Scoring the Deep
Orchestral transcription for some Humpback whale vocalizations patterns

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1.Prolouge

oceanic sounds were associated to whales, even in a mere literary sense whether in marine occupation lifestyle, literature, poetry and even in folklore. It was a scientific and documented fact in 1952[1] with the first recording of what we acknowledge today as a humpback whale vocalization. Later in the second half of the 20th century, the wide range of these vocalizations became popular, and strongly sought after equally by both scientists and musicians[2].

Since the first recording by US Navy engineer Frank Watlington[3] in 1952 that was obtained from a US navy hydrophone[4] installation near Oahu Island, Hawaii and though it is extremely scientific nature, whale vocalizations represented a major influence for many composers and later in the 21st century for Bio-music enthusiasts.

This paper is trying to musically translate some whale vocalizations into solid orchestral techniques with tools of analyzing certain patterns then modeling their Fourier transform in order to create certain musical effects to be used for orchestral instruments.

1.1 Problem of the Research

Composers mainly got influenced by Whale vocalizations in a poetic or a dramatic way whether trying to use program and descriptive music writing approach or to use actual recordings accompanied by the orchestral composition with no fixed solution how exactly

[1] Cholewiak, Danielle M., Humpback whale songs hierarchical structure, The society of Marine-Mammalogy, July 2013

[2] Schevill, W. E., Underwater sounds of the Cetaceans, Oxford, UK, 1964.

[3] "The scientists learning to speak whale", BBC, https://www.bbc.com/future/article/20240409-the-scientists-learning-to-speak-whale

[4] Especially equipped device to record ocean underwater sounds, https://oceanservice.noaa.gov/facts/hydrophone.html#:~:text=A%20hydrophone%20is%20an%20underwater,reproduction%2C%20and%20to%20seek%20prey.

mimic a certain pattern of a whale vocalization on a certain instrument. In addition, the vocalization was treated a majestic nature beauty in general with no thorough treatment for various patterns or styles.

1.2 Objectives of the Research

1- Identifying some distinguished rhythmic and melodically attributed whale vocalizations patterns.
2- Analyzing these patterns with Fourier transform.
3- Illustrating and modeling a new identical as possible and playable for an orchestral instrument.
4- Identifying the proper orchestral instrument to perform the new-modeled sound.

1.3 Importance of the Research

- Applying and adding new orchestral techniques to the classical orchestration repertoire on the basis nature sounds reference thus enriching a long history of imitating nature sounds in the classical music doctrine.

- Rising concerns about climate change and global warming dictates stronger eco awareness is such an important issue. Especially with the means of musical compositions directed to younger generations. Problems such as marine life preserving in Mediterranean countries are of such importance and can be addressed with compositions directed to younger generations.

1.4 Questions of the Research

1- What are the suitable vocalization patterns to be transcript for orchestra?
2- What are the suitable instruments to perform these transcript patterns?
3- How to transcript these patterns with the means of Orchestration and Organology doctrine?
4- What are the equivalent tone colours for whale vocalizations?

1.5 Methodology of the Research

This paper follows analytical content methodology.

1.6 Sample of the Research

Selected excerpts from the album "*Songs of the Humpback whale*" published 1970 by American biologist and bio-acoustician Roger Payne[5].

1.7 Limitations of the Research

Starting 1952 until the present day with no geographical limitations.

[5] https://www.youtube.com/watch?v=sjkxUA041nM&list=PLnJDCrKyKvbZBlpG-HkNCAQ8D9JWrWNPG&index=1

1.8 Terminology of the Research

- **Whale vocalizations:** sounds produced by whales in order to communicate with each other. These sounds vary according to whale species, geographic location and purpose of producing sound itself. There are three main types of sounds: clicks, whistles and pulsed calls. The commonly used term "whale songs" is more associated with recognizable repeated patterns in any given vocalization. The mechanism of producing these vocalizations are very different from humans. Whales use muscle contraction engaging lungs, throat and laryngeals to alternate airflow pressure[6].
- **Humpback whale:** A species of Baleen whale, highly regarded for many appearings in sea and ocean surfaces. It is documented that Humpback whale is highly vocal specially males who are documented for producing songs that can last from 4 to 33 minutes[7].
- **Fourier transform:** Integral mathematical transform that works on outputting a new function based on an input function. The transform is majorly used in music and audio work for modeling sounds based on numeric equation that analyze sounds to its core sine waves. A faster transform sometimes with modern audio software commonly referred to as (FFT) fast Fourier transform. The whole transform and all related applications are based on the French mathematician's _ Jean-Baptiste Joseph Fourier (1768–1830)[8] _ discovery of connection periodic trigonometric functions to producing sound in the form of sine waves[9].
- **Bio-music:** A form of experimental music that depends on nature sounds and excluding any internationally produced human voices and sounds. Sometimes keeping natural body sounds (brain waves, heartbeats,etc) the term can be also used in broader way to include soundscapes and ambient music[10].

2. Historical & Theoretical Framework

2.1 Forgrounding

[6] Jiang, J. J. and others, Whistle detections and classification for whales based on convolutional neural networks, University of Sheffield , 2019

[7] Wildlife.vic.gov.au

[8] Jean–Baptiste Joseph Fourier, French mathematician and physicist.

