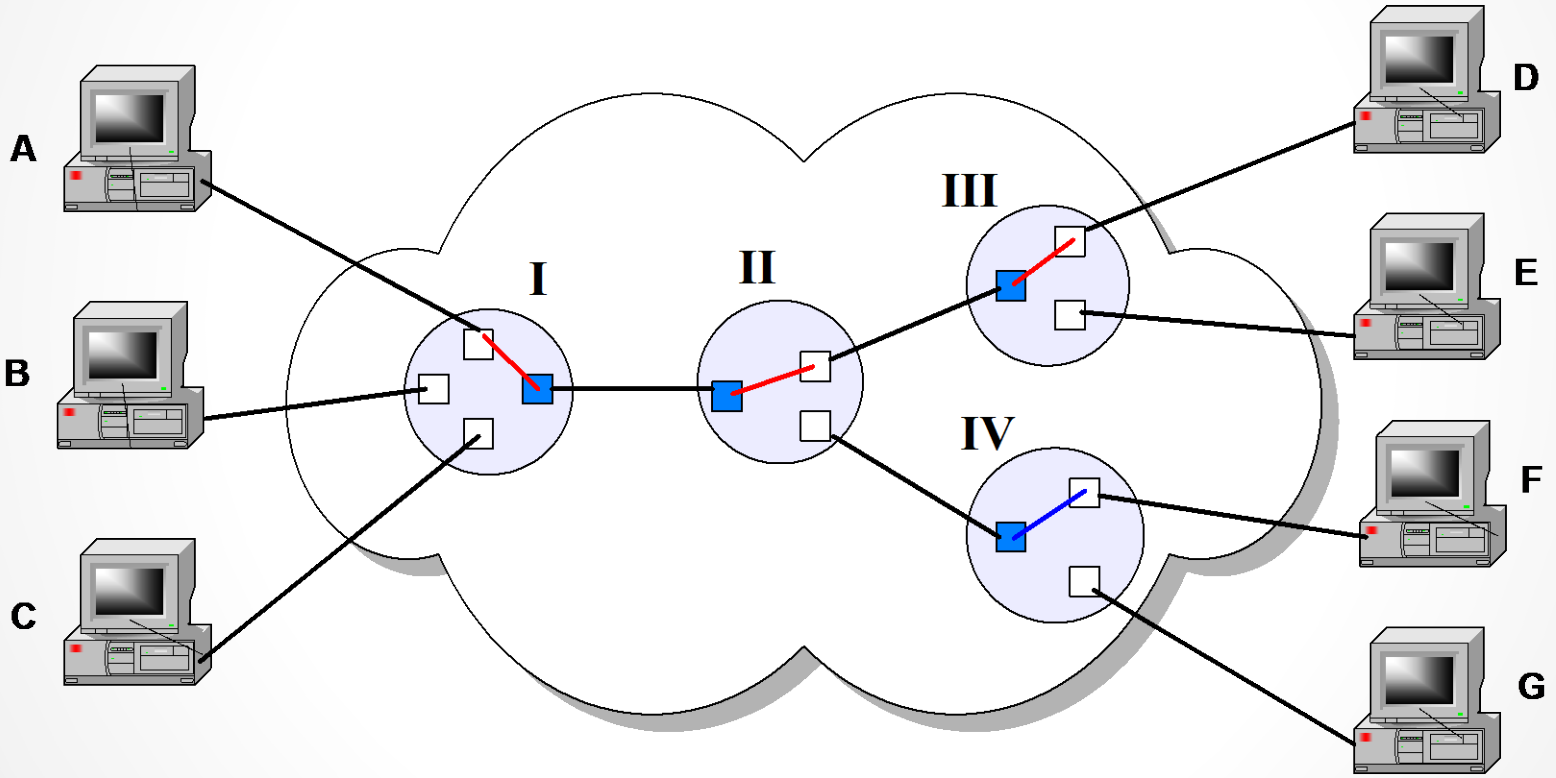
