Statistical Multiplexing of VBR video streams

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Based on : Characterization and Modeling of Video Sources

Presentation Flow

- Uncompressed Video Characteristics
- Compression Techniques
- Compressed Video Semantics
- Burstiness
- Statistical Multiplexing
- Basic Modeling Methods
- General classification
- Conclusions

Video Semantics (1)

- A typical video sequence is usually described as a collection of independent video shots called scenes.
- Each scene is an ordered set of video frames depicting a real-time continuous action
- Except from static real-world scenes, a typical video sequence consists of various artificial effects (e.g. camera movement , zooming,picture in picture,graphics etc.)
- The assumption of scene independence does not seem to hold in most video sequences
- The scenes are in fact correlated.There is a low probability of having a short scene while the probability of having long ones decades relatively slow
- On the contrary to the scene complexity, the scene length seems to be not correlated

Video Semantics(2)

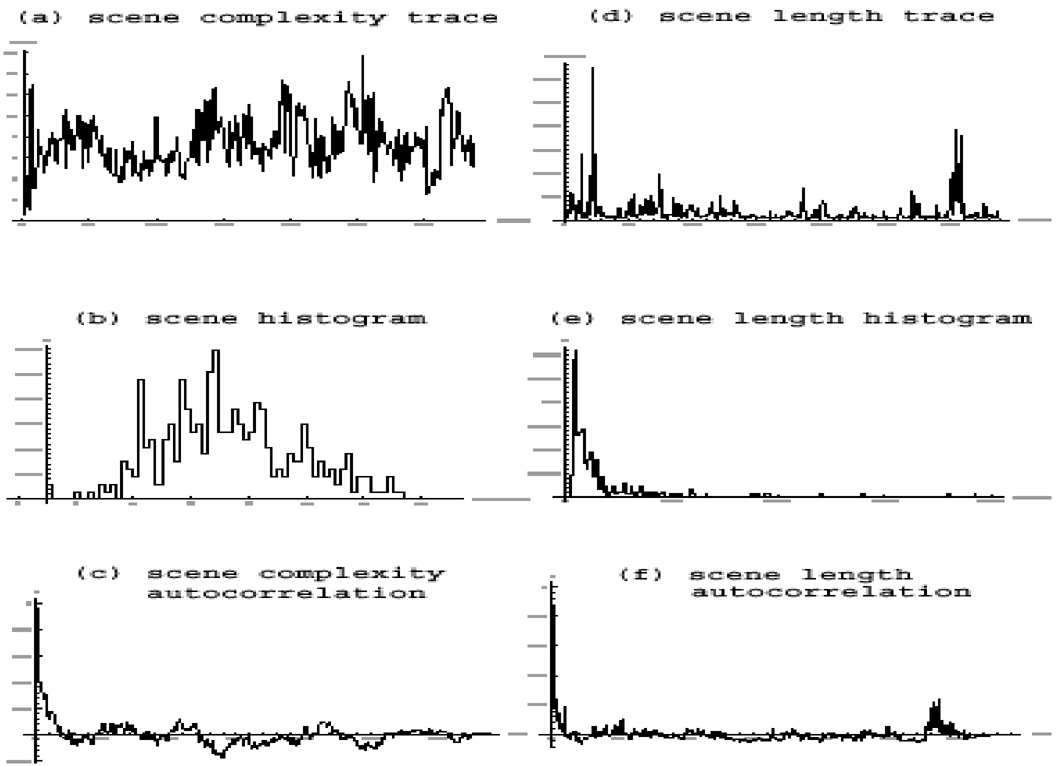


Figure 1. Scene complexity and scene length statistic of movie Forrest Gump (57000 frames)

Uncompressed Video Streams

- The nature of video information sources varies widely depending on:
  - Content of video per scene
  - Scene details and object or camera movement
  - Quality required
  - Various video streams (e.g. videophone,movie,news,etc.) have different statistics (e.g. scene length duration)
- Bandwidth requirements for uncompressed video

  100-240 Mbps
- Uncompressed HDTV streams require around 1Gbps for proper delivery
- Redundancy – need for compression

Video Compression Techniques

- Compression is achieved by removing redundancy
- Redundancy types in video signal:
  - within a video frame (intra-frame): spatial
  - between frames in close proximity (inter-frame) : temporal
- Compression methods:
  - Lossless or lossy
    - Exact recovery or not
  - Symmetric or asymmetric
    - Same amount of computational effort in coder and decoder or not
- MPEG-1
  - Quality similar to that of a VHS
  - Bit-rate approximately 1.2 Mbps
- MPEG-2
  - Broadcast quality video
  - Bit-rate: 4-6 Mbps
  - Wide range for rate and resolution

Characteristics of compressed video

- Statistical behavior is described by using histograms and correlation functions
- Correlations arise as a consequence of visual similarities between consecutive images (or parts of images) in video streams
- Compression results in a reduction in these correlations
- Compressed stream still contains considerable amount of correlations
- Correlation along with different information content of each frame leads to burstiness

Classification of compressed video variability

- **Interframe variability:**
  - Discontinuous variation before and after change of scene
  - Long term
- **Intrascene variability:**
  - Short term
  - Smooth variation with temporal correlations
  - Occasional large variations due to subject and camera motion
- **Intraframe variability:**
  - Variations that have periodicity due to image scanning
  and block processing by encoding techniques
  - Usually smoothed by the use of pre-buffers during encoding and packetization

Burstiness

- One simple definition: Ratio between peak and average bit rate (PAR)
- Burstiness indicates the presence of non-negligible positive correlations between cell inter-arrival times

