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Statistical properties of MPEG video traffic and their impact on traffic modeling in ATM systems

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Abstract

MPEG video traffic is expected to cause several problems in ATM networks, both from performance and from architectural viewpoint. For the solution of these difficulties, appropriate video traffic models are needed. A detailed statistical analysis of newly generated long MPEG encoded video sequences is presented and the results are compared to those of existing data sets. Based on the results of the analysis, a layered modeling scheme for MPEG video traffic is suggested which will simplify the finding of appropriate models for a lot performance analysis techniques.

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13. ABSTRACT ***(Maximum 200 Words)***

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1 Introduction

In B-ISDNs, a major part of the traffic will be produced by multimedia sources like teleconferencing terminals and video-on-demand servers. These networks will work on the basis of ATM and most of the video encoding will be done using the MPEG standard (ISO Moving Picture Expert Group).

There are a number of open issues concerning the transmission of MPEG video on high-speed networks like finding of the appropriate ATM adaption layer, dimensioning of the multiplexer buffers, shaping of video traffic, and monitoring of video cell streams. To solve these problems several performance analyses has to be done and therefore models for MPEG video traffic streams have to be developed. The first step of the model development is a thorough analysis of the statistical data sets of already encoded videos.

At institute of Computer Science at Würzburg, we encoded a variety of video sequences and carried out a thorough statistical analysis to get a detailed picture of the video data stream: moments, histograms, QQ-plots, autocorrelation functions of frame and GOP sizes, R/S-plots. Based on this information and the knowledge about the MPEG coding technique, we propose a layered video modeling scheme. The model can consist of GOP, frame, and cell layer, depending on the requirements of the analysis. For each layer certain stochastic processes are suggested, which may be used for modeling.

In Section 2, we outline the MPEG video encoding technique. Section 3.1 is about the statistical analysis of the encoded sequences and in Section 3.2 the layered modeling scheme is presented. Section 4 concludes the paper.

2 MPEG video encoding

Due to the high bandwidth needs of uncompressed video data streams, several coding algorithms for the compression of these streams were developed.

At the moment, the MPEG coding scheme is widely used for any type of video applications. There are two schemes, MPEG-I [7, 6] and MPEG-II [2], where the MPEG-I functionalities are a subset of the MPEG-II ones. The main difference with respect to video transmission on ATM is that MPEG-II allows for layered coding. This means the video data stream consists of a base layer stream, which contains the most important video data, and of one or more enhancement layers, which can be used to improve the quality of the video sequence.

In this paper, we focus on one-layer video data streams of MPEG-I type. Most of the encoders will use this scheme and in case of multi-layer encoding the statistical properties of the base layer will be almost identical to this type of stream.

The MPEG encoder input sequence consists of a series of frames, each containing a two-dimensional array of *picture elements*, called pels. The number of frames per second as well as the number of lines per frame and pels per line depend on national standards. For each pel, both luminance and chrominance information is stored. The compression algorithm is used to reduce the data rate before transmitting the video stream over communication networks.

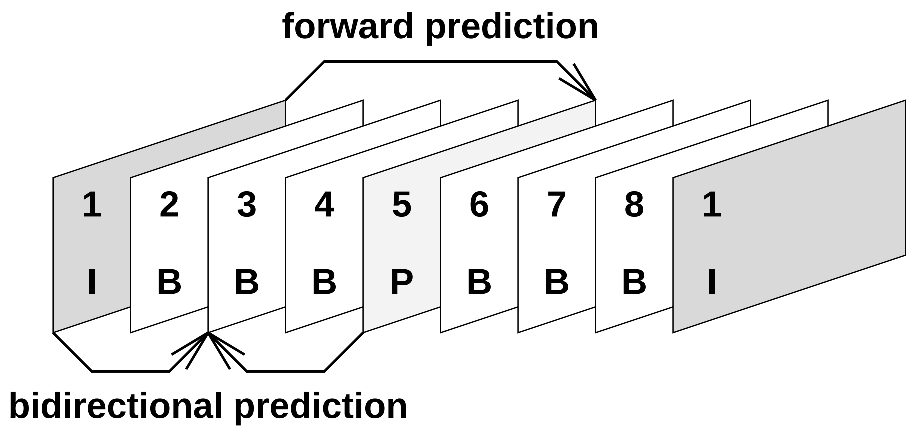

Figure 1: *Group of Pictures of an MPEG stream*

This is done by both reducing the spatial and the temporal redundancy of the video data stream. The spatial redundancies are reduced by transforms and entropy coding and the temporal redundancies are reduced by prediction of future frames based on motion vectors. This is achieved using three types of frames (cf. Figure 1):

I-frames use only intra-frame coding, based on the discrete cosine transform and entropy coding;

P-frames use a similar coding algorithm to I-frames, but with the addition of motion compensation with respect to the previous I- or P-frame;

B-frames are similar to P-frames, except that the motion compensation can be with respect to the previous I- or P-frame, the next I- or P-frame, or an interpolation between them.

Typically, I-frames require more bits than P-frames. B-frames have the lowest bandwidth requirement.

After coding, the frames are arranged in a deterministic periodic sequence, e.g. “IBB-PBB” or “IBBPBBPBBPBB”, which is called *Group of Pictures* (GOP).

3 Modeling of MPEG video traffic

There are several reasons to develop models for video traffic and to use them for the performance analysis of ATM networks.

The first reason is to extract the statistical properties of video traffic which have a remarkable impact on the network performance. We gain a lot of insight, if we are able to reduce the statistical complexity of the empirical video data sets. It is true, that only the frame size trace from the output of a MPEG encoder contains all statistical information about the encoded video, but on the other hand the large number of properties makes it difficult to decide which one is causing performance problems.

Movies (buy cassettes)	
dino	Jurassic Park
lambs	The Silence of the Lambs
TV sports events (recorded from cable TV)	
soccer	Soccer World Cup 1994 Final: Brazil - Italy
race	Formula 1 car race at Hockenheim/Germany 1994
atp	ATP Tennis Final 1994: Becker - Sampras
Other TV sequences (recorded from cable TV)	
terminator	Terminator 2
talk1	German talk show
talk2	Political discussion
simpsons	Cartoon
asterix	Cartoon
mr.bean	Three slapstick episodes
news	German news show
mtv	Music clips
Set top camera	
settop	Student sitting in front of workstation

Table 1: *Overview of encoded sequences*

The second reason is the computational complexity of simulations, particularly on cell level, of ATM networks. It often takes long simulation runs to obtain results of high accuracy. In some cases the numerical complexity can be considerably reduced using traffic models and standard analytical tools like matrix analysis or discrete time analysis.

The third reason is the need for connection traffic descriptors for video traffic. If the traffic model is simple, i.e. it has only a small number of parameters, these parameters can be used as traffic descriptors for CAC and UPC of video connections.

For the development of video traffic models we can both use the knowledge about the coding technique, MPEG-I or MPEG-II in our case, and the statistical analysis of the frame size sequence which we obtain from measurements.

3.1 Statistical analysis of MPEG video sequences

In the following, we will present some statistical measurements from several movies, TV sport events, and TV shows[1], which we encoded at our institute using the UC Berkeley MPEG-I software encoder [5]. Table 1 shows the sequences which we used to produce the data sets.

All sequences mentioned below were encoded using the following parameter set:

[1]To avoid any conflict with copyright laws, we want to point out, that all image processing, encoding, and analysis work was made for scientific purposes. The encoded sequences have no audio stream and will not be made publicly available. Only statistical data sets will be made available to colleagues.

