ALGORITHMIC THINKING AND CENTRAL JAVANESE GAMELAN

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Abstract and keywords

This text explores the notion of central Javanese gamelan (also known as *karawitan*) as rule-based music, examining areas where algorithmic thinking can take place in both performance and composition. Different types of performance techniques are discussed, exploring the degree to which rules can be used to generate melodic content from a notated outline called the *balungan* (meaning skeleton or frame in Javanese). Several applications of algorithms in the contexts of ethnomusicology and composition are presented, with a focus on grammars and rewriting systems. This leads to a discussion of the author's work with rule-based systems in the creation of new music, including integration of computer parts in a live gamelan ensemble through augmented instruments. The chapter concludes with an overview of *Pipilan*: a piece of software developed in Max/MSP for computer-aided composition, which has also been used to facilitate audience participation in performance and installation settings.

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Playing gamelan is an intrinsically communal activity. The music often typifies an aesthetic quality called *ramai*, or *ramé* in Javanese: a feeling of busyness and filling of space, as many instrumentalists create unbroken streams of sound, punctuated by a hierarchy of gong-pulses (Sutton 1996, 258). Gamelan is closely associated with community events such as weddings, a variety of religious and secular ceremonies, and all-night shadow theatre (*wayang kulit*), in which ensembles must call upon a vast repertoire of pieces on demand, interacting with other performers such as dancers and puppeteers. As a result, the playing conventions found in gamelan are flexible, providing opportunities for interaction both within and outside the ensemble that are maintained when the music is played for its own sake.

One of the reasons gamelan has attracted the interest of musicologists and composers of new music – both in Indonesia and abroad – is the way that musicians appear to be capable of working out coherent interdependent parts from a notated outline or by listening to guidance from other instruments. This applies in particular to the central Javanese style (also known as *karawitan*), in which pieces are rarely played exactly the same way twice. Such variability stems from oral tradition, and reflects other aspects of Indonesian culture, such as the variations upon classic outlines found in storytelling and *batik* patterns. Although notation and recording technology are gaining popularity, many musicians believe that traditional works for gamelan (called *gendhing*) only truly exist in the moment of performance, as a combination of all parts in the ensemble (Supanggah 1988; 2011, 181-182).

Musicians traditionally learn to play gamelan from experience, by observing, imitating, and playing from an early age, but recent attempts at formalising the music have produced an assortment of rules abstracted from performance practice. As a result, students with limited experience can fit into an ensemble to play acceptable parts alongside expert musicians; composers who are familiar with the constraints and rules of the tradition can provide musicians with a relatively simple part from which can be generated a complex piece of music. But to what extent can the thought processes behind this rich musical tradition be described as algorithmic? How can composers and theorists draw upon algorithmic thinking, not only to understand and maintain the tradition, but to build upon it?

In this chapter I will discuss some rule-based approaches to learning and performing gamelan music, particularly the central Javanese classical tradition concentrated in the cities of Solo and Jogja, and explore some ways that it can hold inspiration for algorithmic thinking in musicology and new compositions. In

particular I will discuss notions of outlines, generative structures, and methods of elaboration in performance practice. This discussion will be illustrated in the second part by applications in composition and musical research that specifically refer to Javanese music theory. The final part of the article – originally written as a *perspective on practice* contribution to the handbook – is somewhat more reflective, and explores new applications for theory from central Javanese gamelan in computer-aided composition. Examples will be presented from my own practice involving gamelan and live electronics, namely *Augmented Gamelan* and *Pipilan*. In these projects I have used algorithmic processes in augmentation of traditional-style ensembles, and explored ways for audiences to join in the composition and performance processes.[1]

It is difficult to discuss gamelan music theory without becoming familiar with some Javanese terminology, since ostensibly equivalent terms in English can be misleading. Some terms will therefore be reviewed to illustrate key concepts. It is also important to consider that some generalisations overlooking a range of regional and personal variations will be inevitable in a brief chapter such as this. More comprehensive introductions to gamelan music and its cultural context may be found elsewhere (e.g. Sutton 1991; Sumarsam 1995; Pickvance 2005; Supanggah 2011; Cook 1992 for Sundanese practice; Tenzer 2000 for Balinese varieties).

1. THEORETICAL FOUNDATIONS: STRUCTURES AND RULE-BASED SYSTEMS IN TRADITIONAL GAMELAN MUSIC

One way of approaching gamelan music is as the intersection of two systems: its cyclic gong patterns provide robust hierarchies of alternating high and low-pitched pulses, through which are threaded rhythms and melodies of a more linear and intricate nature.[2] It is these latter elements that provide opportunities for personal expression and interaction, as they can be treated in real-time by musicians in various ways, and expanded through different time-scales. Musical time in gamelan is elastic, as melodic lines and rhythms can be stretched out in the course of performance; the same essential pattern might last anywhere from a few seconds to a couple of minutes, with some players doubling up their parts to maintain a sense of flow and musical identity. This temporal expansion can be likened to zooming in on a fractal, revealing hidden structures and contours that appear to refer back to the shape of the whole.

The relationship between instrumental parts in gamelan music performance is often called "polyphonic stratification": many different melodic-rhythmic lines form distinct layers or strata of sound, each maintaining its own character in melodic contour, rhythmic idioms, and relative density (Hood 1982, 52). Attempts to describe

their coherence have led to somewhat more contentious descriptions of these layers as a form of heterophony, involving many simultaneous variations of the same melody (see discussion in Pickvance 2005, 22-23; Perlman 2004, 62). The nature of collective reference points in performance can sometimes be unclear, shifting between contexts. Pieces are ostensibly defined by outlines and instructions, but closer inspection often points towards a fuzzier sort of shared abstraction, made up of various threads played aloud in the ensemble, but not always traceable to a single source.

1.1 Structures and colotomy

The most fundamental characteristic shared by gamelan compositions is that of the gong cycle: a repeated pattern lasting anywhere from a few seconds to several minutes, marked by the largest and deepest hanging gong in an ensemble. Cycles are divided and punctuated by sets of other hanging and horizontally mounted gongs to form what is known as a "colotomic structure" (Kunst 1949). Musicians may create complexity through further subdivision of rhythmic pulses, repetition, phase offset, and the interlocking of similar parts. Other layers of more linear melodies are constructed within idiomatic constraints, relying heavily on a conceptual framework called *pathet* (a term loosely equivalent with mode if approached in terms of pitch, although it has many other connotations; see Pickvance 2005, 52-57; Perlman 2004, 42-43; Supanggah 2011, 299-313). Patterning in gamelan is generally end-weighted; parts tend to anticipate structural markers rather than responding to them. Therefore, if a pattern is expanded or subdivided, its phase is shifted backwards so that its endpoint matches the central pulse (see Figures 2 and 3).

Colotomic structures give shape and identity to traditional gamelan pieces. These formal structures form sub-genres of pieces with closely associated functions in dance and drama, and their names, such as *ladrang*, *ketawang*, and *gendhing* are generally included in the titles of pieces along with *pathet* and other structural information (Pickvance 2005, 37; 81-90). Gong cycles are typically repeated, with often with some variation in treatment, until cued by melodic or rhythmic leaders of the ensemble. This typically occurs through a change in pitch register or tempo, leading to other sections (often the same colotomic structure filled with different melodic information), the end of the piece, or attachment of another piece to form a suite.

1.2 Balungan: melodic outlines and notation

Beyond colotomic structures, most forms of gamelan use some sort of outline, played aloud, that can be used as a shared reference point between musicians. The melodic outline most typically found in Javanese gamelan is called a *balungan*.[3] Literally translatable as skeleton or frame, the *balungan* in musical contexts is a metronomic part, typically written as a series of numbers (see Figure 1).[4] These sequences are

usually split into four-note units called *gatra*, which form the basis of much performance practice and analysis of Javanese gamelan music (Supanggah 2004; 2011, 176; Pickvance 2005, 29).