[9] Hamarsheh, Qadri, Properties if the Fourier transform, Philadelphia University.
https://www.philadelphia.edu.jo/academics/qhamarsheh/uploads/Lecture%2017%20Properties%20of%20Fourier%20Transform.pdf

[10] Eaton, Manford L., Bio Music, Else Press, USA, 1973

The historical and theoretical framework is divided into these main sections. Firstly, a literature review of most important related papers that dealt with music for whale vocalizations. Secondly, providing background information about the transcription process.

2.2 Literature Review

- Cholwiak, Danielle M.:"Humpback whale songs hierarchical structure: Historical context and discussion of current classification issues" Article, Marine mammal science / The Society of marine Mammalogy, 2013.
https://www.researchgate.net/publication/261098973_Humpback_whale_song_hierarchical_structure_Historical_context_and_discussion_of_current_classification_issues

Abstract:

A well-defined criteria comparing various investigations of the whale songs. The article is trying to find common research grounds between various inconsistent documentations through history, also giving a thorough study to the variations of songs, which had been commonly overlooked, the study also gives a deeper look to song metrics and duration with the tools of phrase based analysis.

- Payne, Roger & Mcvay, Scott: "Songs of the Humpback whale" Article, Science, 1971
https://www.researchgate.net/publication/6007737_Songs_of_Humpback_Whales

Abstract:

The article offers a detailed documentation of the Humpback songs (recorded in the album published the same author) in the form graphic notation with thorough research on other determents of Whale sex and attribute during producing sounds. The article also offers a historical background and proofs of connecting these recorded sounds to the Humpback whale and not for other species. The article results to a list of whale songs with different themes and noticeable repeating patterns.

- Delarue, Julien: “Northwest Atlantic Fin whale vocalizations: geographic variations and implications for stock assessments” Thesis, Hawaii Pacific University, 2004.

Abstract:

The basis of this thesis is using analyzed acoustic data for the vocalizations in order to reach beneficial data for stock assessment (important process done by scientists and fisheries consists of collecting and analyzing data about fish stock and its sustainable

yield). The thesis also aimed to use the tools of acoustic analysis to help documenting accurate parameters for the Fin whales. The thesis was able to document eight different call types reflecting the natural sound diversity.

2.3 Second and real encounter with nature

Along the course of history of music literature, nature represented a major influence on the cognitive awareness of composers and audience as well. Many examples of imitating nature sounds can be found worldwide whether it's undeclared bird chirps from Vivaldi's violin passages or orchestral approaches to create soundscape in Beethoven's sixth symphony or poetic story telling in Prokofiev's Peter and wolf or symbolic soundings in many folklores around the world. Yet another discovery _ rather a real solid documentation_ took this influence to completely new level. In 1952, Bermudian Navy engineer Frank Watlington[11] who was working for the US government at the SOFAR station listening for Russian submarines with underwater hydrophones was able to record first documented Humpback whale vocalizations which led to the release of the breakthrough album previously mentioned by Roger Payne in 1970. After that release, whale vocalizations and songs represented even a stronger influence especially after Payne's lecture on the subject at Rockefeller University, New York in 1968 prior to the album release. That influence spread from Judy Collins' pop music and art songs career, to Paul Winter's music approaching World music genre with nature sounds, which generated the wave of Earth music[12].

Two milestone compositions related to whale vocalizations were published in the second half of the twentieth century. Alan Hovhaness' "*And God created the great whale*" premiered in 1970 for orchestra and recorded vocalizations exploring an epic and biblically over-toned aspect of whales. Moreover, George Crumb's "*Vox Balaenae*" premiered in 1971 for electric flute, electric cello and amplified piano with an Avant-garde approach imitating whale vocalizations.

Both compositions portrayed how strong of an influence the vocalizations are and both showed how individual and non-methodical that influence is. Finally, both helped in generating a new current of composing approaches that were polymerized in the 21

[11] Payne, Roger S., Mcvay, Scott, Songs of the humpback whales, Science, Vol. 173, Aug. 1971.

[12] Rothenberg, David, When we talk about animals,
https://www.whenwetalkaboutanimals.org/2019/09/23/ep-23-david-rothenberg/

century with technological achievements, associated with environmental awareness such as Bio-music. In addition, although trying to classify and catalogue the vocalizations was an important process in the field of science, dealing with them musically always took this non-organized fashion and stayed as romanticized influence[13].

2.4 Cetacean[14] singer/songwriter

The process of examining whale vocalizations for the purpose of classification or categorization we can adopt many perspectives and process various models. One can always generalize them with a broad musical performance point of view and label them as previously mentioned: clicks, whistles and pulsed calls. Yet we can revisit this subject. According to Payne[15], One can have a songwriting understanding for these vocalizations and classify them as follows:

Subunit, unit, phrase, theme, song, song session. Where a subunit is the shortest sounding signal and a song session is the longest where more than one song can be produced. This classification was clarified with Payne's graphic notations and it was provided with descriptive classical academic terms as Sensu Stricto[16], Sensu Strictissimo, Sensu Latissimo corresponding (strict or firm speaking, very strict or very firm speaking, broadly speaking) in order.