Sequence	Compr. rate X : 1	Frames			GOPs			Bit rate	
		Mean [bits]	CoV	Peak/ Mean	Mean [bits]	CoV	Peak/ Mean	Mean [Mbps]	Peak [Mbps]
asterix	119	22,348	0.90	6.6	268,282	0.47	4.0	0.59	1.85
atp	121	21,890	0.93	8.7	262,648	0.37	3.0	0.55	1.58
dino	203	13,078	1.13	9.1	156,928	0.40	4.0	0.33	1.01
lambs	363	7,312	1.53	18.4	87,634	0.60	5.3	0.18	0.85
mr.bean	150	17,647	1.17	13.0	211,368	0.50	4.1	0.44	1.76
mtv	134	19,780	1.08	12.7	237,378	0.70	6.1	0.49	2.71
news	173	15,358	1.27	12.4	184,299	0.47	6.0	0.38	2.23
race	86	30,749	0.69	6.6	369,060	0.38	3.6	0.77	3.24
settop	305	6,031	1.92	7.7	72,379	0.18	2.0	0.15	0.27
simpsons	143	18,576	1.11	12.9	222,841	0.43	3.8	0.46	1.49
soccer	106	25,110	0.85	7.6	301,201	0.48	3.9	0.63	2.29
starwars	130	15,599	1.16	11.9	187,185	0.39	5.0	0.36	4.24
talk1	183	14,537	1.14	7.3	174,278	0.32	2.7	0.36	1.00
talk2	148	17,914	1.02	7.4	214,955	0.27	3.1	0.49	1.40
terminator	243	10,904	0.93	7.3	130,865	0.35	3.1	0.27	0.74

Table 2: *Simple statistics of the encoded sequences*

- Each frame consists of one slice;
- GOP pattern: IBBPBBPBBPBB (12 frames);
- Quantizer scales: 10 (I), 14 (P), 18 (B);
- Motion vector search: logarithmic/simple; window: half pel, 10; reference frame: original;
- Encoder input: 384 x 288 pels with 12 bit color information;
- Number of frames per sequence: 40000 (about half an hour of video)

Some parameters might not be optimal with respect to the quality of the MPEG video sequence, because of some hardware limitations. We used a Sun Sparc 20 for the image processing and encoding, and captured the sequence from a VCR with a SunVideo SBus board.

3.1.1 Overview

Table 2 shows the compression rates and the most important moments of the frame sizes, the GOP sizes, and the corresponding bit rates of the MPEG sequences.

For the sake of comparison the statistical data from Mark Garrett's *Star Wars* sequence [4] is also presented.

the From Table 2 we conclude, that typical TV sequences like sports, news, and music clips lead to MPEG sequences with a high peak bit rate and a high peak-to-mean ratio compared to movie sequences. These properties result from the rapid movements of a lot of small objects, which increase the amount of data necessary to encode the sequence.

Unfortunately, even the statistical properties of the sequences of the same category, like movies or cartoons, are not in good agreement. For example, the measurements of *terminator* and *lambs* or of *simpsons* and *asterix* have no moments lying close together. This will lead to difficulties in finding traffic classes for MPEG video, which can be used for CAC and UPC.

In the remainder of this section, we will present a detailed analysis of the statistical data of the *dino*, *soccer*, and *starwars* sequences.

3.1.2 Frame traces

Figures 3, 4, and 5 show the frame size traces of the *dino*, *soccer*, and *starwars* sequences. The I frame sizes are light gray, the P frame sizes black, and the B frame sizes dark gray. The appearance of the three traces is very different. The *dino* trace is rather smooth, whereas the other two traces show a large number of rapid changes in the frame sizes of each type of frames. But although both traces have this property, they look different. The P frames of the *starwars* trace are large compared to the I frames. The *soccer* trace, however, shows very large changes in any type of frames, and the B frames are often of the same size as the P frames. This indicates a lot of movement in the input sequence of the encoder, since the B frames only become large, if the predicted image will be poor because of the amount of movement and additional data has to be encoded to correct these prediction errors. This will be the case for soccer matches and for a lot of other sports events.

3.1.3 Distributions

The Figures 6, 7, and 8 show the frame size histograms of the I, P, and B frames of the *dino* sequence. The dashed curve is a Gamma pdf, which has the same mean and variance as the histogram frame sizes. The good agreement of the histogram and the Gamma curve for the I and P frames becomes more obvious if we use a QQ-plot (quantile-quantile-plot), where the Gamma quantiles are plotted against the histogram quantiles. An agreement with the dotted line indicates that both pdf's are equal. The solid line is for the Gamma pdf and the dashed line is for the Lognormal pdf, which has the same parameters as the Gamma pdf. For the I frame sizes (Figure 9) both the Gamma and the Lognormal pdf are good to very good approximations of the histogram pdf. In case of the P frames (Figure 10) the Gamma pdf is in good agreement, whereas for the B frames (Figure 11) the Lognormal pdf shows better performance.

For almost all encoded sequences, either the Gamma or the Lognormal pdf is an useful approximation of the frame size histogram pdf's of either type of frame. The differences between Gamma and Lognormal approximation performance are not too large in most cases. Perfect agreement of histogram and approximation cannot be achieved due to finite frame sizes.

This leads to the conclusion, that for the modeling of the frame sizes, either histograms, Gamma, or Lognormal pdf's can be used.

If we look at the GOP size distributions, we obtain similar results. Figures 12, 13, and 14 show the QQ-plot for the *dino*, *soccer*, and *starwars* sequence. Again, the Gamma and Lognormal quantiles are plotted against the histogram quantiles. For the sequences considered, the Lognormal distribution is a good approximation of the GOP size histogram, but the Gamma distribution will also be adequate.

3.1.4 Correlations

Time-dependent statistics are important in the case of video traffic, because correlations of the data streams may cause performance problems of the ATM network.

First, autocorrelation functions of the frame sizes and of the GOP sizes are presented. The frame-by-frame correlations are depending on the pattern of the GOP, and, in principle, always look like Figure 15, if the same GOP pattern is used for the whole sequence. The larger positive peaks stem from the I frames, the smaller positive ones from the P frames, and the negative ones from the B frames. This shape reflects the relationship of the mean frame sizes of the frame types. A large I frame is followed by two small B frames. Then a midsize P frame is produced by the encoder, which is followed by two small B frames again. The pattern between two I frame peaks is repeated with slowly decaying amplitude of the peaks.

If a model is needed which reflects the frame-by-frame correlations of an MPEG video traffic stream, the GOP-pattern based shape of the autocorrelation function has to be considered. An approximation of the autocorrelations function is presented in [3].

Based on the frame level correlations, it is difficult to get a clear picture of the long-range correlations of the video traffic stream. Thus, the autocorrelation functions of the GOP sizes, i.e. the sum of the frame sizes of one GOP, are considered.

Figures 16, 17, and 18 show the autocorrelation functions of the GOP sizes of the sequences *dino*, *soccer*, and *starwars*. In addition, the dashed line shows the exponential function, which is matched to the empirical autocorrelation function of the first few lags. A curve of this type appears if the GOP size process is memoryless. If the autocorrelation function of the statistical data is above the exponential function, this indicates dependences in the GOP size process. In Figures 16 and 18 this is clearly the case, whereas the autocorrelation curve and the exponential curve are matching well in Figure 17.

This result makes it difficult to find a GOP layer model which is appropriate for all types of video sequences. On the other hand, it is often sufficient to have a model which is accurate in terms of correlations in the order of frames, i.e. tens of milliseconds. Therefore, it is possible to neglect the GOP-by-GOP correlations and to use only distributions and moments of the GOP sizes to model the GOP size process, e.g. with a Markov chain, an autoregressive process, or simply drawing GOP size samples based on the GOP size histogram.

Another way to detect long-range dependences is to use variance-time plots, R/S plots, or periodograms [1, 8]. Here, we focus on the R/S plots, because it is a robust method

Sequence	*Hurst exponent* H
race	0.99
soccer	0.91
lambs	0.89
terminator	0.89
mtv	0.89
simpsons	0.89
talk1	0.89
dino	0.88
atp	0.88
mr.bean	0.85
asterix	0.81
news	0.79
starwars	0.74
talk2	0.73
settop	0.53

Table 3: *Hurst exponents of the encoded sequences*

to determine the *asymptotic Hurst exponent* H of long time series. An introduction in R/S analysis can be found in [9].

Figures 19, 20, and 21 show the R/S plots, strictly speaking the pox plots, of the frame size sequences of *dino*, *soccer*, and *starwars*. The slope of the street of points on the diagrams is an estimate for the *Hurst exponent* H. The slope is computed using a least squares fit, where the first row and the last two rows of R/S values is not considered. The first row may reflect too many short-range dependence effects, and the number of R/S values of the last row is too small.

