Towards Complexity Studies
of Indonesian Songs

Hokky Situngkir
[hs@compsoc.bandungfe.net]
Dept. Computational Sociology – Bandung Fe Institute
Research Fellow Surya Research International

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Abstract

We see some complex properties from Indonesian music discography by means of music as perceived by Indonesian people. This covers the folk songs, national anthems, popular songs by Indonesian modern artists and performers and also from western popular and classical music as reference. The self-similarity is drawn by using the model of gyration and the internal dynamics of the pitches and durations used in songs is observed by using the logarithmic spiral model. The employed entropy model is also discussed as well as introduction to the calculated dynamic complexity of melodic structure. Some generalization on the flow of music respect to the dynamic complexity is also shown. We discover that at least there are two phases in the played song: the shorter introductory phase that ends in the peak of complexity of the song and the attenuating phase of complexity in which the multiple equilibria of the song is measured. The paper draws some interesting aspects regarding to those parameters and variables on Indonesian melodic corpora.

Keywords: music, self-similarity, spiraling effect in music, melodic entropy, complexity.

wrote a song for everyone, wrote a song for truth,
wrote a song for everyone, and I couldn't even talk to you
John Fogerty - Creedence Clearwater Revival

1. Prolog

Indonesia is place with various ethnicities with also various aspects of culture. An interesting artifact in Indonesian modern culture is music. To a modern Indonesian, there are at least four types of songs popular among the people: ethnic songs, national anthems, indonesian popular songs, and some popular international songs which is dominated by the western industrial music. In the previous work [10], we have discussed the possibility of observing melody as "language" in the statistical analysis in the properties of Zipf-Mandelbrot plot.

Music is a complex artifact made by many components including tone, pitch, rhythm, tempo, contour, timbre, loudness, spatial location, and reverberation [12]. However, in order to simplify our approach, we only put melody into account as the most important elements of music comprised by pitches and durations in a song [7]. The paper reports the statistical observation regarding to the complexity of Indonesian musical corpora, of course, along with few classical western discography as reference.

What we meant here regarding to the statistical observation is the discussions about some features revealing the complexities of some Indonesian melodies. The complexity can be seen for instance by reading the unique musical contours of the melodies, the self-similarities of some songs with some possibilities to see the respective fractal geometry, the dynamic entropy of the melodies and the measurement of its inherent complexity. The motive of the paper is to see that unique types/genres of melodies show specific features. There should be a lot of interesting research directions can be made upon this report in order to grasp the melodic structures of Indonesian musicality.

There have been some research reports related to the work that also invigorates the observation presented here. The work of cross-cultural cognitive musical aspects as discussed by Toivianen and Eerola [13], the mathematical analysis to some Turkish songs [4] are among those. There have been a lot of concern in musicology and even wider, in anthropology, researchers yearn for some possible classification and categories of music, ethnicity, and even individuals or groups involved in the creation of music [1], [3]. This paper modestly expects that some specific quantitative features expressed in the observation might open a good entry and direction for such purposes. In sociology and communication studies, it is widely accepted that inter-culture meetings (e.g.: yielding

social aspects we understand as acculturation) might affect the newly artifact productions, and melodies as the most important element in music, is nonetheless an aspect of it. For example, the presentation and production of traditional music nowadays are not merely using the genuine cultural artifacts. The interesting *campur sari* in Javanic folk songs, etc. might be one from a lot more musical interactions among cultures. A conjecture of this was shown by showing in the report the very distinguishable aspects between discoveries in some music in other part of the world in some pioneered observations with similar statistical approaches we are bringing.
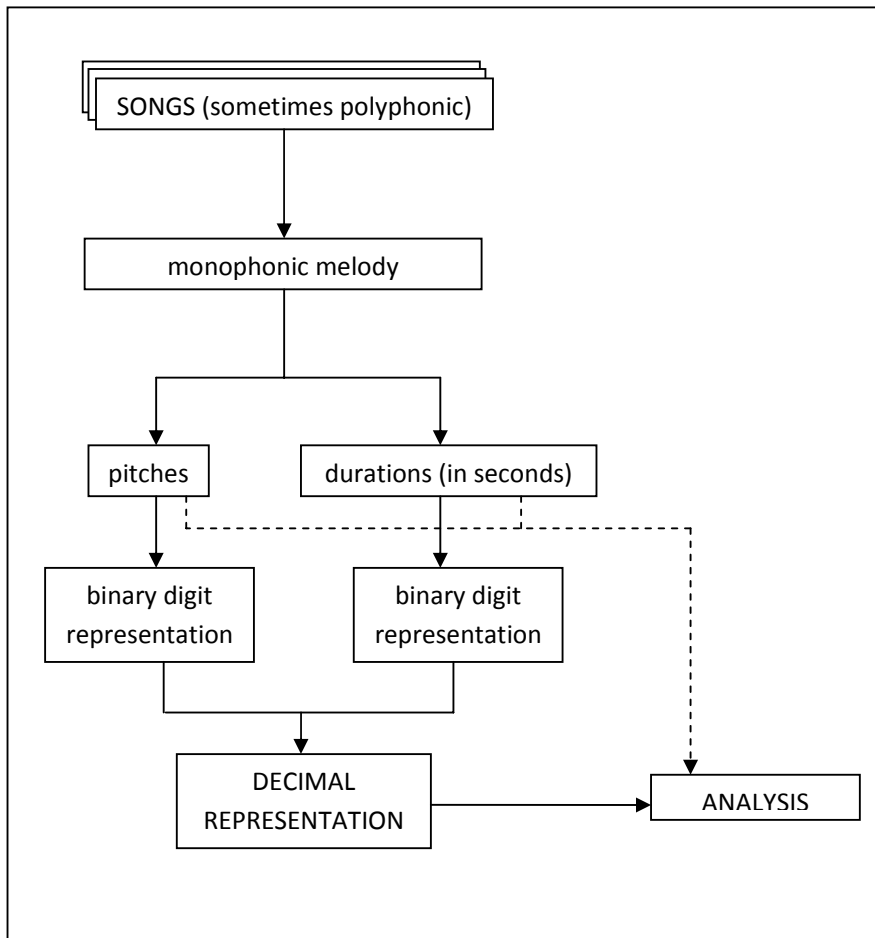
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Figure 1. The data preparation for analysis

The structure of the paper can be described as follows. We introduce some basic concepts related to the data structure used in the research and reminding some aspects of the data preparation as it has been discussed in detail in the previous works [11]. This section is followed by discussions about some melodic aspects related to self-similarity and radial representation of melody in some corpora. The latter section discusses some concepts of entropy we might incorporate in our analysis and information extraction from the discography we observed. Some

general discussions about complexity in music and especially Indonesian musicology as the result of our observation discussed in the latter sections while some future possible directions are also drawn.