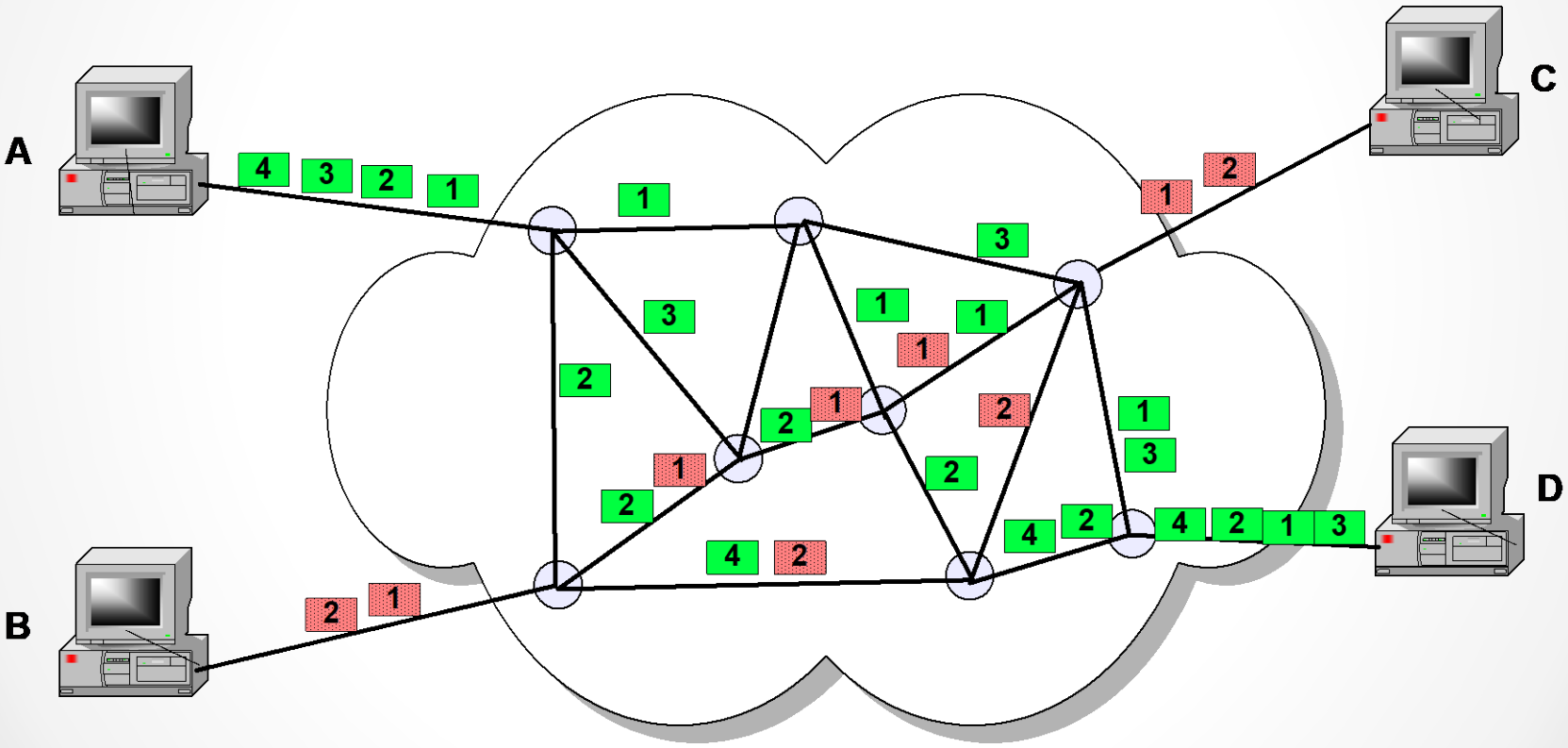
Transmission mode

