rhythmic pattern in SoloJam is represented as a bit string parsed from left to right, whereby, a 1 indicates ‘triggering a beat’ and a 0 represents ‘not triggering a beat’. For each node, we define a utility function which the node uses to evaluate the value of its current rhythmic pattern, both in relation to itself and to the leader, knowing its role as either a bidder or a leader. The following equation specifies part of this utility function:

$$u_i = \frac{c}{(1 + aD_l)(1 + bT_l)} \quad (1)$$

Here, D_l is the hamming distance of a node’s current rhythmic pattern with respect to the leader’s current rhythmic pattern, T_l is the length of time a node has been playing the solo, i.e. the number of bars a node has played rhythmic patterns as a leader, the coefficient a is the importance (in terms of a weighting) given to D_l , the coefficient b is the importance (in terms of a weighting) given to T_l , and c is a normalisation constant. In addition to this, two more conditions completely specify the utility function. These clauses being:

1. The utility is *zero* for a bidder node if D_l goes below $\epsilon\lambda$, where ϵ is a small percentage of the length of the rhythmic pattern (λ).
2. The utility is *zero* for a bidder node if the node has handed over control to a new leader node in the previous time step.

According to the utility function above, the longer (in terms of bars) a node plays a solo as the leader, the lesser it values its current rhythm, indicating boredom or fatigue, of which the node is made aware via the utility function. The node also possesses knowledge about the hamming distance between its own and the leader’s respective rhythmic patterns. This knowledge can be used by the node to come up with rhythmic patterns that are of higher value, given the leader’s rhythmic pattern. The closer a node can match its rhythmic pattern against the leader’s pattern, the higher the node values its own pattern. This remains true as long as the match does not get closer than or equal to $\epsilon\lambda$, allowing for the node to stir clear of intending to play a rhythmic pattern that may be very similar to or exactly the same as that of the leader (as per the first clause above). Additionally, we can see that this specification of utility, taking the leader’s rhythmic pattern into consideration, also provides the node with a gradient (i.e. the closer the rhythmic pattern to that of the leader, the higher its value), which it may make available to the participant in order for them to come up with rhythmic patterns which are slight variations (at least $\epsilon\lambda$ different) of the leader’s rhythmic pattern. As such, in addition to computing deservedness, we see the utility function as a means of instilling coherence in the musical output from SoloJam. Note that D_l forms the main link between nodes (the node in question and the current leader node), and the coefficient a associated with D_l emphasises or otherwise, the strength of this link. We will put this coefficient to use for the investigation carried out in this paper in Section

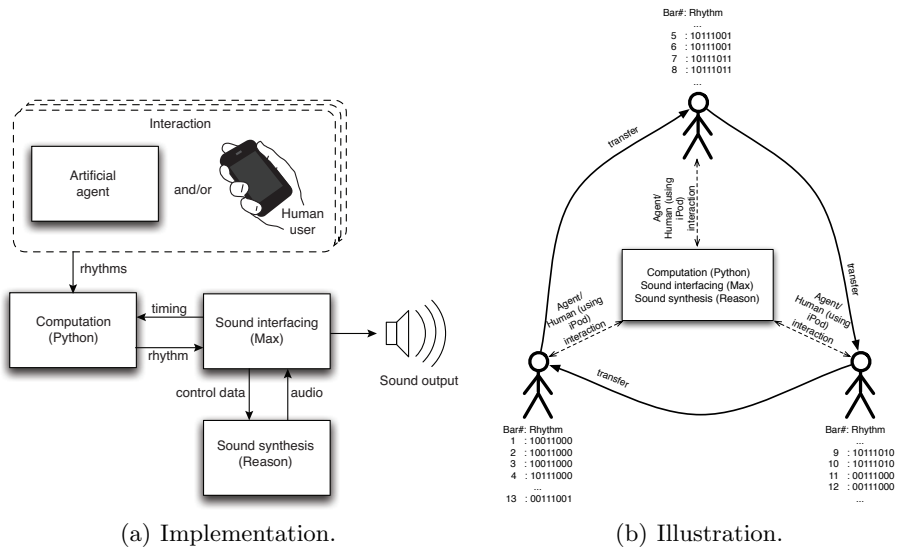
4. The clauses above further indicate a way to carefully consider designing the utility function in order for a globally coherent piece of music to result from local interactions within SoloJam. The first clause suggests for there not to be a perpetual repetition of the same rhythmic pattern by all the nodes of SoloJam, which would be monotonous. The second clause allows for a node to not take over the responsibility soon after it released it, which may happen otherwise, since the node's rhythmic pattern would already be a slight variation of the new leader that took over the responsibility from this node. Not considering this clause may thus reduce the variations that may occur in the music performance in the global sense.