The estimated parameter H for the *dino* sequence is 0.88, for the *soccer* sequence it is 0.91, and for the *starwars* sequence 0.74 is estimated. Time series without any long-range dependences own a *Hurst exponent* of 0.5, whereas time series of computer traffic can have H-values up to 1.0 [4]. It is interesting to notice that the *soccer* sequence has a large H-value, but that the autocorrelation function of the GOPs is decaying exponentially.

It is assumed, that in case of video traffic a larger H-value reflects a larger amount of movement in the video sequence [1]. This is corroborated by Table 3 for most of the encoded sequences. Only the H-values of *talk1* and *starwars* do not go with this assumption. In the case of *starwars* the H-value is low compared to the other movies. However, besides the *settop* sequence, all sequences have H-values, which are higher than 0.73, and the existence of long-range dependencies can be assumed.

If the model of the video traffic should have long-range dependence properties, a class of processes called *fractional differencing processes* may be used [4]. These processes generate time series with given H-values, but it may be difficult to match a given marginal distribution for the generated samples.

3.2 Layered modeling scheme

In this section, we are going to present a layered modeling scheme for the development of MPEG video traffic models[2].

The main information for the model development which we receive from the MPEG way of coding can be concluded as follows:

- There are three frame types: I, P, and B frames.
- A pattern of frame types, called GOP, is repeated continuously to create the encoded frame sequence.
- The frames of one single GOP strongly depend on each other.

Moreover, if we want to create a model on cell level, both the AAL which is used for the transmission of the video and the information, whether the cell stream is shaped before it enters the network or not, should be taken into account.

Based on the information presented up to this point, we are already able to develop a scheme with three layers (cf. Figure 2):

- GOP layer,
- Frame layer,
- Cell layer.

At the moment, higher layers, like scenes, are not under consideration for two reasons. First, each additional layer adds some complexity to the model and we want to have simple models. Second, in most cases the time scale of one GOP, i.e. about half a second, is large enough in the ATM context.

Having decided on the layers, we have to define the statistical properties of each layer and of the way the layers interact.

Based on the results of Section 3.1, we are able to select a stochastic process for each layer, which is appropriate for our purposes or analysis technique, respectively.

After this step, we have to lay down the way the layers depend on each other.

For example, if we want to generate a frame size sequence based on the GOP size process, we have to consider the structure of the GOP pattern, which tells us the order of the types of frames. The simplest way to find the frame sizes based on a GOP size sample is to use a scaling factor for each frame of the GOP, where the scaling factors are the mean sizes of the frames of one GOP devided by the mean GOP size of a given data set. More complex models may use frame size histograms or approximate pdf's to generate the frame size sequence (cf. Figure 2).

[2]An overview of the video modeling literature can be found in [10]

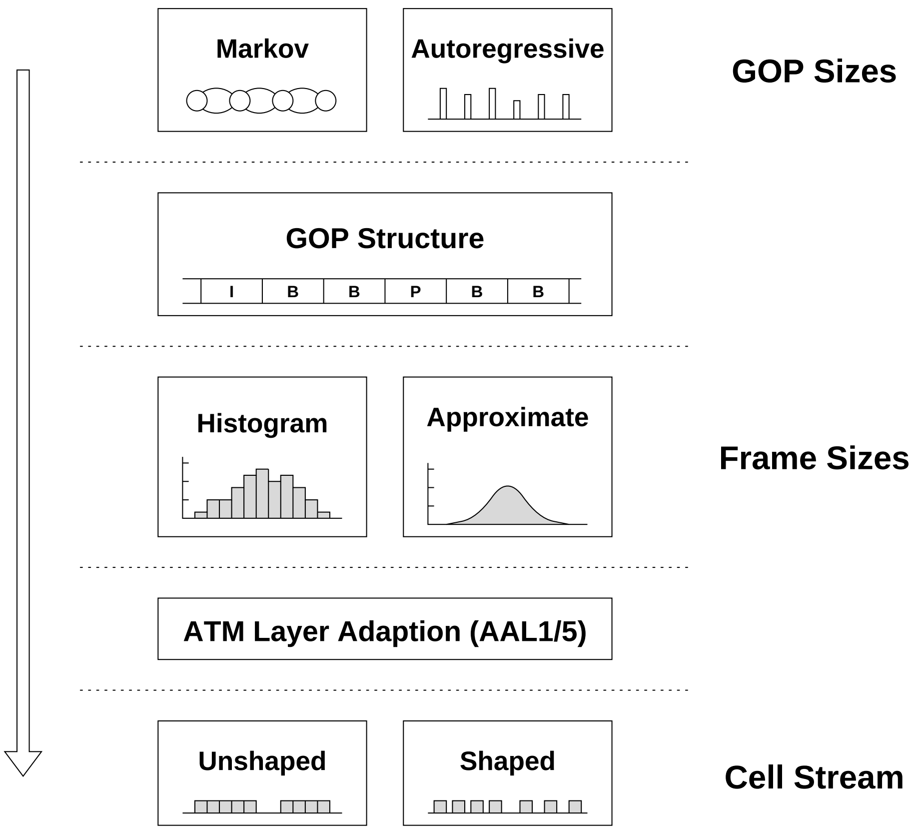

Figure 2: *Layered video traffic modeling scheme*

If we want to obtain a cell level model, we have to make up our mind on the way the frames are broken into cells. This will depend on the considered ATM Adaption Layer (AAL) and on the existence of shaping facilities between video source and ATM network. If a statistical analysis of video cell stream measurements is available, it will be possible to base models directly on this material. This may lead to simpler models for the cell process.

The presented model development scheme is not a recipe to get a perfect video traffic model. It is more like an outline of a variety of stochastic modules and the description how they interact in the case of video traffic. The model developer will have to choose the modules, which are appropriate for his analysis.

We want to point out, that any model should be validated. Any model, even complex ones, are based on simplifying assumptions, like independence assumptions. Thus, to obtain useful and reliable performance analysis results, it is important to know how these assumptions affect the results of the analysis.

4 Conclusions

Modeling of VBR video traffic is often difficult, because of the statistical complexity of the empirical data sets, for example their layered structure and the correlations on several time scales.

In this paper, we present a detailed statistical analysis of new MPEG sequences, which we encoded at our institute. Each sequence consists of 40000 frames. We were able to corroborate several results, which are known from the analysis of other video sequences: 1. the frame and GOP sizes can be approximated by Gamma or Lognormal PDF's, 2. there are long-range dependences in the frame sequences, which lead to *Hurst exponents* from 0.7 up to about 1.0.

The new data sets are also compared to the well known *Star Wars* data set from Mark Garrett. It can be concluded that with respect to the statistical properties the *Star Wars* sequence is a good representative of the class of MPEG video traffic, but that it will be misleading to dimension ATM networks based only on this data set. There are sequences like TV broadcasts of sports events, where performance problems like buffer overflows are more likely than with the *Star Wars* sequence.

Based on the statistical analysis, a layered modeling scheme for MPEG video traffic is presented. We describe the properties of each layer and the way they interact. In addition, some guidance is given on how to develop video models.

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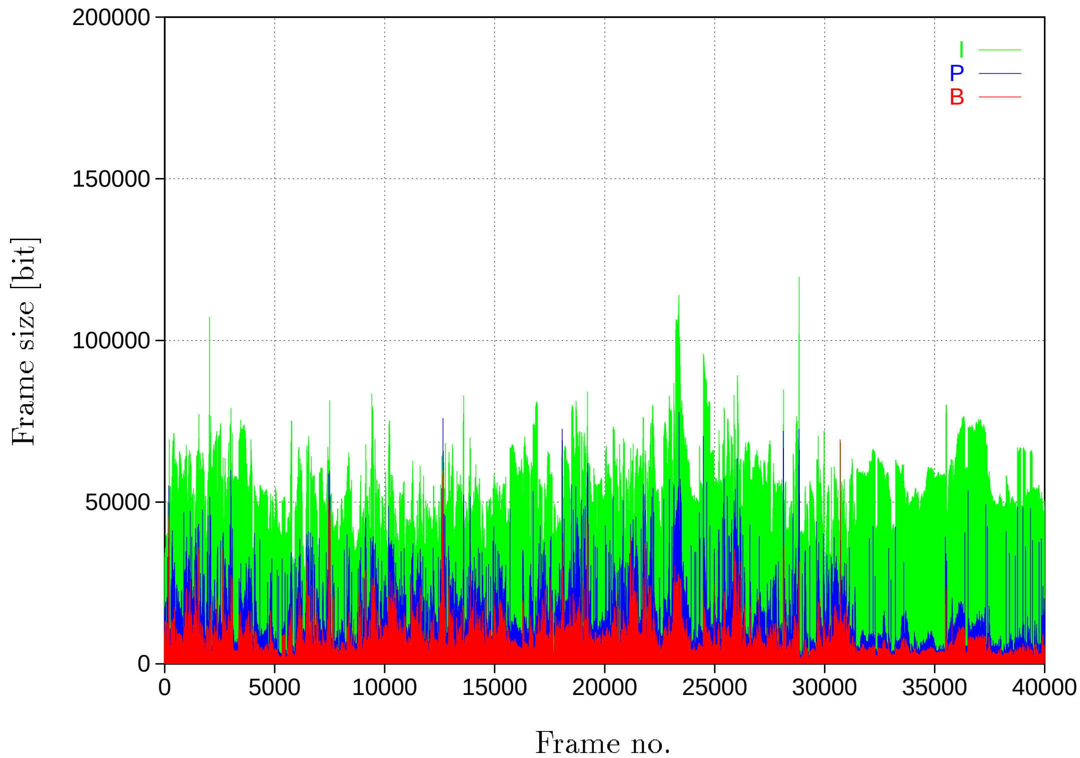