- Circuit switching and packet switching are two common transmission switching techniques.
- Switching is a way to share communication network resources. A switched network consists of a series of inter-linked nodes, called switches, which are hardware and/or software devices capable of creating temporary connections between two or more nodes linked to the switches for data transmission.

Circuit switching

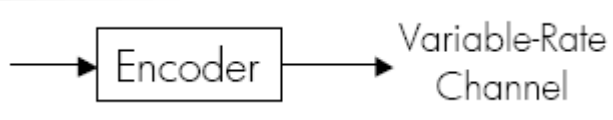


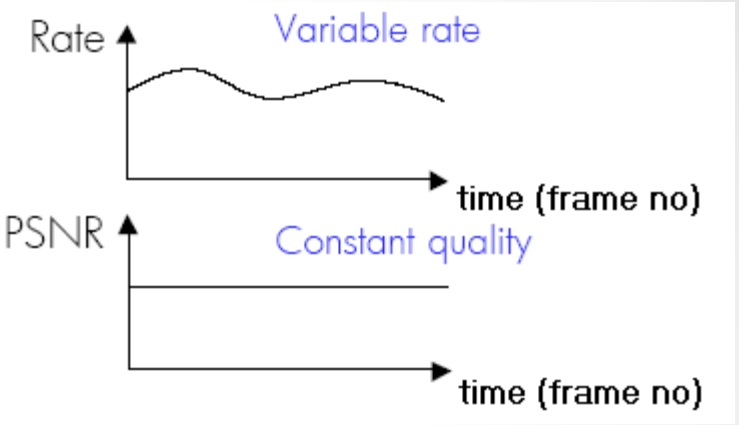
Packet switching



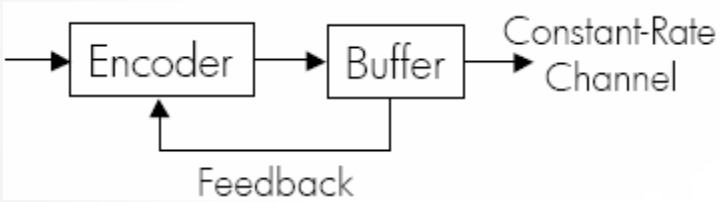
Constant bit rate Vs Variable bit rate

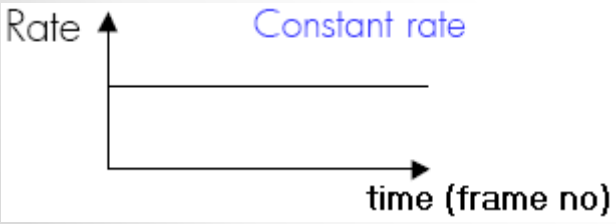
- Open loop encoding Variable bit rate (VBR)

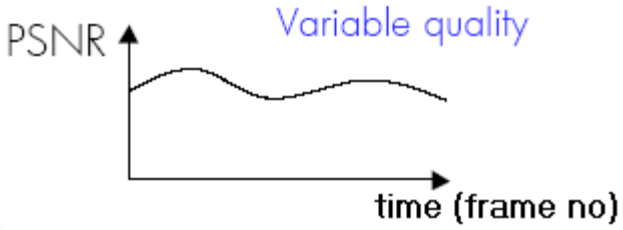


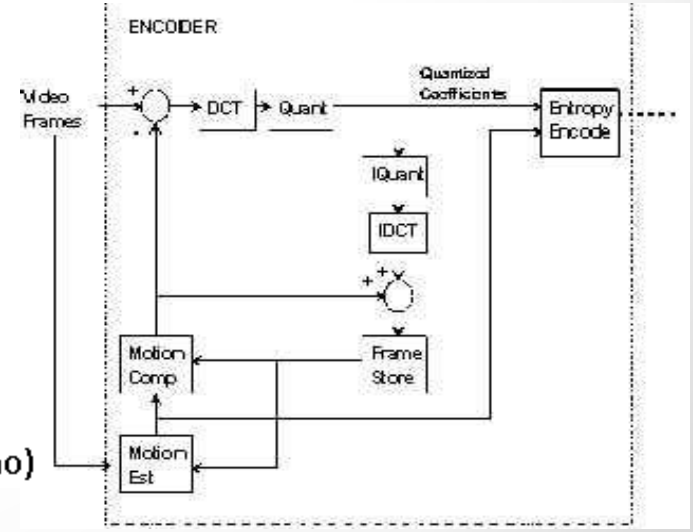


- Closed loop rate control Constant bit rate (CBR)









CBR Vs VBR

- *Tradeoff between quality and bit rate:*
  - Constant quality + Variable bit rate
  - Constant bit rate + Variable quality
- Constant quality corresponds to approximately the same distortion per frame.
  - Can be achieved by constant quantization stepsize for all frames.
- Constant bit rate corresponds to approximately the same bit rate per frame.
  - Can be achieved by using a buffer and feedback to control the quantization stepsize.