The outlines presented by *balungan* can take a variety of shapes, ranging from more dense, prescriptive sequences (Figure 1A) to the sparse *nibani* style (Figure 1B). The latter type of sequence gives the most basic outline on the strongest beats, and is often played at such a slow pace that it might no longer be considered a melody, becoming a set of aural landmarks to confirm the key resting points for phrasing within the wider structure.

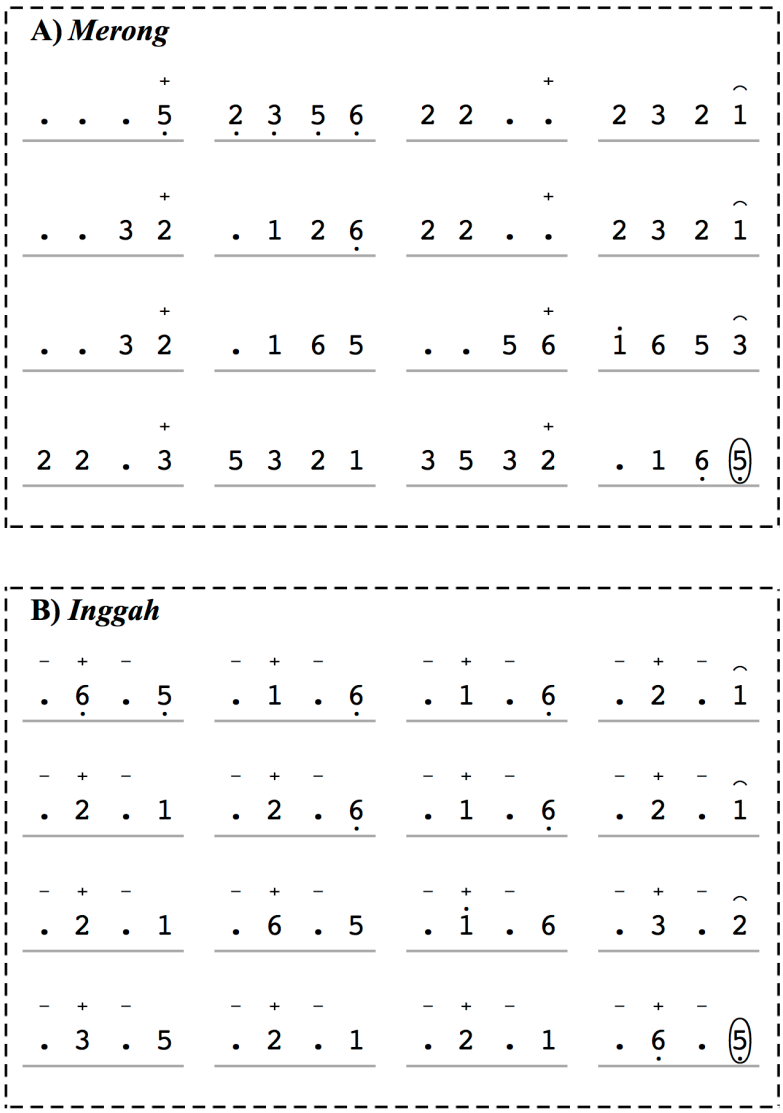

FIGURE 1: Two *balungan* sequences from the traditional Javanese piece *Gendhing Gambirsawit, laras slendro, pathet sanga* (see Drummond n.d.).

Alongside certain vocal parts, the *balungan* (closely matching parts played by a set of keyed instruments called *saron*) is one of the most consistent elements of a

gamelan composition, and was therefore chosen for posterity when attempts to standardise notation were introduced in the late 19th century (Sumarsam 1995, 111).[5] Although notated parts were originally intended to function as memory aids or records of aurally transmitted information, they are increasingly used prescriptively in educational institutions (see Sumarsam 2004 for discussion of teaching methods in Java and abroad). Collections of *balungan* and related songs can be found at bookshops and stalls at shadow puppet performances, and more recently for free download on the Internet. For instance, the Boston Village Gamelan's *Gendhing Jawi* collection hosts over 1600 outlined sequences that are readily usable as notation.

The *balungan* is sometimes considered to be the basis of most parts in the ensemble; early ethnomusicological studies compared it to the *cantus firmus* or "fixed melody" found in other musical systems (see Sumarsam 1995, 145; Perlman 2004, 123). This idea has recently been challenged, as musicians often state that they refer to a less fixed framework, an unplayed or "inner melody" in performance. The opinions of various theorists and musicians on this subject are collected and discussed at length by Marc Perlman (2004; also see Sumarsam 1975; Supanggah 1988; 2011). The *balungan* might be thought of as a quantised version of this internal framework, a convenient point of reference when teaching and learning the music, and confirmation of the resting points of melodic phrasing when played out loud.

It is often assumed that composers work in the classical style by creating a *balungan* sequence, as this tends to be what is written down (Sutton 1987). However, in doing so, they may be working with particular *balungan* fragments or contours as signposts for more complex melodic information and songs with which they are associated. The effectiveness of transmitting traditional works, whether by succinct notation or through observation of other performers, is largely due to the overlapping of rhythmic and melodic information between compositions. Gamelan pieces are frequently composed using recombination of existing material, including instrumental phrases and traditional sung poetry, in a process sometimes referred to as "centonization" (a term borrowed from descriptions of Gregorian chants; see Sutton 1987; Sumarsam 1995, 162). As a result, many musicians learn to play by treating certain frequently-played repertoire, or "prototypical pieces", as a foundation, learning how some patterns can be borrowed, combined, and transposed in relation to other parts, and gradually building knowledge of more specific phrases as unfamiliar pieces are encountered (Brinner 1995).

With this in mind, another point of reference can be found in the form of *cengkok*: more detailed melodic formulae or stock patterns that are often given names, and which can be recognised across variations on different instruments. Complementing the *balungan* and vocal elements, these patterns tend to fit together in certain orders,

serving larger scale idiomatic vocal contours and *pathet*. Knowledge of this area of repertoire can provide familiar pathways for musicians to pass through when approaching unfamiliar pieces without the aid of notation.

1.3 Garap: Idiomatic treatment of musical information

The reinterpretation and elaboration of existing musical material in Javanese gamelan music (including, but not limited to, the *balungan*) is known as *garap* (Perlman 2004, 60; Supanggah 2011). Since there is a great deal of potential for variability throughout the ensemble, it is common to describe this process in terms of improvisation, in contrast to more fixed sequences of other musical systems such as the Western classical tradition. However, musicians rarely have the freedom to play whatever they wish; they must refer back to the central framework, upholding the integrity, *pathet*, and *rasa* (feeling) of the piece, and conforming to playing conventions. As R. Anderson Sutton concludes in a thorough review of the subject of improvisation in gamelan, "while very little is *entirely* fixed beforehand in a Javanese performance, a great deal is *almost* fixed (or expected to be)"; gamelan music involves improvisation, but it would not be appropriate to describe it broadly as improvisatory (Sutton 1998, 87). The type of variability in Javanese gamelan might be described as "idiomatic improvisation", in contrast with free or "un-idiomatic" improvisation: "improvisation serves the idiom and is the expression of that idiom" (Bailey 1992, 18).

Given its constraints, improvisation in traditional practice might be considered a surface detail filling the deeper structures of tuning, mode, and colotomy discussed thus far, in combination with more specific instrumentally oriented grammars (Hood 1972).[6] While this description might seem to undervalue individual creativity, there are appropriate moments for more spontaneous or individualistic actions, most notably through interaction with others. Drummers often play in unplanned interaction with a shadow puppeteer to accompany the movements of characters while mediating cues for the tempo and dynamics of the ensemble. Forms such as *palaran* do not use an explicit *balungan* part, but rather require musicians to follow vocal patterns, adapting to the pace of the singer and mediation from the drummer (see Brinner 1995, 234-244 for a breakdown of this interactive system). Similarly, musicians might play holding patterns or adjust their parts to imitate other players if they lose their way in unfamiliar pieces, especially when playing without notation (sometimes called *ngeli* – floating; ibid. 142).