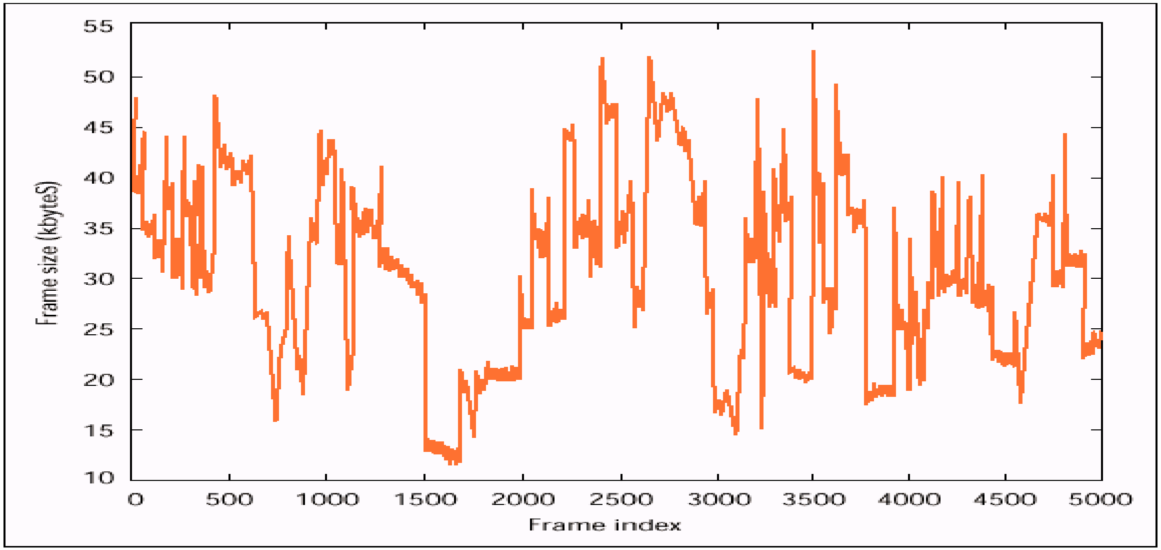
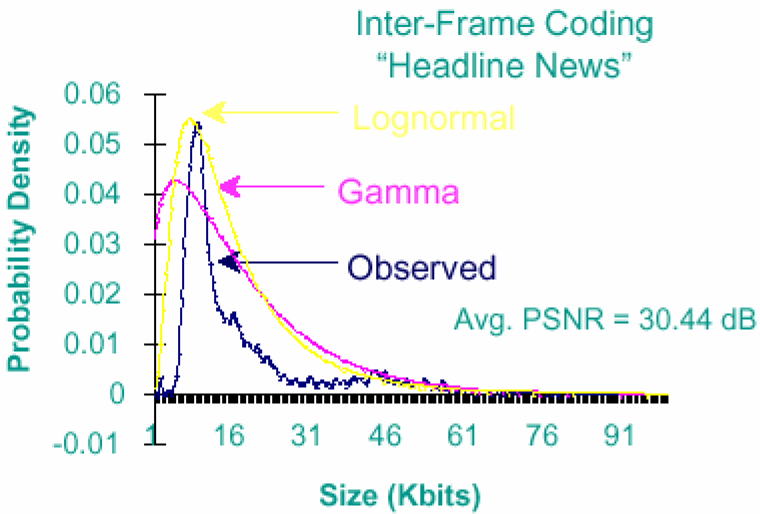


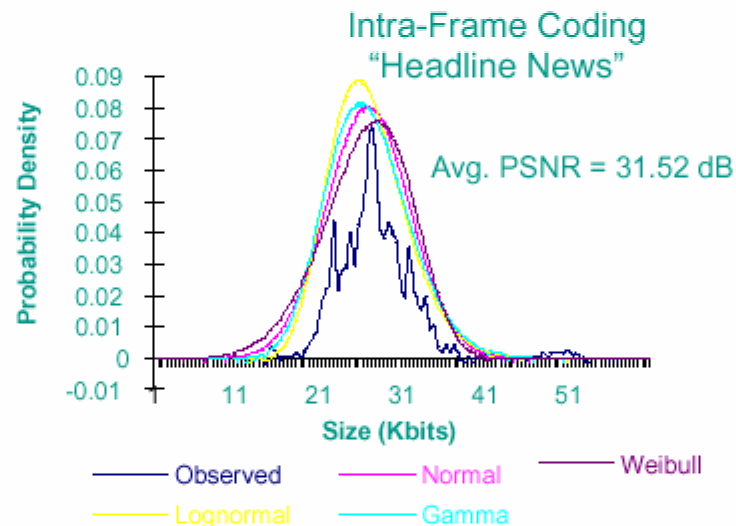
Figure 2. *Fluctuations in the bit rate of a VBR-coded video sequence.*

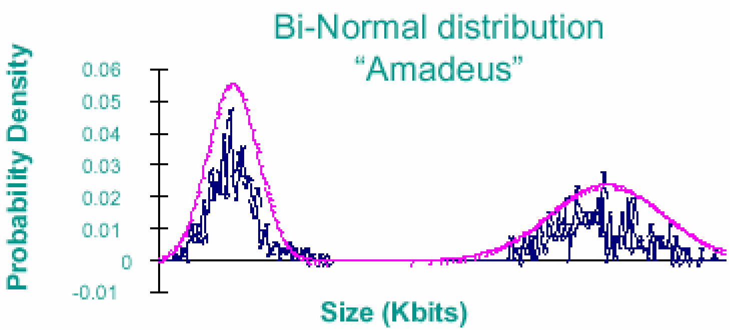
Other Bit-Rate Burstiness Measures

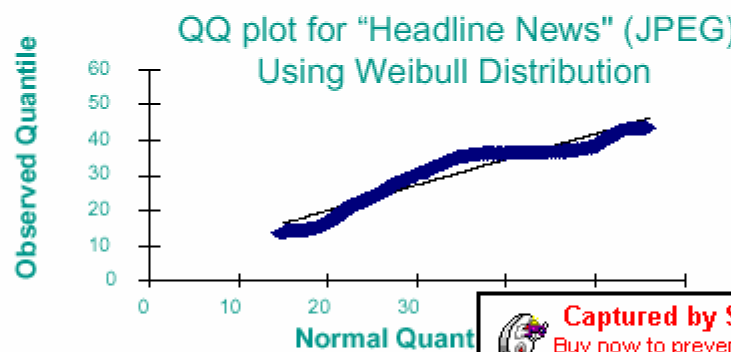
- **Bit-rate distribution**
  - Average bit-rate
  - Peak bit-rate
  - Variance
- **Autocorrelation Function**
  - Expresses temporal variations
- **Coefficient of Variation**
  - Uncorrelated streams have fixed CoV
  - Useful when measuring multiplexing characteristics when VBR signals are buffered and statistically multiplexed
- **Scene duration distribution**
- **Average duration of peaks**
  - Useful to estimate probability of buffer overflow