Video bit-rate control

- Approach 1:
- Allocate same number of bits to each frame.
- $R_i = \frac{R_{Total}}{N}$ R_i is bits for each frame
- CBR encoding
- Issues:
  - Some frames are more complex (more motion activities).
  - Some frames are more predictable (may require fewer bits).
  - Don't consider distortion.

Video bit-rate control

- Approach 2:

$$\min D_{Total} = \sum_{i=1}^{N} D_i$$

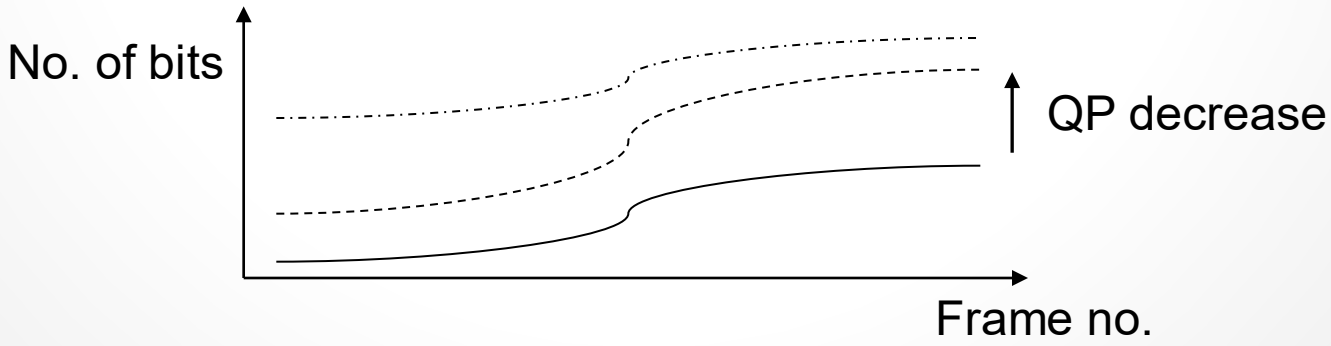
such that

$$R_{Total} = \sum_{i=1}^{N} R_i \qquad R_i \approx \frac{R_{Total}}{N}$$

- Issues:
  - CBR encoding.
  - Compare with approach 1, more flexible. But how many bits need to assign to each frame to minimize the distortion for N frames.
  - Maybe waste if too conserve, or not enough bit in the end if too aggressive.
  - Not optimal.

Video bit-rate control

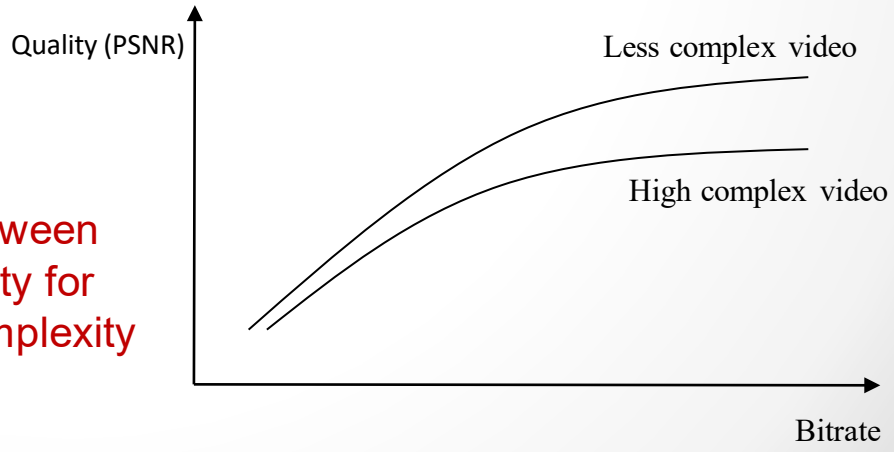
- Approach 3, Multi-pass encoding (VBR)
- Encoder analyzes the entire video many times to estimate number of bit for each frame before the actual encoding process.
- Determine the best possible way to fit the video within the bitrate limits.
- All commercial storage disc (blu-ray, DVD, etc) encode using multi-pass method.