2. Melody in Indonesian Songs

When we talk about Indonesian songs, actually we are dealing with more than anyone can imagine related to music. There are a lot of musical types and genres are enjoyed by Indonesian, from ethnic music, national anthem, popular songs, and of course, the internationally recognized songs from the multinational music industries. It is obvious that the hunger for some statistical aspects and features of music would never be satisfied for the rapid music production is always be there with innovative and artistic ideas from musicians or artists as well as the rapidly growing computational methods and modeling that capable to be exploited for further analysis.
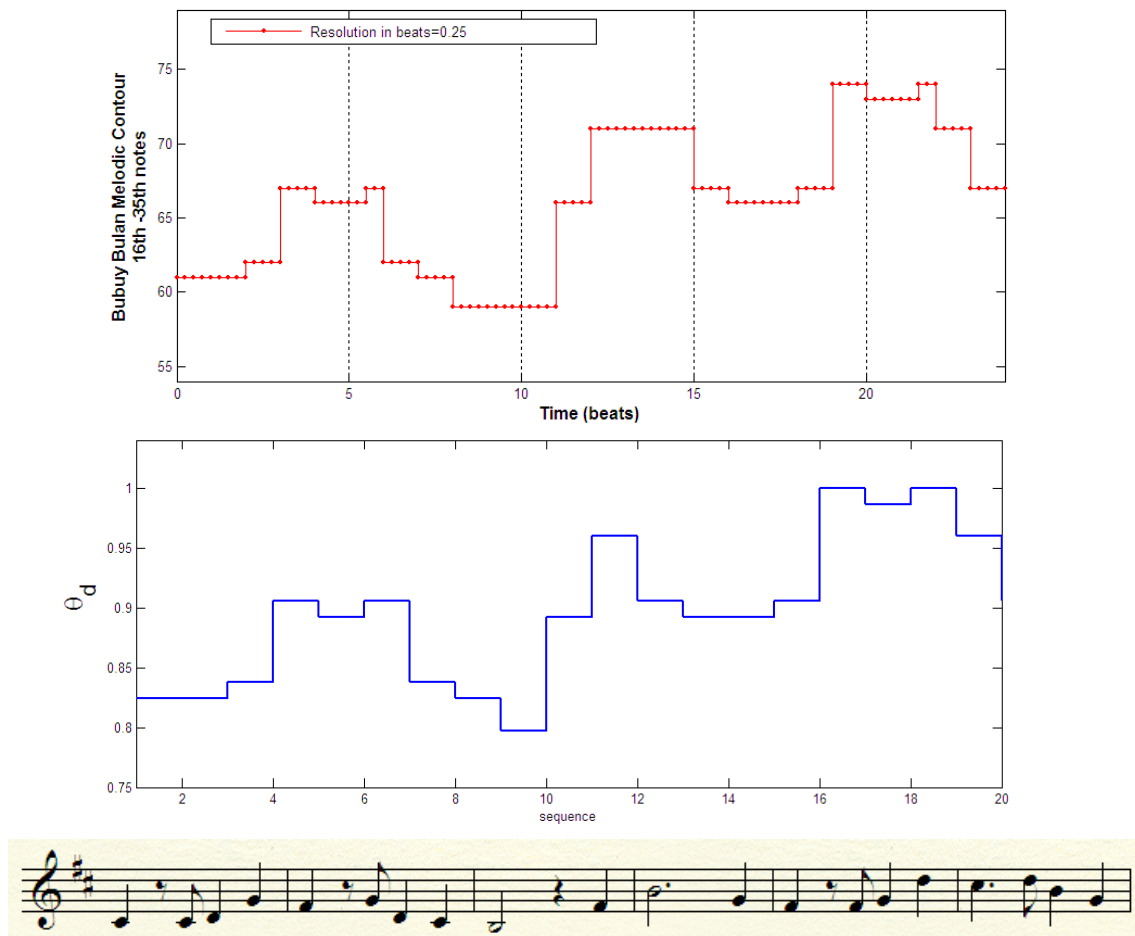
Figure 2. The representation of the 16th-35 notes of *Bubuy Bulan (*Sundanese folk song) in its representation of standard melodic contour (*top*) and the transformation as used in the paper (*below*).

In this report, we use the monophonic note sequence for the song analysis. We must clean the songs before we are able to analyze the songs and the cleaning methods are omitting some polyphonic aspects of the available songs and then converting the songs. The procedures we do before the analysis is depicted in figure 1. The more detailed discussion about preparing the data can be referred to [10]. The heart of this data representation is to having single representation for a pitch and the duration of it, a contrast to major works in this field distinguishing the pitches and the duration elements in musical corpus. Thus, we would have a set of decimals $\theta_d \leftrightarrow \theta_b$ which is comprised by the respective pitch and duration in the form of binary. An argument to have such model for songs is based on realization that it is more comfortable to talk about a note directly with its respective durations for analysis of a song. [10].

Figure 2 shows that by using our representation, the yielded contour of sequences of notes in a song are not very different with those shown by the "standard" melodic contour representation (plotting the notes as represented by decimals in its ordinate and the time beats in the horizontal axes). We use the representation of θ_d (which is normalized with its maximum value in each sequence so that $\theta_d = [0,1]$) to analyze more than a hundred of Indonesian discography in the definition as songs that are widely recognized by Indonesian in classifications as follows,

- *Indonesian Folk Songs*, the songs that are mostly accompanied by lyrics and melodic pattern sensitive to certain ethnic languages in Indonesia. However, some of the ethnic or traditional songs are with the national theme while some other are about local life dynamics as perceived by traditional and ethnic artists or people. The songs of this category are called with their respective ethnicities, for example, Javanese songs (*e.g.: Suwe Ora Jamu*), Minangnese songs (*e.g.: Ayam den Lapeh*), Sundanese songs (*e.g.: Bubuy Bulan*), Malukunese songs (*e.g.: Hela Rotan*) and so on.