Each of the instruments in the ensemble generally has a clearly defined role, and is associated with a set of playing conventions or "instrumental idioms" (see Brinner 1995, 55-56; Perlman 2004, 43-49; Matthews 2014, 13-16). At their most basic level, these provide the techniques needed for sound production, appropriate pitch range and

dynamics, and stylised elements such as damping. Idiomatic conventions can also extend to the way that outlines can be treated (often through application of abstract patterns or repertoire of stock phrases), and ways to respond to and interact with other instruments in the ensemble. Furthermore, some sub-families of instruments are played together to create patterns that complement each other and interlock, such as the *imbal* patterns played on the *saron* or *bonang*, and *pinjalan* or *banyakan* spread across the ensemble (see Figure 4; Sutton 1991, 49-51; Pickvance 2005, 170-183; Supanggah 2011, 288; Brinner 1995, 223-226). These treatments can vary between contexts; the same instruments can be associated with a range of techniques according to regional styles, or the same musician might play a given instrument differently for dance or shadow puppet theatre.

Different types of patterning are linked to the classification of gamelan instruments as either "loud" or "soft"-style (referring to the relative volume of the instruments in an unamplified setting). Loud-style instruments mostly consist of thick-keyed metallophones and gong-chimes, and their parts tend to make direct reference to the outline provided by the *balungan*. The soft-style family comprises instruments with thinner keys, stringed instruments, and xylophones, and are generally associated with vocal parts and more elaborate melodic figurations.

Some more specific playing methods are connected to the physical construction and affordances of the instruments. For example, some loud-style instruments such as the keyed *saron* are restricted to a single octave, and so must employ a characteristic "folding" of melodies back upon themselves in order to match the multi-register lines of other instruments and voices, while preserving the integrity of melodic contour (Pickvance 2005, 111-112). When referring to certain notes on sets of gongs that might not span a whole octave, substitutes at appropriate intervals must be found (ibid., 209-210). Instruments are often played as fast as comfortably possible (called "saturation density" by Hood 1982, 115), and in many cases rhythmic density is connected with the resonant decay and tessitura of the instrument; the higher the pitch range of the instrument, the faster it tends to be played in relation to others in the same family.

Other conventions are dependent on the behaviour of other players, the most common example being the drummer. For example, the choice of drum and related patterns can dictate the degree of ornamentation in different performances of the same piece, and speed changes from the drummer are often are used to cue temporal expansion (Pickvance 2005, 61-62; Brinner 1995, 225; Sumarsam 1974). Patterns played on the instruments representing the colotomic structure and *balungan* can be sped up or slowed down to follow these cues, for the most part retaining their sequence. However, many other instrumental parts are expected to maintain a steady

pulsation, creating an unbroken stream of melodic-rhythmic information, and so musicians in these positions switch to faster patterns as the rest of the ensemble slows down. This situation has led to the formalisation of several levels of relative rhythmic density (called *irama*), that can be brought into play during performance.[7]

The amount of freedom afforded to gamelan musicians often increases with the rhythmic density of instrumental parts in relation to the central pulse and *balungan* sequence. This is observable both vertically, through instruments that are played faster according to their pitch class, and horizontally, as instrumentalists elaborate upon rhythms and melodies through temporal expansion (although some parts such as the *bonang panerus* remain dependent on the behaviour of others, as described below). As the spaces between the structural points become sparser, there is more room for melodic divergence and interaction. However, the integrity of the ensemble in relation to the foundations of the piece takes priority; it is extremely rare for spontaneous elaboration to lead the ensemble away from conventional structures.

1.4 Types of melodic patterning in central Javanese gamelan

Some loud-style parts can be learnt as abstract patterns to be applied to a notated *balungan* sequence, typically involving the segmentation and repetition of phrases. For example, on the set of gong-chimes called *bonang*, a pair of *balungan* notes can be repeated in alternation before being played by the rest of the ensemble. This technique is called *pipilan*, and can be used to direct other players by indicating the contour of approaching sequences or shifts in register (see Figure 2; Pickvance 2005, 147; Sutton 1991, 53).[8] The basic pattern is often refined by omitting the strongest final beat, and accentuating the damping of each note as the next one is played.

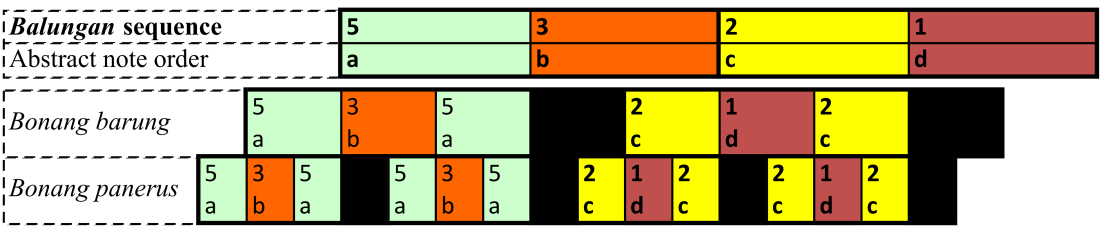

FIGURE 2: Repetition and phase offset of a *balungan* sequence using the *pipilan* technique, Solonese style.

This kind of activity is typically stratified across several instrumental layers. The main *bonang* has a higher-pitched counterpart (called the *bonang panerus*), which repeats the same basic pattern at double the rhythmic density. Tiered patterns such as these, with a rest on the strongest beat giving way to the note played on the next

instrument in the hierarchy, create a texture characteristic of gamelan music. They reflect the subdivision found in the fundamental colotomic structures, helping to establish a sense of integrity and self-similarity in the parts played across the ensemble.

The same principle is used in temporal expansion, as note pairs from the central sequence can be repeated to fill the space provided (see Figure 3; in practice the player might construct a new reference melody in order to avoid extensive repetition at higher densities). When the drummer slows the central pulse to cross into the next rhythmic density level, players of loud-style instruments may double the repetitions of each note-pair. The number of strokes played is inversely proportionate to the tempo of the static structure of the *balungan* and gongs.

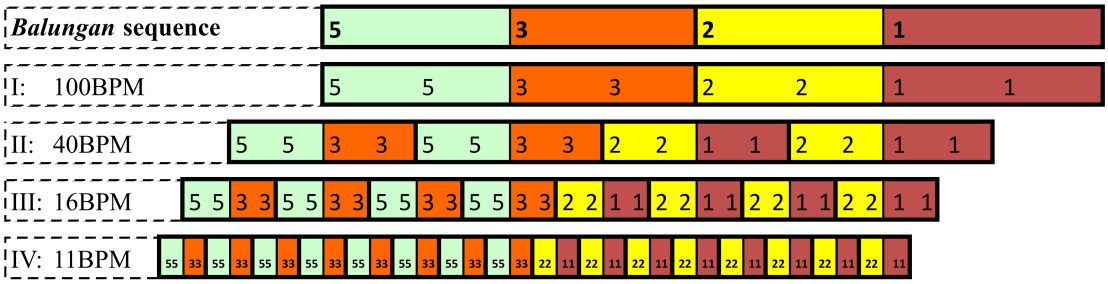

FIGURE 3: Elaboration of a four-note sequence (5 3 2 1) using the *saron panerus* (*nacah rangkep*, Solonese style). Formal density levels shown with approximate tempo for the *balungan* sequence.

Patterns that refer to each note of the outlined sequence in this manner are dependent on certain types of contour. More idiomatic note substitutions might take place if the outline travels outside a given instrument's tessitura, creates an unusual leap (such as some intervals crossing into other octaves), or if adjacent notes are repeated. Furthermore, sparse *balungan* sequences like the *nibani*-style patterns shown in Figure 1B provide limited notes with which to work, calling for deployment of specific phrasing.

One way to bypass this problem is to use interlocking patterns, which in Javanese practice typically only make direct reference to the strongest middle and end notes in the outlined sequence. These are generally shared between two instruments, and can create predictable textures by borrowing adjacent notes in the scale (see Figure 4). This type of patterning provides a simple way to support underlying melody without taking contours into account, proving useful for modern compositions that might draw less upon established repertoire, and can also lend a lively feel to performance.

