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Time frequency analysis of patent ductus arteriosus disease in dogs

***Abstract**. This study is based on the analysis of the heart sound signals taken from different auscultation areas of three dogs diagnosed with Patent Ductus Arteriosus (PDA). The analyses were started by introducing the mathematical substructure of the methods used. Then the phonocardiographic signals taken from the three dogs were assessed in terms of time-amplitude (t-a) and frequency amplitude (f-a); subsequently, the components of the signals in time-frequency dimensions were examined. As a result of these analyses, the importance of the auscultation area and time-frequency examination in the diagnosis of the PDA disease was demonstrated.*

***Streszczenie.** W artykule zaprezentowano analize shgnałów serca z różnych obszarów ciała trzech psów cierpiących na chorobę Patent Ductus Arteriosus. Przeprowadzono analizę harmoniczną sygnałów w dziedzinie czasu. (**Czasowo-częstotliwościowa analiza sygnałów serca psów cierpiących na chorobę ductus arteriosus**)*

Keywords: Patent Ductus Arteriosus, Heart sounds, Spectrogram.
Słowa kluczowe: sygnały serca, analiza czasowo-czestotliwościowa..

Introduction

In the 19th century the French mathematician J. Fourier demonstrated that any periodic function can be represented as the sum of an unlimited number of complex exponential periodic functions.

If we were to express any signal as a function dependent upon time in the form of *x(t)*, in order to represent this function in the form of various complex exponential functions, the function would need to be multiplied scalar with the exponential functions and summed for the duration of the time interval. The formulas below represent the Fourier and inverse Fourier transforms respectively [1].

(1) $$X(f) = \int_{-\infty}^{\infty} x(t).e^{-2j\pi ft}.dt$$

$$x(t) = \int_{-\infty}^{\infty} X(f).e^{2j\pi ft}.df$$

After several years, Fourier's ideas were generalised and it was found that non-periodical functions could also be represented in this way.

The discrete time *x(nT)* signal which is calculated by the sampling of the continuous time *x(t)* signal at times of $t = nT$ can be represented in terms of unit impulse functions as follows:

(2) $$x(n)=\sum_{k=-\infty}^{\infty} x(k)\delta(n-k)$$

The Fourier transform of this discrete time signal gives the signal's frequency spectrum and helps identify which frequency components are more concentrated.

The discrete time Fourier transform (DTFT) of discrete time signals are defined as follows:

(3) $$X(\Omega) = \sum_{n=-\infty}^{\infty} x(n)e^{-j\Omega n}$$

DTFT decomposes a discrete time signal into continuous frequency components. Therefore, the DTFT of a discrete time signal is a continuous function that is dependent on frequency.

DTFT is defined as an infinite summation but the summation needs to be finite for the calculation methods; Furthermore, the digital signal processor and computers used for these calculation techniques also require discrete value functions.

Since, in practice, all signals are defined by a bounded interval, the Fourier transform becomes a finite summation. The Fourier transform needs to be calculated for each frequency value in this interval, whereas; in order to calculate the frequency spectrum of a signal, it is sufficient to take into account one period of the discrete time frequency which is periodic with . This basic period of is divided into N number of equal intervals.

$$\Omega = \frac{2\pi}{N}k \quad , \quad k = 0,1,......., N-1$$

Consequently, since the Fourier transform values for number of discrete frequency values take the form of , dependent on k variable, it is called a discrete Fourier transform (DFT) and, by means of DFT, the Fourier transform for a signal can be calculated with arithmetic methods.

The discrete Fourier transform of a signal is defined as follows [2]:

(4) $$X[k] = \sum_{n=0}^{N-1} x(n)e^{-j(2\pi/N)kn} \quad k = 0,1,......., N-1$$

It is possible to calculate DFT more quickly by using the symmetry and periodicity properties of the phase factor in the Discrete Fourier transform

(5) $$W_N = e^{-j(2\pi/N)}$$

The sample rarefaction in time and sample rarefaction in frequency methods which enable this are called the Fast Fourier Transform (FFT). With FFT, the calculation load is reduced from level to levels and therefore, in practice FFT is always used[3].