- *National Anthems*, the songs with patriotic themes expressing the joy of life as Indonesian people, mostly with Indonesian lyrics sung at many places and occasions in Indonesia. Some songs in this category are *Gugur Bunga, Indonesia Pusaka, Satu Nusa Satu Bangsa.* Some songs in this category has an interesting and well known pattern of *Keroncong Musik*, the music popular in Java, *e.g.: Sepasang Mata Bola.*

- *Indonesian Popular Songs*, the modern popular songs broadcasted in mass media and become a part of popular culture mostly among youths. However, as well as some international popular music and songs, there is sensitivity of time in this category of songs. Some songs in our discography for this category, e.g.: *Kugadaikan Cintaku* (sung by Gombloh)*, Bunda* (sung by Potret), *Juwita Malam* (classic popular song with several times to be re-released by different artists), *Dibalas dengan Dusta* (sung by Audi).

- *International Songs*, this category is used – as a matter of fact – as referential to Indonesian popular songs. Some songs in this category, *e.g.: I want to Break Free* (Queen), *Morning Has Broken* (Cat Stevens), *Now and Forever* (Richard Marx), *It Must Have Been Love* (Roxette).
- *Melody from Classical Corpus,* while the original form of this category are in the form of symphonies, operas, etc., we use some limited songs as reference the previous categories.

3. Melodic Self-similarity

Figure 2 shows the ups and downs of the notes a long with their durations, while we can also represent the melodic contour in the phase diagram depicting the transitional pattern of a note to another note, $\theta_d(\tau)$ vs $\theta_d(\tau+1)$ [10]. Gündüz & Gündüz [4] shows that we can see the internal structure of the song by starting our observation from here. A previous work on time series data has also incorporated this kind of method [9].
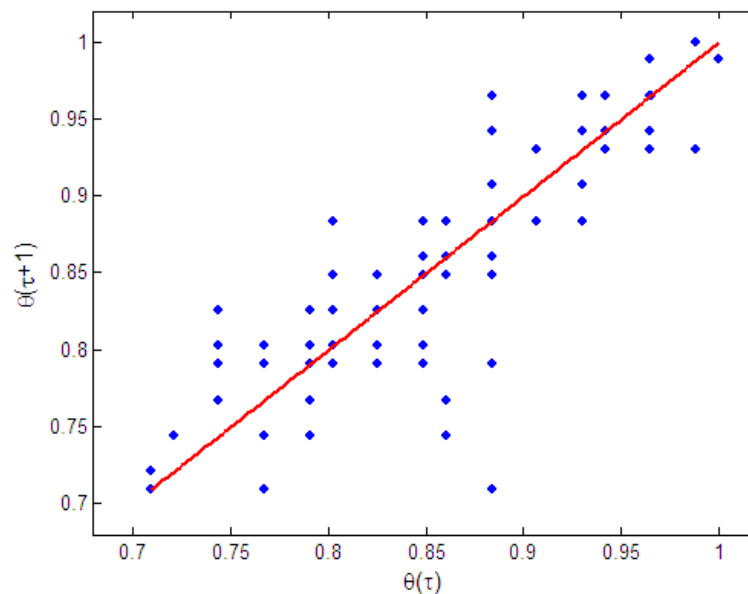
Figure 3. The trend line of the normalized in the phase space of $\theta_d(\tau)$ vs $\theta_d(\tau+1)$ from Indonesian popular song, "*Kaulah Segalanya*" popularized by Ruth Sahanaya.

Any song shows the trend line as illustrated in figure 3. The trend line can actually showing the structure of pitches and durations emerging the melody as we enjoy. We can see the trend line, as some kind of 'axis of rotation' in the song dynamics. The line is in the form of standard linear equation of $y = mx + c$, we could have the axis of rotation of R_g in the form of

$$R_g = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(n_{i+1}-y_{i+1}\right)\cos\alpha\right]^2}{(n-1)}}$$ (1)

where $\alpha = \tan^{-1} m$. Thus, simply speaking we can say that the concept of gyration radius, R_g, is made up by vertical distance between the position of θ_d relative to the trend line. This variable shows how compact the melodic structure of a song is. The smaller value of R_g shows the scattering along the diagonal axis of the trend line: the smaller it is, the more compact the melodic structure is. Table 1 shows some results representing the categories.
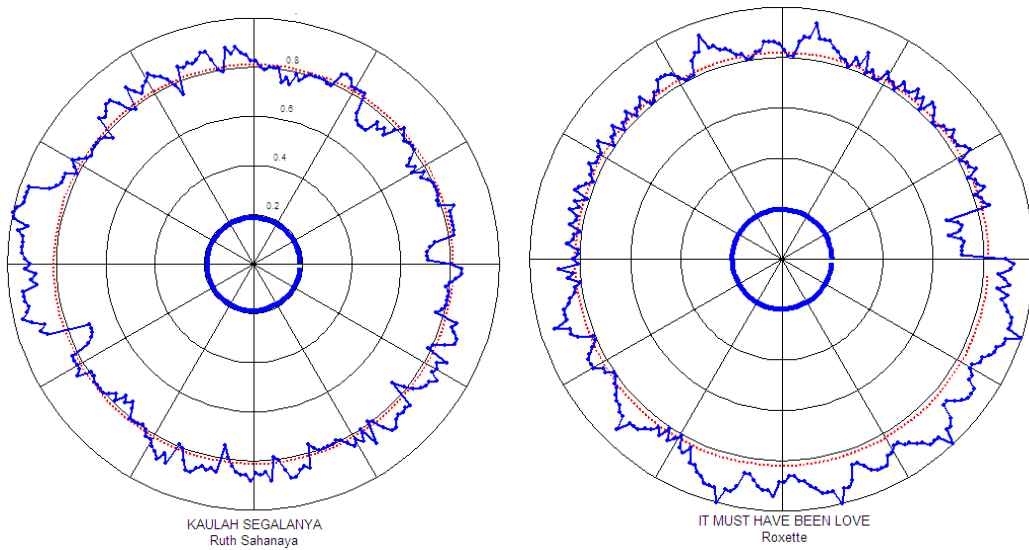
Figure 4. Visualization of radial movement of two popular songs, "*Kaulah Segalanya*" sung by Ruth Sahanaya and "*It Must Have Been Love*" by Roxette. The circle in the middle is the value of R_g and the red dotted line is the gradient of the trend line.