A purely scientific classification can be obtained with audio data analysis, which is the main tool of communication between the whales and us. In their study[17], Berchok, Bradley and Gabrielson attempted to classify the vocalization to two types. First,

[13] Towards late Romanticism and 20th century music, the influence of nature sounds was an essential component in composers' skillset. The works of Gustav Mahler to be considered a major milestone in this field. Famous performers' guiding such as "Wie Ein Naturlaut" (sound like nature) in his first symphony.

[14] Marine-biologists term for Marine Mammal,
https://dictionary.cambridge.org/dictionary/english/cetacean

[15] Payne, Roger S., Mcvay, Scott, Songs of the humpback whales, Science, Vol. 173, Aug. 1971.

[16] https://dictionary.cambridge.org/dictionary/english/sensu-stricto

[17] Berchock, Catherine L. and others, St Laurence Blue Whale vocalizations revisited, Pennsylvania state college, 2006.

Infrasonic[18]calls typically low in frequency (less than 20Hz) and they in order can be divided into three types with spectrum attribute description: monotonic, down-sweep and hybrid. Secondly, the audible calls and they were melodically descried as down-sweep, blurp, grunt and bubble.

One can address the vocalization in terms of structure. Payne and others dissected the larger in structure vocalizations into commonly used musical form structure such as AB or ABA. Payne also refined his majorly cited classification adding another structure unit: Sub-phrase to correspond sequence of one or more units repeated in a series. Which can lead us to the following classification that can also be used a guideline to delineate vocalizations by Cholewiak[19]

1- Consecutive units of similar structure can be regarded as parts of a sub-phrase.
2- Repetitive structures such a sub-phrase can be regarded as a phrase.
3- Transitional phrases are combining units from two different phrases such as AB, AB, **AD**, CD, CD.
4- Phrases should be regarded with flexibility and understanding to the concept of variations.
5- Duration of phrases should be measured including the interval between phrases.
6- Reviewing multiple records for the same vocalization session (song) is essential for assigning phrase presence and structure.

2.5 Information on the Research Sample

2.5.1 Songs of the Humpback whale, album by Roger Payne, Capitol Records, USA, 1970.

2.5.2 Data processing: Three certain excerpts are selected due to the applicability of their musical nature. Then exposed to spectrum analysis, which reveals the FFT [20] information, and then a musical score is put and exposed to the same analysis. Aiming to produce the closest spectrum possible.

The paper uses WavePad Audio Editor© software for playing, editing, analyzing and de-noising samples and score. Another software is used, Tone Generator© for corresponding

[18] relating to or denoting sound waves with a frequency below the lower limit of human audibility, https://dictionary.cambridge.org/us/dictionary/english-malaysian/infrasonic

[19] Cholewiak, Danielle M., Humpback whale songs hierarchical structure, The society of Marine-Mammalogy, July 2013

[20] Commonly used initial for the transform, https://www.nti-audio.com/en/support/know-how/fast-fourier-transform-fft

and checking the musical nature of both score and samples. Both software applications are produced by NCH©[21] software company.

2.5.3 Score and samples treatment and proximity:

For targeting the closest results in matching the musical nature of samples and score, certain procedure needed to be done for both:

- Both samples and score are exported or treated as software data entry on the same sample rate of 44100 Hz.
- Both samples and score are de-noised with a suitable amount of added reverb. Then normalized by applying sinusoidal envelope[22].
- There was no white noise or hydro-noise total removal from sample not to extract essential frequencies from the samples.

2.5.4 Frequency equations:

The paper fundamentally relies on the applications of the fast Fourier transform, and as a mathematical equation, the following clarifications are essential[23]:

1- For sake of tonal accuracy, the samples are extremely short in time, with a maximum of 4 seconds. So regarding function in the transform equation:

$$F(\omega) = \int_{-\infty}^{\infty} f(t) \exp(-i\omega t)\, dt$$

The integral for resulting the functions are not ∞ and -∞ but it will be 0 and 4 whether in the ∫ format of the transform or the Σ original format for the sine and cosine equations.

2- For the sake of musical auditability there are two thresholds of frequency, a lower of ≅ 127 Hz and higher of ≅ 365 Hz so the function of ω will be built upon the previous thresholds.

[21] Australian audio software company, https://www.nchsoftware.com/index.html

[22] Smooth, sinewave like sound envelope Mathew, Tony and others, Music synthesis using sinusoid generators, International journal of scientific engineering, Vol. 3, 2015. https://www.ijser.in/archives/v3i2/15021501.pdf

[23] Pain, H. J., The physics of vibrations and waves – sixth edition, Imperial college of science and technology, London, UK, John Wiley & sons, 2005.

3- The previous two points apply as well for the spectrum equation[24]:

$$S(\omega) \equiv \left| \mathscr{F}\{E(t)\} \right|^2$$

Where $\omega \cong 172 - 365$ and $\boldsymbol{t} \cong \mathbf{0} - \mathbf{4}$

4- The paper used the reverse transform to double check the results with means of matching spectrum analysis of the final score against the sample.
5- The transform was also applied to the tone-generated tonal proximity to check frequency wave spikes.