3.2 Implementation

Fig. 1 shows the building blocks of the implementation of SoloJam. Fig. 1(a) outlines the schematic of the implementation of SoloJam. The current SoloJam scenario has been implemented on a Macintosh computer, in conjunction with iOS devices for human interaction within the scenario. The setup can be broken down into 4 modules: the Computation module, the Interaction module, the Sound interfacing module, and the Sound synthesis module.

The Computation module is implemented in Python and simulates our approach for effective participation described in Section 3.1, with a thread representing each node. These threads interface with the Interaction module as well as the Sound interfacing module. The Interaction module can function in two ways. If an artificial agent is to be part of the node, the thread in the Computation module representing this node is made to implement the functionality of the agent in terms of the manner in which this agent comes up with rhythmic patterns. If a human user is to be part of the nodes, iOS devices (specifically iPod Touch) are used for sensing human motion, and specifically for SoloJam, sensing the shaking of the device (using the built-in inertial sensors). The signals from shaking are sent as Open Sound Control (OSC) [14] messages to a thread in the Computation module associated with the device, which are then converted into rhythmic patterns within this thread. The bit strings representing rhythmic patterns are further sent as OSC messages to the Sound interfacing module, together with the utilities/bids (computed within the Computation module) of leader/bidder node rhythmic patterns at every bar.

The Sound interfacing module is implemented as a Max/MSP patch. It serves as a control module for the SoloJam scenario, accepting strings of rhythmic patterns, synchronising and converting them to control signals for the Sound synthesis module. The audio streams from the Sound synthesis module are channeled back to the Sound interfacing module for mixing and effects processing. The Sound interfacing module also performs a visualisation of various aspects of the system, such as node utilities. The Sound synthesis module is currently instantiated as a virtual sound module rack in Reason. A drum kit synthesiser module is used for each node. Reason is controlled by the Sound interfacing module through ReWire. MIDI signals are sent to the synthesisers, and the audio streams are sent back to the Sound interfacing module.



(a) Implementation.

(b) Illustration.

Fig. 1. Building blocks of the implementation of SoloJam showing (a) a schematic of the implementation of SoloJam, and (b) an illustration of the SoloJam scenario within the context of this implementation.

Fig. 1(b) illustrates the SoloJam scenario within the context of the aforementioned implementation. It shows 3 agents or human users participating in the scenario. The rhythmic patterns associated with each participant at various bars are shown. These rhythmic patterns are fed in to our auction based approach for effective participation simulated by the Computation module. As per the rhythmic patterns shown, one possibility for the transfers of responsibility of playing solos is indicated in the figure.

4 SoloJam with Participants

We now look at how the auction based approach proposed in this paper, together with the proper design of the utility function, enables effective participation within the composition. We primarily look at the case where artificial agents are considered as simulating the behaviour of participants with little or no musical training, and act within SoloJam as participants. The case where SoloJam involves human participants is also discussed.

4.1 SoloJam with Artificial Agents: Enabling Participation

Although SoloJam involves human interaction, in order for behavioural equivalence across the participants, we consider experimenting with artificial agents in this section. Moreover, an artificial agent can be designed to behave as a participant with little or no musical training with little effort. As such, we get

artificial participants behaving in a specified manner operating the respective nodes similarly. This allows for evaluating a base line system, which is a system that should work even if all the nodes are operated by participants with little or no musical training. Otherwise, one could argue that a human operator may influence the system towards having the requisite functionality, even if the system did not work. Thus, artificial agents allow for controlling the nature of the interaction of the operator, removing human induced functionality into the circulation of solos, which may be hard to account for.