The discussion about the abstract gyration dynamics in melodic movement has brought us to visualization of the melody in a song into radial visualization. The visualization is quite simple by transforming the plot of $\theta_d(\tau) \rightarrow \theta_d(\phi)$ where $\varphi = [0, 2\pi]$. An example of the result is shown in figure 4 where we compare two popular songs: Indonesian *Kaulah Segalanya* and international hit *It Must Have Been Love*. Figure 5 shows the visualization for some of Indonesian folk songs and Indonesian National Anthems – both groups are plotted in the scaled radial diagram so that we concern the form of the $\theta_d(\phi)$ visualization only. Interestingly, we can see the pattern of self-similarity within songs and in other cases the similarity between songs in the same group.
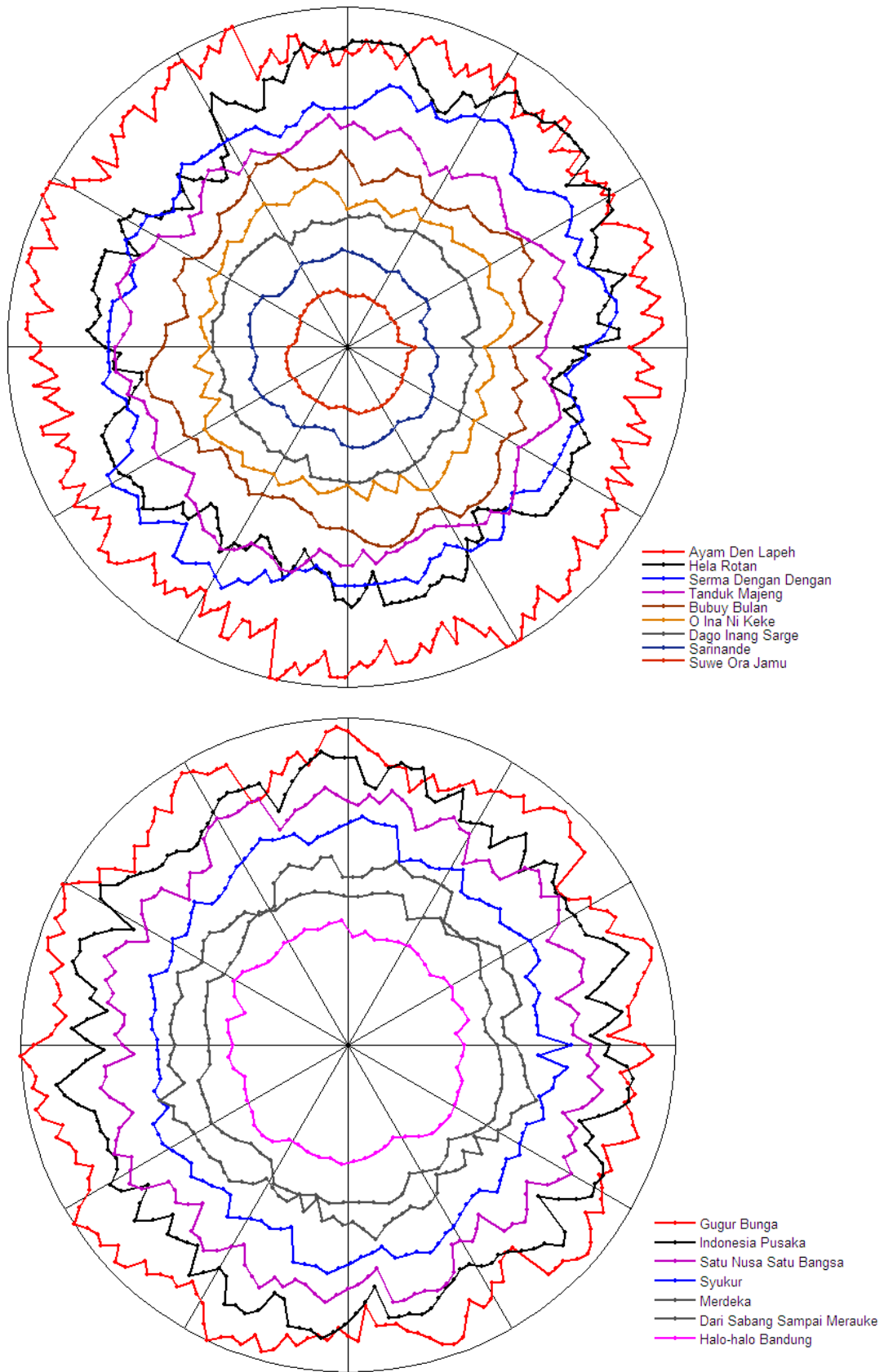
Figure 5. Scaled Radial Movement of Songs in Folk Song Category (*above*) and National Anthems (*below*).
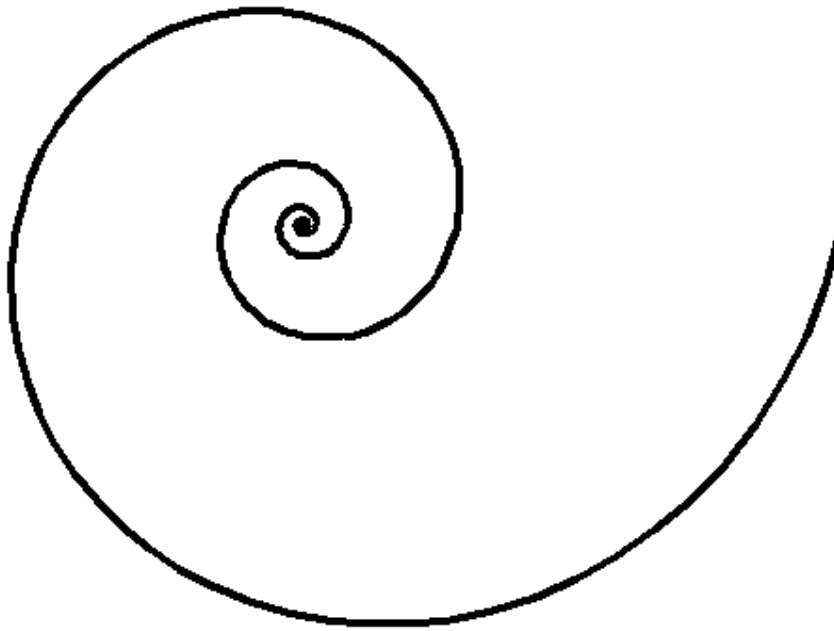
Figure 6. Illustration of logarithmic spiral in terms on α .
If $\alpha = 0$ it turns out to be a circle and if $\alpha = \pi / 4$ it turns out to be simple spiral.

