

# A Computational Model of the Music of Stevie Ray Vaughan

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## ABSTRACT

Every musician who improvises has a unique musical vocabulary, which may be perceived in his or her compositions. In this paper, we explain our design of a computational model that predicts the creative decisions made by the blues musician, Stevie Ray Vaughan for various input scenarios. Our design brings into effect the fact that creative works involve the use of pre-existing structures stored in the creator's mind or knowledge base, retrieved and reconstructed on the basis of appropriate rules, which are triggered by the nature of specific input. The model was partially implemented as a limited production system using a probabilistic method. It was tested with three different input scenarios. The model predicted the musician's decisions with a limited degree of accuracy. The tests provided valuable insight on ways to improve the current performance and suggested revising the definition of a musical pattern to include specific limits on its duration.

## Keywords

Musical creativity, computational modeling, production system, creativity modeling.

## ACM Classification Keywords

I.2.4 Knowledge Representation Formalisms and Methods: Representations (procedural and rule-based)

## INTRODUCTION

Every musician has a unique musical vocabulary, which he or she uses in creating music. Our objectives for designing this computational model were, a) to capture the cognitive style of a particular blues musician: Stevie Ray Vaughan, and b) to predict the improvisational decisions made by Stevie Ray Vaughan for given input scenarios, during the creative process of making music, and thus illustrate some aspects of his cognitive style.

This effort was on account of three kinds of motivational reasons. First, there is a theoretical basis for this effort. It is

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widely agreed that one of the key attributes of a creative work is the extent of its originality. The originality of any creative work is perceived by the uniqueness with which previously existing ideas are combined to form this new body of work.

Koestler [1] termed the connection of two previously unconnected “matrices” or knowledge spaces as bisociation. We attempt to illustrate bisociation by mapping out the contribution of different knowledge spaces towards the creation of single bodies of music, or songs, by one musician.

Second, there is a motivation behind using a computational model as the model of choice. A model may be loosely defined as the representation of a theory about some real-world phenomenon. It allows us to focus on certain aspects of realistic phenomena while abstracting out irrelevant details. A computational model entails developing a process theory, expressing this as a computer program and simulating it [2]. This requires “definitional and conceptual precision, and clarity of assumptions” made. Computational models allow us to incorporate a “level of realism” without sacrificing “analytic focus” [2]. In addition to these merits, computational models can act as powerful metaphorical tools for understanding creative processes. Our goal here is to explain certain aspects of Stevie Ray Vaughan's creative process by predicting his musical decisions, given his emotional goals/mental states, and compositional goals. We construct metaphors by mapping what we wish to understand (*the metaphrand*) onto something we do understand (*the metaphier*) [3]. The two domains we are dealing with here, when examining Stevie Ray Vaughan's creativity are music and psychology. To get a clearer understanding of his creative process, we wish to map some aspects of his creative process (*the metaphrand*), onto a computational model (*the metaphier*). We emphasize that by using a computational model we are not proposing that the music creation process is intrinsically computational. Rather, computational models provide us with techniques that enable us to capture certain key aspects of the creative process.

Third, there is a motivation behind using Stevie Ray Vaughan as the subject of our case study. Vaughan's contribution to the blues/blues-rock genre cannot be overstated. He is widely considered to be one of the few

musicians responsible for reviving the blues in the 1980s [4]. Not only was his influence felt by several of his contemporary musicians and peers in the genres of blues and rock & roll such as Eric Clapton, Buddy Guy, John Lee Hooker, and Bonnie Raitt [5], but is also still present in the style of current blues-rock musicians such as Kenny Wayne Shepherd.

Besides his importance in terms of musical contribution, Vaughan's musical style is more restricted to blues and blues-rock idioms unlike the style of other guitar players such as John McLaughlin and Robben Ford. This provides us with a better opportunity to capture key aspects of his style within the precise nature of a computational model.

Scientific approaches to the study of creativity such as the method of experimental psychology identify universal principles or general theories referred to by psychologists as nomothetic principles [6]. These scientific approaches do not explain how a particular individual has performed a particular act of creation. So, the individual's uniqueness is not captured. What we need is "a cognitive science of the individual" which involves a combination of nomothetic principles with "idiographic understanding", or "insight into the particularities of the individual".

This model addresses the requirements of this approach by initially studying the particularities of the individual and then simulating them. The model attempts to provide insight into the creative process of a particular individual, who in our case is Stevie Ray Vaughan.

According to Jeffrey George<sup>1</sup>, coordinator of guitar studies in the School of Music at the University of Louisiana at Lafayette, students pursuing music as a course of study are not taught how to improvise. They are essentially provided with "tools" or musical vocabulary, which may be used for playing music. For a beginning jazz musician these tools would be musical elements such as scales, harmonies, chords and chord voicings [7]. As a first step to improvisation a musician learns to emulate solo performances of other musicians who have influenced him or her, keeping in mind the context in which that solo was composed. A computational model could provide insight into the improvisatory decisions made by the particular musician in musically different situations.

## **MUSIC AND COMPUTATIONAL MODELING**

Two main kinds of models in cognitive musicology are competence models and performance models. Competence comprises the knowledge possessed by musicians, by way of musical concepts, skills etc. Competence models provide theories regarding the organization, representation and understanding of this knowledge by the musician. However, they do not explain how the musician uses this knowledge while performing. Performance models, deal with predicting

how the musician uses his or her knowledge in a given scenario. One of the methods used in modeling musical activity is an indirect method that involves examining the end product generated by the musician. This involves attempting to understand musical activity by "knowledge engineering in reverse" [8].

