MODELING THE SELF-SIMILAR BEHAVIOR OF PACKETIZED MPEG-4 VIDEO USING WAVELET-BASED METHODS

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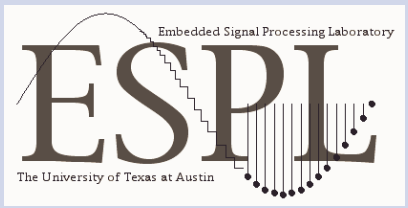

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Motivation

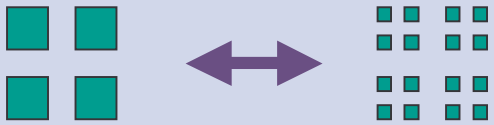
- Network performance implications of self-similar nature of network traffic [Leland *et al.*, 1993]
- Long-range dependence (LRD) in variable bit rate (VBR) video [Beran *et al.*, 1995]
  - Video sources cannot be modeled accurately by traditional short-range dependent Markov chains
  - LRD traffic sources may exhibit self-similar scaling
- Modeling video sources for admission control and resource allocation for streaming video
  - Need models that capture behavior of VBR video source at application-level at different time scales
  - Difference between *application-level* self-similarity and *network-level* self-similarity [Ryu & Lowen, 1997]

Goals

- Study scaling behavior in sample MPEG-4 traces
  - Traces (time series) represent number of bytes per frame as generated by an MPEG-4 encoder
- Investigate the effects of compression ratio on the self-similarity of video traces
  - Self-similarity in network traffic is in general due to many factors such as user behavior, heavy-tailed file sizes, link diversity, and protocol diversity
  - Compression might also contribute to self-similarity

Background

- Scaling models
  - Self-similarity (long time scales)
  - Fractals, specifically multifractals (short time scales)



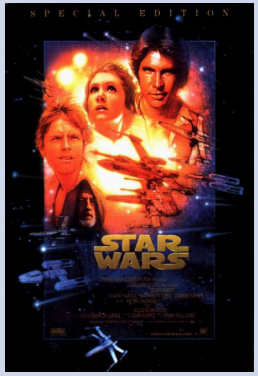
- Wavelets provide natural framework for analyzing self-similar processes
  - Enables analysis of a non-stationary process with stationary increments through a stationary sequence of wavelet coefficients
  - Converts long-range dependent time series into sequences of short-range dependent wavelet coefficients

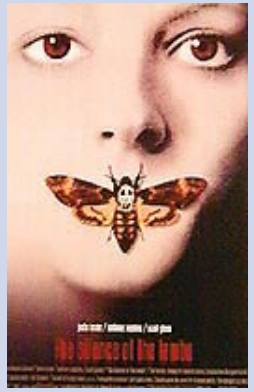
$$\psi_{j,k}(t) = 2^{j/2}\psi(2^j t - k)$$

$$\phi_{j,k}(t) = 2^{j/2}\phi(2^j t - k)$$

MPEG-4 Traces

- Used MPEG-4 traces available from the Telecommunication Networks Group, Technical Univ. of Berlin [Fitzek & Reisslein, 2000]
- Studied traces of *Star Wars IV* and *Silence of the Lambs*
- Video resolution
  - 176 × 144 pixels (QCIF) with 8 bits/pixel
  - Suitable for transmission over wireless networks to mobile devices
- Traces measure number of bytes arriving in 40 ms (corresponding to 25 frames/s)