From what pictured in figure 4 and 5, we can see the self-similar patterns in Indonesian songs, and in order to see more properties of the songs, we can visualize the radial distribution of notes and pitches in each song. We do this by sorting θ_d and plotted the ranked notes and pitches in a song. Interestingly, the pattern of logarithmic spirals would be emerged as seen in the examples in figure 7. The logarithmic spirals can be written mathematically as [6, 14]

$$\rho = a \exp(b\phi) \tag{2}$$

where a and b are constants and as shown in figure 6, we can write

$$\cot \alpha = \frac{dr}{rd\phi} \tag{3}$$

thus,

$$\frac{dr}{d\phi} = ab\exp(b\phi) = br \qquad (4)$$

and we have

$$b = \cot\alpha \qquad (5)$$

so that we have another parameter indicating the spiraling effect of a song [4],

$$\alpha = \cot^{-1} b \qquad (6)$$

The greater the value of α, the more notes in the song tends to move outward in spiraling effect. In the visualization in figure 7, it is obvious that the song *Kaulah Segalanya* moves outward relatively more than the song *It Must Have Been Love* by recognizing the singer of the former song is well-known with her ability to cover high amplitude notes.
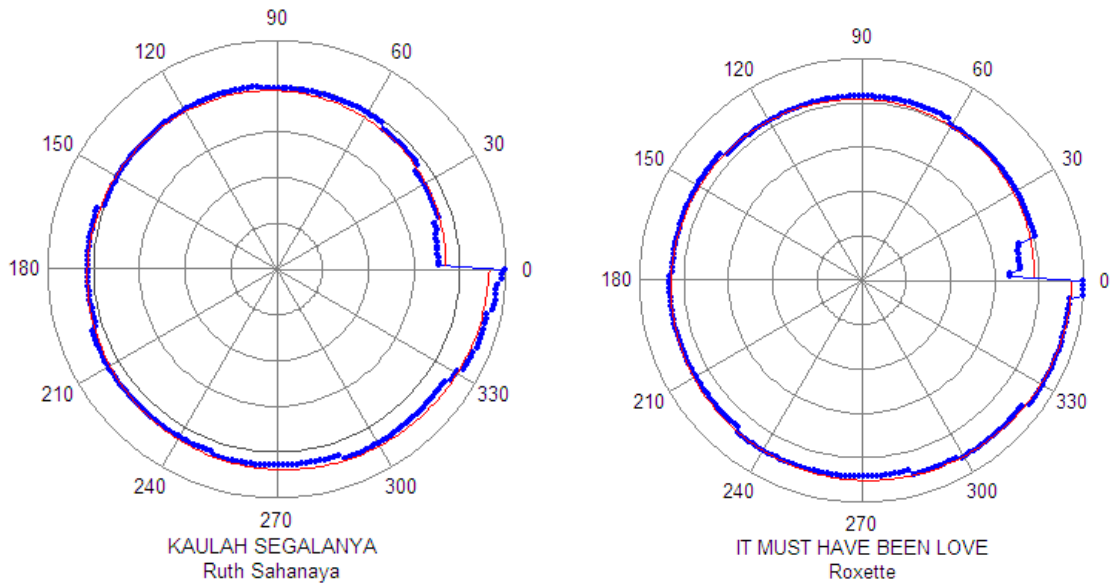
Figure 7. The comparison of two popular songs regarding to the radial distribution of θ_d
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Of course the usage of the notion about the 'spiral effect' must be straightened here for in the common practice of art, this may gives polysemy. Nonetheless, the spiral effect is related to the strength of repelling effect of the gyration when notes are in a song.

Table 1[1]

Gyration Radius and spiral coefficient in some songs in our discography

SONGS		Gyration Coefficient R_g	Spiral Coefficient α	Song Negentropy	Song Complexity Coefficient
Classical	*Ode To Joy (from Beethoven's 9th Symphony)*	0.1974	2.7751	3.1989	0.4996
	The First Violin of Mozart's Symphony 40	0.1895	1.9222	6.0026	0.4404
Indonesian Anthem Songs	*Syukur (H. Mutahar)*	0.1546	1.6187	3.8193	0.4470
	Gugur Bunga (Ismail Marzuki)	0.1707	1.6258	4.0859	0.4563
	Halo-halo Bandung (Ismail Marzuki)	0.0901	1.4742	2.6424	0.5544
	Dari Sabang sampai Merauke (R Suhardjo)	0.1273	1.4719	3.0481	0.4957
	Hari Merdeka (H. Mutahar)	0.1316	1.7011	3.5608	0.4739
	Satu Nusa Satu Bangsa (Liberty Manik)	0.1151	1.567	4.1278	0.4235
	Indonesia Pusaka (Ismail Marzuki)	0.1112	1.5873	3.8517	0.4726
International Modern Pop Songs	*Now and Forever (Richard Marx)*	0.164	1.6164	4.2437	0.4371
	I want to Break Free (Queen)	0.116	1.4251	4.8442	0.3901
Indonesian Popular Songs	*Kugadaikan Cintaku (Gombloh)*	0.2298	3.3066	3.8640	0.5087
	Kaulah Segalanya (Ruth Sahanaya)	0.1891	2.1041	3.9634	0.5076
	Kemesraan (Iwan Fals)	0.1862	2.0966	3.1411	0.5428
	DIbalas dengan Dusta (Audi)	0.0916	1.0616	4.0104	0.4163
	Bunda (Potret)	0.1601	1.2636	5.2837	0.3427
Indonesian Folk (ethnic) Songs	*Suwe Ora Jamu (Javanese)*	0.2366	2.8833	1.9253	0.6639
	Bubuy Bulan (Sundanese)	0.195	2.0399	3.3494	0.4970
	Serma Dengan-dengan (Simalungunese)	0.2086	1.7246	4.5985	0.3604
	Ayam den Lapeh (Minangnese)	0.1318	1.441	5.0253	0.3810
	Dago Inang Sarge (Bataknese)	0.086	1.0431	3.5493	0.4448
	Tanduk Majeng (Maduranese)	0.1742	1.5598	3.9498	0.4251
	Hela Rotan (Malukunese)	0.2237	3.4344	3.7477	0.5083
	O Ina Ni Keke (Minahasanese)	0.1389	1.7504	3.2032	0.5124

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[1] Only few songs from our discography are shown here for the limited space.