A few existing computational models in music cognition were reviewed prior to our implementation. Thom's Band-out-of-the-Box (BoB) [9], attempts to trade "short solos" with a real musician during the process of improvisation. It restricts the learning phase to a maximum of 15 minutes, during which the musician is asked to play, with a few pre-set conditions such as tempo and accompaniment. This input stream of musical data is captured and organized into pitch classes based on their frequency of use. Then probabilistic methods are applied to generate patterns that simulate the style of the musician whose input stream was used as "warm up" data. While the model emulates certain elements of the musician's style it does not provide insight into the creative aspects of the musician's style. It does not provide any input conditions that influence the musician's creative decisions.

Eck and Schmidhuber [10] designed a model using recurrent neural networks to learn from an input stream in a specific musical style and generate new instances of the given musical style. This principle could also be applied to generating instances of a particular musician's style instead of a musical genre. However, since the inputs of the network are in the form of single notes rather than emotional, stylistic and structural parameters, it does not provide any insight into the creative decisions made by a particular musician, just as in the case of Thom's BoB.

Walker's ImprovisationBuilder acts like a computer improviser in group improvisations [11]. Walker uses certain norms in conversational analysis in his design to determine when another musician is "soloing, accompanying, or not playing". He believes that musicians "build melodic solos from phrases" as opposed to individual musical notes. This is one aspect where ImprovisationBuilder differs from BoB and the Eck and Schmidhuber network model. ImprovisationBuilder generates solos using several methods, two of which are: concatenating short musical phrases to form a solo, and randomly selecting notes within the scale to form a solo. The first method is comparable to the improvisation of a musician in real life. Musicians tend to use short sequences of notes, or musical phrases, which define their musical style. The melodic phrases need to be pre-programmed in the required style by an expert. ImprovisationBuilder could be customized to generate solos in the style of a particular musician. However, just as in the case of the two previously mentioned models, it does not provide any kind of insight into the creative decisions made by the musician, since all the learning is performed through musical phrases in the absence of any emotional or structural input parameters.

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<sup>1</sup> J. L. George, personal communication, Feb 23, 2005.

Riecken's WOLFGANG uses emotional goals to make compositional decisions [12]. For simplicity, these emotions are restricted to four kinds: Happiness, Sadness, Anger, and Meditativeness. The user varies the degree of emotion by using weights based on which WOLFGANG composes. WOLFGANG's approach of using emotional potentials could also be extended to the study of a particular musician's style.

Among the four models mentioned, WOLFGANG's approach of using emotional inputs is relevant to our model. However, we will use two enhancements over WOLFGANG. First, our model will use several emotional/mental state inputs instead of being restricted to the four emotional inputs of Happiness, Sadness, Anger, and Meditativeness used by WOLFGANG. Second, in addition to emotional/mental state inputs, we will also use structural and stylistic inputs in our model. The knowledge base in our model will consist of pre-programmed musical phrases or patterns instead of single notes, similar to ImprovisationBuilder.

## METHODOLOGY

We implemented our model as a limited production system. Production systems fall under the category of symbolic artificial intelligence (AI) systems. A production system consists of three components, which are the *global database*, a *set of production rules*, and a *control structure* [13]. The global database consists of all the data needed by the system. Production rules are condition/action rules. Whenever a certain condition is satisfied, then a specified action is or may be performed. So, the set of production rules may be thought of as IF...THEN constructs [14]. The control structure determines the sequence in which production rules are triggered. In case several rules apply to some information in the global database, a conflict-resolution strategy in the control structure selects the best rule to be executed.

As Figure 1 depicts, the process of creation is modeled as follows: Before creating or composing a song, or giving a personal rendition of a cover song, the musician already has some goals in mind with respect to the structure of the song, its style and its emotional content, indicated in Figure 1 as *Initial State*. These emotional, structural and stylistic goals are represented as *E*, *S*, and *T*. The musician starts with this *Initial State*, having either loose or concrete predetermined goals. The next step involves using his or her preexisting domain of musical knowledge to achieve the desired goal. This preexisting domain of knowledge is represented as *Stored patterns* in the *Memory* component in Figure 1. When composing music, a majority of the content of the song is derived from the musician's previously stored knowledge. However, there is always a possibility for the musician to add to his existing memory during the process of creation, on account of external influences (as indicated in Figure 1) and thus expand his domain. These external influences may be in the form of ideas generated by listening to other musicians,

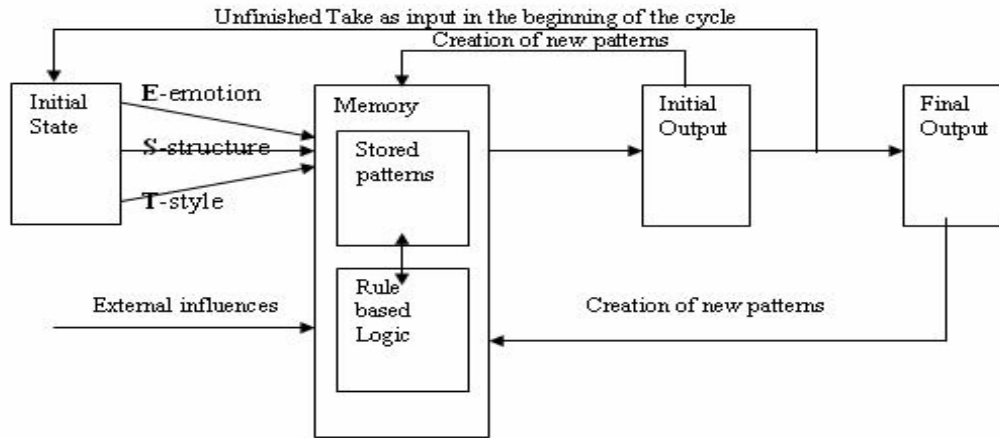
playing with other musicians, or both. So, the domain can continue to increase during the process of creation. Once the song is composed, either the musician will be satisfied with the initial outcome or will want to further refine it as he or she finds a certain element or elements of it unsatisfactory. So the cycle repeats, in the latter case. However, the starting point now involves clearer and more concrete goals of the final outcome than before. This step is indicated in Figure 1 as *Unfinished Take as input in the beginning of the cycle*.