We primarily investigated the effects of the utility function specification within SoloJam, considering the manner in which knowledge about the leader node affects the circulation of solos within the group of participating nodes. Since we are only interested in the effect of the utility function on the circulation, fixing other factors which may influence the circulation, makes a plausible case for using artificial agents with a fixed behaviour. In this study, these artificial agents use the notion of mutation to generate the bit strings that represent rhythmic patterns. This mutation is such that the agents can flip each bit in their bit string with a probability $1/\lambda$, where λ is the length of the rhythmic pattern. In so doing, the agent generates a new rhythmic pattern, which is a mutation of its old rhythmic pattern. This mutation based rhythmic pattern generation process is essentially used by bidder nodes in every bar they have to bid in, as they search for slight variations of the leader's rhythmic pattern. We limit our study with agents to the case where, once the leader starts playing their solo, they do not change their rhythmic pattern for the duration of the solo (which should be some bars long), i.e. a solo is made up of repetitions of the same rhythmic pattern. This limitation allows us to clearly observe if the bidder nodes are indeed able to search for slight variations of the leader's rhythmic pattern, which, upon winning the auction, they eventually play.

Note that the coefficient a , within Equation 1, signifies the importance (in terms of a weighting) that a node gives to the distance D_l between its current rhythmic pattern and the leader's current pattern. Setting the value of this coefficient to 0.0 within a node, allows for switching off knowledge about the leader node. In essence, the node then only knows its own rhythmic pattern and the duration it has played a rhythmic pattern when acting as a leader. Setting a to a positive value makes the node consider knowledge about the leader. We take $a = 0.0$ and $a = 1.0$ in order to explicitly investigate the effects of not disclosing and disclosing respectively, the knowledge about the leader node to other nodes. Note that the leader node remains unaffected from a change in the value of a , because D_l is zero for it, thus making a irrelevant.

We can now detail the effects of such knowledge within the workings of SoloJam, specifically looking at the nature of the decentralised circulation of solos and also the coherence that can be achieved in the generated piece of music. We first look at the piece resulting from the system, and then provide a discussion based on the evolution of the utilities of the nodes, both with respect to such knowledge. For our study, we use the following parameter settings: *Rhythmic pattern length* (λ) = 8, $\epsilon = 0.1$, *Node count* = 3, $c = 2$, $b = 0.05$.

Observations About the Resultant Piece. Figs. 2 and 3 show snapshots of rhythmic patterns that are generated when the agents play SoloJam, under two specific cases, one where bidder nodes do not consider using knowledge about the leader’s rhythmic pattern when evaluating their own rhythmic patterns, and the other where they do so. These two cases are realised by $a = 0.0$ (Fig. 2) and $a = 1.0$ (Fig. 3) respectively within the part of the utility function (Equation 1) used by each node for this evaluation.

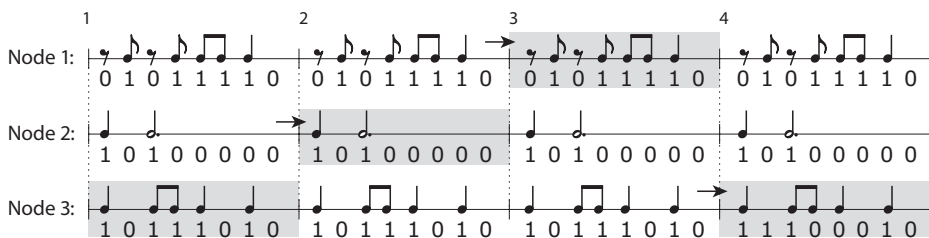


Fig. 2. Snapshot of the rhythmic patterns when $a = 0.0$. There is maximal circulation of responsibility of playing solos (at every bar). The musical output is incoherent as there is no mutation towards closer rhythmic patterns by bidders. In effect, there is no active participation via mutation. Enabling participation is not effective.