Statistical Characterization (VBR Video)









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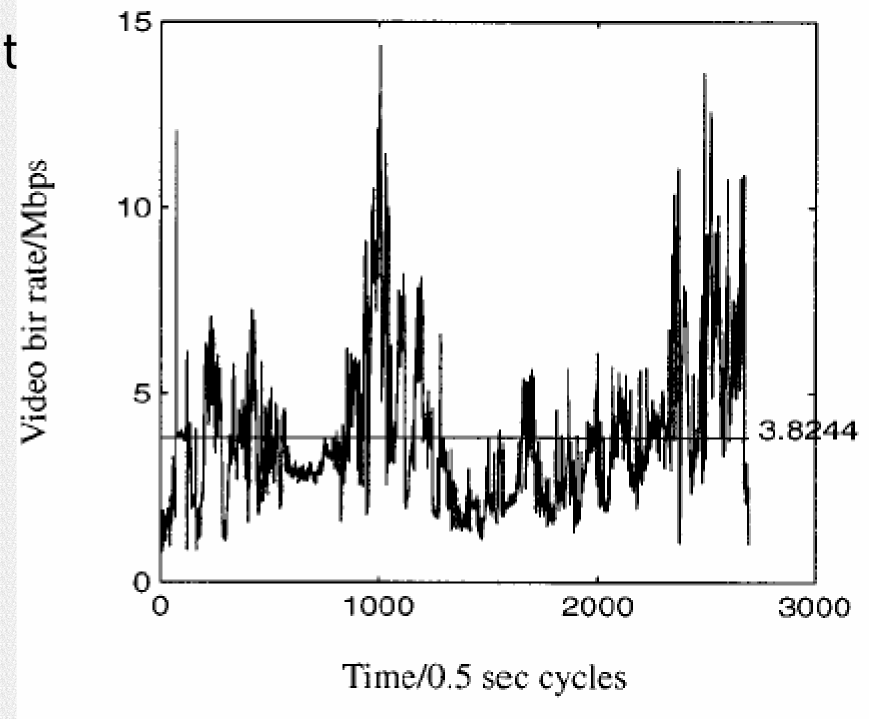
Burstiness – Network issues

- "If much of the traffic is bursty it results in poor network performance"
- The above is true when deterministic multiplexing is used by the network:
  - Each connection is allocated its peak bandwidth
  - Large amounts of bandwidth is wasted for bursty connections
- If burstiness is adequately reflected in network management it can lead to multiplexing gain
- Need for statistical multiplexing

VBR vs CBR

- Constant Bit Rate (CBR)
  - Video coded at constant bit rate
  - Quality of picture varies
- Variable Bit Rate (VBR)
  - Quality of picture keeps constant
  - Encoder output at varying bit rate



MPEG-2 VBR video trace.

VBR vs CBR

	CBR	VBR
Peak Rate (1)	Lower	Higher
Average Bit Rate (2)	Higher	Lower
Streaming Difficulty	Easy	Difficult (3)

Comparison between CBR and VBR

(1) The bit rate in CBR is compared to the peak rate of VBR
(2) The average bit rate of VBR is summation of frame size divided by the total time
(3) Streaming difficulty is compared with reference to the effectiveness of utilizing the resources