The Gabor Transform, proposed in 1946 by Dr. Gabor who worked in the field of communication, enabled the regional frequency analysis of any scanned signal by the shifting in time of a constant function defined as a window function, and taking the Fourier Transform of the signal. Thus, the Fourier Transform of the windowed signal contains the time information in addition to the frequency components of the signal. The window function used in the transform is the Gaussian function bounded in time and frequency domains. With a new algorithm proposed in 1965, the Gabor Transform was expanded to the "Short-Time Fourier Transform" (STFT), where different window functions are used. This transform model constitutes a useful solution, especially for computer applications.

Short-Time Fourier Transform (STFT)

The signal is passed through a defined window in the time domain and then the Fourier Transform is applied. The window function is shifted on the time axis in a way that covers the whole signal; thus the frequency results (frequency spectrums) of the signal in time intervals at the width of the window function are obtained. Thus, in a way, the change in the signal's frequency result over time, is obtained. The formula which enables the STFT transform is given as below [4]:

(6) $$KSFD(\tau, f) = \int_{-\infty}^{\infty} [x(t).w^*(t-\tau)].e^{-j2\pi ft} dt$$

Here; $x(t)$ is the actual signal, w(t) window function, * complex conjugate notation, shift in time. STFT consists of the FD of the signal multiplied by a window function. For each t and f, a new set of STFT coefficients are calculated. Thus, whilst FD is a function of frequency only, STFT is a function of both frequency and time and STFT in this state is three dimensional (the third dimension being amplitude). STFT gains importance if the signal is not stationary. In this case, the signal is divided into segments which are considered to be stationary and the FD of each segment is different. When the signal is stationary, the FD of each segment becomes the same as (or similar to) each other and thus STFT and FD become the same as (or similar to) each other.

The window function used in the Short-Time Fourier Transform, being of a fixed width during scanning, results in the signal's rapidly-changing high-frequency changes not being exactly segmented in the time domain. As a solution to this problem, instead of fixed width windows, the idea came about of using wide window functions to catch the slow changes in the signal and of narrow window functions where rapid changes occur; and, as a result, the subject of Wavelet Transform Analysis emerged.

The main area where STFT analysis becomes useful is the analysis of non-stationary signals. In this way, accurate information can be acquired as to how the frequency of the signal changes over time, whereas; in stationary data, the FD and STFT transform may indicate that the frequency components of the signal did not change over time or changed slightly [5], [6].

STFT of discrete time $x(n)$, $n=0,1,\ldots,N-1$ signal [10,11,12].

(7)
$$x(n, w_k) = \sum_{m=0}^{N-1} x(m).w(n-m).e^{-jw_k m} = \sum_{m=0}^{N-1} x_n(m).e^{-jw_k m}$$

And $x(n)$ signal's spectrogram [7] ,

(8) $$S_{STFT}(n, w_k) = \frac{1}{N} \left| x(n, w_k) \right|^2$$

Patent ductus arteriosus (PDA)

The passage (ductus arteriosus) between the two main arteries (aorta and pulmonary artery) of the heart, is normally open in developing fetuses , but should close following birth; PDA is the condition in which this orifice remains open (patent) after birth.

Since the baby derives oxygen from the mother's blood while in the mother's uterus, the baby's blood does not need to go to the lungs to be oxygenated. Therefore, blood coming into the pulmonary artery (lung artery) passes to the aorta through this duct (ductus arteriosus) between the pulmonary artery and aorta. Since the baby needs to use its own lungs after birth, blood needs to go to the baby's lungs to be oxygenated and this passage needs to close. Normally, this orifice closes when the newborn baby takes its first breath. If it does not close completely within 3 days, PDA is diagnosed [8].

In auscultation, wide pulse pressure; a trill in the second left intercostal interval (systolic and/or diastolic); pulsus celer et altus (rapid, sharp pulse); paradox copulation in the second heart sound; continuous (machinery) murmur in the first and/or second intercostal interval; outward displaced and/or hyperactive left ventricle impulse is heard [9].