These figures show the rhythmic patterns as bit strings and in music notation, for each node in the system. Since we have 3 nodes, 3 lines with bit strings and music notation correspond to each node, as indicated. These lines can be read from left to right for each node. At the end of the 3 lines, the reader can continue at the left of the next 3 lines (see Fig. 3), and so on. Each bar is clearly marked as enclosing the respective rhythmic patterns (of length 8 bits) for each node. The shaded regions denote the current leader. An arrow between bars denotes a rhythmic pattern being sufficient for a transfer to happen. Mutations within a pattern from a previous bar for a node are denoted by dotted circles. The numbers above bars are bar numbers, wherein a range means that the rhythmic pattern is repeated for all the bars in that range, without any mutations or transfers.

For the case with $a = 0.0$, the 3 nodes do not mutate their respective rhythmic patterns over successive bars. Moreover, the transfer of control of responsibility for the solo happens in every bar, as indicated by the shaded regions in the figure. For the case with $a = 1.0$, we can see a more interesting final result: it can be seen that at bar 21, the rhythmic pattern with which Node 1 bids in the auction held by Node 3 (the then leader), varies less (different by 1 bit) from Node 3’s rhythmic pattern, as compared to the rhythmic pattern associated with Node 2 (different by 2 bits). Node 1 wins this auction in this bar, and from bar 22 onwards until bar 42, plays its rhythmic pattern. At bar 23, Node 2 and 3 mutate their rhythmic patterns, a further mutation happening at bar 29 for Node 3. Note that in bar 23, Node 3 comes up with a rhythmic pattern that is

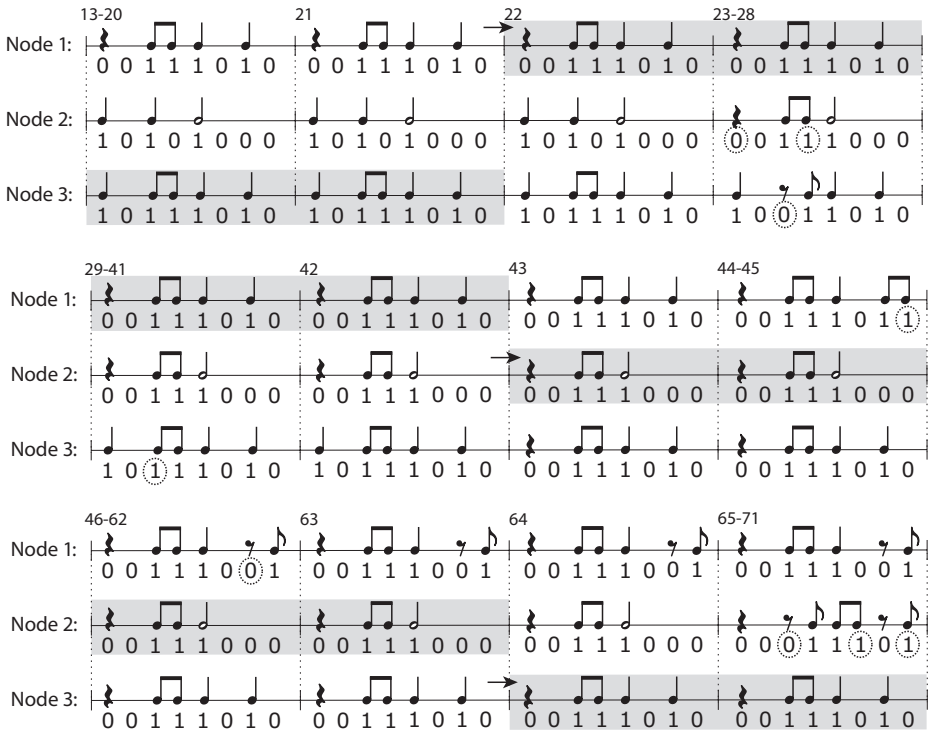


Fig. 3. Snapshot of the rhythmic patterns when $a = 1.0$. Decentralised coherent control is exhibited. The circulation of responsibility of playing solos happens after the leader having played their rhythmic pattern for some bars. Coherence results from the nodes actively searching for closer variants, via mutation, of the leader's rhythmic pattern, and the closest rhythmic pattern being played by the respective bidder, provided the bidder wins the auction. Enabling participation is effective.