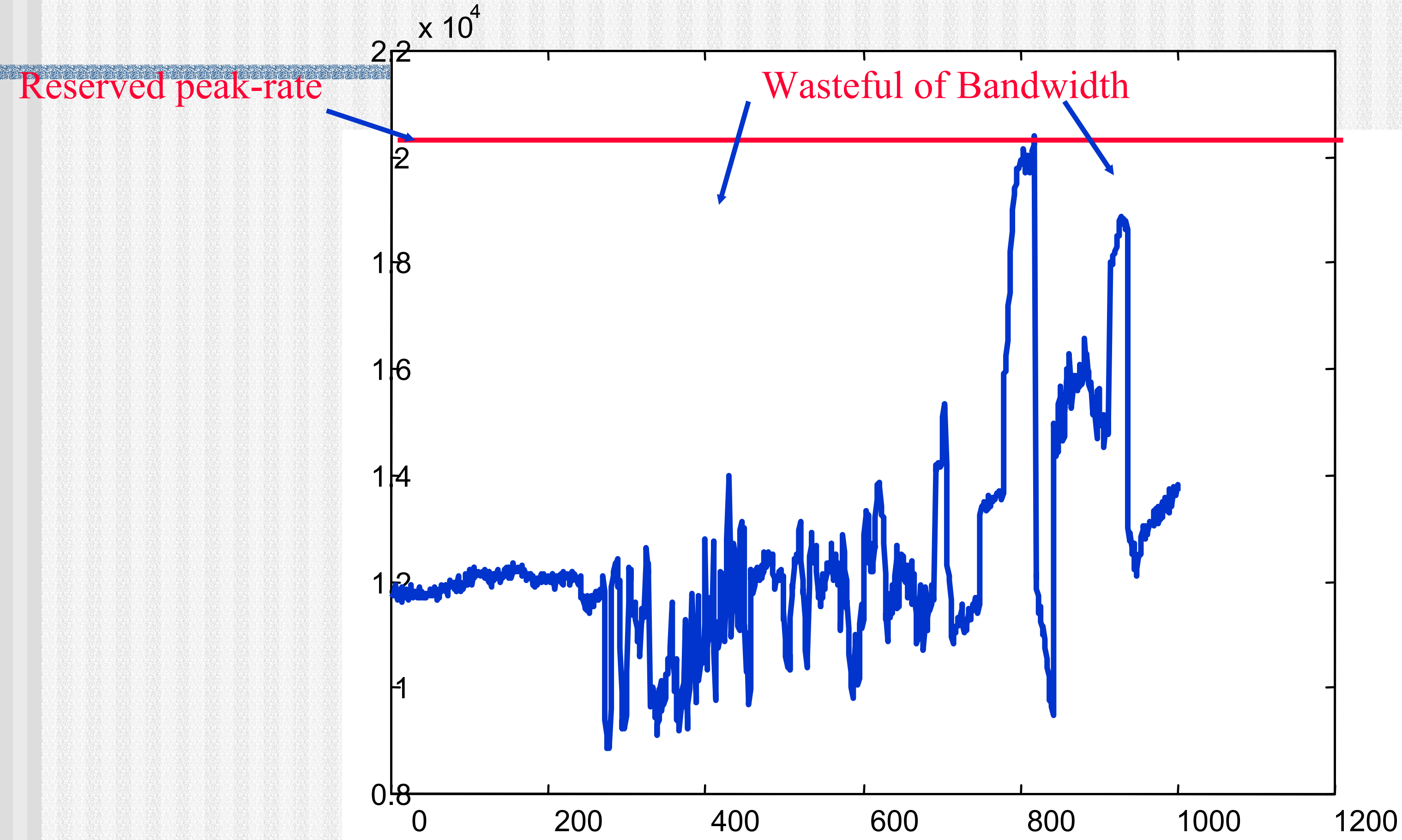
Challenge of VBR streaming

- Allocate Peak Rate
  - Waste bandwidth other than at Peak Rate
- Allocate average Rate
  - Not enough bandwidth for transmission when required bit rate higher than average rate.
- Allocate bit rate as required
  - Peak rate not reduced
  - Many transitions of transmission bit rate

What to do ? (1)

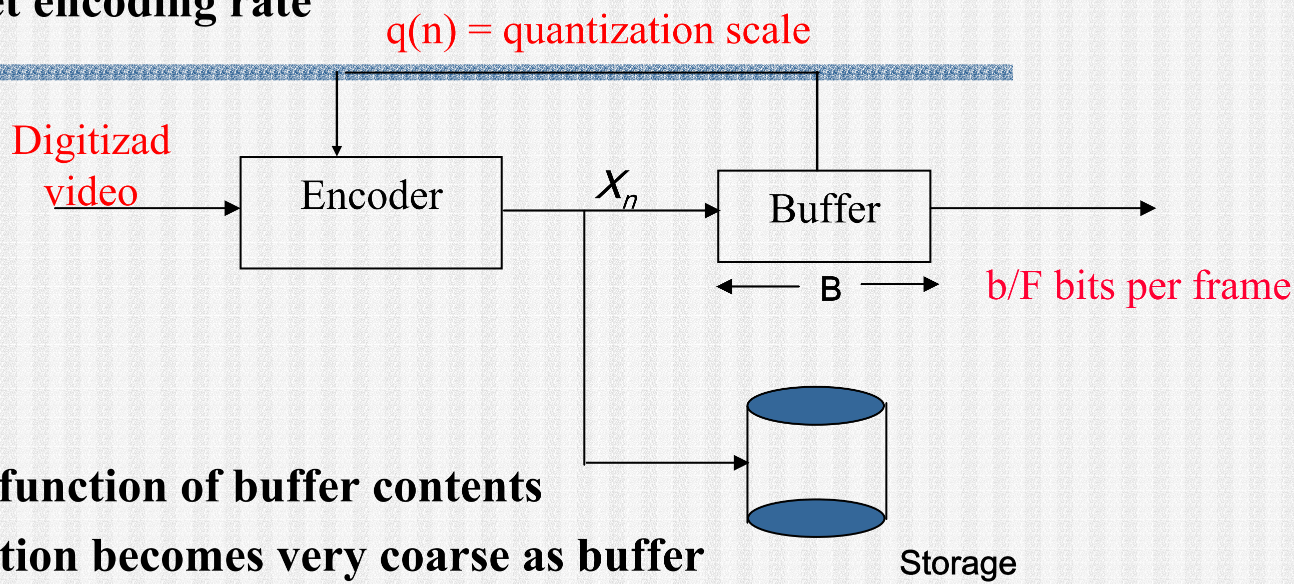
- **Conservative rich**: reserve peak required bandwidth.
  - Wasteful, costly:ratio of peak to average rate may be over 5:1.
- **Conservative poor**:
  - compress to specified bandwidth

Peak Bandwidth reservation



CBR Video Encoding

- **b = target encoding rate**



- **q(n) is a function of buffer contents**
- **quantization becomes very coarse as buffer contents approaches B**
- **Why is it always blurry exactly when it starts getting interesting ?**