Quality Vs Bitrate

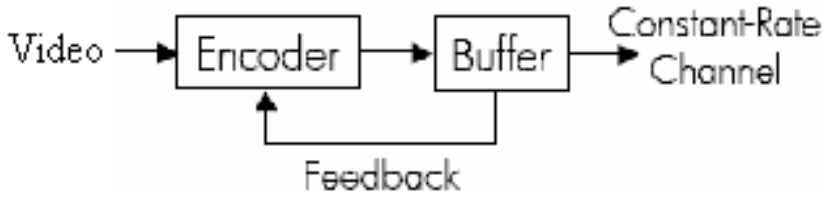
- Current video encoding standards do not specify how to control the bitrate.
- The shape of the relational curve depends on the video complexity and contents.
- By giving the desired bitrate or the corresponding quantization parameter (QP), but without prior knowledge of the video sequences, how to efficiently encode the video sequences to achieve the highest visual quality of the encoded video.

Relationship between bitrate and quality for different video complexity



Proportional output buffer occupancy feedback

- The simplest bitrate control algorithm involves setting the quantization parameter proportional to the output buffer occupancy.



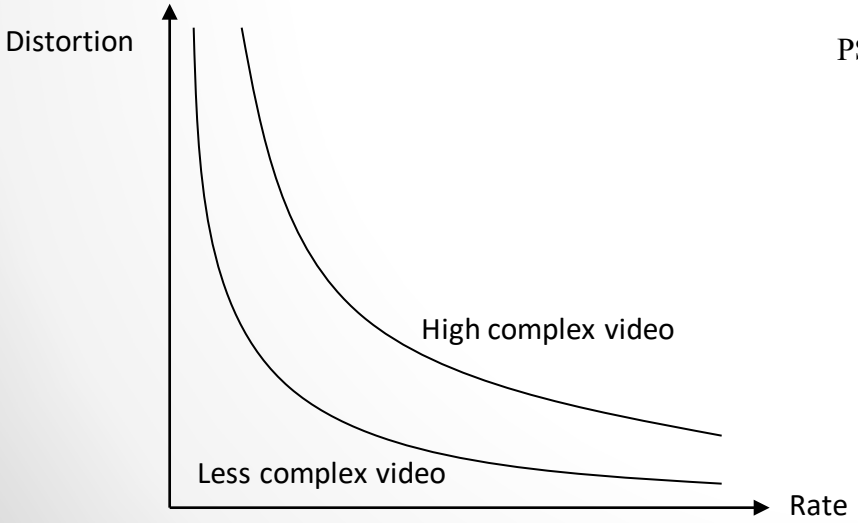
- The quantization parameter QP is set using the following expression:
  - QP = D * Buffer_occupancy + Offset

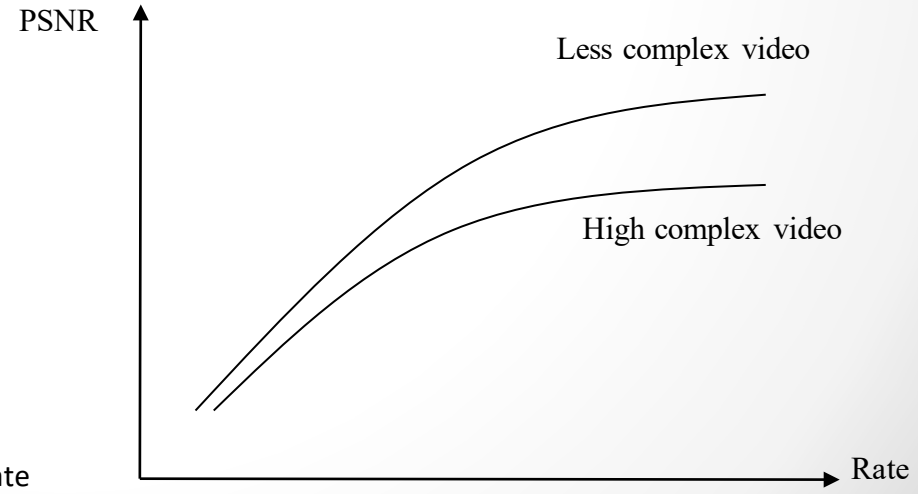
QP range 10-50 → Offset 10 → D 40

  - Buffer_occupancy is the number of bits currently in the output buffer,
  - D is a division_factor to give values of QP within a suitable range,
  - Offset is an integer offset to make sure QP cannot fall below the predetermined value.