The stronger the spiral coefficient (α) the more tendency the usage of more notes of which higher values of θ_d, practical speaking the higher frequency of pitches. Most national anthems do not have relatively very high spiral effect contrasted to some of folk song and popular song for instance. This makes sense for national anthems are not supposed to be too dynamic in its variations of pitches and durations. However, some popular songs might also become not too spiraling by its theme and genre. In table 1, we can see apparently that the popular song like *Bunda* sung by Indonesian music band, Potret, has the lowest spiraling effect while other popular song, even though within really different genre, *I Want to Break Free* sung by Queen, also have small coefficient.

5. The Entropy and Complexity of Melodic Structure

The exploitation of the concept entropy to musical analysis and song analysis are always interesting. Some previous works has discussed about the complexity of music in the terms of entropy of pitch class distribution and entropy of interval distribution [12] and in return to be discussed in cross-culture musical analysis in [12]. The entropy of a melodic structure is usually measured respect to the number of notes [11] as the number of the microstates in a song [7]. Here, we would put into account not only the number of notes solely. Our measurement would be more like the one proposed in [4] but yet we would use variable θ_d as the basis of the calculation instead of the notes only. The idea is to capture the level of possible micro-states in the terms of numbers of notes and pitches controlled by other notes and pitches.
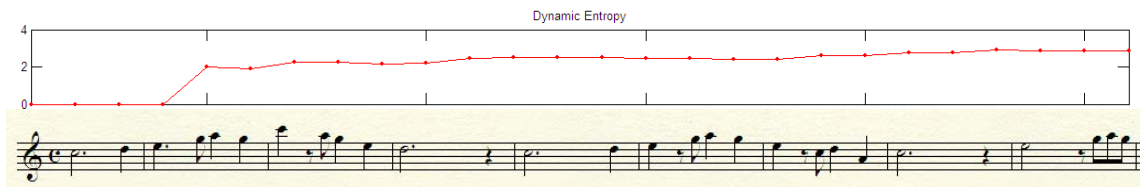

Figure 8. The dynamic calculation of entropy (First parts of *Tanduk Majeng*, Maduranese folk song)

In a sequence of melody, if we denote k_i as the number of types of notes after a specific note $[\![\theta_d]\!]_i$ then, the entropy of the single pitch and duration is

$$p_{[\![\theta_d]\!]} = \frac{k}{N} \tag{7}$$

where $N = \sum_i k_i$, thus the entropy of all the melodic structure can be written as,

$$S(p_{[\![\theta_d]\!]_i}) = -\sum_i p_{[\![\theta_d]\!]_i} \log_2 p_{[\![\theta_d]\!]_i}$$ (8)

Obviously, the entropy of a melodic structure deals with what note is "controlled" by a former one [4]. In advance, the maximum entropy of all melodic structure can be calculated as,

$$S = \log_2 N$$ (9)

Here, the complexity of a song can be calculated as [cf. 12],

$$H = \frac{S(p_{[\![\theta_d]\!]_{song}})}{S_{max}} = \frac{-\sum_i p_{[\![\theta_d]\!]_{song}} \log_2 p_{[\![\theta_d]\!]_{song}}}{\log_2 N}$$ (10)

It is also worth to discuss about negentropy [4], as the parameter showing the degree of organization, or simply speaking, the order of the song.

$$Neg = S_{max} - S(p_{[\![\theta_d]\!]_{song}})$$ (11)

The interesting part of the offer from equation 8, 9, 10, and 11 is that the possibility to see the real time order and disorder state of the song as per time, per addition of θ_d, like the one exemplified in figure 8.

Glancing over the entire entropy and complexity plots, we could see some patterns in terms of entropy, negentropy, as well as complexity of a song. From our observation over all the songs, the songs seems to have the entropy rapidly higher in first notes, until later the entropy fluctuates in certain values showing the multiple equilibria. The order and disorder phases are shown here in the long run of a played song. The maximum entropy is always growing bigger as understood from the nature of the additions of possible microstates as long as there is a tone played. However, the differences across songs are the way the song ends whether in the state of organization ($Neg > S$) or vice versa.

In figure 9, we can see some result obtained from observation to the work of Mozart and Indonesian classic composers to the national anthems. The pattern of the dynamics showed by the

entropies is similar but the difference arouse in the way the complexity grows within a song. Mozarts' seems not decreasing very drastically over the long part of the symphony, a contrast to the other three depicted in the figure.
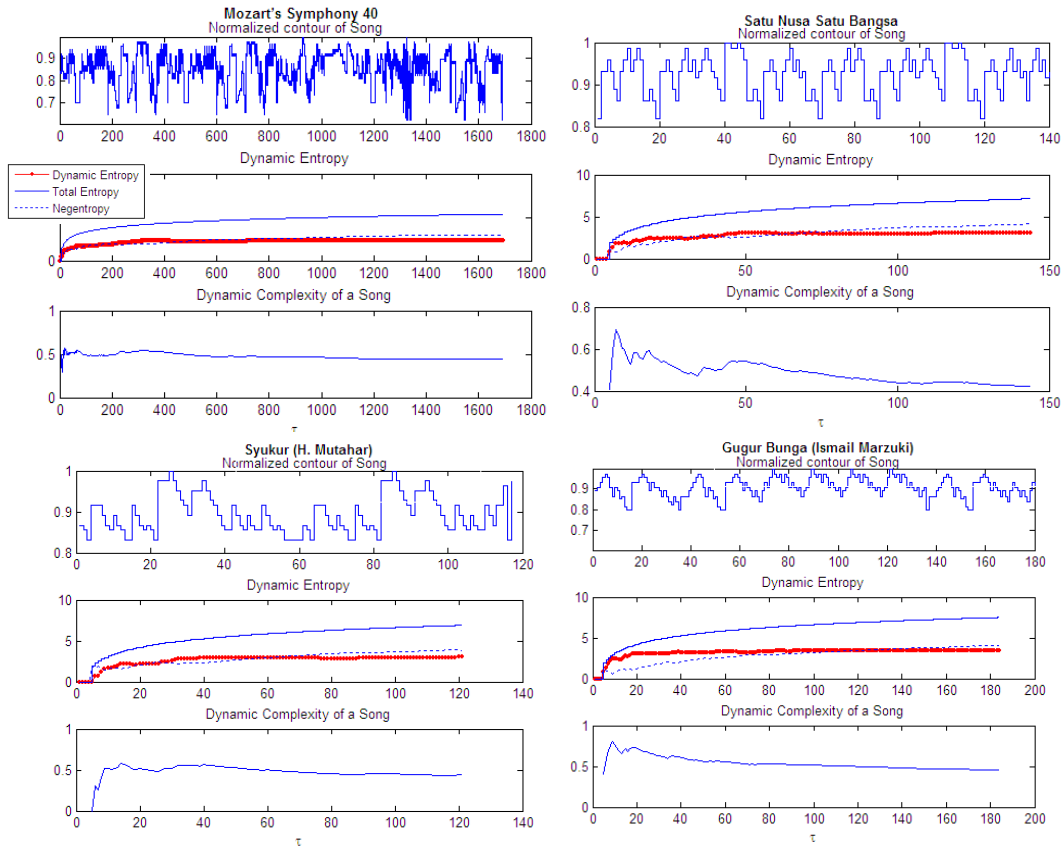