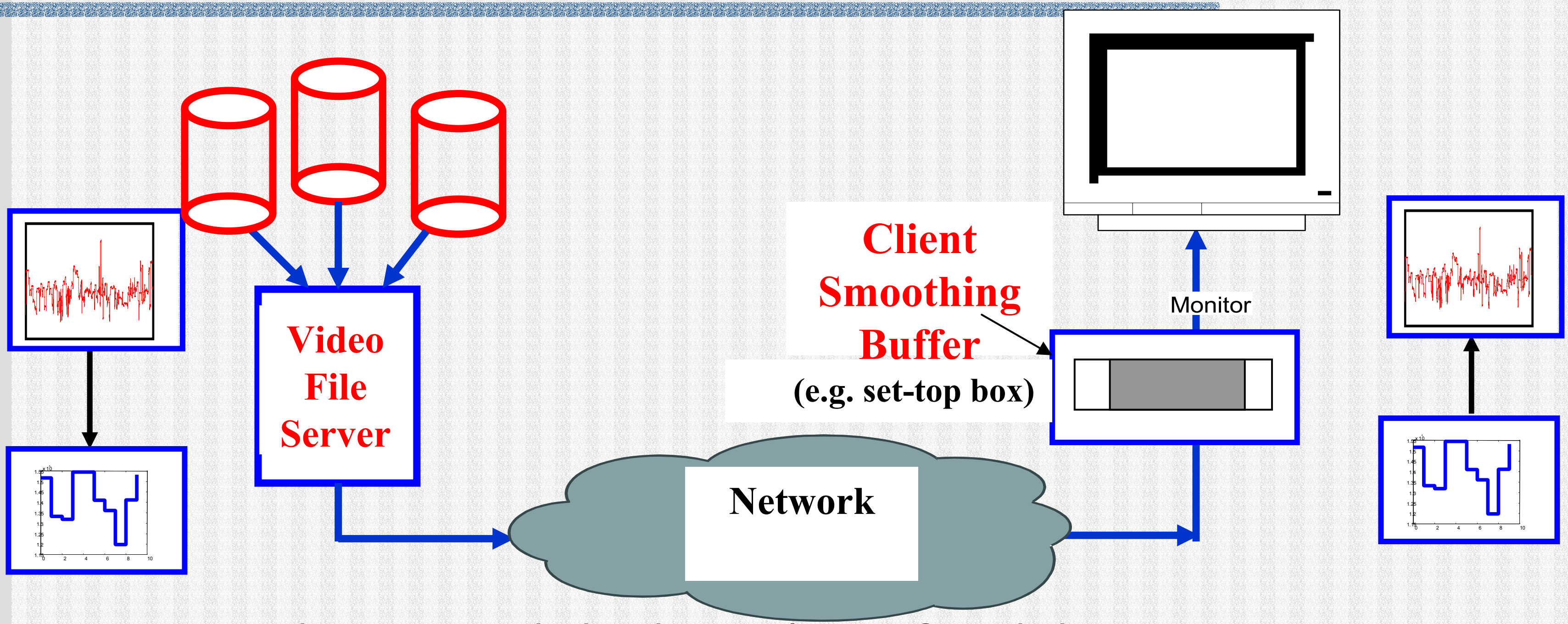
What to do ? (2)

- Practical solution: trade bandwidth for memory.
- With large storage space: trickle the stream, playback from memory
  - need huge space
  - how about live broadcast?

What to do ? (3) Smoothing of Pre-Recorded Video

- **Solution :** reduce burstiness by ***prefetching*** video frames into the client playback buffer
  - **Emerging applications:**
    - Distance learning
    - Movies, advertisements
    - Virtual reality

Network Environment

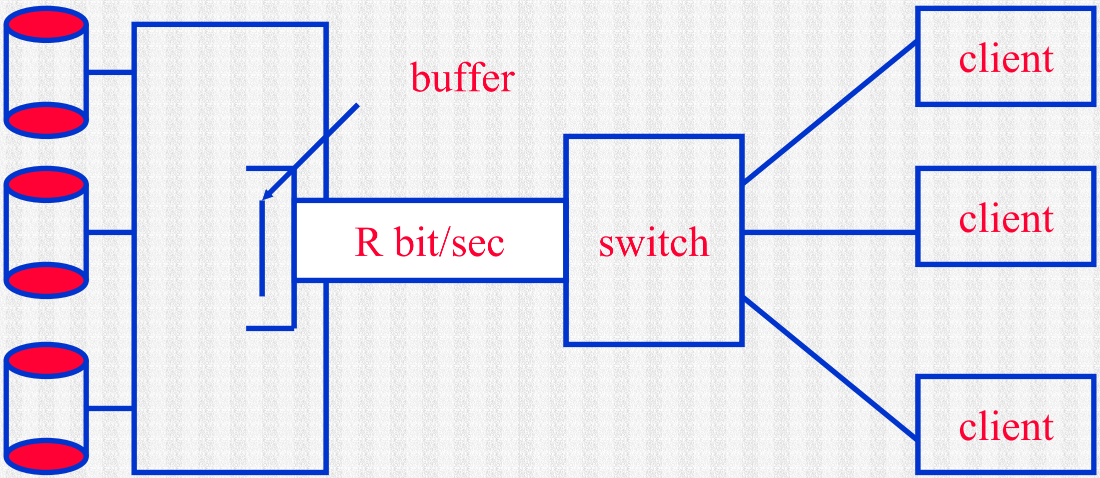


- Server with pre-recorded video on large, fast disks
- Network, perhaps with rate or delay guarantees
- Client sites with buffer space for video playback

Optimal Smoothing

- Proposed in “Supporting Stored Video: Reducing Rate Variability and End-to-End Resource Requirements through Optimal Smoothing”
- Proposed by James D. Salehi, Zhi-Li Zhang, James F. Kurose, and Don Towsley
- Proposed in May 1996

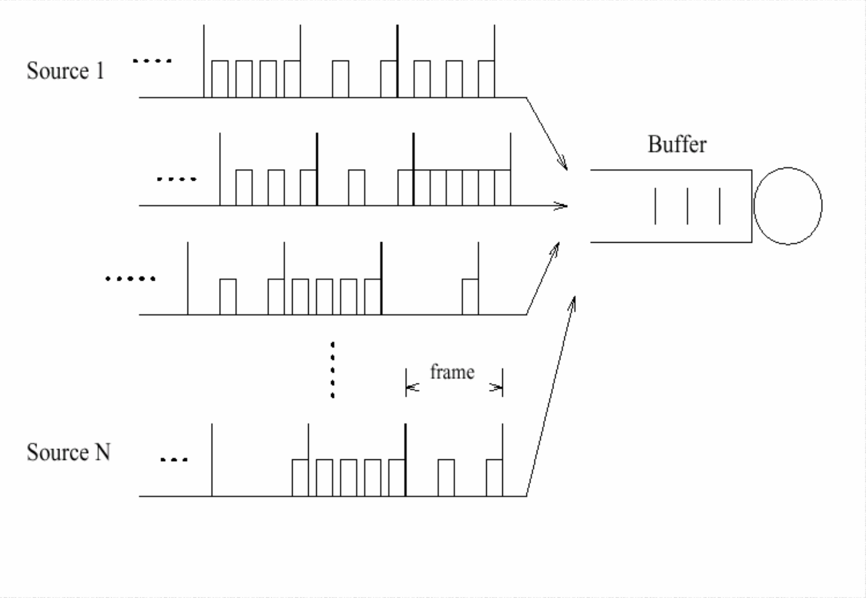
Statistical Multiplexing of VBR video



- Open - loop VBR encoding
- True interactive video: Video begins playback immediately
- Loss occurs when aggregate input rate to buffer exceeds R.