During any of the initial, unedited compositions the musician might like some of the elements created, although he or she might feel that the song as a whole needs further refinement prior to becoming the final product. These created elements represent a hybrid element generated from his or her existing knowledge or domain. If these hybrid elements enable creativity based on the musician's goals, on account of which the result appeals to the musician, then there is a possibility of the musician incorporating some of those elements as additions to his or her domain. This step is illustrated in Figure 1 as *Creation of new patterns* from the *Initial Output* stage to the *Memory* stage. This process of addition of a changed pattern or a hybrid pattern to the domain, and thus its expansion is possible even after the *Final Output* stage (as indicated in Figure 1).

For the purpose of our implementation certain assumptions were made. We assumed that the musician had already acquired the necessary patterns, or building blocks for composing a song, and they are stored in his memory. So, his memory during the process of creation of a song is assumed to be constant; that is, we ignore the role of external influences. Our framework assumes that the process of creation involves retrieval of building blocks and their reconstruction. Our goal was to use the model to predict the musical patterns used by the musician, given a combination of input parameters, with a certain degree of accuracy and thus attempt to show some of the musician's improvisatory decisions.

Hence, the model will end at the *Initial Output* stage shown in Figure 1. Since memory is fixed, and learning is not a feature incorporated in the existing model, new patterns discovered during testing were not added to the predefined memory. Before the process of creating a song begins, the musician is clear about certain aspects of the composition and has definite goals. The relevant properties of the song can be divided roughly into three areas: Emotional Content/Mental States, Structure of the song, and Style of the song, represented as *E*, *S*, and *T* respectively in Figure 1.

*E* includes emotions such as Sadness, Anger, Love, Yearning, and Happiness, as well as mental states and intentions such as Sarcasm, Satire, Sense of Warning, and Preparedness. *T* indicates the style of the song. Style includes genres and sub-genres such as Blues, Blues-rock, Shuffle, Rock, Pop-rock, Boogaloo, Jazz, and Funk.



**Figure 1. Overview of stages in the creative process**

*S* indicates structural details of the song like the tempo of the song: Slow, Medium slow, Medium, and Fast based on beats per minute; and the format in terms of the number of bars for chorus and verse: 8-bar, 12-bar. The *E*, *T*, and *S* details were listed out as separate variables in the program. They act as the input parameters for the program. Each variable is assigned a weight from 0 to 1 based on its significance in the song. A weight of 0 indicates the absence of that particular emotion, while a weight of 1 indicates maximum importance. In addition to the *E*, *T* and *S* parameters, an *H* parameter indicating the history of the song was also recorded. This indicates whether the song is an original composition or a rendition of a cover song. While our implementation did not use the *H* parameter as an input, this parameter was recorded for informational purposes, as it might be beneficial to future implementations. Table 1 provides a list of all the *E*, *T*, *S*, and *H* parameters used as inputs for the program. The performance of this computational model relies strongly on the design of the *Memory* component which represents Vaughan's knowledge base or domain. The memory component consists of two functional sub-components: *Stored patterns* and *Rule-based Logic* as shown in Figure 1.

The *Stored patterns* sub-component serves as storage for all possible musical phrases or patterns that we were able to extract from Vaughan's knowledge base. Each musical pattern is stored with reference to the major scale and the octave it is played in. A musical pattern could be a sequence of notes or chorded notes. A pattern may be defined as a short musical phrase spanning in length from less than a bar to a few bars, played either in a lead or a rhythm context, and ending either at a pause in time or at a point of musical resolution. Points of resolution usually are the root note, the fifth note, or the flat fifth note, with or without vibrato. However, they may occasionally include the flat third note or the flat seventh note, with or without vibrato. In the case of a pattern using the major scale and the major pentatonic scale, the third note or the seventh note could also act as a point of resolution. In addition to these notes, a slide down from a

single note or chorded notes is sometimes used as a point of resolution. An example of a musical pattern is:

**1 b3 4 5[2<sup>nd</sup>]**

This indicates a short musical phrase starting with the root note, followed by the flat third, the fourth, and then the fifth. The "2<sup>nd</sup>" indicates that the entire phrase is played in the second octave on a six-string guitar tuned in the standard sequence of E A D G B E. This notation includes several technical nuances with regard to Vaughan's blues guitar style such as bends, hammer-ons, pull-offs, trills, slides etc. The notation was developed using some of the symbols in guitar tablature. All patterns are represented relative to the major scale. A few examples of this notation are mentioned here.

**1 b2 2 b3 3 4 b5 5 b6 6 b7 7 1**

This represents the twelve consecutive notes in standard Western music with a half note interval between each, represented sequentially.

**4<sub>bend</sub>(5)** This represents a bend from the fourth note to the fifth note in the first octave.

**1<sup>vib</sup>** Vibrato on the root note in the first octave.

**1<sub>slidedown</sub>[2<sup>nd</sup>]** Sliding down from the root note in the second octave.

**b7<sub>bend</sub>(1)<sup>2</sup>** A bend from the flat seventh in the first octave to the root note in the second octave.