Figure 9. Melodic Contour, Entropy, and Complexity of some songs Mozart's and Indonesian Anthems.

An interesting pattern arouse as we see the folk song corpora (figure 10) in which we found that most of them are ended with higher negentropy relative to its dynamic entropy. This means that the song seems to build an organization throughout the song. The folk songs seems to be lasted in the state of order, a little bit different with ones in other categories of song. However, there are also some other songs with ended in the state where entropy is bigger than the negentropy (*Suwe Ora Jamu* and *Ayam den Lapeh*). This is interesting facts that we can see apparently in the dynamics of the folk songs.

The more various patterns occur in the playing of popular songs. This is visualized in figure 11, the entropies and complexities of Indonesian popular songs. Like in figure 8, the songs in the popular songs are dominated by the ending of the lower organization index (negentropy) relative to its respective entropy.
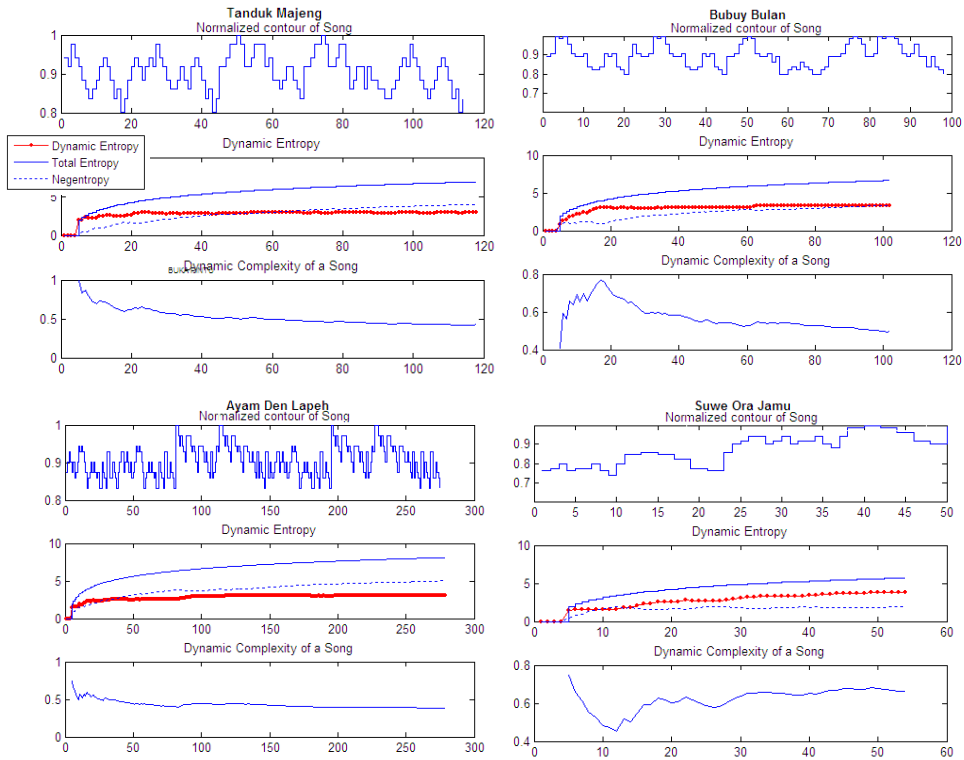
Figure 10. Melodic Contour, Entropy, and Complexity of some Indonesian Folk Songs.
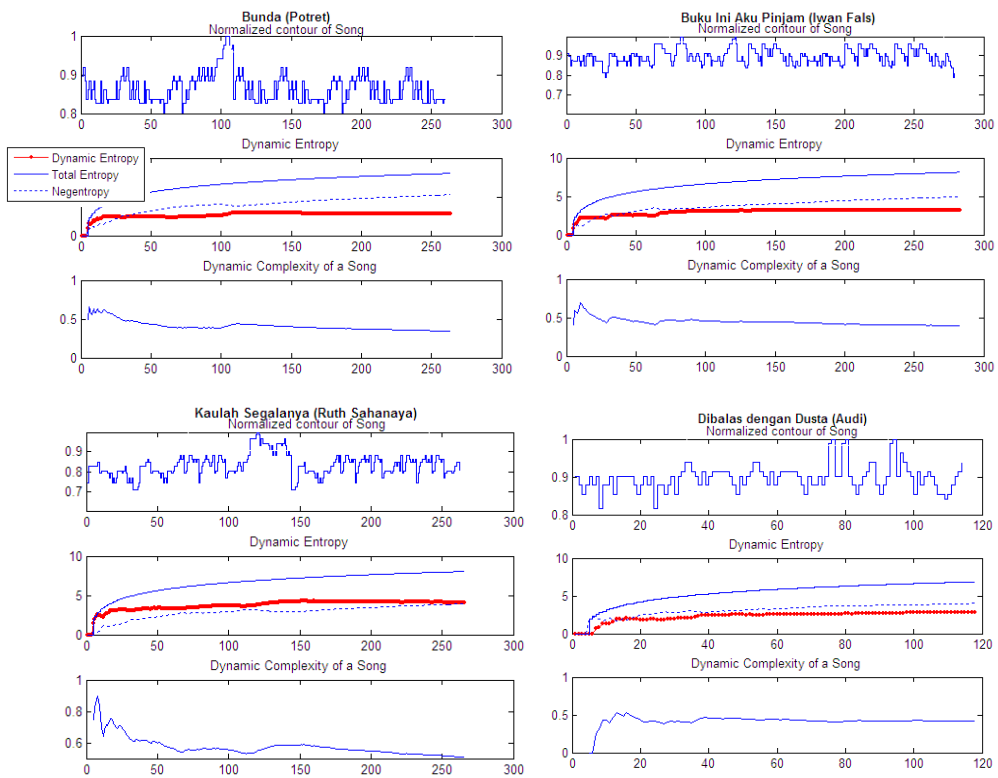

Figure 11. Melodic Contour, Entropy, and Complexity of some Indonesian popular songs.