Figure 3: *Frame size trace of the* **dino** *sequence*

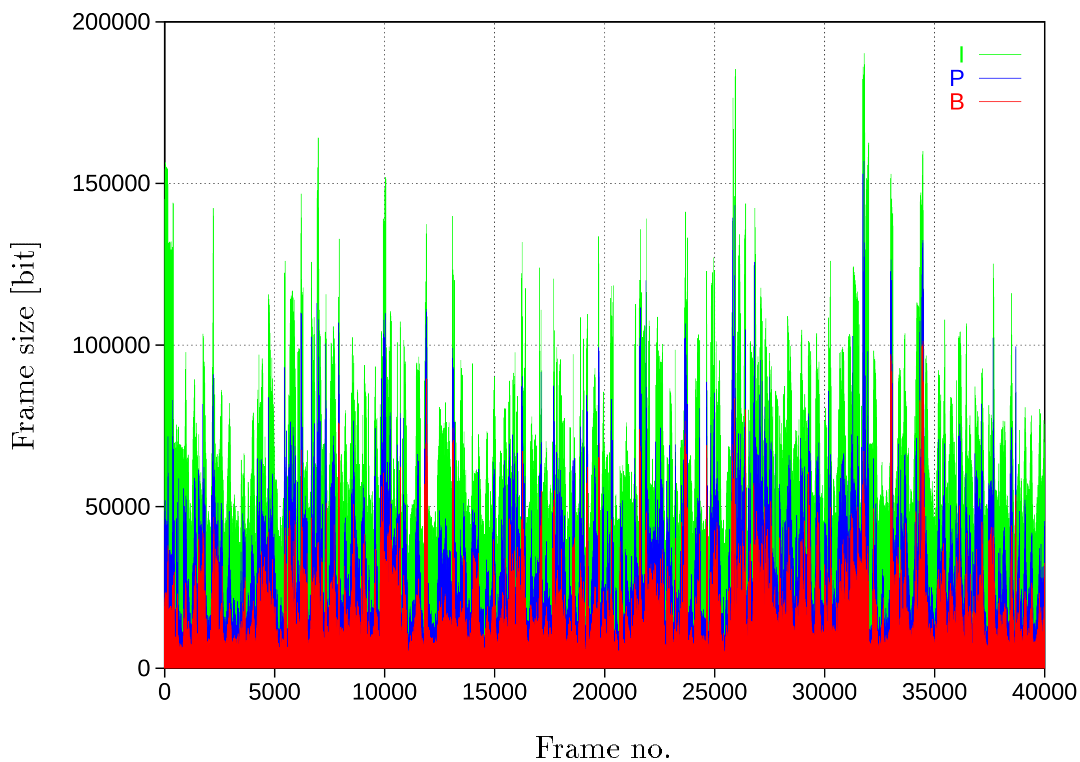

Figure 4: *Frame size trace of the* **soccer** *sequence*

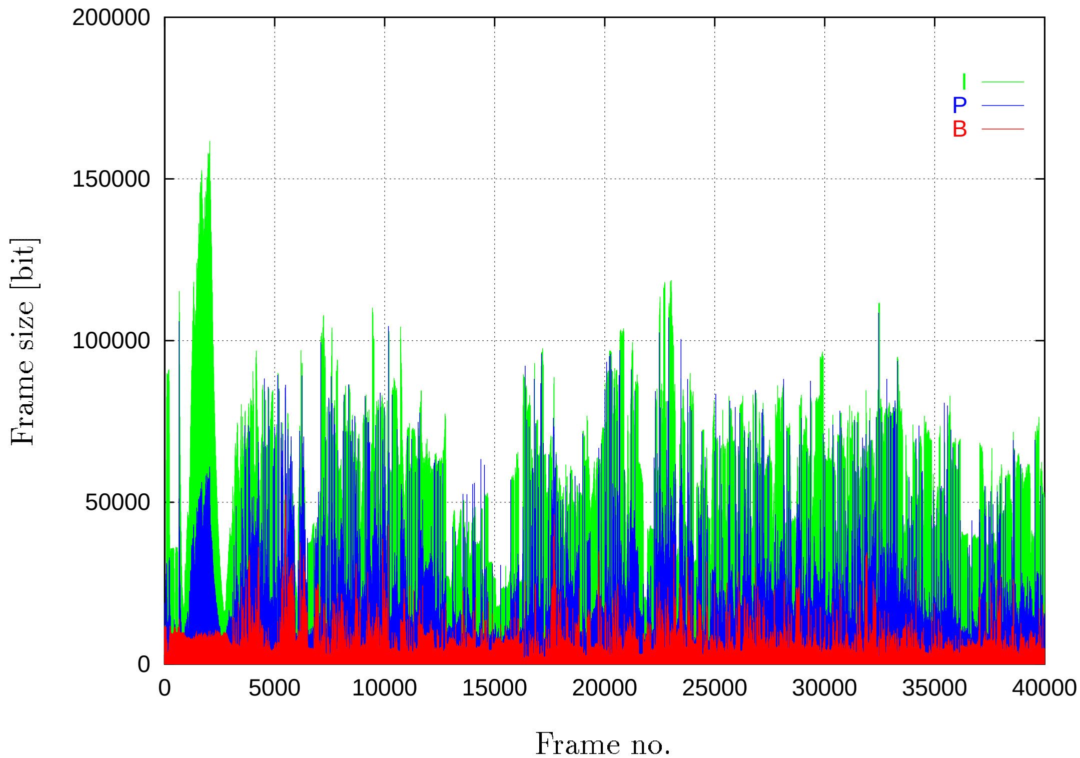

Figure 5: *Frame size trace of the* **starwars** *sequence*

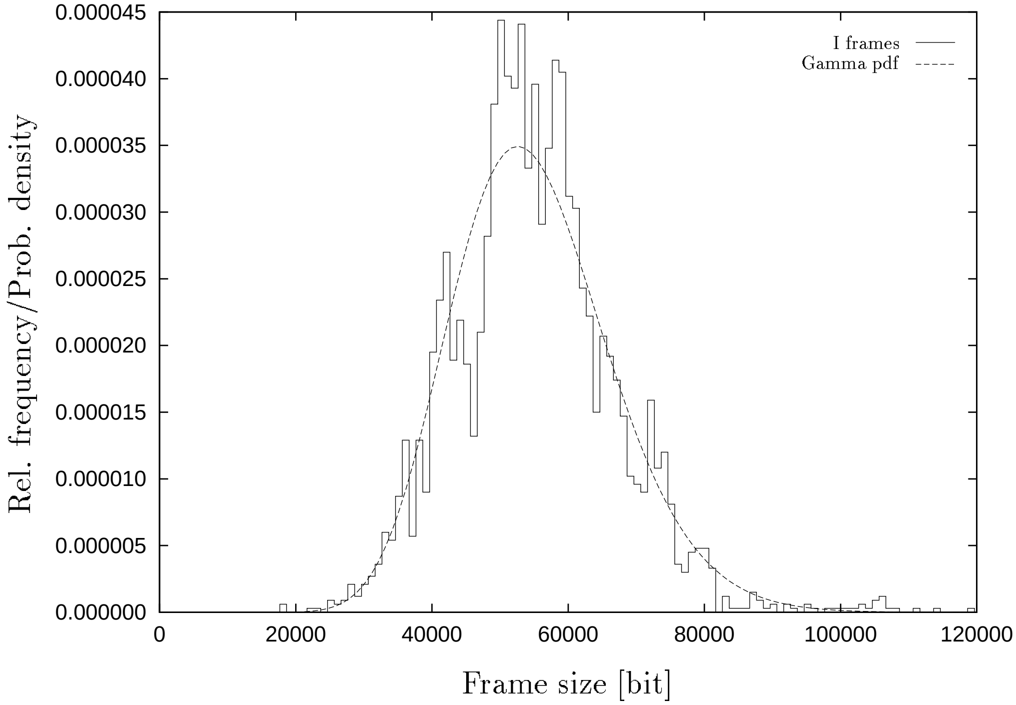

Figure 6: *Histogram of the I frame sizes of the* **dino** *sequence*

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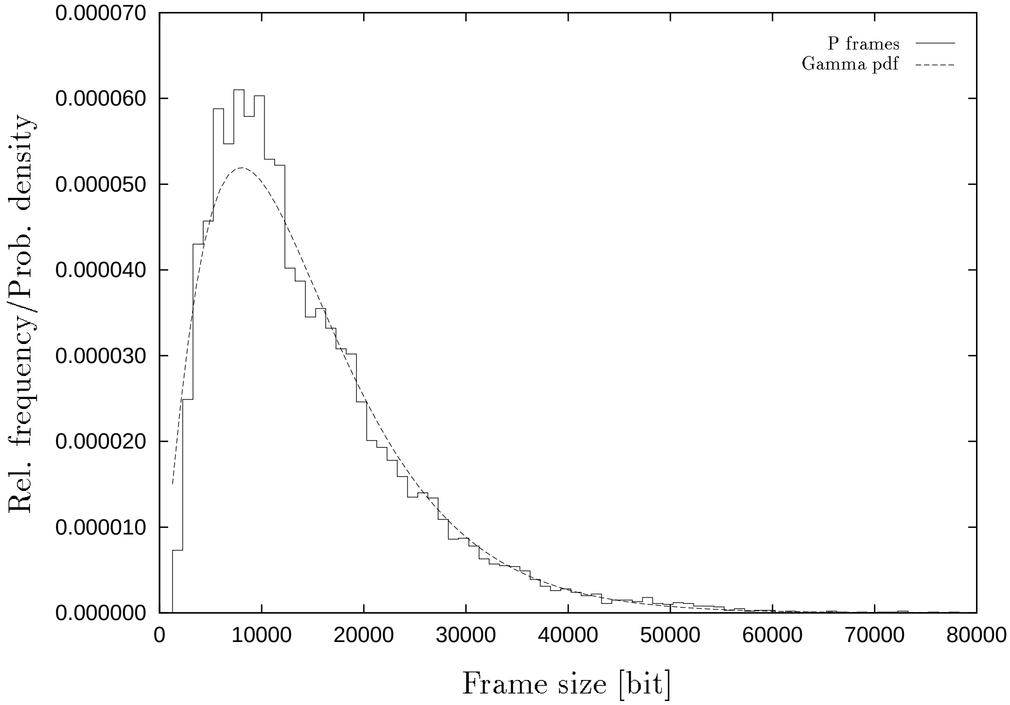