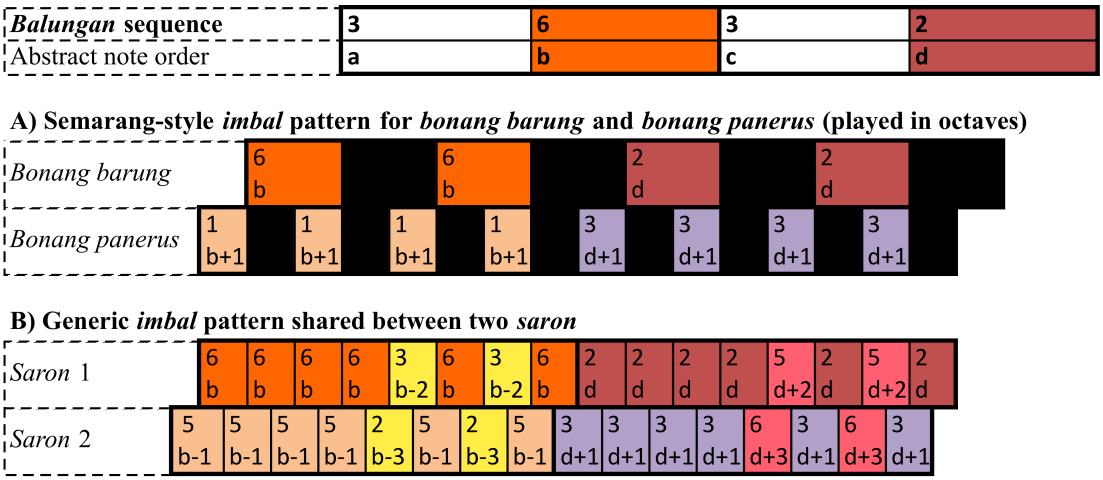

FIGURE 4: Two examples of interlocking patterns based on a *balungan* sequence (3 6 3 2), using strongest notes and adjacent places in the *slendro* scale.

Beyond the basic loud-style conventions described thus far, playing gamelan relies on knowledge of a multitude of more concrete rhythmic and melodic idioms. The notion of the *balungan* as the basis (or at least an indicator) of all parts is put under strain when considering vocal parts and soft-style instruments, such as the *gender, rebab*, and *gambang*. Players of these instruments employ somewhat more fluid and variable parts – although they may draw upon the *balungan* for guidance or constraints, they also share a repertoire of melodic patterning in the form of *cengkok*.

Cengkok are in themselves abstract sequences that must be elaborated upon and joined appropriately by musicians at the time of performance.[9] While largely compatible with notated outlines, *cengkok* often follow their own internal melodic contours, implying that a different framework might be taken as a reference. Furthermore, players might choose alternative *cengkok* for the same *balungan* contours at different times for the sake of variety, or in order to respond to other parts and fit the register of the collective internal melodic movement.

These factors become particularly apparent through temporal expansion. *Cengkok* can be expanded by inserting holding patterns in their middle, or by recombining existing patterns, either as fragments or in their complete forms (Sumarsam 1974, 164). Figure 5 illustrates how each change in density level places more significance on the mid-points of each phrase, until every note of the *balungan* sequence is preceded by the equivalent of a full *cengkok* in level IV. For example, the *dualolo* and *tumurun* patterns (which exist as both compressed and full-length versions) can sometimes be combined to form a whole *tumurun* pattern in the next density level. As musicians are given more freedom to interpret material in stretched-out sections, certain patterns may prompt a move towards appropriate mid-point notes that diverge

from the outlined sequence, before re-joining the rest of the ensemble on the most important structural resting points.

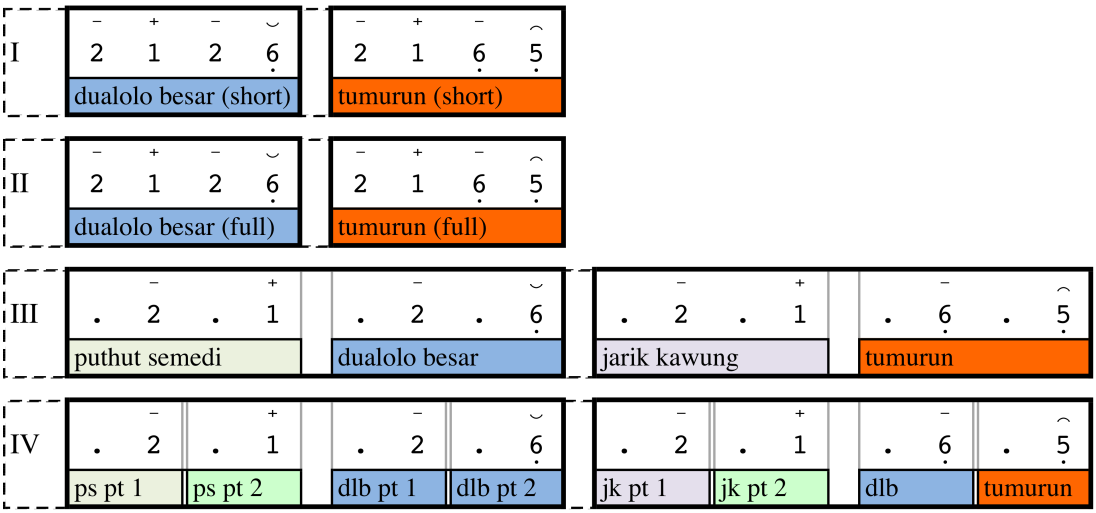

FIGURE 5: Examples of named patterns for treatment of the phrase 3 2 3 1 3 2 1 6 (*pathet manyura*), expanded across four density levels. For examples of *cengkok* notation see Martopangrawit 1973; Scholtz 2004; Polansky 2005.

Some conventions have been established for approaching these instruments in pedagogical contexts. Some common contours of *balungan* phrases can indicate appropriate patterns, and a player may choose *cengkok* by looking at a target note from the outline in relation to that of a preceding phrase; the main number sequence can be annotated with the names of these patterns (see Figure 5; Sumarsam 2004, 78-79; Martopangrawit 1973; Polansky 2005). However, these might be thought of as "coaching rules": explicit information used in the teaching process that does not fully describe the skill to be conveyed, ideally acting as a stepping stone to acquisition of more refined implicit knowledge (Perlman 2004, 22-23).[10]

Whether filling out *pipilan*-type patterns or selecting combinations of *cengkok*, many of the rules taught to beginners only work on a relatively small selection of classic pieces before exceptions are encountered. Some have logical connections to the *balungan*, such as replacement of notes in anticipation of stronger ones in adjacent phrases, overriding the structural points implied by the highly quantised sequence (known as *mlesed* – "slipping" – see Perlman 2004, 55; also *salah gumun*, ibid. 62; Supanggah 2004, 4).[11] Others refer to parallel phrases in sung parts and other instrumental idioms. As a result, creating a rule-based system that relies on the

analysis and treatment of outlined sequences alone can become a somewhat complicated endeavour.

2. APPLICATIONS FOR ALGORITHMIC REPRESENTATION AND COMPOSITION OF GAMELAN MUSIC

2.1 Gamelan and algorithms in musicology

Attempts at constructing generative grammars based on melodic patterning and gong structures in gamelan have mostly been aimed at describing existing works rather than creating new ones (e.g. Becker & Becker 1979; Becker 1980, 105-114; Hughes 1988). Grammars developed by Becker & Becker were used to identify the basis of particular forms, presented as an attempt to understand and identify innovation in composition (1979, 32). Hughes's subsequent analysis emphasises notions of deep structure and surface structure in terms of the *balungan*, suggesting that some forms are frozen versions of the temporal expansions that take place in performance practice (1988).

Grammars and related rule systems can also be useful in representing performance techniques, and the way that these structures are filled. The processes used in playing many of the "loud"-style instruments might be thought of as rewriting systems based on information from the central *balungan* sequence. The examples in Figures 2 and 3 illustrate letter-based systems commonly used to explain these processes (e.g. Pickvance 2005, 147; Perlman 2004, 57; Matthews 2014, 32; Grupe 2015, 33). However, these abstractions are of limited value without representation of spontaneous analysis, decision-making, and interaction taking place throughout the ensemble in performance.