3. The Analytical Framework of the Research

3.1 Forgrounding

Three samples were transcript from the album in this paper. Corresponding three major characteristics of whale vocalizations: sweep, short sweep (unit), and bubble or grunt. Orchestral instruments where chosen based on reaching the most accurate ADSR[25] sound envelope for the vocalization sample. Yet the transcription , though based and scored on a certain tone, aims to be flexible in migrating to other tones.
The basic tone in each score can be treated as a pitch class set[26] in order to apply in other octaves regardless of the loyalty to the original sample in matching the spectrum.
The paper refers to the newly found effects in the three score as follows: ***wvi***, ***wvii*** and ***wviii*** using English as a reference language and putting initials for "Whale Vocalization". The term can be translated into common score languages as follows:

Italian: ***vb*** for vocalizzazione delle baleen.
German: ***vw*** for Vokalisierung von Walen.
French: ***vb*** for vocalisation des baleines.

3.2 Solo whale

Album index: track (Solo whale), 00:02 to 00:06
Transcription instruments: Cello, Muted French Horn.
Premise: the major characteristic sweep of whale vocalization.

[24] Chaudhiri, R. N., Waves and Oscillations, New age international publishers, New Delhi, 2010

[25] The basic four characteristic for any given sound: Attack, Decay, Sustain and Release. Also referred to as "Envelope" / Mathew, Tony and others, Music synthesis using sinusoid generators, International journal of scientific engineering, Vol. 3, 2015. https://www.ijser.in/archives/v3i2/15021501.pdf

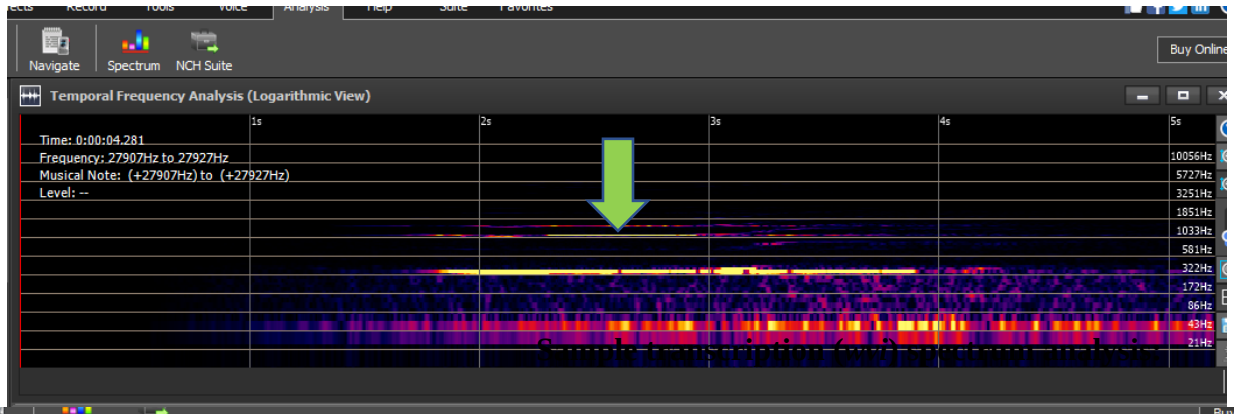
[26] set of all pitches that are a whole number of octaves apart, Pitch class of "C" with all the octaves can be symbolized in math as Cn, Berry, Wallace, Structural function in music, Dover pub. NY, 1987

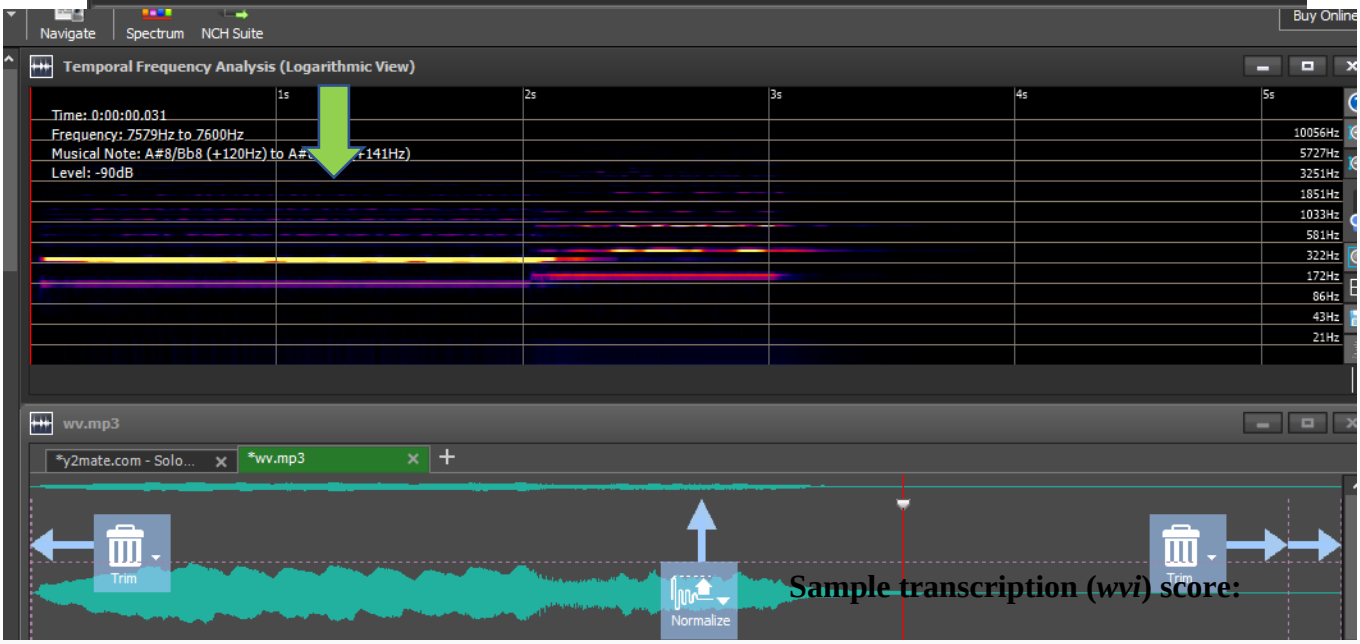
Techniques: for strings: wide vibrato / Glissando. For Winds: muting, Glissando can be applied as well, but according to player technique, and it can also be replaced by bends.