Clinical Applications

Three year old Shetland breed male dog

a) Stethoscope Area: Left side base

Heart Rate

Bradycardia: No, Tachycardia: No, Normal range: Yes

Heart Rhythm

Rhythm Character: Irregular, Premature Beats: No, Long Pauses: No

Extra Heart Sounds

Murmur: Yes, Systolic: No, Diastolic: No, Continuous: Yes, Gallop: No, Systolic click: No, Other Sounds: No

Auscultation Diagnosis

Continuous murmur with small sinus arrhythmia.

(Continuous murmur audible during all systol and diastol, reduced in diastol).

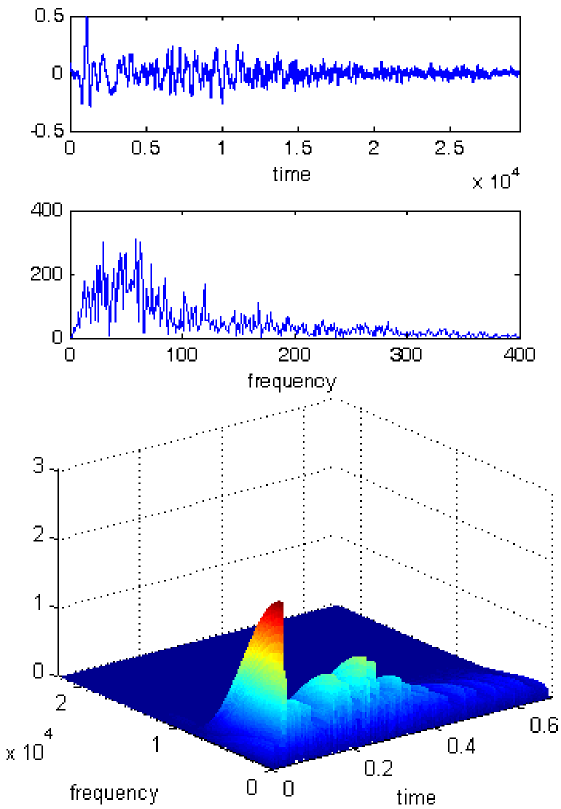

Fig.1. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the heart sound signals taken from the first base area of Application 1

In the t-a graph, a continuous murmur in systol (reduced during diastol) is observed. In the f-a graph, there are frequency components concentrated in the 0-200 Hz band. A continuous murmur is also clearly seen in the three dimensional spectrogram.

b) Stethoscope Area: Left side : apex
Heart Rate
Bradycardia: No, Tachycardia: No, Normal range: Yes
Heart Rhythm
Rhythm Character: Regular, Premature Beats: No, Long Pauses: No
Extra Heart Sounds
Murmur:Yes, Systolic: Yes,Diastolic: No,Continuous:No
Gallop: No, Systolic click: No, Other sounds: No
Auscultation Diagnosis
Light early systolic murmur audible only from the left apex

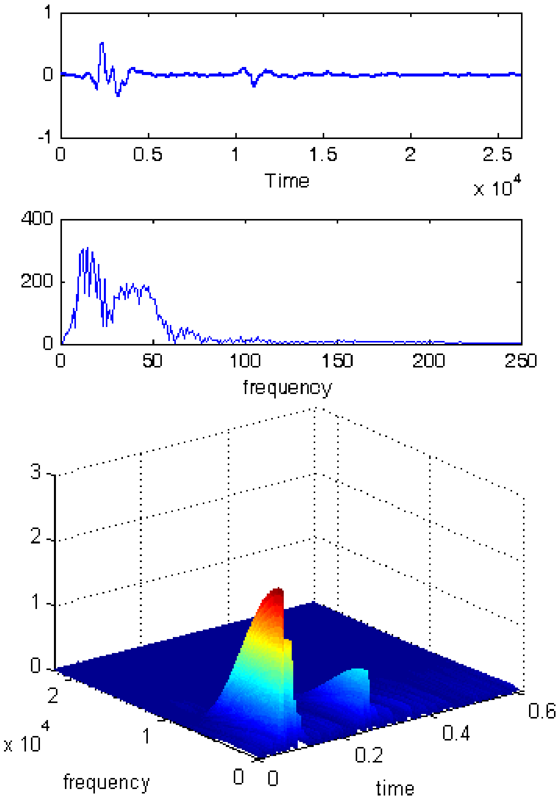

Fig.2. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the heart sound signals taken from the apex area in Application 1

In the t-a graph, a light early systolic murmur is discernible, albeit with difficulty. In the f-a graph, these time frequency components are observed to be compressed within approximately the 0-100Hz band. S1, S2 and early systolic murmur are discernible more easily in the three dimensional spectrogram.