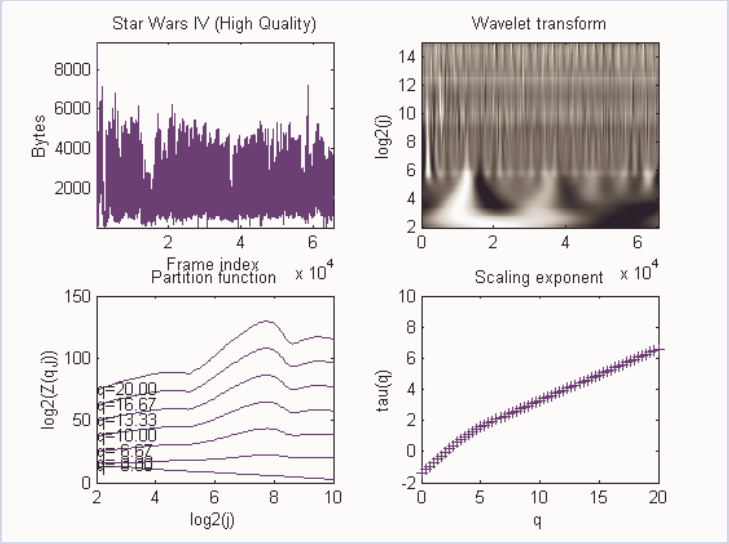


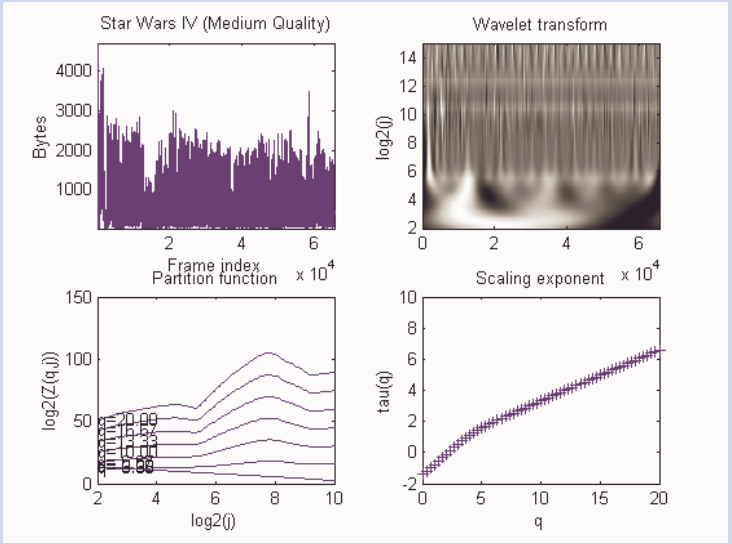


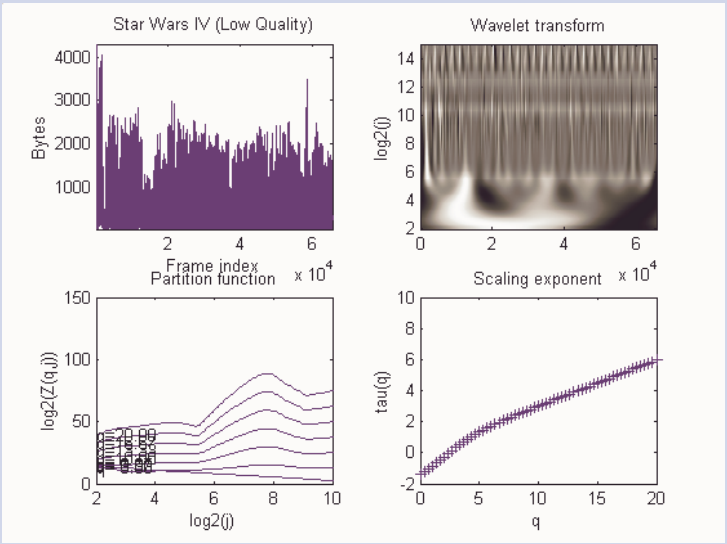
Methodology

- Wavelet decomposition: $X(t) = \sum_{j,k} d_{j,k} \psi_{j,k}(t)$
- Partition function: $Z(q, j) = \sum_{k} \left| C_j d_{j,k} \right|^q$
  - Characterizes burstiness
  - An abrupt burst will generate a large wavelet coefficient
  - Large coefficient magnified by raising it to power q across scales
- Scaling exponent: $\tau(q) = \liminf_{j \to \infty} \frac{\log Z(q, j)}{\log j}$
  - Represents asymptotic decay of partition function