Coefficient marking frequency: ≅365 Hz, marked with a green arrow in the spectrum shots.

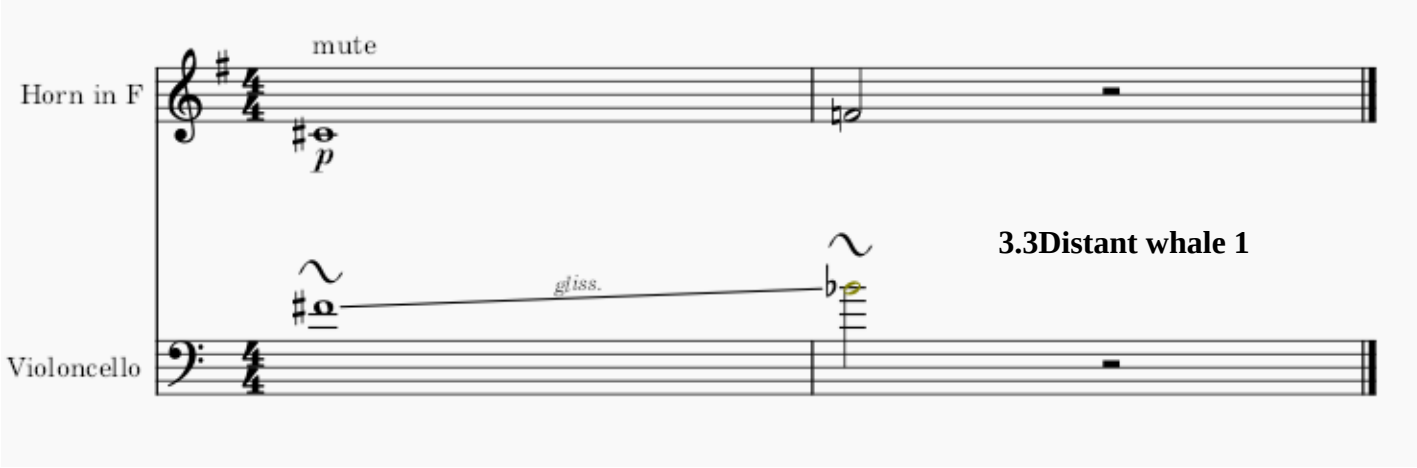
Corresponding tone frequency spike: ≅ F#

Vocalization sample spectrum analysis:





Sample transcription (*wvi*) score:



3.3Distant whale 1

Album index: track (Distant whale), 00:45 to 00:49

Transcription instruments: Euphonium.