Statistical Multiplexing 1/2

- The statistical multiplexer can be seen as a finite capacity queueing system with buffer size B (in cells) and one server with service rate C



Statistical Multiplexing Model 2/2

- In statistical multiplexing, a VBR connection is allocated its “statistical” bandwidth (less than its peak but more than its average bit rate)
- The statistical bandwidth of a connection depends not only on its own stochastic behavior but also strongly on the characteristics of existing connections
- Bandwidth gain is attained by allowing the sum of the peak rates of the input streams exceed the service rate of the multiplexer
- This results in queuing and possible buffer overflow
- Need for estimates for a number of independent multiplexed signals:
  - Total statistical transmission bandwidth
  - Resulting utilization
  - Required buffer size
  - Probability of buffer overflow
  - Rate of packet discard
  - Distribution of packet delay

Different approaches for video source modeling

- Use detailed stochastic source models
  - Matching various statistics of video source
  - Content-based approach
  - Different approach for Real-time video sources

- Use stochastic bounds to characterize a source

- Characterize each video source by a deterministic time-invariant traffic envelope

Noticed features of coded video

- The distribution of bit-rate variations is bell-shaped
- The auto-correlation is close to a decaying exponential function
- Coefficient of variation increases duo to positive correlation of the bit-rate distribution
- When multiplexing a series with no temporal correlations less data accumulates in the buffer than would with a real video signal

Estimation Loss Probabilities

- Convolutions can be numerically difficult.
- Central Limit Theorem: simple but possibly inaccurate
- Chernoff Bound : fairly tight bound
- Large-deviation approximation: refinement of the Chernoff bound

Gaussian Approximation

- Each connection is characterized by the average and the standard deviation of its bit-rate
- The method is based on the simplifying assumption that if the number of sources multiplexed is large,total traffic behaves as a ***Gaussian*** process with mean and variance the sum of the means and variances of the sources, respectively
- Closed form for two useful estimates
  - Overflow probability
  - Upper bound for cell loss probability
- It treats all connections as if they have the same cell loss requirements

Video Quality and Bandwidth Renegotiation

- **In most systems video is still transmitted through CBR transmission channel.**
- Since both channel capacity and end-to-end delay are limited in the CBR transmission, quality degradation is inevitable.
- Even when the channel capacity is higher than the average bitrate, the degradation still occurs because an output buffer cannot **absorb long-term excess of bitrate**.
- Solution for this problem is to use ***bandwidth renegotiation***. Frequency of degradation occurrence can be used as a quantitative measure of video quality.

Statistical Multiplexing Gateway

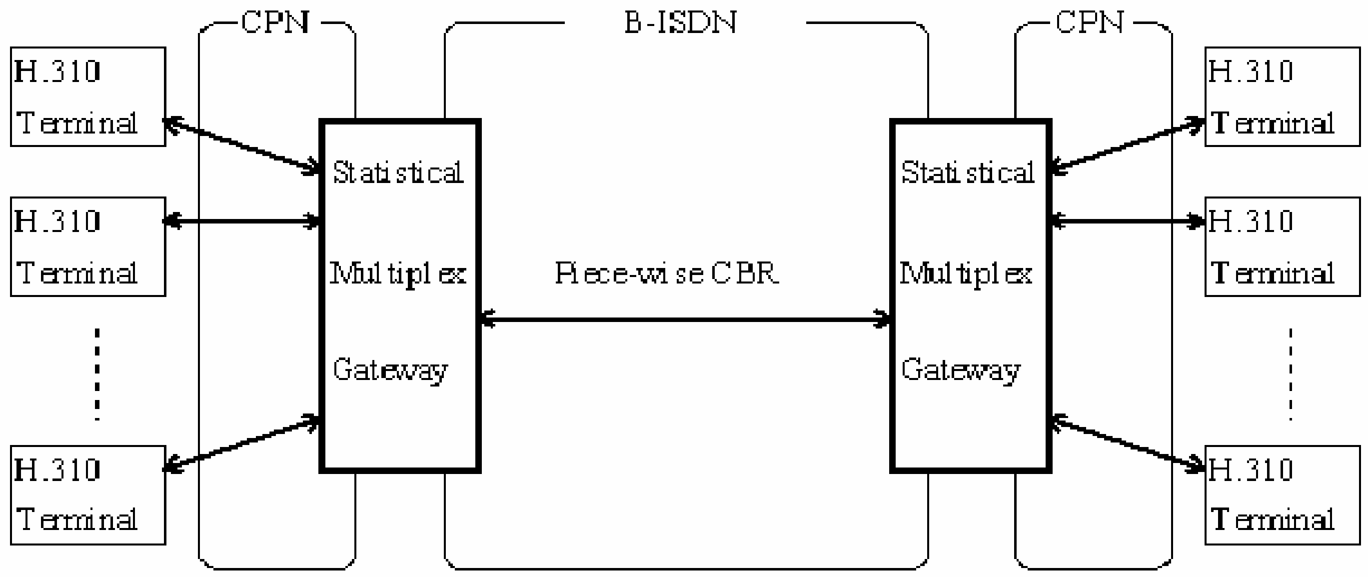
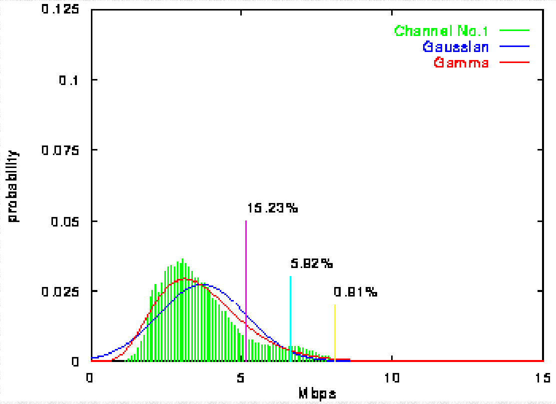