A majority of Vaughan's frequently used musical phrases (licks) can be traced back to his influences. Some of his key influences are Albert King, Jimi Hendrix, and B.B. King. Each influence is represented programmatically as an array. Any pattern traced back to that particular influence is labeled and stored as an element of that array. In addition to influences, arrays are also created on the basis of technical relevance. For example, a pattern played as a rhythmic phrase rather than a lead or a solo phrase is stored in a Rhythm array. Arrays are also created on the basis of genre or musical context.

E Parameter	T Parameter	S Parameter	H Parameter
<i>E_Sadness</i>	<i>T_Blues</i>	<i>S_Twelve</i>	<i>H_Original</i>
<i>E_Yearning</i>	<i>T_BluesRock</i>	<i>S_CandR</i>	<i>H_Cover</i>
<i>E_Frustration</i>	<i>T_RandB</i>	<i>S_Eight</i>	
<i>E_Relief</i>	<i>T_PopRock</i>	<i>S_Slow</i>	
<i>E_Upbeat</i>	<i>T_Shuffle</i>	<i>S_MediumSlow</i>	
<i>E_Satire</i>	<i>T_Rock</i>	<i>S_Medium</i>	
<i>E_Happiness</i>	<i>T_Funk</i>	<i>S_Fast</i>	
<i>E_Love</i>	<i>T_Jazz</i>		
<i>E_Hope</i>	<i>T_Boogaloo</i>		
<i>E_Reform</i>			
<i>E_Repent</i>			
<i>E_Strength</i>			
<i>E_Preparedness</i>			
<i>E_Sarcasm</i>			
<i>E_Spitefulness</i>			
<i>E_Anger</i>			
<i>E_Humor</i>			
<i>E_Pain</i>			
<i>E_Fear</i>			
<i>E_Warming</i>			
<i>E_Helplessness</i>			
<i>E_Hopelessness</i>			
<i>E_Toughness</i>			

**Table 1. E, T, S, H input parameters**

If a pattern is played exclusively in the context of jazz, and cannot be traced to a particular influence, it is labeled and stored in a Jazz array. When a pattern cannot be traced back to a particular influence, or classified under any of the existing arrays, it is stored in a separate array labeled *Other*. The *Rule-based logic* sub-component of *Memory* decides the selection of specific musical patterns from the available patterns in the *Stored patterns* sub-component, based on the input parameters for Emotional Content/Mental States, Structure and Style. A rule informs us about the probability of a particular phrase or pattern being selected from all the existing arrays, based on the combination of input variables and the weights assigned to them.

For example, if Vaughan has a preconceived goal for a song, with *Sadness* as a definite emotion/mental state, and a *12-bar blues* format, we may have the following rule in pseudocode:   
*If (E\_Sad > 0.8) && (S\_Twelve > 0.8) && (T\_Blues == 1)*  
*{ A2 = 0.95;}*

Here *E\_Sad* denotes sadness, *S\_Twelve* denotes a 12-bar format, and *T\_Blues* denotes the style of the song. The rule states that if *Sadness* has a weight of over 0.8, with the song definitely in the blues style, and a weight of over 0.8 for having a 12-bar format, then there is a 95% probability that Vaughan will use the pattern *A2* for his composition. Several rules are generated based on the combinations of *E*, *T*, and *S* parameters. For a given combination of input parameters, a set of patterns or phrases along with their probabilities are retrieved and displayed as output. The generated output is tested against the actual patterns found in the song to provide a measure of the performance of the model.

A total of eleven songs representing Vaughan's style were studied from two of his albums [15][16]. These songs will be referred to by their abbreviations shown in Table 2. After studying the eleven songs, patterns extracted from them were grouped into six categories based on influence and technical

relevance. These six categories are *Albert King*, *Jimi Hendrix*, *B.B. King*, *Rhythm*, *Jazz*, and *Other*.

Albert King was one of Vaughan's strongest influences. His style is felt in Vaughan's compositions. Certain features in a pattern characterize the pattern as bearing resemblance to Albert King's style. King's style of playing involves use of repeated and exaggerated bends, sliding down, sustained and prolonged bending followed by a release. His style may be observed in songs such as *I'll play the blues for you* [17]. Two examples of specific features in Vaughan's patterns, which enable us to categorize them under the *Albert King* category, are:

- bending from the fourth note to the fifth note, followed by a normal or extended release back to the fourth note.
- a series of repetitive bends from the fourth note to the fifth note, with the final bend executed slower than the previous bends;

Song	Abbreviation
<i>Texas Flood</i>	<i>Tex</i>
<i>Taxman</i>	<i>Tax</i>
<i>Change It</i>	<i>Chi</i>
<i>Chitlins Con Carne</i>	<i>Ccc</i>
<i>Cold Shot</i>	<i>Cos</i>
<i>Couldn't Stand The Weather</i>	<i>Cow</i>
<i>Empty Arms</i>	<i>Emp</i>
<i>The Sky Is Crying</i>	<i>Sky</i>
<i>So Excited</i>	<i>Exc</i>
<i>Crossfire</i>	<i>Cro</i>
<i>Tightrope</i>	<i>Rop</i>

**Table 2. List of Songs**

Jimi Hendrix was another important influence in Vaughan's musical style. His style may be observed by listening to

songs such as *Voodoo Chile (Slight Return)*, *Crosstown Traffic*, and *Gypsy Eyes* [18]. Two examples of the features in Vaughan’s patterns that enable us to characterize them as *Hendrix*-influenced patterns are:

- phrases beginning with a bend from the fourth note to the fifth note or a flat fifth note, and resolved by a bend from the flat seventh note to the root note, usually with strong vibrato;
- trills from the flat seventh note to the root note.