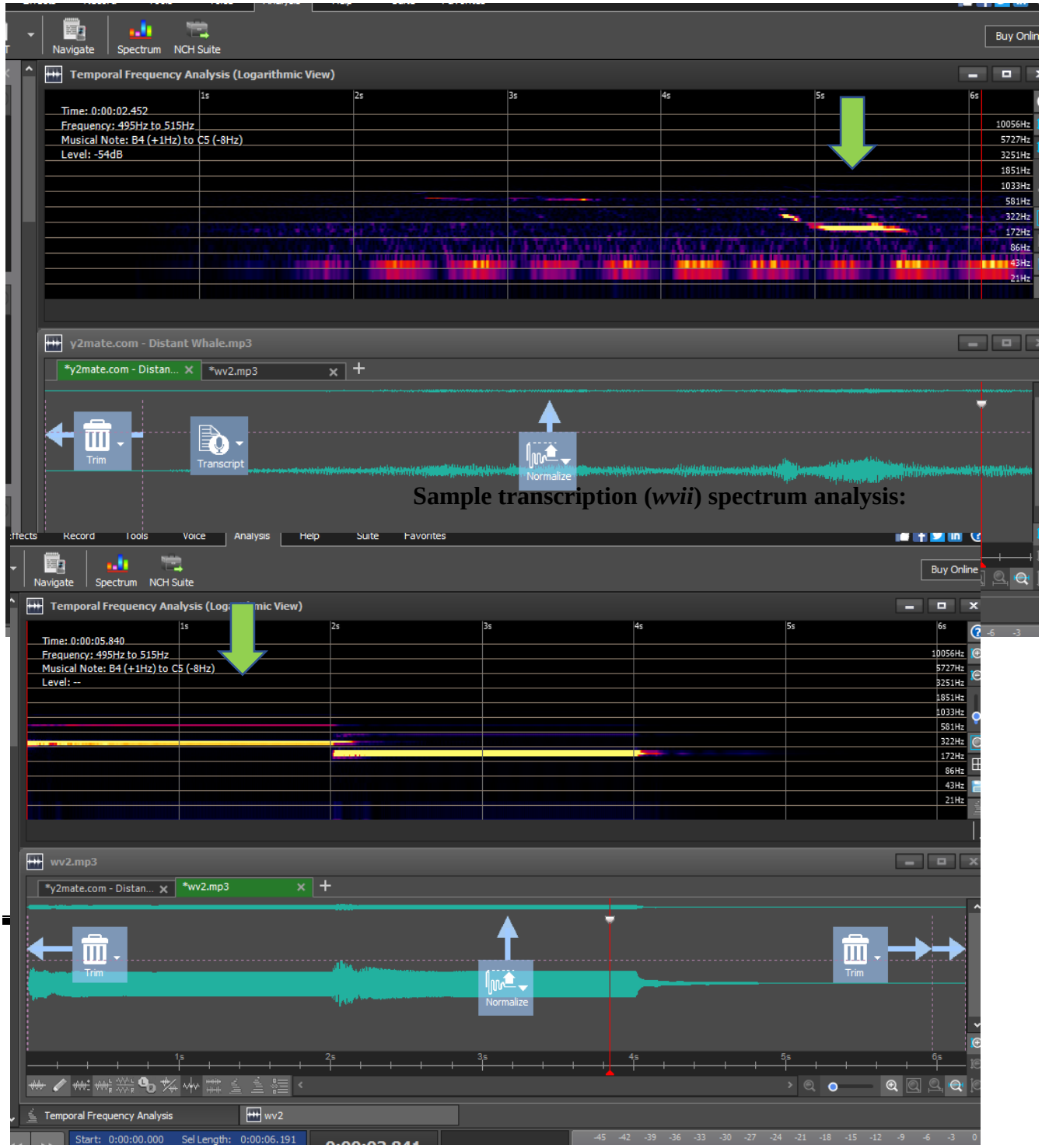
Premise: softer sweep, tender sounds forming units in sub-phrases, high-pitched vocalization.

Techniques: Bends / wide vibrato / short Glissando / lip over-articulation.

Coefficient marking frequency: ≅172 Hz, marked with a green arrow in the spectrum shots.

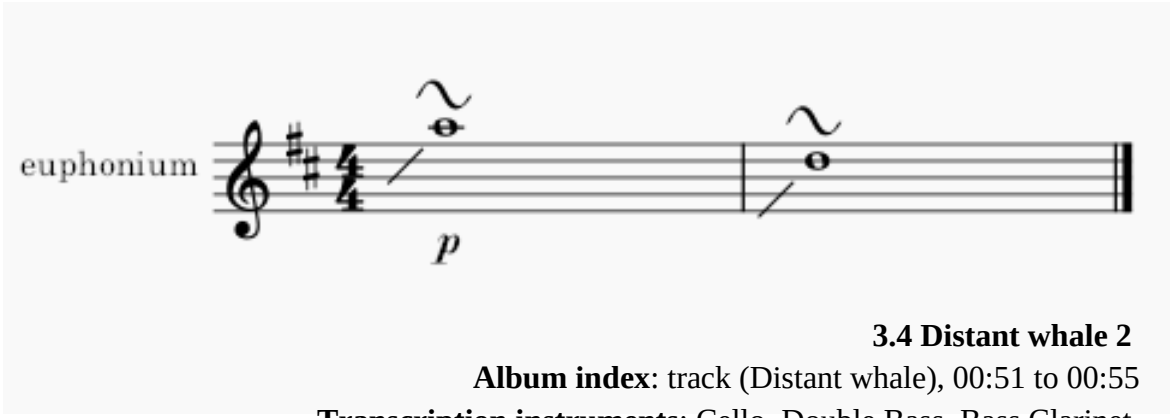
Corresponding tone frequency spike: ≅ G

Vocalization sample spectrum analysis:



Sample transcription (*wvii*) spectrum analysis:

Sample transcription (*wvii*) score:



3.4 Distant whale 2

Album index: track (Distant whale), 00:51 to 00:55

Transcription instruments: Cello, Double Bass, Bass Clarinet.