Rate - distortion (R-D) model

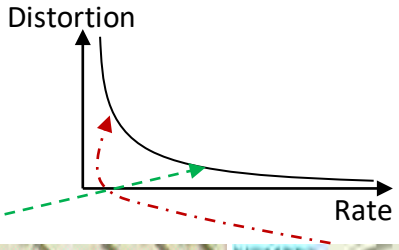
- The performance of the video quality is mostly determined by
  - the number of bits used to code the picture or bitrate,
  - the effect of using such bitrate – usually indicate by the distortion.
- For different input data, we may have different R-D curves, and more complex video data may have higher distortion.





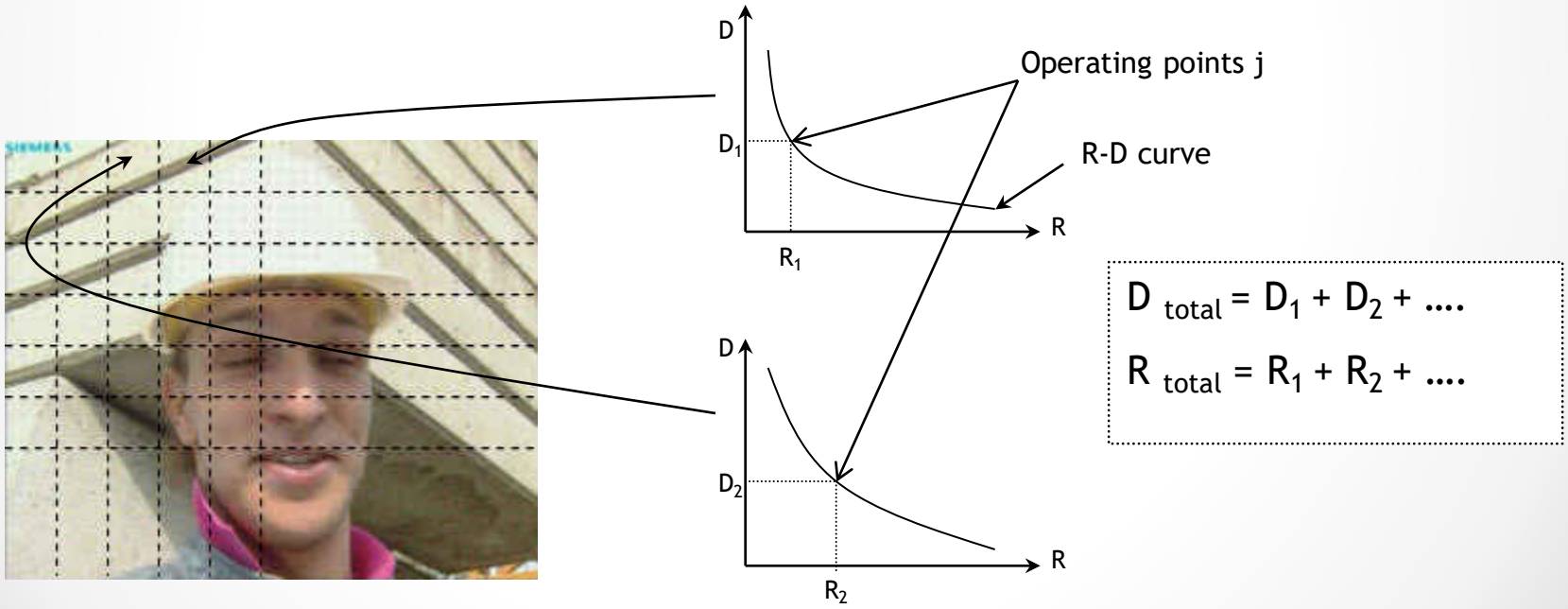
Rate - distortion (R-D) model

- We use one picture of video sequence "Foreman" as an example to show the R-D relationship.
- We encode "Foreman" by using QP=4 and QP=28 respectively.
- The number of bits use to encode the picture are 20kB and 5kB respectively.