Since the continuous murmur typical of PDA, seen in the base area, does not occur at the apex, if only this area was considered sufficient during auscultation, the disease could have been missed.

Three year old Shetland breed male dog
a) Stated complaint: Gets tired more quickly than normal
Stethoscope Area: Left side: base
Heart Rate
Bradycardia: No, Tachycardia: No, Normal range: Yes
Heart Rhythm
Rhythm Character: Irregular, Premature Beats: No, Long Pauses: No
Extra Heart Sounds
Murmur: Yes, Systolic:No, Diastolic: NoContinuous:Yes
Gallop: No, Systolic click: No, Other sounds: No

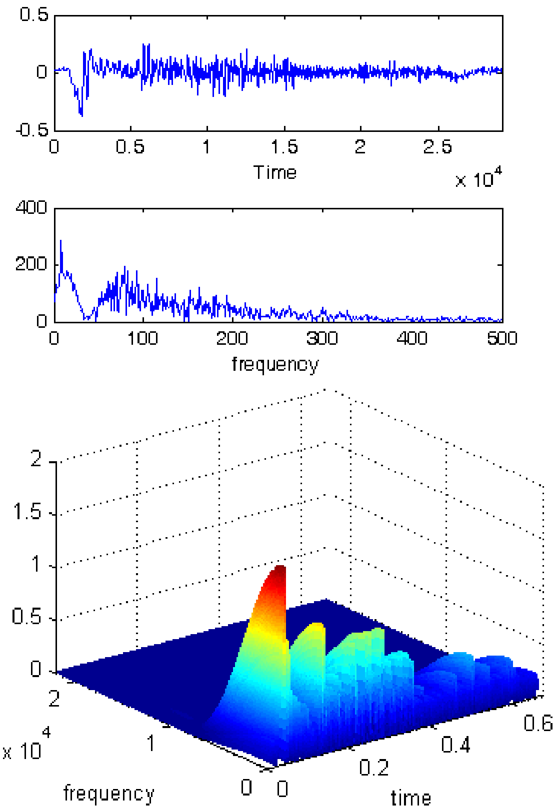

Fig. 3. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the heart sound signals taken from the base area in Application 2

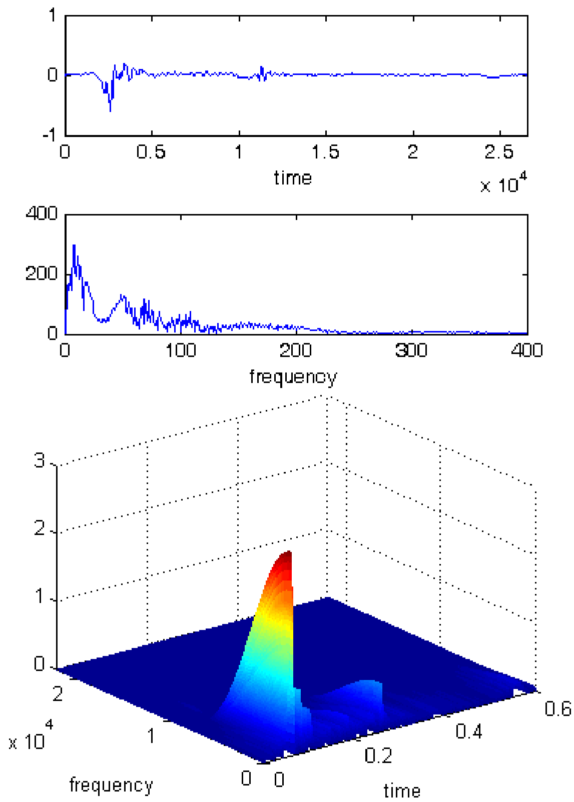

Fig.4. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the heart sound signals taken from the apex area in Application 2

In the t-a graph, S1 and S2 are not clear but a continuous murmur is observed. In f-a, there are frequency components distributed over the 0-300 Hz band. However, S1, S2 and a continuous murmur are clearly observed in the three dimensional spectrogram.