In table 1, we can see the value of some songs' negentropy and the overall complexity as calculated in the end of the song. The more a song varies in the usage of pitches and durations, the more complex the song is, while the more sequence of pitches and durations used more frequently the more the organizational structure of the song is revealed (as depicted by the negentropy). Of course if in a song the negentropy is very high the song becomes boring and the lesser it is, the more difficult the songs to be enjoyed. However, it is not always the bigger negentropy would be linearly related to the calculated complexity. An interesting example is the long song from Mozart's #40th Symphony comprised by more than 1500 notes has relatively low complexity but very high in the index of organization. To have an interesting and easy to be grasped song probably laid upon these two constraints, while the inner dynamics of the songs portrayed by the two previous parameters, the gyration and the spiral index.

6. Discussions

The self-similarity of a song can be visualized in the radial diagram of a song as shown in figure 5. The latter observation has brought us to the spiral dynamics that can be modeled by using the logarithmic spirals. The boring melodic structure would be yielded by the structure of very low values of spiral coefficient while in return, too big spiraling effects within a song made the song becomes harder to be enjoyed. However, there is something interesting as we try to make a sort of generalization as we observe a lot of corpora of songs. It is in the dynamic complexity of the song from the first played note till the last tone it plays.

A simple generalization is depicted in figure 12. Most of songs seem to follow the way the ups and downs of the complexity index as shown in the figure. First notes flow to grow the complexity (τ_1) or can we say the phase to introduce the pattern in the whole songs until they accumulate to the maximum complexity of the songs. The next steps are the attenuating phase of complexity as the complexity (sometimes rippling) decreases till the end of song is reached (τ_2). We can formally write that the second phase is always taking longer time than the former one.

$$\tau_1 < \tau_2 \tag{12}$$

There might be several peaks in the decreasing phase of complexity but yet, the second peak seems to be smaller than the previous one, or vice versa, there might be a smaller peak is coming right before the general peak of complexity throughout the song. In the sense of dynamic entropy of a song, we could see that the decreasing phase is the multiple equilibria of the song as enjoyed by the

listener. Furthermore, the inequality of formula 12 might become the thing that should be related to human cognitive system since the longer phase of τ_1 might make the listener having more effort to enjoy the beauty of the song.

This very interesting general pattern is found in our observation over our discography. Nonetheless, more empirical results is encouraged to have the generality that might obtained in the dynamical analysis of the song.
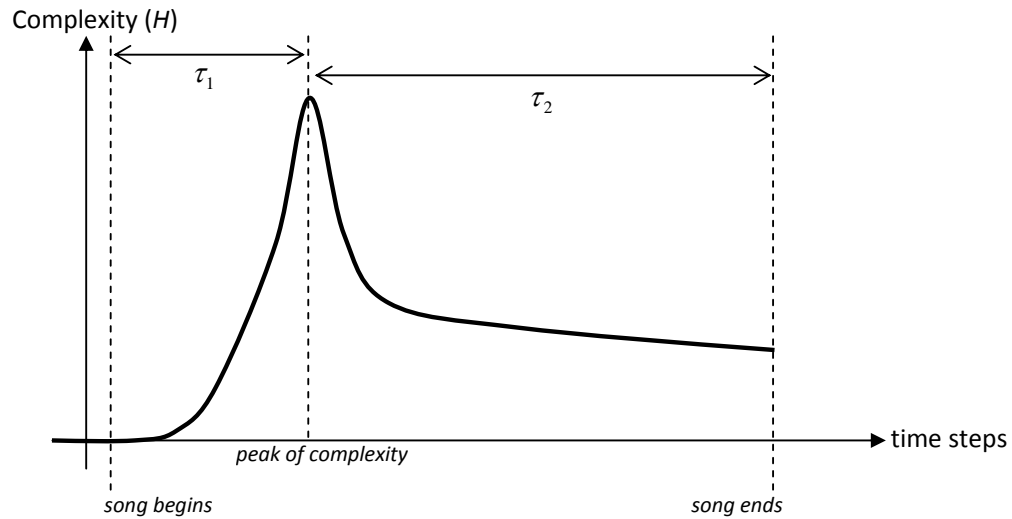

Figure 12. The flow of complexity within a song.

6. Concluding Remarks

We have shown some complex property of the music as perceived by Indonesian people: folk songs, national anthems, and popular songs, as well as some reference to the arts of classical and popular western music. We show that the self-similarity is shown in most of the songs, while there is also some self-similar pattern in the same categories of music. The way the use of the variations of pitches and durations is represented by the gyration coefficient depicting the dynamicity of the song and the (logarithmic) spiral coefficient reflecting the tendency of each songs to show the spiraling effect by means of the numbers of variations and tonal movements within.

From our observation we found that melodic structures of Indonesian songs are varies through both gyration and spiral coefficient. However, some conjectures are discovered that Indonesian anthems are more likely to have smaller spiraling effects relative to folk songs and popular songs, even the classical western melodies we used as reference. However, from the observation by using the concept of entropy, we found that there is a great similarity between the

Indonesian anthems with the classical western melodic structures giving us some insight of the process of the creative process of the making of the songs in the category.

Another interesting findings are that the Indonesian folk songs tends to end up in the form of organized structure with the negentropy tends to be bigger with the entropy as the index of regularity in each song. This is contrast with those we could apparently observe in the popular and national anthem songs.

We also discover some conjecture for further generalization for a like further research on songs. The flow of the most songs seems to be rapidly hiking the complexity as the melodic introductory phase until the note flows found the maximum complexity. This phase is then followed by the attenuating phase of complexity as reflected by rippling decreasing complexity.

Further research directions can be conducted by incorporating some aspects regarding to the enlargement of the corpora, not only covered Indonesian music but a lot more from various cultures and musical sources.

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