Star Wars IV

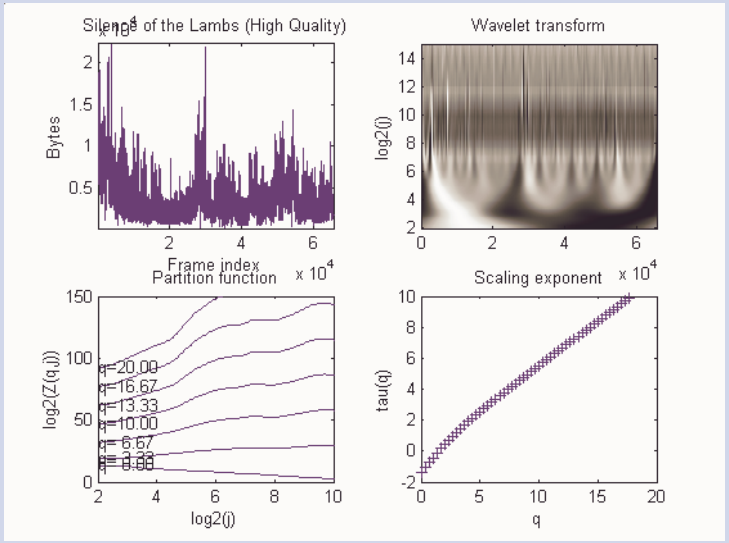


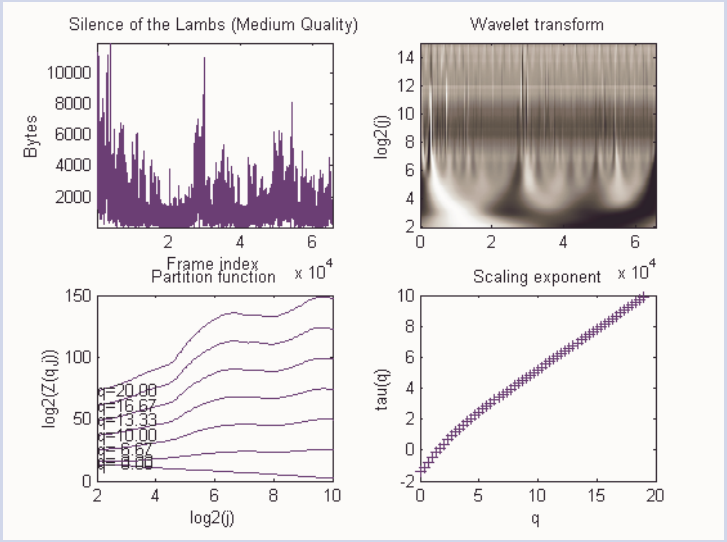


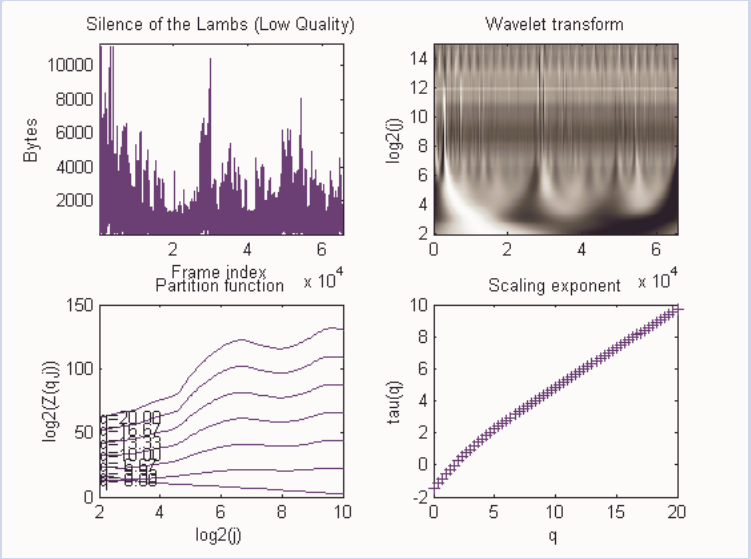


Quality	Compression Ratio
High	27.62
Medium	97.83
Low	142.52

Silence of the Lambs







Quality	Compression Ratio
High	13.22
Medium	43.43
Low	72.01

Analysis of Results

- Trace of bytes/frame: burstiness, non-stationarity
- Continuous Wavelet Transform
  - Gaussian Wavelet
  - Repetitive (or periodic) pattern of traffic over many scales (i.e. self-similarity)
- Partition Function
  - At fine scales, slope of curves increases non-linearly with increasing *q*
  - Dips in the curve imply “interesting” fractal behavior [Gilbert, 2001]
- Scaling Exponent
  - Non-linearity of the curve implies that the time-series is multifractal

Conclusions

- MPEG-4 encoder generates video traffic that has multifractal properties
- Wavelets can be used to construct efficient models for self-similar and multifractal network traffic sources
- *The compression ratio does not affect multifractal behavior of video*