Figure 7: *Histogram of the P frame sizes of the* **dino** *sequence*

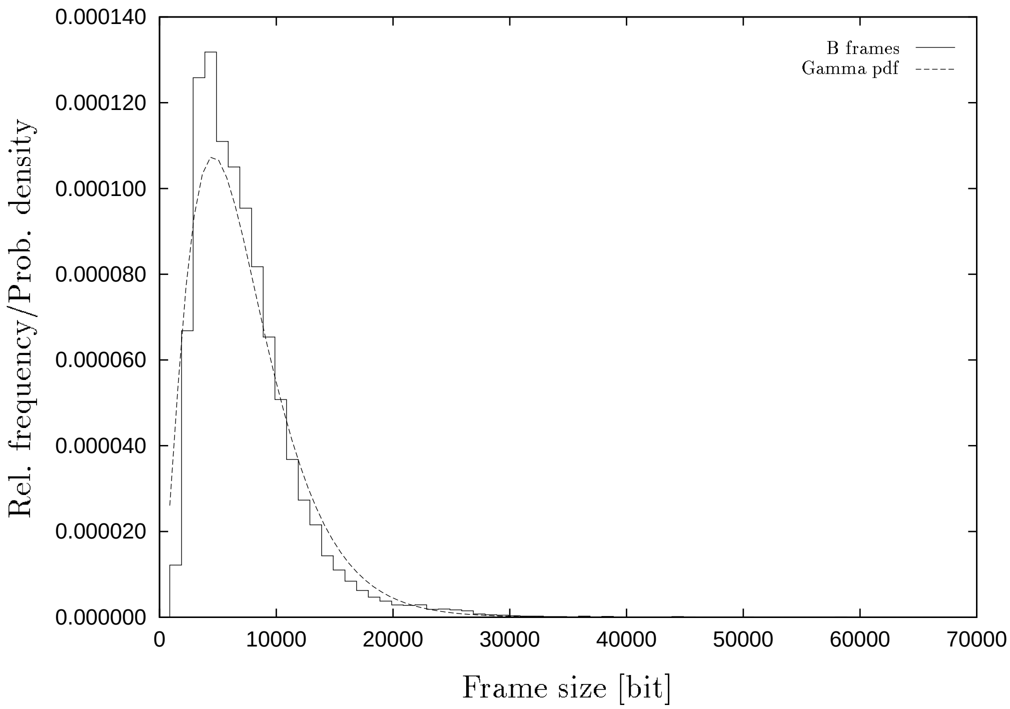

Figure 8: *Histogram of the B frame sizes of the* **dino** *sequence*

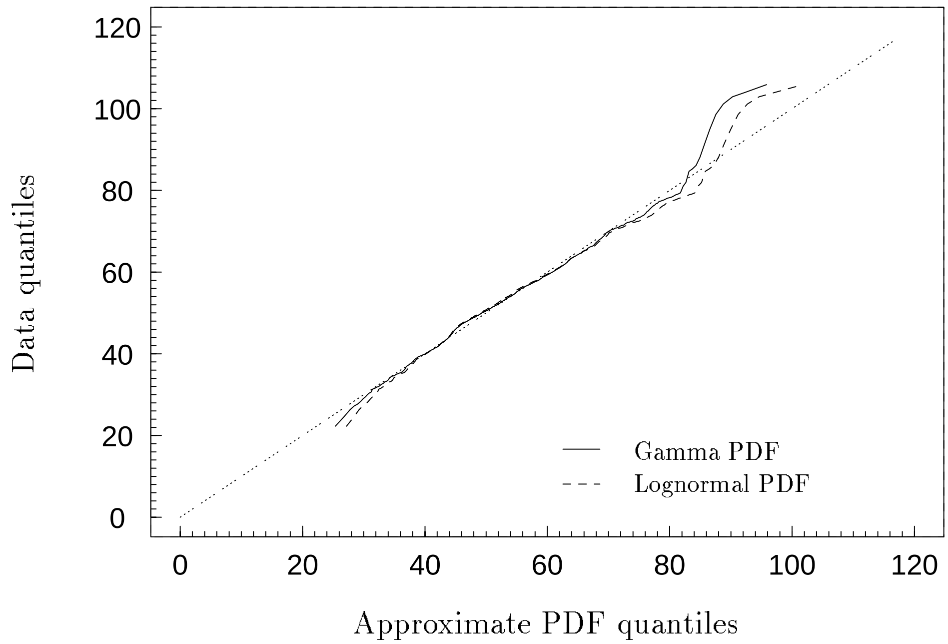

Figure 9: *QQ-plot for the I frame sizes of the* **dino** *sequence*

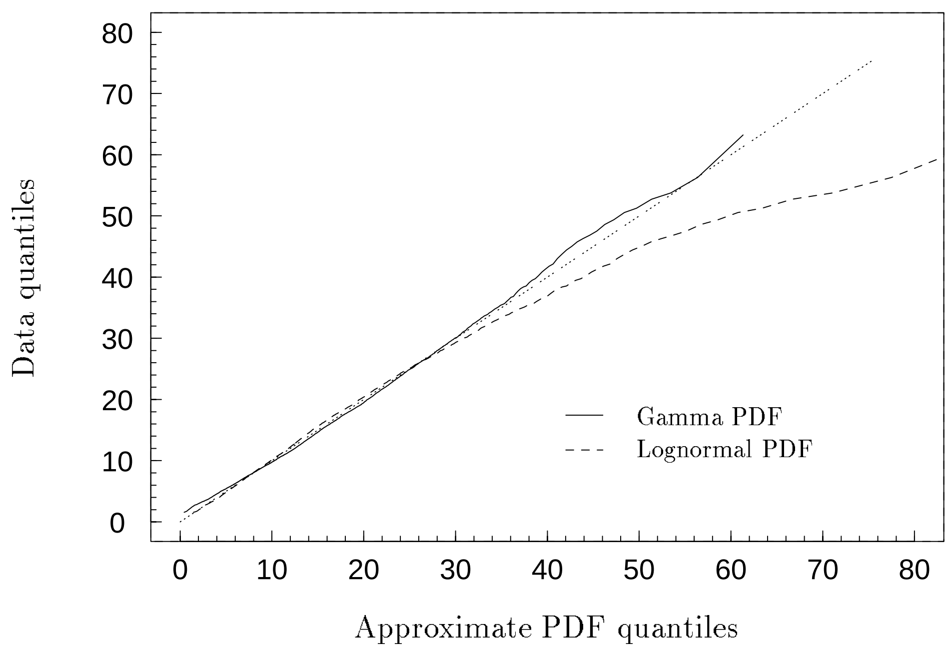

Figure 10: *QQ-plot for the P frame sizes of the* **dino** *sequence*