2 bits different from the leader, as compared to its rhythmic pattern in bar 22. This is because the rhythmic pattern in bar 22 has its value reduced to zero in the following bar in accordance with the utility function. Thus, any mutation of that rhythmic pattern in the bar following that will have a value greater than zero. As such, this mutation will replace the previous rhythmic pattern. Other than such a situation, the mutations that are generated over time take the nodes closer to the rhythmic pattern of the leader, as can be seen in the figure. In bar 42, there is a tie between Node 2 and Node 3, which is broken randomly and Node 2 takes over the responsibility of playing its rhythmic pattern as a solo. In bar 44, and then in 46, Node 1 mutates towards a closer variant of Node 2. This is followed by a tie again in bar 63, which is then broken randomly in favour of Node 3. In bar 65, Node 2 mutates away from Node 3, again due to the nature of our utility function, as described above. It is clear from Fig. 3 that the nodes actively search for closer variations of the leader's rhythmic pattern via

mutation, and the node (that is sometimes decided upon by a tie break) with the closest match, becomes the leader in the next bar, provided this node wins the auction.

Discussion Based on the Utilities of Nodes. Fig. 4 plots the utilities of the rhythmic patterns of each node, as individually evaluated by these nodes using the utility function described in Section 3.1, and the sum of these utilities. These figures correspond to the snapshots of the pieces from the system (Figs. 2 and 3).

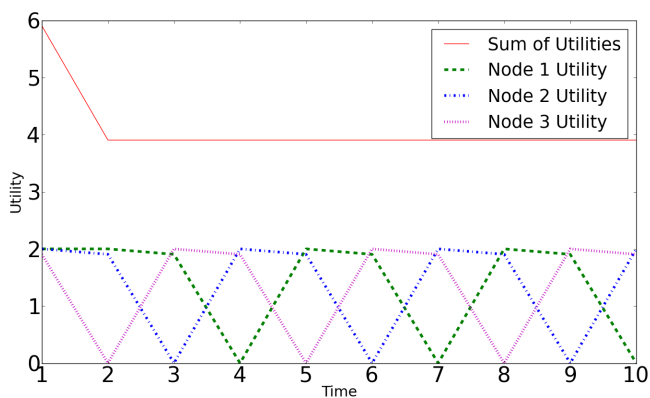
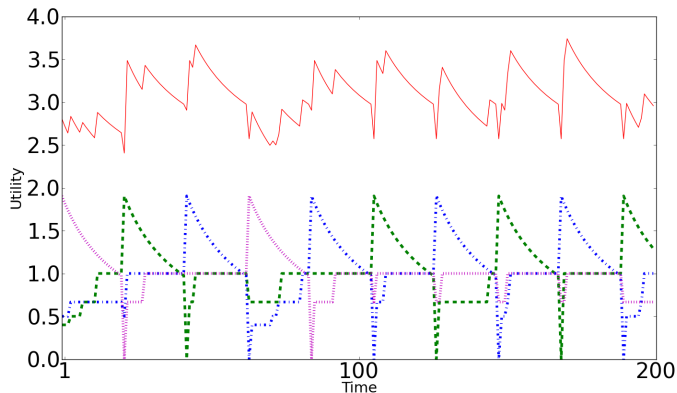
(a) $a = 0.0$ (b) $a = 1.0$

Fig. 4. Utilities of nodes (a) without ($a = 0.0$) and (b) with ($a = 1.0$) knowledge about the leader's rhythmic pattern.

As observed with the corresponding piece (Fig. 2), for the case when $a = 0.0$, the transfer of control happens at every time step, thus a leader node only ever plays its rhythmic pattern for one bar. The auction held by the leader