Similarly, B.B. King’s style may occasionally be perceived in Vaughan’s songs. It involves bending notes in the major scale and the major pentatonic scale and mixing them with notes in the blues scale and the minor pentatonic scale. If a pattern is used for playing rhythm, and cannot be traced to a particular influence, that pattern is categorized under the *Rhythm* group. Patterns that are used in the context of Jazz, but do not exhibit features from any of the groups of *Albert King*, *Jimi Hendrix*, *B.B. King*, and *Rhythm*, are categorized under the *Jazz* group. Patterns that do not fall under any of these categories are stored in the *Other* group. Each category is referred to in the following manner.

Albert King	A
Jimi Hendrix	J
B.B. King	B
Rhythm	R
Jazz	Z
Other	O

From the eleven songs studied, 46 patterns were extracted and grouped under the *Albert King* category; 16 patterns were extracted and grouped under the *Jimi Hendrix* category; 19 patterns were extracted and grouped under the *Rhythm* category; 11 patterns were extracted and grouped under the *Jazz* category; 1 pattern was extracted and grouped under the *B.B. King* category; and 79 patterns were extracted and grouped under the *Other* category. They are summarized as follows:

Albert King,	A = {A1 to A46};
Jimi Hendrix,	J = {J1 to J16};
Rhythm,	R = {R1 to R19};
Jazz,	Z = {Z1 to Z11};
B.B. King,	B = {B1};
Other,	O = {O1 to O79}.

We now provide an example to illustrate how *E*, *S*, and *T* parameters are extracted from each song, how weights are assigned to each of these parameters, and how patterns are transcribed. *Texas Flood* [15] was originally a song composed by Larry Davis and Joseph Scott. It may be considered to be a traditional blues song with a 12-bar format. The tempo of the song is slow. The lyrics of the song indicate emotional hardships of a long-distance relationship, sadness on account of not being able to continue with the relationship, and a sense of relief at the thought of letting go.

We observe the following parameters for *E*, *S*, and *T*.

Emotional Content/Mental States (*E*): Sadness, Yearning, Frustration and Relief.

Style (*T*): Blues.

Structure (*S*): 12-bar, Slow tempo.

History (*H*): Cover song.

The song is clearly a sad song. About two-thirds of the song indicate yearning and frustration, while only a third of the song talks about a sense of relief. The song is a blues song not only on the basis of its style or genre, but also on account of its emotional content. Vaughan emphasizes the emotional content by using classic call-and-response technique, with his vocal and guitar interplay. So we assign weights to the above parameters as follows:

$E\_Sadness = 1.0, E\_Yearning = 0.7, E\_Frustration = 0.7,$   
 $E\_Relief = 0.3.$

$T\_Blues = 1.0.$

$S\_Twelve = 1.0, S\_Slow = 1.0, S\_CandR = 1.0.$

$H\_Cover = 1.0.$

Based on this song, we were able to extract patterns, J1, J2, J3, J4, A1, A2, A3, A4, A5, A6, A7, O1, O2 and O3, all of which will be stored in *Memory*. Some of these patterns are explained here.

J1:  $4^2_{bend}(5)^2 5^2 1^3 b7^2_{bend}(1)^{2vib}$

Vaughan uses either J1 or a slight variation of it in a call-and-response context.

A3:  $1 1 b3 1[3^{rd}] b7 4_{bend}(5)_{release}(4) b3^{vib} 1_{slidedown}[2^{nd}]$

In pattern A3, the first four notes are played in the third octave, and the rest are played in the second octave. The bend from the fourth to the fifth followed by a release back to the fourth, followed by the flat third, and then resolved with a slide, is a very characteristic Vaughan phrasing.

J2:  $b7^1_{trill}(1)^2 4 b5 5[1^{st}]$

J2 is used when resolving to a fifth. It involves using a trill from the flat seventh to the root, and is a Jimi Hendrix influenced lick.

After the collection of *E*, *T*, and *S* parameters and the entire list of patterns from the eleven songs, various frequencies are calculated. First, input frequencies are calculated. Input frequency of a particular input parameter is the number of songs that parameter appears in. We also examine the relationship between songs and pattern groups. This information informs us about the existence or non-existence of patterns belonging to a particular group in a particular song. The frequency of occurrence of a pattern within a song, and the number of songs containing the pattern, are both necessary for finding a rule-set between the input parameters and Vaughan’s musical response to that particular input scenario. These two frequencies are referred to as Pattern Frequency and Song Frequency.

Pattern Frequency (PF): The number of times a pattern appears within a song. The same pattern may have a different frequency for each song.

Song Frequency (SF): The number of songs in which a pattern appears.

Since the length of each pattern is not fixed in time, and patterns can be deciphered in several ways, it is important to consider partial matches of patterns while computing frequencies. During the analysis and memory building phase, we assume a threshold value of 0.5 for taking a pattern into consideration as a partial match. Any pattern with a match less than 0.5 is ignored in frequency computations. In order to account for partial matches, we introduce two terms, Pattern Frequency with Partial Matching (*PFPM*) and Song Frequency with Partial Matching (*SFPM*).