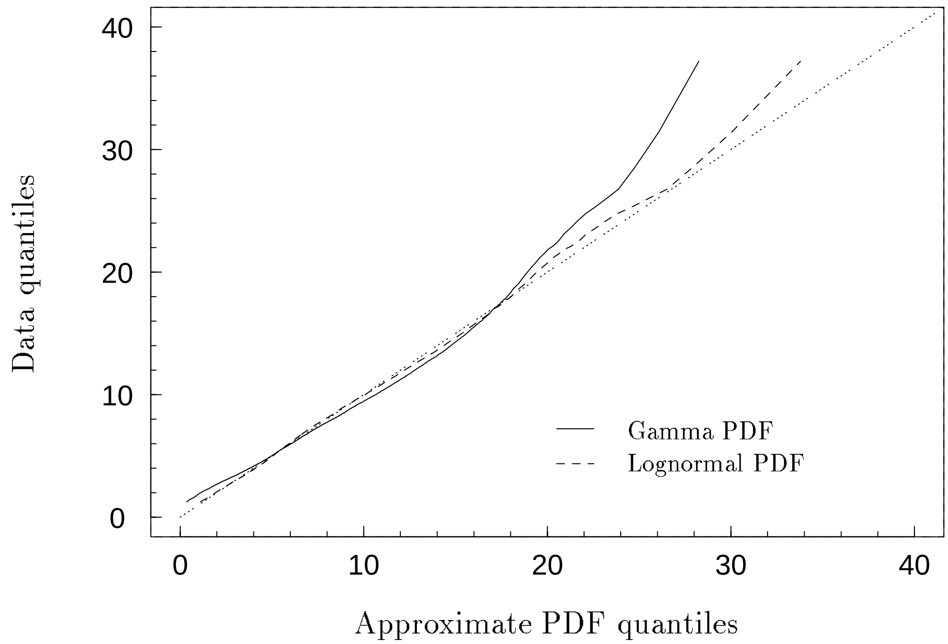

Figure 11: *QQ-plot for the B frame sizes of the* **dino** *sequence*

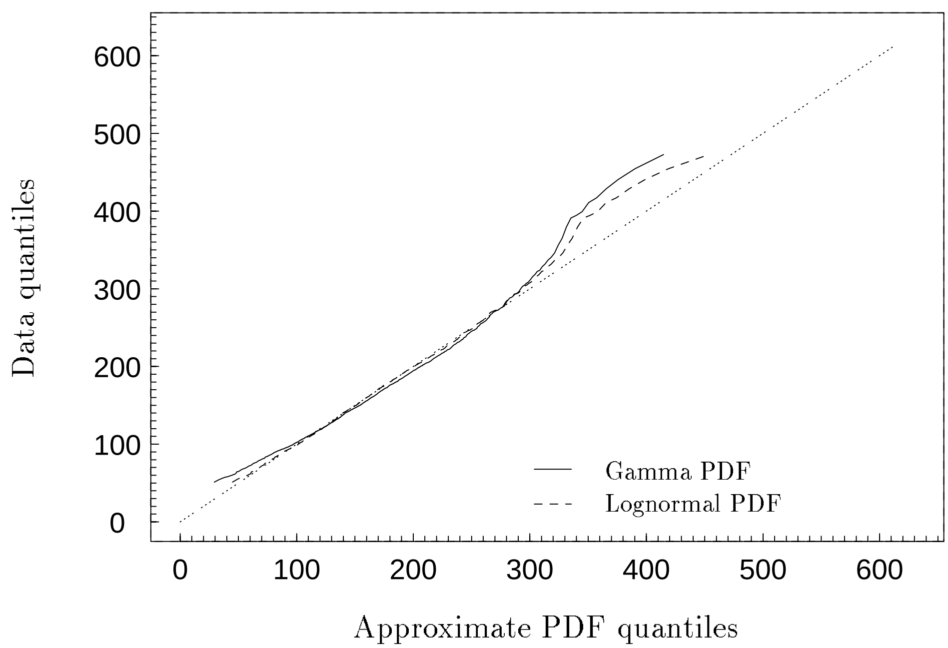

Figure 12: *QQ-plot for the GOP sizes of the* **dino** *sequence*

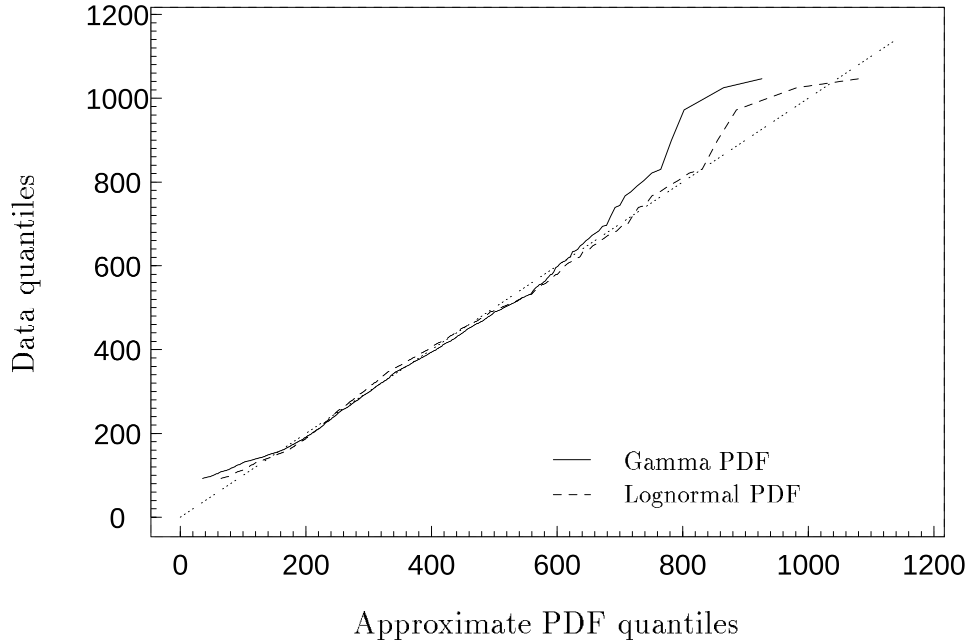

Figure 13: *QQ-plot for the GOP sizes of the* **soccer** *sequence*

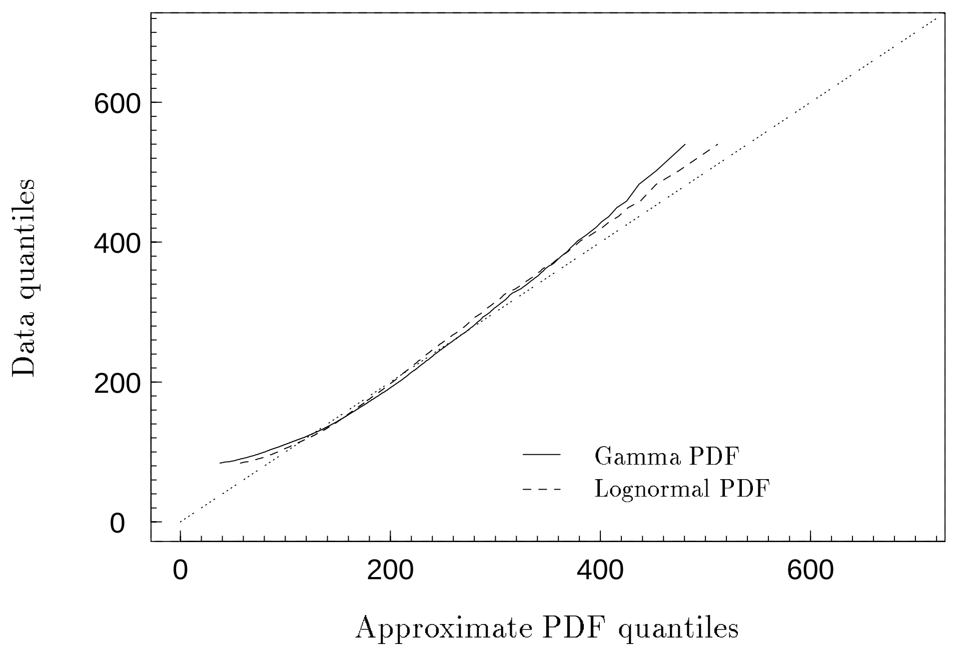

Figure 14: *QQ-plot for the GOP sizes of the* **starwars** *sequence*