immediately leads to the bidder who was not the previous leader, to take over the control from the leader, thus becoming the new leader, but for only one bar. This happens due to the nodes not considering using the knowledge about the leader's rhythmic pattern, and thus having a utility and bid of $u = c = 2.0$, if they were not the leader in the immediate previous time step. The process of such transfer of controls carries on. Note that all possible mutations of rhythmic patterns for a bidder who was not the leader in the previous bar, have the same value of 2.0. Thus, the agent has no pressure towards coming up with bids of higher value. We see however, that there is not enough time for the bidders to search (via mutation) for new rhythmic patterns. This is because when a mutation results in a new rhythmic pattern, the previous rhythmic pattern has its value equal to the value of this new rhythmic pattern at all times, be it in the round after the round in which the node was the leader (the value for both rhythmic patterns is 0.0 in this case), or the rounds after this (value is 2.0). As such, the rhythmic patterns with which the nodes started with in the first bar, either as a leader or bidder, remain as the rhythmic patterns associated with these nodes forever, as can also be observed in the corresponding piece for the $a = 0.0$ case (Fig. 2). In effect, coherence remains an issue, since the initial rhythmic patterns of the nodes will not necessarily be slight variations of each other. Moreover, the fact that nodes play their rhythmic patterns for only one bar, goes against the whole idea behind playing solos, unless of course playing for only one bar were to be a requirement from the composition. Most importantly, however, the agents are not able to actively participate to explore the composition. The current utility function with $a = 0.0$ is thus not suitable for being used when participants are to play rhythmic solos within a band-like setting, or else there would be maximal circulation of control (at every bar, thus no solo being played), the musical output will be incoherent, and there would be no active participation.

For the case when $a = 1.0$ however, the playing of solos and transfer of control over time happens in a more favourable manner with respect to the envisaged goal of local interaction producing a resultant globally coherent piece of music, or decentralised coherent circulation. Fig. 4(b) shows spikes in the node utilities, which indicate the start of nodes playing their rhythmic pattern as solos, and these utilities deplete over time. Whilst the leader node's rhythmic pattern utility depletes, the bidder nodes have their artificial agents search towards slight variations of the leader's rhythmic pattern, as indicated by the increase in their utilities over time. As a result, the leader gets to play its rhythmic pattern as a solo for some time and then hands over control to the bidder managing to search and bid to play the closest variation of the leader's rhythm, as observed with the corresponding piece in Fig. 3. The flat regions in the utility graphs (Fig. 4) indicate agents associated with bidder nodes having found rhythmic patterns at a distance D_i of $\epsilon\lambda$ from the leader's rhythmic pattern. Note that there are always multiple rhythmic patterns that the agent could come up with, all of which differing by distance $\epsilon\lambda$ from the leader's rhythmic pattern, which can be seen as the flexibility in the composition that may be explored by a participant based

on their preferences, e.g. preferring one rhythmic pattern over another, even though these rhythmic patterns have the same utility assigned to them by the device. The artificial agents mimicking participants have thus been enabled to play rhythmic solos in a decentralised and coherent fashion via the consideration of a utility function that takes the knowledge of the leader's rhythmic pattern into account. The agents must now, as compared to the case where $a = 0.0$, actively participate to search for a rhythmic pattern, and upon being the leader, play them. The solos that get played adhere to the composer defined boundaries as defined in Section 2, and the system maintains a decentralised coherent circulation. As mentioned before, having a decentralised coherent circulation shows that the system enables the agents to play through the composition effectively.

It would be interesting to consider how the increase in the number of nodes affects the resultant behaviour of the system, with nodes possessing a utility function such as the one defined in this paper, for the case with $a = 1.0$. We leave this as future work.

4.2 SoloJam with Human Users

SoloJam with human participation was also implemented. As mentioned before, human participation involves a human user using a device that allows for the exploration of the composition. The iPod Touch devices that we use for human participation, one for each human user, have a thread each in the Computation module representing them. Upon shaking the device, the signals from this shaking are received by the associated thread and converted into a rhythmic pattern, which becomes the candidate rhythmic pattern for the next bar for the node in question. The human user, unlike the agent, may change the rhythmic pattern in any bar when part of a leader node.

A video of SoloJam with human participation can be found online⁴. The first part of the video shows some sounds and sound effects played together with the sound output of SoloJam. These sounds and effects are part of a further extension of the SoloJam scenario, and are not relevant to the discussion of this paper, thus we leave their discussion to the future. The second part shows three people using iPod Touch devices to play through the piece, playing rhythmic solos as leaders, and bidding for playing slight variations of the leader's current rhythmic pattern as bidders. Fig. 5 shows a labelled screenshot of this video. The Max/MSP patch (our Sound interfacing module described in Section 3.2) in the background visualises the utilities (three horizontal bars at the top right part of the patch) for each node. The top horizontal bar is the utility associated with the person on the right (Node 1). The middle horizontal bar is associated with the person on the left at the back (Node 2). The lower horizontal bar is associated with the person on the left at the front (Node 3). The reader is advised to only focus on the rhythmic patterns resulting from the users shaking their devices and the horizontal bars representing utility for each node. The circulation of solos in this particular video follows the sequence: *Node 3* → *Node 1* → *Node 2*.