These two terms may be explained with examples. Let us assume that 100% of a pattern *A2* appears 5 times in a song *So1*. 60% of *A2* appears 3 times in the song *So1*. So, *PFPM* of *A2* in the song *So1* is:  $5(1) + 3(0.6) = 6.8$ .

So, if *N* is the number of different matching percentages over the threshold for a pattern appearing in a particular song,  $p_i$  is the  $i^{\text{th}}$  percentage, and  $n_i$  is the number of times the pattern appears for the  $i^{\text{th}}$  percentage, then

$$PFPM = \sum_{i=1}^N n_i (p_i / 100) \quad (I)$$

Among all the songs studied, let us assume that a pattern *A2* appears at a matching percentage above the minimum threshold in 3 songs: *So1*, *So3*, and *So5*. We consider only the maximum percentage match for pattern *A2* in each song. A maximum of 100% of *A2* is found in song *So1*. A maximum of 70% of *A2* is found in song *So3*. A maximum of 50% of *A2* is found in song *So5*. So, *SFPM* of *A2* among all the songs studied is:  $1+0.7+0.5 = 2.2$ .

So if *N* is the number of songs in which a pattern appears with a matching percentage over the minimum threshold and  $p_i$  is the  $i^{\text{th}}$  maximum percentage, then

$$SFPM = \sum_{i=1}^N (p_i / 100) \quad (II)$$

Our partial implementation was tested against patterns in the *Albert King* and *Jimi Hendrix* categories. *PFPM* is not used for rule generation in this implementation. *SFPM* is used for rule generation in this implementation. Table 3 provides us with information about songs using patterns from the *Hendrix* and *Albert King* groups, as well as other groups. Using this information along with the information collected in the pattern extraction stage, we map a table for *Jimi Hendrix* patterns and *SFPM* values, and a table for *Albert King* patterns and *SFPM* values. Initially every pattern is given an *SFPM* of 1. *SFPM* values are computed in the order of patterns from shortest length to longest length. Tables 4 and 5 show the computed *SFPM* values of the first eight Hendrix and Albert King patterns. Two examples of *SFPM* calculations are provided here:

1) *A44* is played in its entirety as a part of *A22* and *A16*, both of which are found in different songs. So, *SFPM* of *A44* is  $1+1+1 = 3$ .

A44:  $5^{\text{slidedown}}$   
A22:  $[5^3 \& 1^4]^{\text{slidedown}}$   
A16:  $4_{\text{bend}}(5) \text{ b3 } 1^{3\text{vib}} \text{ 1 1 b3 } [5^3 \& 1^4]^{\text{slidedown}}$

2) At least 6/7th (85%) of *A8* is in *A26*, which is in a different song. So, *SFPM* of *A8* = 1.85.

A8:  $[4_{\text{bend}}(5)]^* \text{ 5 b3 } 1^{\text{vib}} [3\text{rd}]$   
A26:  $11 \text{ b3 } 4_{\text{bend}}(5) [4_{\text{bend}}(5)]^* \text{ 3 b3 } 1^{\text{vib}} \text{ b3}_{\text{bend}}(4) [3\text{rd}]$

*SFPM* values of all the patterns for each song are calculated and totaled. Since a total of 11 songs have been studied for this model, each pattern can have a total *SFPM* no greater than 11 and no less than 1.

Since the model is implemented for only two categories, *Jimi Hendrix* and *Albert King*, we store patterns for only those two categories. They are represented as strings. Then, arrays are created to represent the two categories. These arrays are filled with the *SFPM* values of all the patterns, in their sequential order. Since each of the *E*, *T*, and *S* input parameters have different weights, we consider 0.3 as the minimum weight required for an input parameter to be included as part of the rule generation process. Any parameter below this threshold is ignored. Input frequencies of all the 39 *E*, *T*, and *S* input parameters are stored.

We use Bayes theorem to predict the probability/percentage of a pattern being used for a given set of input parameters. According to Bayes theorem, if there are two events *A* and *B*, *Probability of occurrence of B, given A* = (*Probability of occurrence of A and B*) / (*Probability of occurrence of A*).

	A	J	Z	R	O	B
Tex	√	√			√	
Tax	√	√			√	
Chi	√			√	√	
Ccc		√	√			
Cos				√	√	
Cow	√	√		√	√	
Emp	√	√		√	√	
Sky	√	√			√	
Exc	√			√	√	
Cro	√				√	
Rop				√	√	√

Table 3. Songs vs. Groups

Pattern	SFPM Tex	SFPM Tax	SFPM Cow	SFPM Emp	SFPM Sky	Total SFPM
J1	1	0.8	0.8	0	0	2.6
J2	1	0	0	0	0	1
J3	1	0	0	0	0	1
J4	1	0.8	0.65	0	0	2.45
J5	0	1	0	0	0	1
J6	0	1	0	0	0	1
J7	0	1	0	0	0	1
J8	0	1	0	0	0	1

Table 4. SFPM values for Hendrix category patterns

Pattern	SFPM Tex	SFPM Tax	SFPM Chi	SFPM Cow	SFPM Sky	SFPM Exc	SFPM Cro	Total SFPM
A1	1	0	0	0	0	0	0	1
A2	1	0	0	0	0	0	0	1
A3	1	0	0	0	0	0	0	1
A4	1	0	0	0	0	0	0	1
A5	1	0	0.6	0	0	0	0	1.6
A6	1	0	0	0	0	0	0	1
A7	1	0	0	0	0	0	0	1
A8	0	1	0	0	0.85	0	0	1.85