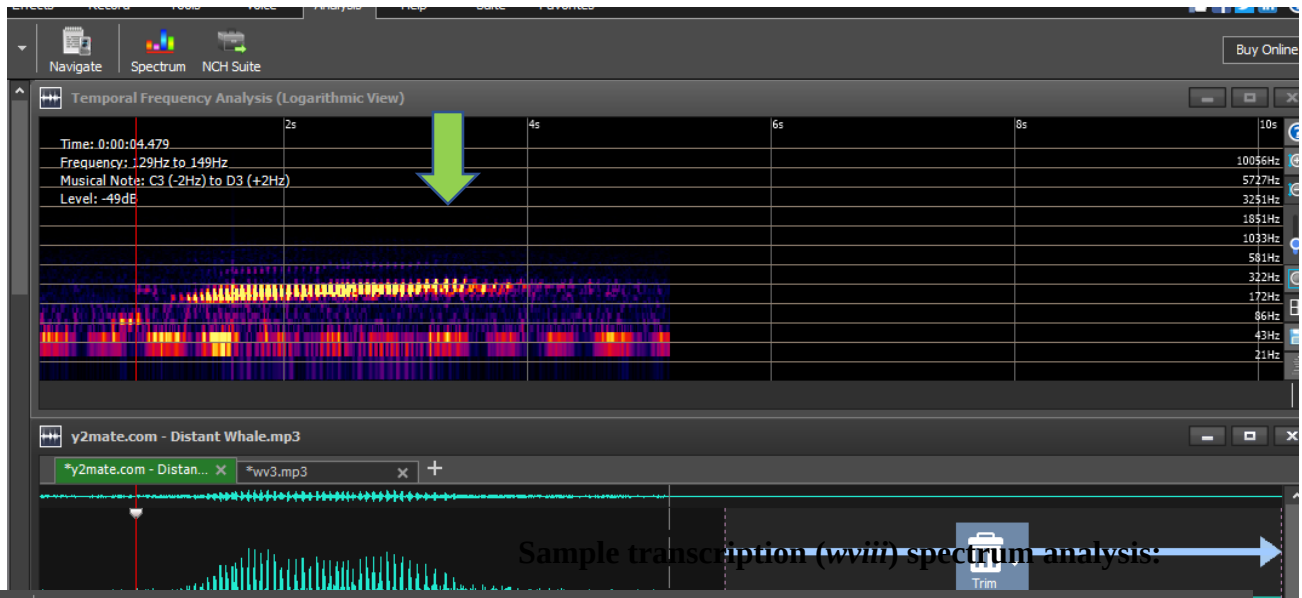
Premise: Bubble, Grunt, percussive type of vocalization.

Techniques: for strings: Wide vibrato / Bended staccato / Staccatissimo / Glissando / Pizzicato / Down-bow “Martellato”. For winds: Wide Vibrato / bended staccato / Staccatissimo / Glissando (accordingly).

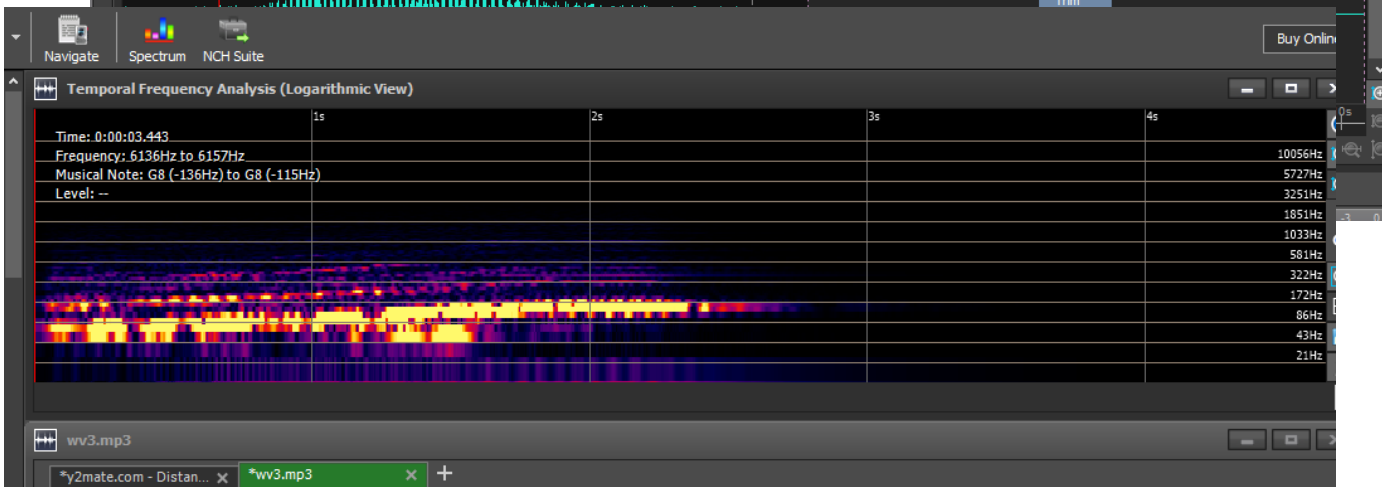
Coefficient marking frequency: ≅215 Hz, marked with a green arrow in the spectrum shots.