A practical application for systems such as these is the testing of rules by making them explicit through computer-based synthesis, and mapping out the type and degree of contextualisation required for them to work. This was the impetus for the *Virtual Gamelan* project, which started at the Institute of Ethnomusicology in Graz, and involved the construction of a framework for the interpretation of traditional music using Supercollider (an audio programming language). Although the majority of the project's code and audio output have yet to be made public,[12] the developers' writing on the subject presents a comprehensive discussion of the issues surrounding part selection and generation as well as data structures for representing pieces and performance conventions (Schütz and Rohrhuber 2008).

Building upon the numerical systems conventionally used to represent gamelan music, the software adopts approaches called literate and interactive programming in which the code is built into the interface, and therefore becomes integrated with the

notation (ibid., 132). The software is based on analysis of *balungan* sequences coupled with a rewriting system: patterns are generated by rewriting abstract note pairs unless the input sequence matches a list of phrases, which are ordered for priority (ibid., 160-161). The project also presents interesting approaches to hierarchy and interaction, including creating parameters for musicians' "empathy" and "confidence" to emulate shifts in timing across an ensemble (ibid., 179-182).

While reliable algorithmic treatment of traditional repertoire through the framework was achieved only to a limited extent within the initial timeframe of the *Virtual Gamelan Graz* project, an extension to the project conducted by the Institute of Ethnomusicology explored the use of fixed computer sequences to test theoretical assumptions (Grupe 2015; 2016). In lieu of an automated model, a group of expert Javanese musicians were asked to evaluate sequences created in a commercial sequencer based on rules taken from lessons and textbooks. The ensuing discussions confirmed problems with deriving formal structures from conventional learning methods, in particular reliance on the *balungan* sequence alone for synthesis, but also focussed on issues relating to phrases played by the computer exactly as they would be notated. In particular, Grupe notes that "surface structures" in treatment, such as micro-timing and embellishment, appeared to hold as much salience as deeper structural issues (which he defines as "'correct' notes and patterns"; 2015, 41), highlighting a holistic approach taken by musicians.

2.2 Algorithmic approaches in new composition for gamelan

Gamelan music has a complicated relationship with notions of composition, not least because of the open nature of elaboration, and the frequent reuse of existing material. Although equivalent terms in Indonesian exist (such as *komponis*), many Javanese composers identify more with the role of an arranger or compiler (*penyusun*; see Roth 1986). Just as traditional works are pieced together from fragments of melody or *cengkok*, innovation in contemporary practice often takes place through the combination of whole pieces into suites, and their reinterpretation with different types of treatment or vocal parts. Such larger scale treatments are described in the same way as individual variations, called *garapan*. Where traditional structures or outlines such as *balungan* are not always present, the same essential processes are maintained: contemporary composition in Java often takes place through rehearsal process, with parts generated by musicians within guidelines, rather than being prescribed by a single person (ibid).

While there are concerns that traditional practice is experiencing something of a decline, elsewhere the music continues to change to fit with new technology and popular culture, integrating notation and recording, and occasionally sharing the stage with synthesisers and other instruments. A popular Indonesian genre called *campur*

sari (meaning a mixture of styles, and often implying use of Western-style instruments) sometimes calls for traditional forms to be played alongside the auto-accompaniment functions of commercial keyboards. Applications for computers and mobile devices enable students to play in classrooms or practice at home where instruments are not available (e.g. Tempo 2009; Wells Music Academy n.d.). Gamelan has attracted many composers from outside the tradition, and the patterns and flexibility of performance practice have been cited as inspiration in contemporary experimental, minimalist, and process-based approaches.[13] New movements of composers have also emerged both in Indonesia and abroad to work directly with gamelan ensembles in different ways: bringing updates to traditional styles, fusion with other musical cultures, and exploration of possibilities presented by creation of new forms of instruments (Roth 1986; Supanggah 2011, 50; House 2014).[14]

Notwithstanding problems with representing gamelan music as it is played in classically-oriented groups, the application of formalised rules has provided a fertile ground for new compositions. Treatment of outlines as found in traditional practice – whether performed by musicians or automatic processes – allows for greater levels of abstraction, and thus enables concentration on different types of detail. However, while existing structures might appear to hold convenient frameworks for composition, attempts at direct emulation without full understanding of the music's grammars and idioms (both in terms of phrasing and instrumental practice) can be restrictive. Abstraction of rules can prove difficult without tying into specific phrasing or modal frameworks, or can lead to work being received as pastiche composition if followed too closely. Instead it can be more beneficial for composers coming from outside the tradition to explore explicit synthesis with elements from their own backgrounds, which often entails an adaptation of performance conventions (Sorrell 2007).

For some composers, chance operations have been a sufficient means of emulating the surface complexity of gamelan music, although such approaches can also highlight expectations of idiomatic phrasing held by performers and listeners. The first recorded attempt at computer-aided composition for gamelan was conducted by a group of scholars at Gadjah Mada University in Indonesia with the aim of testing modes represented by *pathet* (Surjodiningrat et al. 1977). The research centred on software written in the general-purpose programming language *Fortran*, which was used to treat melodic information as abstract sequences of numbers, identifying a library of possible phrases taken from traditional pieces. These were recombined to fit into traditional structures through processes based on randomisation, creating *balungan* sequences. The resulting outlined parts generally did not conform to conventions that facilitated instrumental treatment, and were received critically by the musical community when presented in conventional formats (Sutton 1987, 69).

These processes have been echoed in new musical contexts without traditional constraints, such as Lydia Ayer's predominantly random part generation in her work for gamelan and tape (1996), and Markov chains in Max Worgan's generative score for the shadow puppet piece *The Sound Catcher* (2009). Patrick Hartono, an Indonesian composer who trained in electroacoustic music before working with gamelan, claims to experience patterns in gamelan music in terms of the spatial relationships between the instruments rather than their pitches (p.c. 2015). In Hartono's case, a loose imitation of the ensemble through granular synthesis – although possibly unrecognisable as such to a traditionally oriented player – maintains focus on the macro structure of the work and the parameters most important to the composer.

Established Javanese performance conventions have been used to reinterpret other musical styles in seminal American gamelan compositions (e.g. Diamond 2000), as well as otherwise non-musical information such as Lou Harrison's sonification of a social security number in his piece *Lagu Socieseknum* (see Miller and Lieberman 2004, 159). While not always set out in terms of strict rule sets or instructions, pieces such as these typically use outlines inspired by traditional practice – quantised information that affords interpretation through existing instrumental idioms. The composers' knowledge of rules and conventions, whether explicit or implicit, allows them to create sequences that will be treated predictably, or generate more detailed instructions accordingly.

Modifying playing techniques from gamelan is by no means a Western innovation. Composers working on the edges of traditional idiom, such as Ki Nartosabdho (an arranger, composer and shadow puppeteer popular in the 1960s) have introduced a range of techniques both new and adapted from older styles or regional variations. These have been borrowed by other composers and performing groups, and many have since been integrated into mainstream practice (see Sutton 1991, 220-233; Pickvance 2005, 15).

However, the creation of explicit new rules for performance, designed to be passed on and applied by other musicians, might be considered a rarity amongst contemporary Indonesian composers. Comparable frameworks have been explored elsewhere; for instance, the composer John Jacobs has developed what he calls *extended garap* – a set of techniques and stock phrases built upon traditional repertoire through trial and error and rehearsal process, which add to the possibilities of time signatures and polyphony within the conceptual framework of Javanese gamelan music (2013). According to Jacobs, this kind of approach is crucial to countering the mechanical feel often encountered when asking musicians to read detailed, through-composed pieces directly from notation (p.c. 2015).