b) Stethoscope Area: Left side: apex
Heart Rate
Bradycardia: No,Tachycardia: No,Normal range: Yes
Heart Rhythm
Rhythm Character: Regular,Premature Beats: No,
Long Pauses: No
Extra Heart Sounds
Murmur: Yes,Systolic:Yes,Diastolic: No,Continuous: No
Gallop: No,Systolic click: No,Other sounds: No
In t-a, no murmur can be determined during diastol except for an early systolic murmur. The f-a graph contains frequency components in the 0-120 Hz band. It is clearly observed in the three dimensional spectrogram that there is no murmur in diastol.

10 year old female domestic shorthair dog
a)Stethoscope Area: Left side: base
Heart Rate
Bradycardia: No,Tachycardia: No,Normal range: Yes
Heart Rhythm
Rhythm Character: Regular,Premature Beats: No
Long Pauses: No
Extra Heart Sounds
Murmur: Yes, Systolic: No, Diastolic: No Continuous: Yes, Gallop: No, Systolic click: No
Other sounds: No

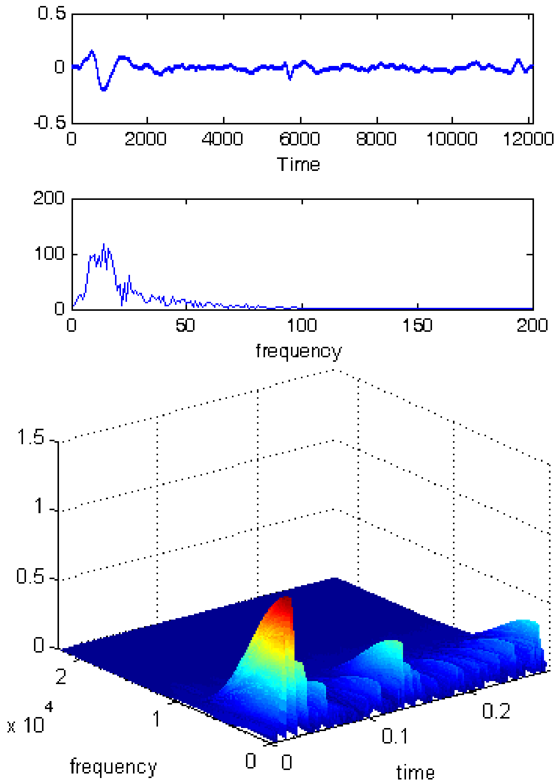

Fig. 5. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the heart sound signals taken from the base area in Application 3

In the t-a graph, a continuous murmur is not seen clearly. The f-a graph contains frequency components in the 0-100 Hz band. S1, S2 and a continuous murmur are clearly observed in the three dimensional spectrogram.

b) Stethoscope Area: Left side: base
Heart Rate
Bradycardia: No,Tachycardia: No, Normal range: Yes
Heart Rhythm
Rhythm Character: Irregular, Premature Beats: Yes
Long Pauses: No
Extra Heart Sounds
Murmur:Yes, Systolic: No, Diastolic: NoContinuous:Yes
Gallop: No, Systolic click: No, Other sounds: No
Lung Sounds
Normal: No,
Abnormal with:
Crackles: No, Wheezes: No
Increased BV sounds:Yes, Other: No