Corresponding tone frequency spike: undetermined

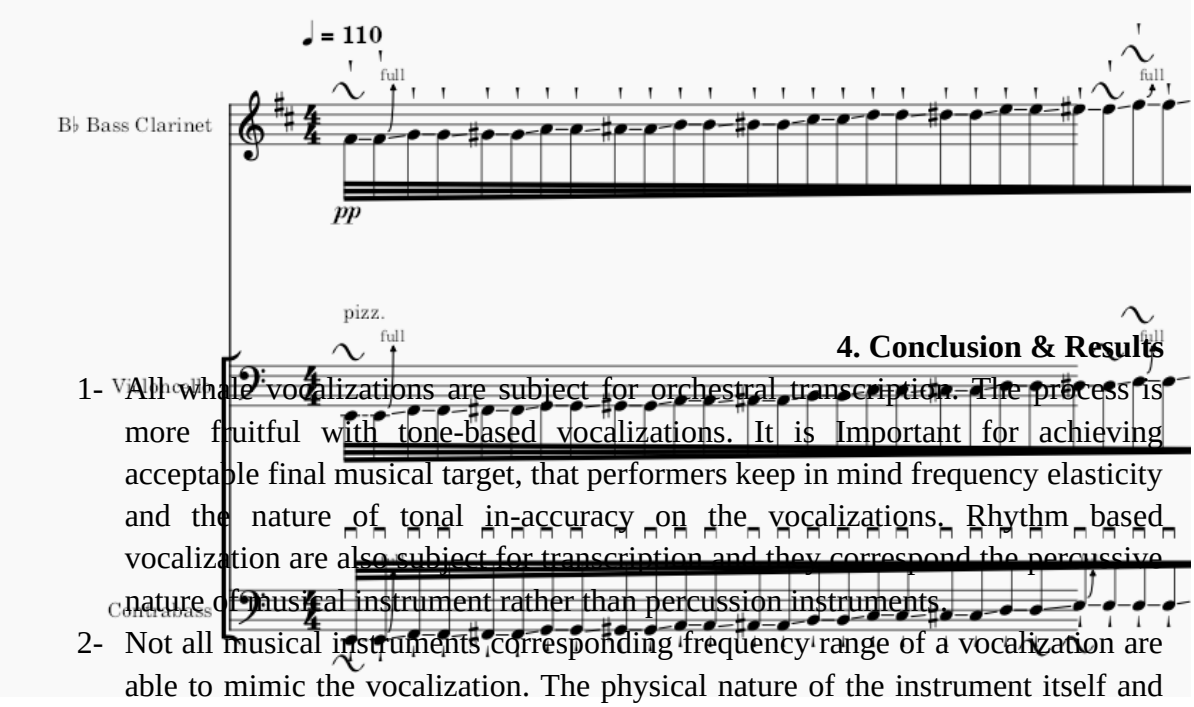
Vocalization sample spectrum analysis:



Sample transcription (*wvii*) spectrum analysis:



Sample transcription (*wviii*) score:



4. Conclusion & Results

1- All whale vocalizations are subject for orchestral transcription. The process is more fruitful with tone-based vocalizations. It is Important for achieving acceptable final musical target, that performers keep in mind frequency elasticity and the nature of tonal in-accuracy on the vocalizations. Rhythm based vocalization are also subject for transcription and they correspond the percussive nature of musical instrument rather than percussion instruments.

2- Not all musical instruments corresponding frequency range of a vocalization are able to mimic the vocalization. The physical nature of the instrument itself and acoustic nature as well are crucial determents. Larger instruments playing tone in the extreme high register are highly capable of mimicking the vocalizations. Aerophones are expected to perform better with tone-based softer vocalizations but Chordophones can add the proper amount of intensity for more intense and harsher in sounding vocalizations, all serving the porpoise of meeting the actual ADSR of the vocalization.

3- Instrumentation and performing techniques of diluting sound and intentional tone inaccuracy and tone gliding are highly recommended to mimic the vocalizations. Glissandos in general and wide vibrato and lip over-articulation in winds were used in the paper. Pizzicato and hammer like staccato are used to achieve the rhythmic nature of pulsed vocalizations. Muting devices can be added to instruments to portray the muffled whispering nature of some vocalizations.
4- Aerophone instruments are necessary when attempting to transcript whale vocalization. Then other tone colours should be added accordingly to the nature of each vocalization.

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Hamarsheh, Qadri, 2012	*Properties if the Fourier transform*, Philadelphia University.
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Payne, Roger S., Mcvay, Scott, 1973	*Songs of the humpback whales*, Science, Vol. 173.
Schevill, W. E., 1964	*Underwater sounds of the Cetaceans*, Oxford, UK.

Concise

The paper is attempting to offer a transcription of Humpback whale vocalizations to orchestral instruments. After examining and transcription examples with means spectrum analyzer, a new list of sounding effects for

instruments can be used in general and in compositions addressing environmental issues especially engaging younger generations.

Keywords:
Whale vocalizations / Bio-music / Orchestration / Spectrum analyzer / musical instruments

ملخص البحث

تدوين الأعماق

تدوين موسيقي ابعض نماذج تصويت الحوت الأحدب

يحاول البحث طرح تدوين أوركسترالي لبعض نماذج تصويت و أغاني الحيتان بناءاً على التوثيقات العلمة البحرية لأصوات الحيتان و مزاجتها بتراث تقنية الكتابة الأوكسترالية. بعد

اختيار عينة من بعض النماذج و تحليلها بمحلل الطيف الصوتي و ايجاد المناظر الموسيقي الآلي الأوركسترالي لها، يمكن توفير قائمة جديدة من المؤثرات الصوتية الجائز استخدامها بشكل عام أو في نوعية خاصة من المؤلفت الموسيقية المعنية بقضايا الوعي البيئي و بخاصة الموجهة للأجيال الناشئة. تأتي الورقة على ضوء تراث طويل من تأثر فن التأليف الموسيقي الجاد بأصوات الطبيعة.

كلمات مفتاحية:

تصويت الحيتان / موسيقى أحيائية / كتابة أورسترالية / محلل طيف صوتي / آلات موسيقية