Such processes have also been extended to computer-aided composition. The *Virtual Gamelan Graz* framework allows for composition involving the manipulation of rules by editing the rewriting system or applying alternative types of data input, although such development has yet to be implemented in practice (Schütz and Rohrhuber 2008). Max Worgan created an imaginary ensemble borrowing interlocking patterns from Javanese and Balinese playing styles for the *Shadow Catcher*, using real-time elaboration upon *balungan* sequences to respond to shadow puppets via video tracking (Worgan 2009). These approaches are generally rooted in contemporary teaching and learning methods that support the notion of rule-based gamelan performance, as will be discussed in further detail below with regards to my own practice.

3. Case study: Computer Aided Composition with Augmented Gamelan and Pipilan

My first contact with gamelan came through classes at the Southbank Centre in London, as an electronic musician seeking inspiration and some sort of theoretical framework for instrumental performance. Initially attracted to the timbre and tuning of the instruments, I felt refreshed by the logical approach taken to working out parts, and the apparent ease with which I could fit into such a large ensemble. I was also taken with the way that melodic structures could be spontaneously expanded and contracted in time, which felt reminiscent of granular audio time-stretching processes (Roads 1996, 440-446). I spent much of the ensuing ten years studying gamelan in London and Solo, reinforcing my learning by developing a set of patches in Cycling 74's *Max* software, and cultivating collaborations for gamelan and electronics, including *Augmented Gamelan*. Although I do not consider algorithmic composition to be my primary activity, my contact with gamelan music has driven me towards a search for flexibility, challenging assumptions that introducing technology might imply a move towards fixed sequences or pre-recorded material, and towards working on rule-based systems rather than individual pieces.

One of the principal aims of the *Augmented Gamelan* project is to explore the borders of tradition and the influence of physical construction of instruments on their associated idioms. The instruments are modified by attaching speakers to their bodies, playing synthesised sounds in order to stimulate metallic resonances, while projections or lights indicate each note as it is being played (see Figure 6). These parts can be created dynamically through a combination of sensor readings and pattern generation handled by custom software. As a result, the gestural and timbral possibilities of the instrument are expanded, and a computer and human player can

share both the physical instrument and a melodic outline as foundations for part generation and interaction.

For example, in *Bonang Study* (2011) for augmented gamelan instruments and computer, several sine tones are played through transducers attached to a set of gong-chimes, using patterns generated from a *balungan* sequence in synchronisation with an ensemble. Matching the treatment performed by their human counterpart, the synthesised parts anticipate each note, extending the attack and decay of the acoustic instrument, at times giving the impression that it is changing shape (Matthews 2014, 168-181; a similar effect is produced through the amplitude envelopes pictured in Figure 7). The resulting part provides a layer of textural elaboration interwoven with the traditional melodic elements, and can be temporally expanded and contracted in the same fashion.

FIGURE 6: *Pipilan* software controlling a set of instruments from the *Augmented Gamelan* ensemble at Hackoustic Festival, Machines Room, London 2016.

Initial experiments in composing for gamelan and electronics indicated that fixed note sequences for each instrument would be impractical for these purposes. In emulating a traditional ensemble with pre-sequenced material, every phrase must be prepared for several instrumental parts, and potentially duplicated and expanded

across a range of rhythmic density levels. A simple change in outlines, structural information, or tempo can have dramatic consequences, necessitating substantial reworking of these sequences. Furthermore, interaction is fundamental to gamelan music, which in turn requires flexibility for a computer-based system.

I sought to address these issues by building a framework in Max/MSP to recreate traditional music first, with the intention of exploring material from outside the idiom in the future (Matthews 2014, 140-167). The resulting software – named *Pipilan*, after the traditional convention of segmenting and repeating notes from a sequence – has formed the foundation for performances with the *Augmented Gamelan* ensemble, as well as installations in which audience members are invited to interact with generative music processes.

Pipilan is based on a set of rules for the real-time treatment of *balungan* sequences, with exceptions entered via a GUI in the manner of annotating notation. Part generation is performed with a combination of direct reference to the *balungan* and selection of entirely fixed patterns, with a pattern matching and rewriting system similar to the *Virtual Gamelan Graz* framework (Schütz & Rohrhuber 2008, 160-161). By accumulating a database of variations as individual pieces are entered, a larger framework can be constructed in reflection of the learning processes that beginner musicians undergo. The instruments emulated are mostly of the loud-style set (such as the *bonang*), as their idioms refer directly to the *balungan* sequence and are most easily represented with rules. These parts provided a natural starting point for integration with live musicians, with the understanding that they could fit into a gamelan ensemble to play basic but compatible patterns, just as a beginner can employ coaching rules to join more experienced players.

The hierarchy of instrument types in the gamelan lends itself to representation with an object-oriented model. Since instrumental sub-groups frequently share decisions on note selection that lead to repetition or interlocking patterns, these can form the basis for classes. For example, emulations of the *bonang barung* and *bonang panerus* parts shown in Figure 2 might inherit the same note selection functions, but differ in their density and therefore also their number of repetitions. Synthesised parts can also be created as children of the appropriate instrument classes, generating envelopes for timbral and spatial parameters alongside more conventional note events. This model enables development of complementary electronic processes tailored to each instrument, which can provide the basis for an augmented ensemble to move through a piece in unison.

Using traditional repertoire as a starting point for these rule-based systems became restrictive in the context of new composition, since outline sequences not fitting traditional contours in a given mode might produce unusual results or call up

references to arbitrary fragments of songs. As a result, the initial system was neither accurate enough to be of use to serious gamelan composers, nor flexible enough to generate interest amongst collaborators with a stronger background in electronic music. This problem stimulated the development of a system intended to establish a direct link between input and output sequences, ensuring that any phrase would be playable, but with the potential to accommodate traditional rule sets as exceptions. Consequently, the main instrumental layers in *Pipilan* use a set of simplified rules, largely based on a single octave range, and amalgamated from several loud-style instrumental techniques (see Figure 7). A collection of basic pattern-types are used to generate abstract sequences to refer back to the central outline, which in turn create note events and control ramps for synthesiser parts. Depending the pulse of the central clock, these patterns are automatically repeated to fit different rhythmic density levels, complemented by audio time-stretching through granular synthesis techniques. The rules and reference patterns used for rewriting can also be modified as the sequence plays, allowing for auditioning of parts during composition, and a move towards rudimentary live coding of the playing styles as an element of performance (see Magnusson 2011).

While the *balungan* is retained as a model for input, unidiomatic material such as phrases from other musical systems or non-musical data can be accommodated, provided that sequences can be broken into pairs; the software has been used effectively with random numbers, live input from audience members, information live-tracked from synthesisers at dance-oriented *Algorave* events, and even sequences of light recorded through photoresistors. Through this somewhat more generic approach I hope to illustrate decision-making in gamelan without the complications of more specific phrasing conventions in traditional practice, and thus open it up to audiences with a more casual interest in the music.

Among the other benefits of using this system has been the ability to stretch compositions out from the scale of minutes to hours – an extension of traditional temporal expansion that would be impractical for a human ensemble. It has also been useful in synchronising players with computer parts – for example, where click tracks are required, it is possible to create individual streams of information for each musician, with a level of detail appropriate to their chosen instrument. Live interaction with acoustic instruments can be simplified by matching common player choices (such as a move from low to high pitch registers at key points in order to change sections), potentially reducing the resolution needed for analysis of audio input.