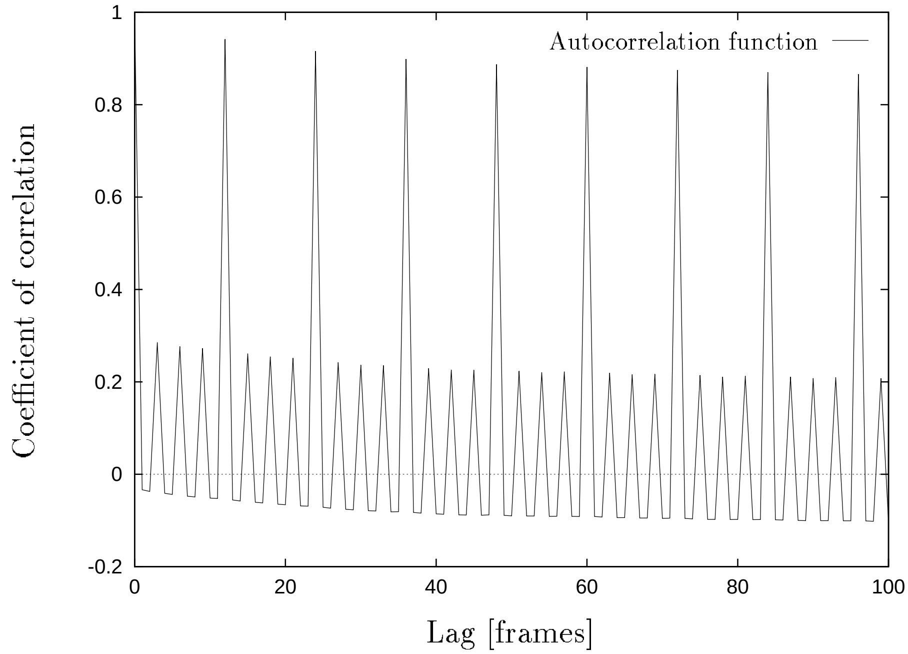

Figure 15: *Autocorrelation function of the frame sizes of the* **dino** *sequence*

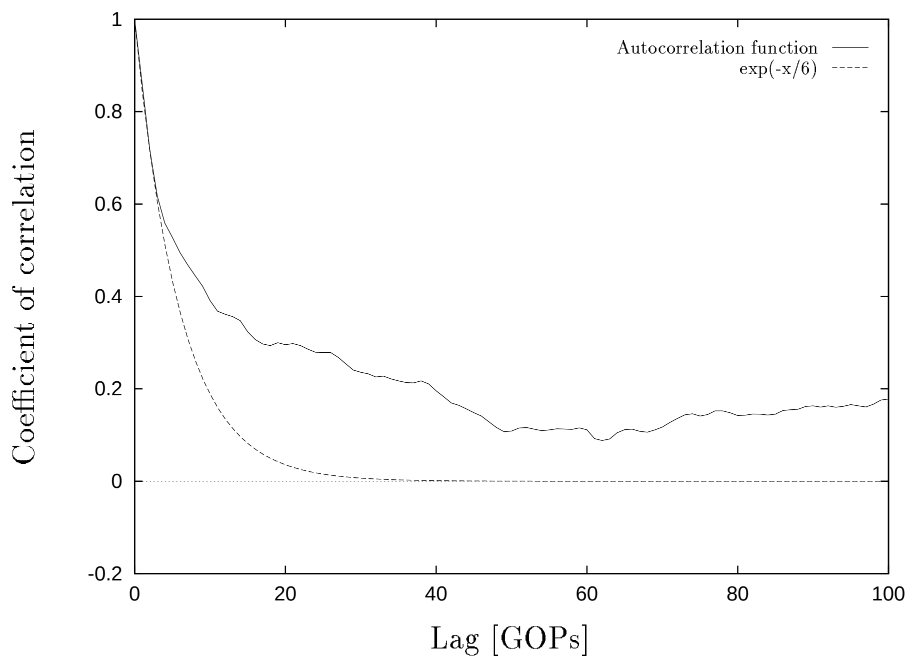

Figure 16: *Autocorrelation function of the GOP sizes of the* **dino** *sequence*

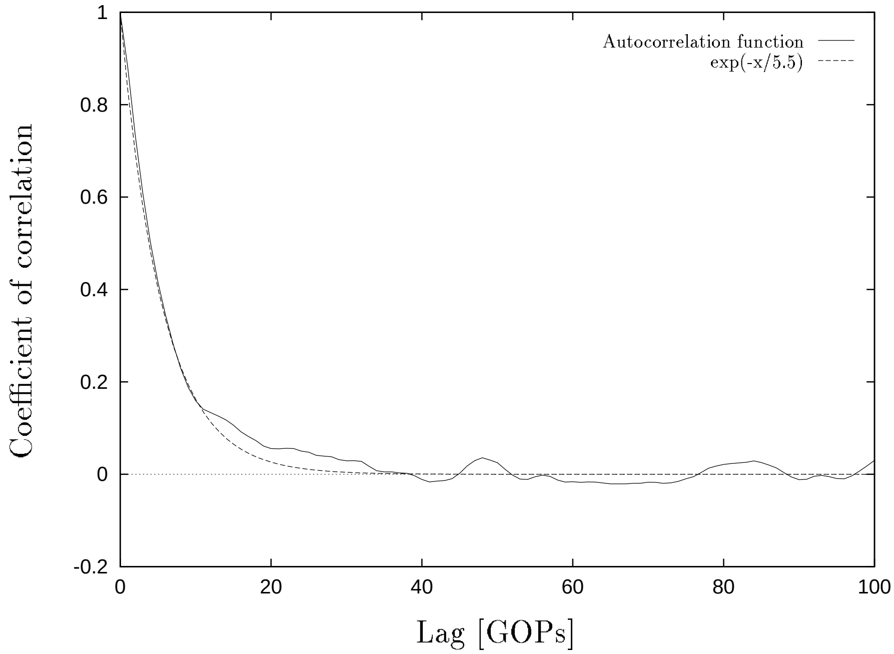

Figure 17: *Autocorrelation function of the GOP sizes of the* **soccer** *sequence*