**Table 5. SFPM values for Albert King category patterns**

In our case,  $A$  is the set of input parameter(s) used in the context of pattern  $B$ . **SFPM** values are used to provide an indication of the occurrence of patterns. Input frequencies are used to provide an indication of the occurrence of input parameters, based on the number of songs. We will use an example to illustrate how formula II may be used. Let us assume there are 3 songs,  $So1$ ,  $So2$  and  $So3$ .  $So1$  and  $So2$  are Blues songs. Hence,  $T\_Blues$  is 1 for both  $So1$  and  $So2$ . However,  $So3$  is a Rock song. Hence,  $T\_Rock$  is 1 for  $So3$ . The pattern  $P1$  has an **SFPM** value of 1 in  $So1$ , 0.8 in  $So2$ , and 0.5 in  $So3$ . Then the Probability of  $P1$ , given  $T\_Blues = (\text{Total SFPM of } P1 \text{ (for songs with } T\_Blues)) / (\text{Input frequency of } T\_Blues) = (1 + 0.8) / 2 = 0.9$ .

This indicates that there is a 90% chance of  $P1$  occurring in a song with  $T\_Blues$  as an input parameter. Based on the 11 songs studied, we may assume with certainty that at least one input parameter from  $S$  and one input parameter from  $T$  are used in every song. Hence, we consider combinations with a minimum of at least 2 parameters: 1 from  $S$ , and 1 from  $T$ . We also consider combinations of 3 parameters: 1 parameter each from  $E$ ,  $S$  and  $T$ .

Upon calculation and storage of confidence/probability values for all *Hendrix* and *Albert King* patterns, with all possible 2 and 3 input parameter combinations (having at least 1 parameter each from  $S$  and  $T$ ), we define the rule-based logic using conditional rules. For an input parameter to be considered, it should have a weight no less than a *minWeight* threshold. For a rule to be considered, the confidence/probability value should be no less than a *minThreshold* value.

The goal of the program is to provide a set of likely *Hendrix* and *Albert King* patterns with their probabilities/partial match percentages used by Vaughan for a given set of input parameters. The input parameters along with their weights are provided by the user in the form of a text file. Weights of all the input parameters are initialized to 0 in the program. The user specifies a value between 0 and 1 for each parameter in the text file. A weight of 0 for a particular parameter indicates the absence of that parameter, while a weight of 1 indicates maximum presence of that parameter. The file is read and stored in a buffer by the program. Each line of the file is parsed and the weight of the corresponding input parameter is updated based on the value specified by the user.

## RESULTS AND ANALYSIS

The model was tested on three different songs performed by Stevie Ray Vaughan. Test 1 was performed on the song *May I Have a Talk With You* [15]. Test 2 was performed on the song *The House is Rocking* [16]. Test 3 was performed on the song *Life Without You* [16]. Then the performance of the model was computed. Based on a detailed analysis of lyrics and music,  $E$ ,  $T$  and  $S$  parameters were noted as the following, for Test 1.

$E\_Frustration = 1.0$ ,  $E\_Satire = 1.0$ ,  $E\_Love = 0.2$ ,  $E\_Hope = 0.2$ ,  $E\_Preparedness = 1.0$ ,  $E\_Sarcasm = 1.0$ ,  $E\_Anger = 0.3$ ,  $E\_Warning = 1.0$ .

$T\_Blues = 1.0$ .

$S\_Twelve = 1.0$ ,  $S\_CandR = 1.0$ ,  $S\_Slow = 1.0$ .

When these parameters were fed as inputs into the program, the following results were generated.

*Hendrix Array*:

- A 100% chance that  $J1$ ,  $J2$ ,  $J3$  and  $J4$  will be played.

*Albert King Array*:

- A 100% chance that  $A1$ ,  $A2$ ,  $A3$ ,  $A4$ ,  $A5$ ,  $A6$ ,  $A7$  and  $A40$  will be played.
- A 75% chance that  $A33$  will be played.
- There is a 71% chance that  $A37$  will be played.

The minimum threshold for a pattern to be considered was 50%. The actual patterns played in the song contained 83% of  $J1$ , 60% of  $J2$ , 83% of  $J4$ , 78% of  $A1$ , 67% of  $A2$ , 70% of  $A3$ , 67% of  $A5$ , 73% of  $A6$ , and 100% of  $A40$ .

We determined the average performance error by computing the difference between *Expected Results* and *Observed Results*, and by dividing the difference with the number of patterns. So for example,  $J1$ ,  $J2$ ,  $J3$ ,  $J4$  are supposed to have a 100% chance of appearing in the song in Test 1, for the given input parameters. Therefore, average error =  $((100-83)+(100-60)+(100-0)+(100-83)) / 4 = 43.5\%$ .

In test 1 the program predicts *Hendrix* patterns with 56.5% accuracy. By a similar calculation, we observed that the program predicts *Albert King* patterns with 45.5% accuracy. So, performance of the program in test 1 for the *Hendrix* and *Albert King* categories is 51%. Based on the results from the three tests as shown in Table 6, we observe that the model predicted *Hendrix* category patterns played by Vaughan with 53.1% accuracy.

Tests	Hendrix Performance %	Albert King Performance %	Total Performance %
Test 1	56.5	45.5	51
Test 2	44.6	54.2	49.4
Test 3	58.2	33.3	45.7
Average	<b>53.1</b>	<b>44.3</b>	<b>48.7</b>

**Table 6. Summary of Performance Results**

It predicted *Albert King* category patterns with 44.3% accuracy. It predicted *Hendrix* and *Albert King* patterns with a combined accuracy of 48.7%. We noticed that the performance was better for *Hendrix* patterns than for *Albert King* patterns, possibly because the 11 songs used for building Vaughan's memory represented his *Hendrix* influence more exhaustively than his *Albert King* influence.