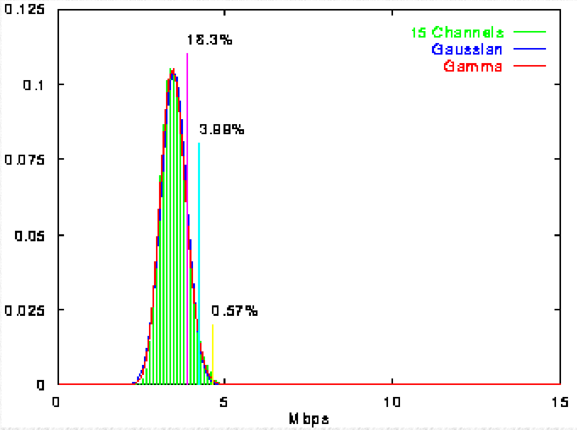
Figure 1: System block diagram of the proposed statistical multiplexing gateway.

Video Quality and Bandwidth Renegotiation/Cont.

- To guarantee an acceptable video quality, degradation occurrence should be minimized, e.g. less than 5%, or 1%. To achieve an acceptable video quality, the required bitrate ***C*** is formulated as,
- $$C = \mu + \alpha\sigma \qquad \textbf{(1)}$$
- where μ is an average bitrate, α is a factor to determine a frequency of degradation occurrence and σ is a standard deviation.

Group of Pictures (GOP) averaged bitrate histograms generated by a fixed quantizer scale MPEG-2 encoder





he GOP averaged bitrate histograms for single video channel (left) and fifteen multiplexe video channel (right) with their Gaussian and gamma distribution fitted curves.

The fluctuation of the quality factor α

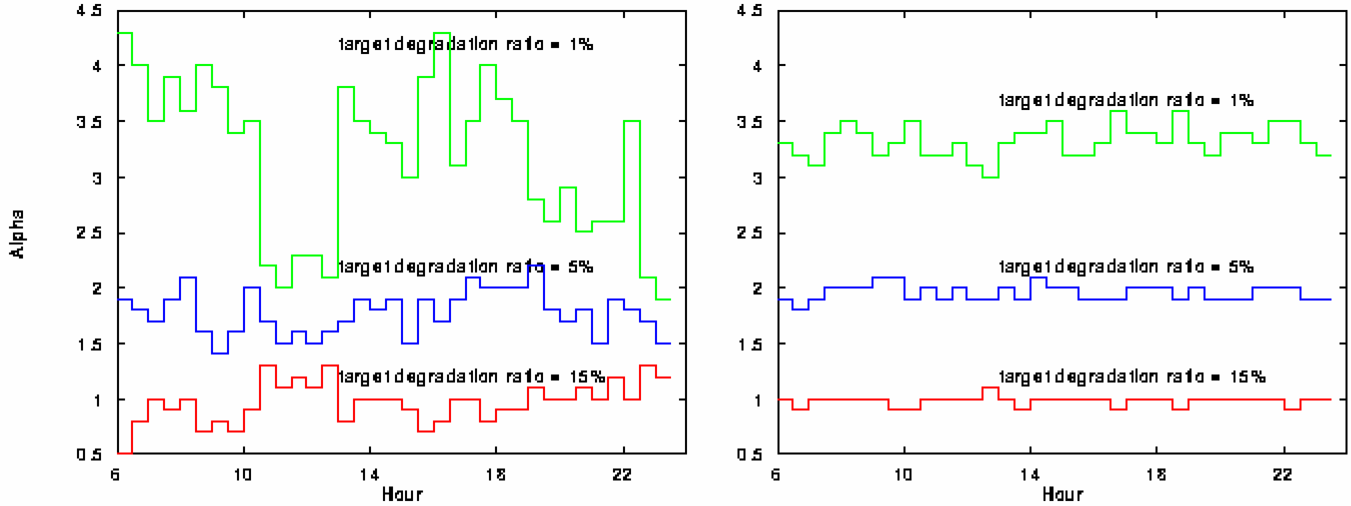


Figure 3: The fluctuation of the quality factor α to maintain targetted degradation occurance ratios for single channel case (left) and for fifteen multiplexed video channel case (right). The α is calculated every 30 minutes. The string "Alpha" is used for Y axis instead of α, because the character α is not available in the graphs.

Model Analysis

- When the video bit rate generation is modeled as a ***Gaussian*** process and each video source is uncorrelated, the required bit rate per channel of ***L***-multiplexed video channels ***C*** is derived from Equation (1) as
- $$C = \mu + \alpha \frac{\sigma}{\sqrt{L}} \qquad \textbf{(2)}$$
- where μ is an average bit rate per video channel, α is a factor to determine a frequency of degradation occurrence,σ is a standard deviation per video channel .
- On the other hand, an average of the required bitrate for bandwidth renegotiation is formulated as
- $$E[C_m] = \mu + \alpha \sqrt{\sigma^2 - \frac{1}{m^2} \sum_{i=1}^{m} \sum_{j=1}^{m} \gamma(i-j)} \qquad \textbf{(3)}$$