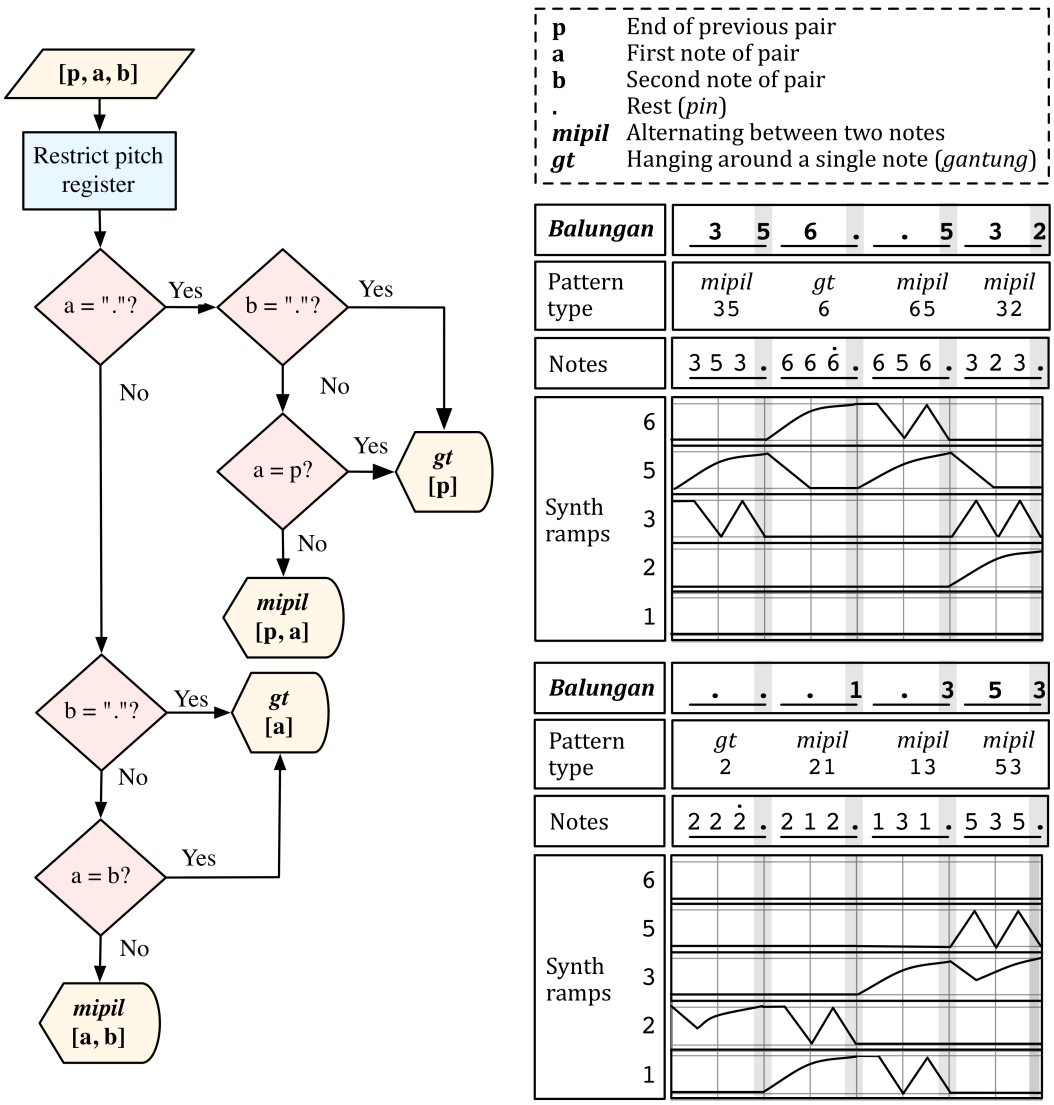

FIGURE 7: Flow of part selection in *Pipilan*, with example treatment shown on right. Synthesiser parts represent oscillator amplitude and generic timbral control data.

The scope for real-time integration of electronic parts with the gamelan can be expanded by building links between traditional pitch-based patterns and other domains, such as timbre and spatialisation. Creation of one-to-one mappings to parameters in these areas can be problematic, as idiomatic variations and ornaments are often reduced to artefacts lost in an interesting but dislocated complexity. It is often more appropriate to create analogous processes to fit the target medium, taking information from a central outline, and creating parallel streams of events that link to the note sequences at key moments.

Cases such as these can involve an approach to mapping that is broadly compatible with the Javanese notion of individual instrumental idioms coexisting and interacting in performance. For example, a version of *Pipilan* adapted for Ambisonic

spatialisation generates parts from a central sequence in two ways: the selection and repetition of notes as pitches by virtual instruments, and the movement between equivalent values in space through polar interpolation. Rather than imposing a connection to the traditional parts by linking parameters to individual notes of the outline (which might be considered unidiomatic or difficult to perceive in terms of spatial movement), the resulting movement is comparable to the convergence and divergence found in traditional Javanese music (see Perlman 2005, 62-74). Just as some instrumental parts temporarily move away from the influence of the *balungan* to find their own idiomatic path to the endpoint of a phrase, these equivalent synthesiser parts take a roundabout route to navigate a spherical arrangement of speakers before re-converging with resting points in the predetermined spatial sequence.[15]

This layering of approaches was exemplified in a multichannel performance/ installation at MUMUTH in Graz in 2015. Taking place in a concert hall following a traditional performance by the Southbank Gamelan Players, visitors were encouraged to collaborate in the creation of a long piece of music by writing a *balungan* sequence (see Figure 8). The changes in the structure were reflected in parts played by a virtual ensemble responding in real-time; certain instrumental and synthesised parts also moved through the space. Members of the gamelan ensemble were inspired to join in on instruments, adding further layers by following the same outline as the computer, either by listening for changes or reading the constantly-shifting central sequence projected above the instruments. Although the algorithmically generated part was mechanical in comparison to this fluid improvisation, its robustness facilitated a unique exploratory interaction between audience and performers, simultaneously linked to spatial movement.

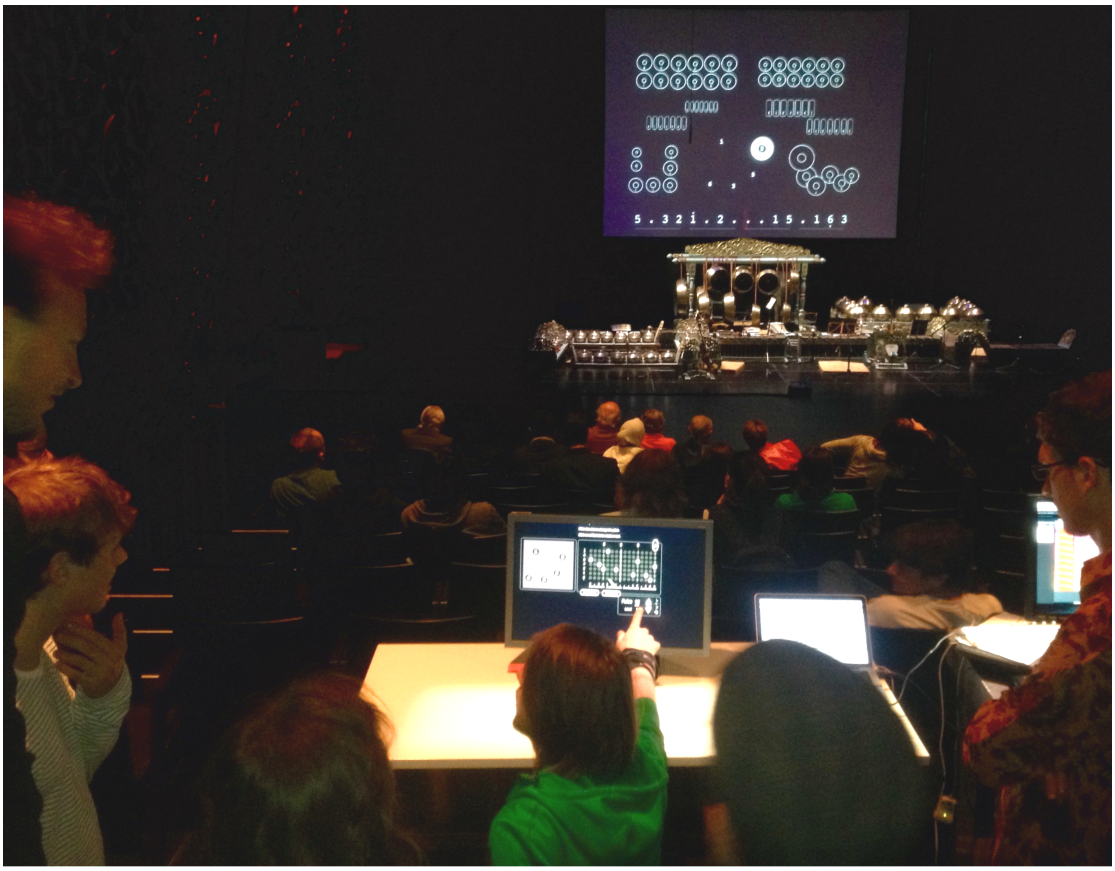

FIGURE 8: Audience members composing live using *Pipilan* in a multichannel Ambisonic installation at MUMUTH, Graz, 2015. Photo by Brad Smith.