We also found that *Albert King* patterns were predicted more accurately in songs with a 12-bar format, probably because *PFPM* values for *Albert King* patterns were higher in songs with a 12-bar format, thus providing a more accurate representation of Vaughan's style. *PFPM* values indicate the frequency of occurrence of a pattern within a particular song. We considered only *SFPM* values for this model. *SFPM* values indicate the number of songs in which a pattern occurs. Based on the results, we observed that the model performed better with blues songs having slow tempo, a 12-bar format, and call-and-response features characteristic of typical blues songs, indicating that at this point Vaughan's memory had been built in a way more suitable to predict patterns from songs in the classic 12-bar blues style.

We observed that several new patterns, not captured by the model in the learning/memory building stage, such as *S1*, *S2*, *S3*, *S4*, *S8* and *S9* in Test 3, were discovered in the testing phase. Size of a pattern, in terms of number of notes, affected performance only when the size of the pattern was extremely large when compared to other patterns. Pattern duration had a strong effect on the model's performance, as shown in Table 7 and Figure 2. The effect was direct in the case of *Hendrix* patterns. In the case of *Albert King* patterns, the effect of duration on performance was not as direct, though it was clearly noticeable. Performance of the model was poor for patterns less than 0.38 bars in duration. Maximum performance was achieved with patterns 0.38 bars in duration. As the duration increased from 0.38 bars, performance of the model decreased.

Approximate duration in bars	Average Performance %
0.25	0
0.38	97.2
0.5	74.4
0.75	60.2
1	6.9
1.25	18.3
1.5	18.8

Table 7. Average pattern duration vs. performance

## CONCLUSIONS

The uniqueness of the notation used to represent musical patterns, developed as a part of this implementation is its ability to capture melody along with technical nuances specific to the guitar, and to represent them as strings within a program, enabling us to store the pattern within a program using the constraints of the programming language. It also facilitates pattern matching in order to find partial matches of patterns.

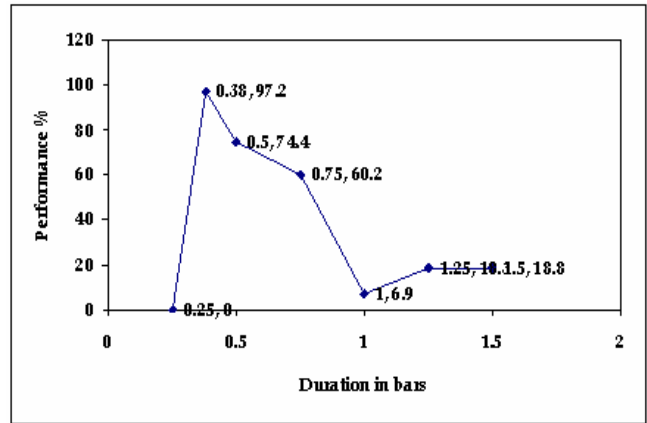


Figure 2. Pattern duration vs. performance

The notation used currently could be improved to indicate time relative to a bar or a measure, so that partial matches of patterns may be determined more accurately. The current partial implementation of the model predicts some of Vaughan's improvisatory decisions with a certain degree of accuracy especially for songs in the style of 12-bar blues.

At this point the model does not achieve the desired performance necessary to fully understand Vaughan's musical decision-making process. It is still at a preliminary stage, as indicated by the results. However, the model is significant on account of two reasons:

- 1) It illustrates that the proposed methodology works, and acts as a template for building a more improved, comprehensive and accurate prediction model of Vaughan's musical style; and
- 2) Although this model is specific to one particular musician, it lays down the foundation for a generic methodology required to build a computational model to understand a wide variety of musical styles.

Studying several other songs of Vaughan throughout the period of his recording career, covering an extensive range of emotions/mental states as well as styles, in addition to the 11 songs already studied in this implementation, will extend the memory of this model, enable us to obtain a more accurate representation of Vaughan's knowledge base, and thus increase the performance of the model.

As of now, rules are generated on the basis of *E*, *S*, and *T* input parameter combinations involving a maximum of 1 parameter each, from *E*, *S*, and *T* respectively. This limits rule generation to combinations with a maximum of 3 input parameters. Including combinations involving more than 1 parameter each from the *E*, *S*, *T* input categories, could address more realistic scenarios.

Pattern duration should be approximately 0.38 bars since performance is maximum with patterns of that duration. A pattern shorter in duration than 0.38 bars does not exhibit repetitive characteristics, for it to be considered a "pattern."

Since exclusion of *PFPM* values in rule generation is a possible reason for inconsistencies in performance, including *PFPM* values along with *SFPM* values in rule generation could result in improving the performance.

Musical improvisation consists of two main phases: 1) reusing ideas from the musician's knowledge space/matrices/schemata, and 2) combining these ideas in unique, original ways. The preliminary focus of our model is on the first phase. Our goal is to expand this model in the future so as to illustrate how the musician recombines these ideas to create unique musical output. In this model, input parameters representing emotions/mental states were extracted from the lyrics of the song. Partial weights were assigned to emotion/mental state input parameters within a song on the basis of the percentage of that parameter indicated by the lyrics of the song. The methodology may be improved to include a more objective method of extracting emotion/mental state parameters involved in a song and assigning weights, not only from the lyrics of the song, but also from the actual mental state of the musician (determined by additional research) at the time of performance of that particular song. This method should be refined over time and eventually standardized.

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