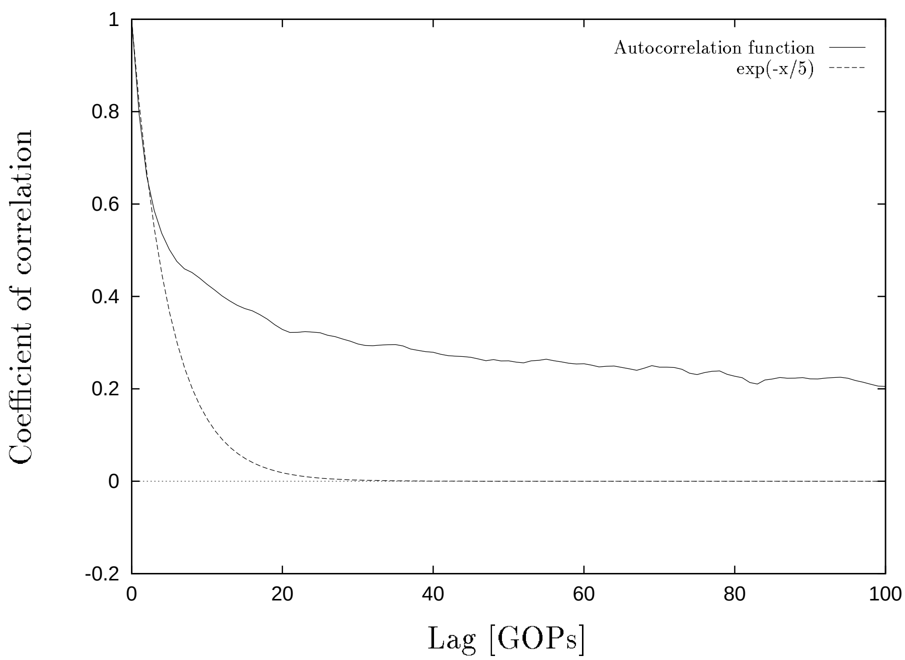

Figure 18: *Autocorrelation function of the GOP sizes of the* **starwars** *sequence*

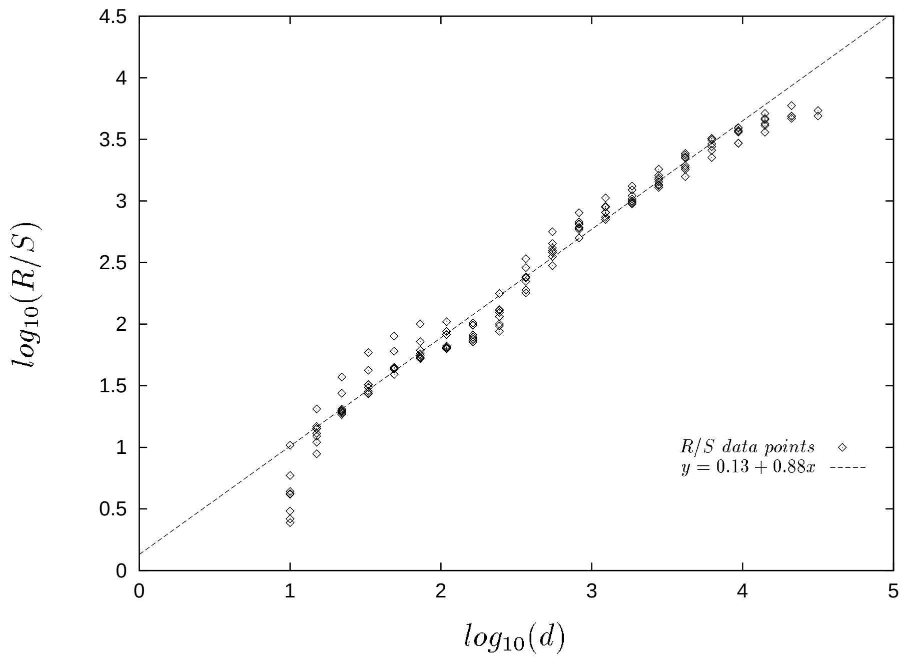

Figure 19: *R/S plot of the frame sizes of the* **dino** *sequence*

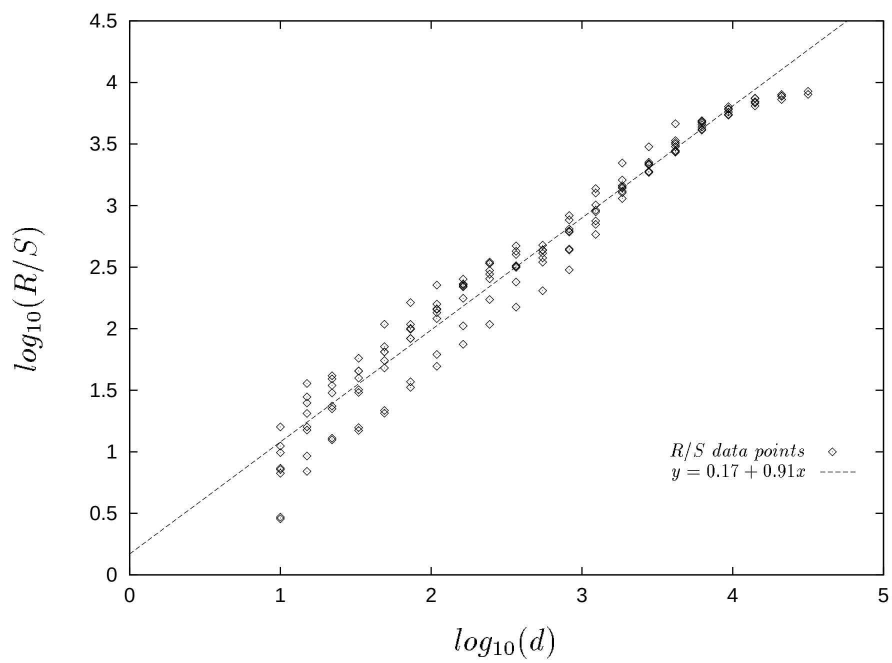

Figure 20: *R/S plot of the frame sizes of the* **soccer** *sequence*

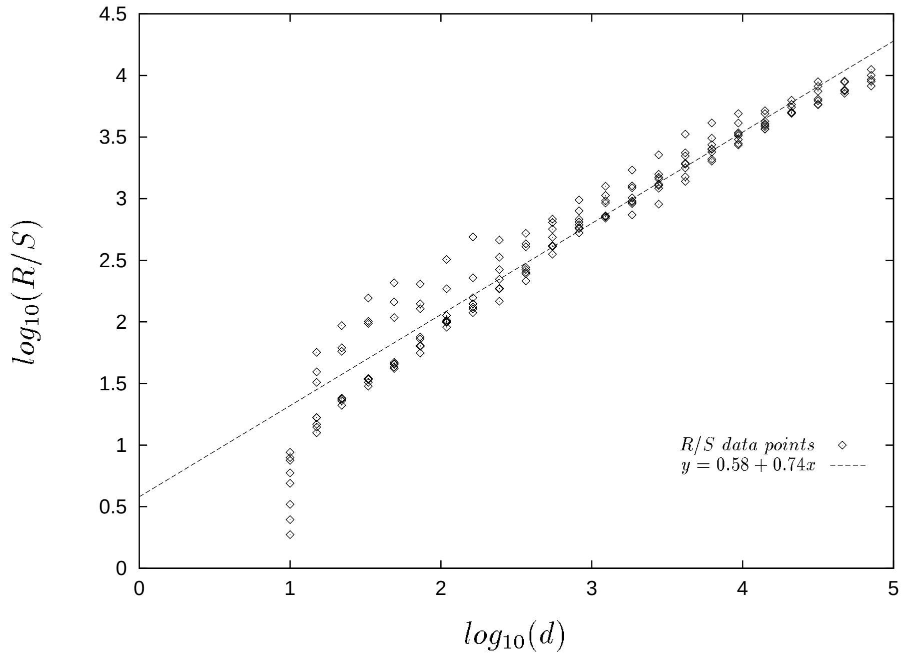

Figure 21: *R/S plot of the frame sizes of the* **starwars** *sequence*

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