4. CONCLUSION

The examples of rules and more general algorithmic thinking explored in this chapter are important aspects of gamelan music, but – echoing Sutton's comments on improvisation (1998) – it would be an over-generalisation to describe the tradition as predominantly or explicitly rule-based. Formal rules have been embraced in educational settings, but as the *Virtual Gamelan Graz* project has highlighted, it seems that expert musicians tend to take a more holistic approach. Furthermore, rules and grammars might only be considered a snapshot if seeking to represent existing musical practice, particularly one of a living tradition such as gamelan.

While contemporary methods for teaching gamelan music might indicate shortcuts to part generation, few appear to translate well to reliable computer representation. Many problems in this area stem from taking the minimal notation of the *balungan* sequence as the basis for synthesis of all parts, where in practice it often acts as a context-dependent signpost for other un-notated information. With this in mind, it may be more beneficial to investigate ways of analysing more complex information, with the aim of creating new forms of abstraction to build upon. A *balungan*-type

sequence may then be used to form a bridge between different types of interpretation, including those of a computer and human performers, much as it mediates the loud and soft-style instrumental approaches in traditional contexts.

Despite the apparent impracticalities of emulating whole ensembles, some of the ideas presented in this chapter might facilitate a movement towards aural approaches to learning and composition where instrumental resources, players, or recordings are not available – enabling testing of rules, and previewing outlined compositions before approaching musicians. As well as recreating existing styles, there is much to explore through the potential of interactive and generative systems in new music less constrained by traditional obligations. While some common approaches to theory might be regarded as misconceptions of how gamelan music works, the imposition of Western ideals, or coaching rules usually intended to be discarded, why shouldn't the results of these be used in creating new music?

Traditional practice provides a useful model in which a structure is exposed both audibly and visually, and can be expanded and contracted in time. Rules designed to aid beginners can provide interesting ways to generate coherent complexity; implemented as generative algorithms, they might be set to evolve by themselves, or enable interaction and structured improvisation with a computer system. Perhaps most exciting of all is the prospect of manipulating outlines and rules as part of performance, in a feedback relationship with players or audience. Since it has been suggested that traditional gamelan pieces only exist through the combination and interaction of many parts in real-time, it seems appropriate that future gamelan-inspired composition, electronic or otherwise, might be presented the same way.

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NOTES

[1] The approaches in my practice discussed here were developed as part of my Ph.D. research at Middlesex University (Matthews 2014), with support from the Arts and Humanities Research Council.

[2] This relationship can be found in the most common form of pieces in which the entire gamelan is played together, called *gendhing*. Other more predominantly linear forms such as *pathetan* do not rely on rigid frameworks of gongs or *balungan* described below, instead placing emphasis on interpretation, elaboration and interaction based on a vocal or fiddle part (Brinner 1995, 245-267; Sumarsam 1974, 164-166). The relationship between gong cycles and linear melody has been compared to broader cyclic and linear approaches to time in Javanese culture (see Hoffman 1978; McGraw 2008).

[3] Some musicians do not identify these sequences as melodies, preferring the term *rangka* (framework; Martopangrawit in Perlman 2004, 103). In some varieties of gamelan found in West Java, musicians refer to structures called *patokan,* which are typically played directly by a set of pitched gongs, and can be notated to facilitate performance (Swindells 2004, 104-109; Cook 1992, 18). A similar melodic line exists in Balinese gamelan theory, which is referred to as *pokok* (essence), and played by a set of keyed bass instruments. The *pokok* sequence can be used as the basis for elaboration, providing the notes for a variety of interlocking parts called *kotekan* (Tenzer 2000, 53-54). While the *pokok* sequence's generative qualities are more consistent than its Javanese counterpart, the patterns derived from it are generally fixed in advance, at the point of composition, rather than being treated by musicians in real-time (ibid., 130).

[4] All examples in this chapter are presented in the standard *kepatihan* cypher-based notation system. By convention the notes of the five-tone *slendro* scale used here are numbered 1 2 3 5 6 (from low to high).

[5] Cases of *balungan*-style outlined notation have been traced back to the 15th Century (Sumarsam 1995, 316). Tenzer notes that similar notation of *pokok* sequences were formerly used in Bali, called *grantangan* (2000, 122).

[6] See Wakeling (2010) for discussion of issues around structuralist approaches to theorising gamelan, in particular highlighting incongruity with research based on rehearsal and performance processes.

[7] Five formal *irama* levels are typically recognised in Solonese style (Pickvance 2005, 60; Supanggah 2011, 292). These are commonly measured by marking the number of notes played on the *saron panerus* against the central *balungan* pulse, ranging from 1:1 to 16:1. Transitions between *irama* levels can be performed as a shared musical gesture by acceleration and deceleration of the central pulse, creating an impression of elasticity. Tempo thresholds for transitions vary between contexts; maintaining density relationships when changes might otherwise expected can be used to great effect in creating tension or space, particularly in dance accompaniment.

[8] *Pipilan* (and its verb form *mipil*) can be translated as "picking away". This instrumental technique creates parts sufficient for other players to follow instead of notation if unfamiliar with the piece in question. In some cases the *bonang* has been used to disseminate spontaneous compositions to other players (Supanggah 2011, 151-152).

[9] The resulting parts, which take into account a range of parameters including performance context, personal style, and interaction with other musicians, are called *wiled* or *wiletan* (Supanggah 2011, 286). Supanggah compares variability in the performance of *cengkok* to patterning in *batik*, in which named outlines generally remain recognizable but the manifestation varies between artists (ibid., 283). For further discussion of *cengkok* and the term's etymology, see Sumarsam 1995, 229-234.

[10] The rules for beginners presented in the teacher Widiyanto's "Gambang 101" (Putro 2010) illustrate an underlying principle of many soft-style techniques: playing a pattern to "hang" around the previous note played, followed by a bridging pattern to the next important part of the sequence.

[11] In cases such as these it may be more appropriate to suggest that the *balungan* diverges from the inner melody represented by the soft instruments (Perlman 2004, 147). The *balungan* is also constrained by its own idioms, such as avoidance of repetition of notes in *nibani*-type sequences, which can lead to many cases of such divergence.

[12] Some source code from the framework is available online (https://github.com/musikinformatik/VirtualGamelan/, accessed 03/02/2016).

[13] Steve Reich was notably influenced by contact with Balinese gamelan, borrowing conventions for cueing and interaction in works based on repetition, and encouraged future composers to explore the structures of non-Western musics rather than simply imitating their sound (Reich, 2002). Connections between gamelan and the minimalist genre have been explored through a set of compositions in the *Returning Minimalism* series by Yantra Productions; the liner notes include comments by professional Javanese musicians and composers on perceived contrasts in playing styles and aesthetics (Yantra Productions, 2011).

[14] It has not been possible to focus here on the multitude of successful works that take more general influence from gamelan music or use the instruments or samples for other purposes. Examples of process pieces using gamelan outside its traditional context include Michael Parsons's *Changes* (written in 1981 with strong influence from change ringing – see House 2014, 58), and Daniel Goode and Larry Polansky's *Eine Kleine Gamelan/Computer Music* – a piece first adapted for computer realisation

in HMSL and subsequently ported to Max (http://eamusic.dartmouth.edu/~larry/ek_project/, accessed 01/06/2015). Material from traditional gamelan has also been the subject of mutation with other styles of music in the work of Polansky (1996) and Cope (1991).

[15] This mapping of melodic information to points in space was inspired by the installation piece *Framework* by Hughes and Jacobs (2012), in which the spatial motion was pre-recorded, rather than algorithmically generated.