⁴ <http://www.fourms.uio.no/videos/SoloJam.mov>

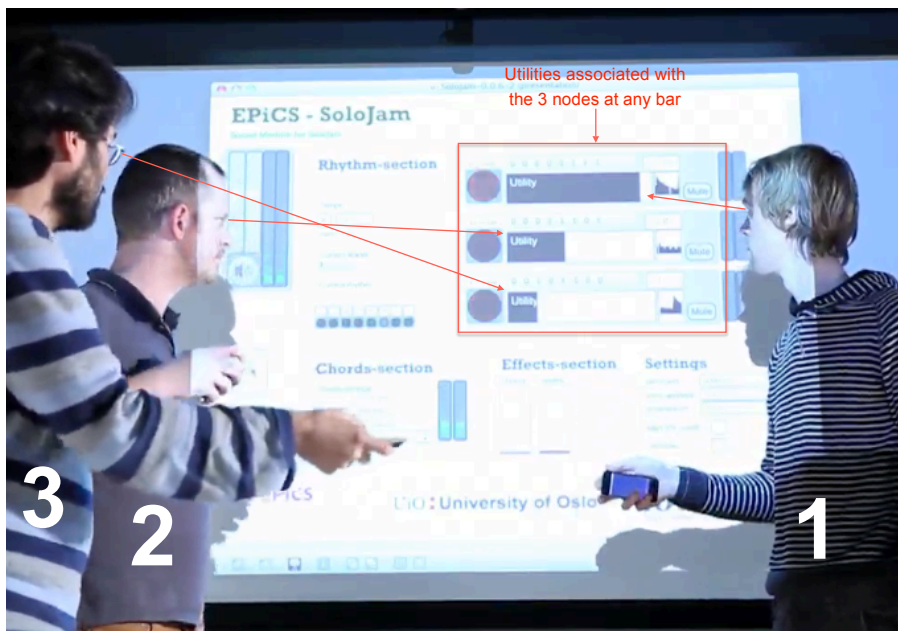


Fig. 5. Labelled screenshot of the video of SoloJam with human participation.

In the video, it is possible to see that the bidder node whose rhythmic pattern is closest to that of the leader node, has a utility higher than that of the other. Also, the transfer of responsibility happens when the leader node's utility goes below the utility of the highest bidder node. Furthermore, the bidder nodes have their rhythmic pattern utilities increased, as and when they come up with closer (in terms of hamming distance) variations (but not exact copies) of the leader's rhythmic pattern. Thus, our approach encourages human users to come up with rhythmic patterns that are slight variations of the leader. The closest bidder is then aptly rewarded by this bidder becoming the leader, once this bidder wins the auction held by the leader.

5 Conclusions

We have outlined and discussed the issue with enabling participants with little or no musical training to play together in the interactive music system SoloJam. An approach inspired by the Economic sciences, specifically borrowing the concepts of auctions and utility, is proposed in order to address this issue. Nodes that possess the capability of evaluating the deservedness of being able to take on the responsibility of playing the solo starting in the next bar (via a utility function), and auctioning and bidding capabilities, are shown to exhibit decentralised co-ordination when circulating solos in SoloJam. Furthermore, a careful

design of the utility function enables participants (simulated by artificial agents) to come up with an output that is musically coherent. This is highlighted by the manner in which the agents, as bidders, search towards higher utility variants of the leader node's rhythmic pattern. These variants, in fact, are slight variations of the leader node's rhythmic pattern. We further exhibit human user participation within SoloJam supporting our approach. In effect, decentralised coherent circulation that results from our Economics inspired approach, demonstrates the effectiveness of the approach towards enabling participation within SoloJam. Having proven the concept, our next step will be to conduct usability tests with human participants having different types of musical backgrounds. In addition to testing the system with participants with little or no musical training, we are also interested in seeing how music students and professional musicians interact with the system.

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