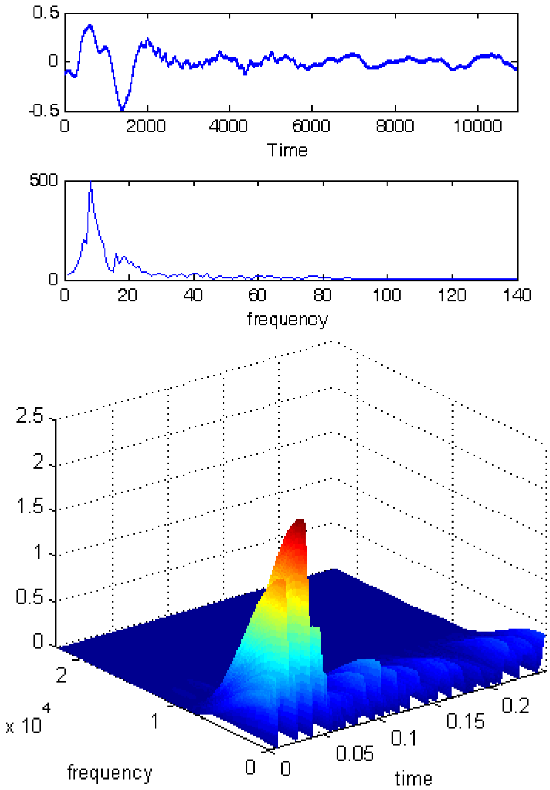

Fig. 6. Time-amplitude, frequency-amplitude and three dimensional time-frequency graphs of the other heart sound signals taken from the base area in Application 3

In the t-a graph, although S1 appears clearly, S2 is mixed with a continuous murmur. The f-a graph shows frequency amplitudes in the 0-40 Hz band. Large amplitude S1 and small amplitude S2 and continuous murmur occurs in the three dimensional spectrogram.

Results

1. PDA type continuous murmur (to and fro) (Fig.7), whilst not appearing clearly in t-a and f-a graphs, is clearly observed in the three dimensional spectrograms.

The characteristic of a heart murmur is that it starts immediately after S1, peaks in coupled S2 and reduces during diastol. In short, it is the crescendo-decrescendo type of murmur covering all systol and diastol and peaking in S2.

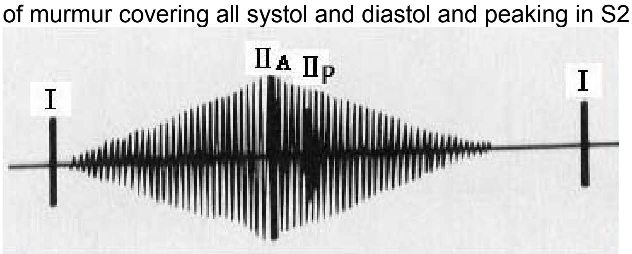

Figure.7- To and fro type of continuous murmur observed in PDA disease

2. The area where the auscultation is performed is important in order to observe the PDA type murmur. Although the murmur is observed in the base area, the murmur in diastol is not observed in other areas, which may cause the disease to go unnoticed.

REFERENCES

[1] Bracewell R. N., The Fourier Transform & Its Applications, (McGraw-Hill Science, 1999).

[2] Chu E., Discrete and Continuous Fourier Transforms: Analysis, Applications and Fast Algorithms,(Chapman & Hall/CRC, 2008).

[3] Zonst A.E., Understanding the FFT, (Citrus Press., 1995).

[4] Suppappola A.P., Applications in Time-Frequency Signal Processing, (CRC Pres., 2002).

[5] Debbal S.M., Bereksi F.-Reguig, Cardiac murmur analysis using the short-time fourier transform, *Journal of mechanics in medicine and biology*, vol. 6 n. 3, pp. 273-284.

[6] Kim I.Y., Lee S.M., Yeo H.S., W.T. Han W.T., Hong S.H., Feature extraction for heart sound recognition based on time-frequency analysis, The 21st Annual Conf. and the 1999 Annual Fall Meeting of the Biomedical Engineering Soc. ~ BMES/EMBS, 1999~.

[7] Boutana D., Djeddi M., Benidir M., Identification of Aortic Stenosis and Mitral Regurgitation By Heart Sound Segmentation On Time-Frequency Domain, The 5th International Symposium on Image and Signal Processing and Analysis ~ISPA 2007~, Sept. 27-29,2007.

[8] Barry D.T., Wood J., Time Frequency Transforms Of The Human First Heart Sound, 13. Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 31 Oct.-3 Nov., 1991.

[9] Brusco M., Nazeran H., Digital phonocardiography: a PDA-based approach, The 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society ~IEMBS '04~, 2004.

[10] Park M.K., Pediatric Cardiology Handbook, (Mosby, 2002).

[11] Khan M.G., Encyclopedia of Heart Diseases, (Academic Pres., 2005).

[12] Springhouse, Auscultation Skills: Breath & Heart Sounds, (Lippincott Williams & Wilkins, 2002).

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