Model verification using simulation results

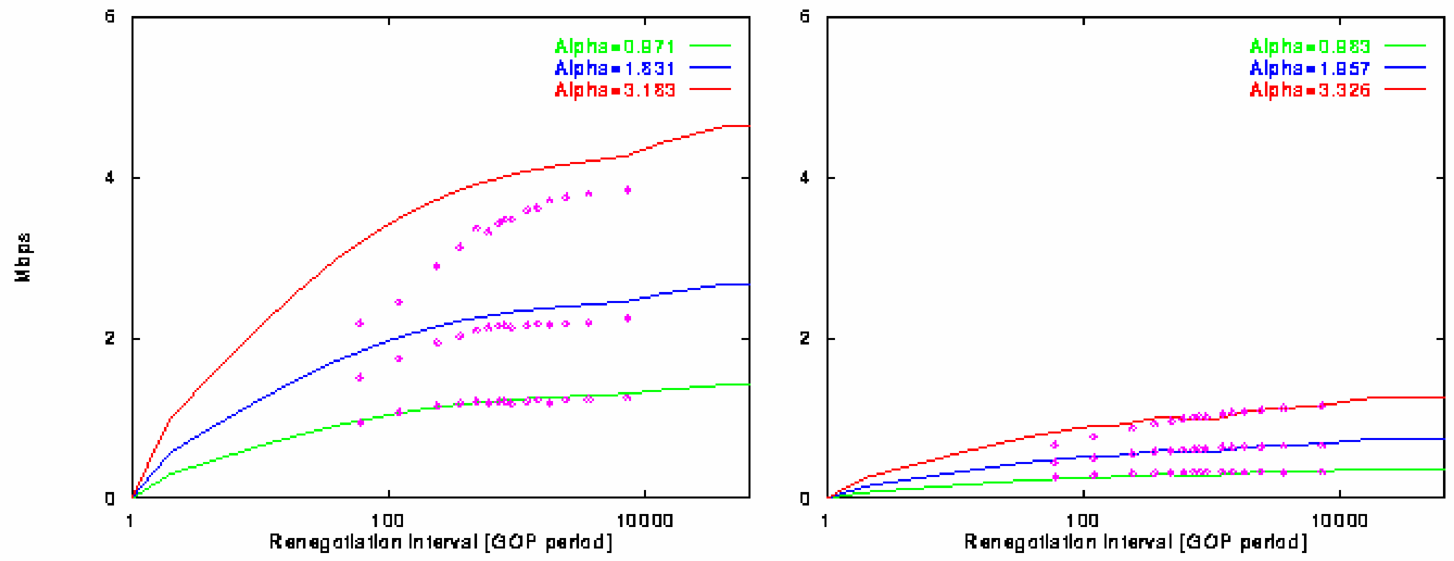


Figure 4: The comparison between the theoretical and experimental results for single video channel case (left) and fifteen multiplexed vid
channel case (right). The string "Alpha" is used for parameter label instead of α, because the character α is not available in the graphs

Table 1: Theoretical and experimental result summary for 5% degradation.

	without renegotiation	every 30 second renegotiation	renegotiation gain (Experimental)
single video channel μ=3.47Mbps	μ+2.75Mbps	μ+1.89Mbps	0.86Mbps
15 video channel mux μ=3.47Mbps/channel	μ+0.75Mbps/channel	μ+0.49Mbps/channel	**0.26Mbps/channel (0.21Mbps/channel)**
statistical multiplexing gain (Experimental)	**2.00Mbps/channel (1.73Mbps/channel)**	1.40Mbps/channel	

Deriving the number of admitted streams and the required Buffer size B

- From **Eq. 3** it is possible to derive the number of possible admitted streams for in a CBR channel, according to:
-
- $$N = \left\lfloor \frac{Channel\_bw}{E[C_m]} \right\rfloor \qquad (4)$$

$$PDF_{total} = PDF_1 \otimes PDF_2 \cdots \otimes PDF_i \cdots \otimes PDF_N \qquad (5)$$

- Where PDF_{total} is the probability density function of the aggregated stream and it equals to the convolution of all stream *PDF's*
- In the case of few streams (above 10) the *Gaussian* approximation will be good approximation for PDF_{total} .

Buffer Analysis /cont.

- $$B\left[Bits\right] = K \cdot \int_{Channel\_rate}^{Maximum\_aggregating\_rate} PDF\left(r\right) dr \cdot T_{GoP} \qquad (6)$$

- Where, *K* is the normalized factor for the *PDF* curve the *Channel rate* is the constant bit rate of the multiplexer output, the *Maximum_aggregating_rate* is the Maximum total bit-rate of the aggregated stream , and T_{GoP} is the time duration of the 1 period of *GoP*.

$B\left[Bits\right] = K \cdot P_{loss} \cdot T_{GoP}$

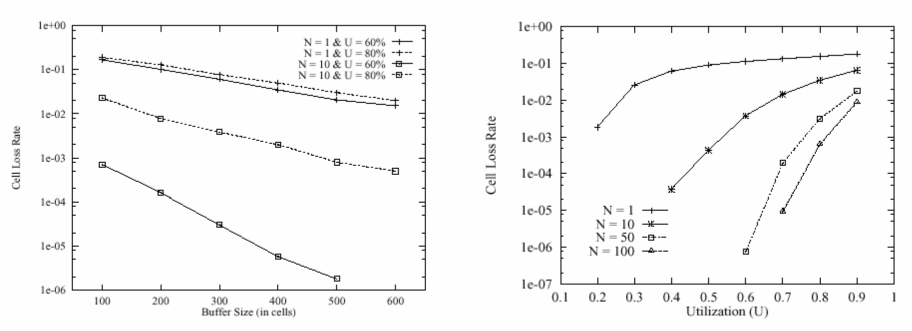
$$B\left[Bits\right] = K \cdot P_{loss} \cdot T_{GoP} \qquad (7)$$

Modeling Conclusions (1/2)

- Utilization:sum of the average bit-rates to channel capacity
- Definition

$$\mu_p(n) \triangleq \frac{n \times \text{Utilization at } N = 1 \text{ and } P_{avg} = p}{\text{Utilization at } N = n \text{ and } P_{avg} = p}$$

- Results from simulation indicate that there is an improvement in cell loss performance as more video streams are multiplexed when using both the actual data and the corresponding model.(close performance)



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