Rate - distortion (R-D) model

- Video compression is conducted macroblock by macroblock, so each macroblock has a different rate-distortion curve.
- The R-D curves are form by many pairs of operating points.



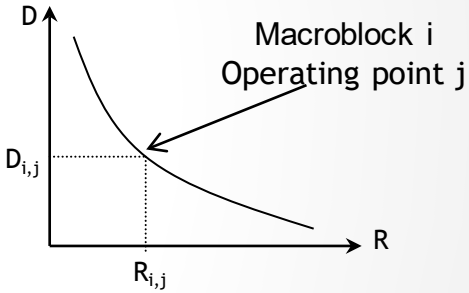
Rate - distortion (R-D) model

- Need to find the optimal operating point for each individual macroblock such that
  - the total distortion for the entire frame is minimum,

$$D_{total} = \sum_{i=1}^{N} D_{i,j}$$

  - and the total bitrate is within the target bitrate.

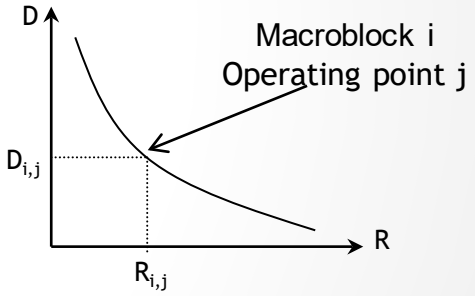
$$\sum_{i=1}^{N} R_{i,j} \le R_{budget}$$



    - where j is the optimal operating points for macroblock i,
    - $R_{i,j}$ is the bitrate for the macroblock i at the optimal operating point j,
    - $D_{i,j}$ is the distortion for the macroblock i at the optimal operating point j.

Rate - distortion (R-D) model

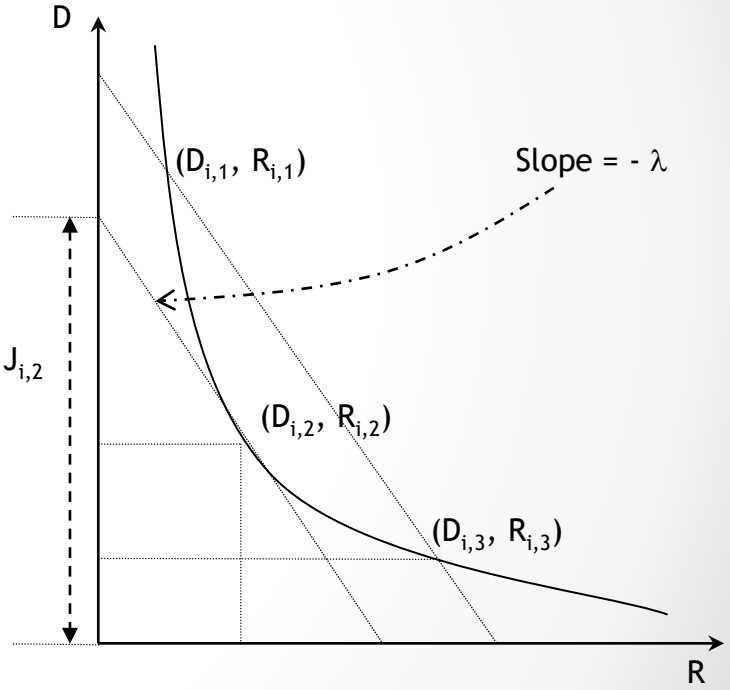
- Constrained function is difficult to optimize as there are many parameters need to be considered together under the constraint.
- Lagrangian optimization can be used to solve this problem.
- In Lagrangian optimization, the distortion term is weighted by a factor against a rate term.
  - min {J}, where $J_{i,j} = D_{i,j} + \lambda R_{i,j}$
  - => $D_{i,j} = - \lambda R_{i,j} + J_{i,j}$



- Lagrangian rate-distortion function J is minimized for a particular value of the Lagrangian multiplier λ, where λ is a non negative real number.

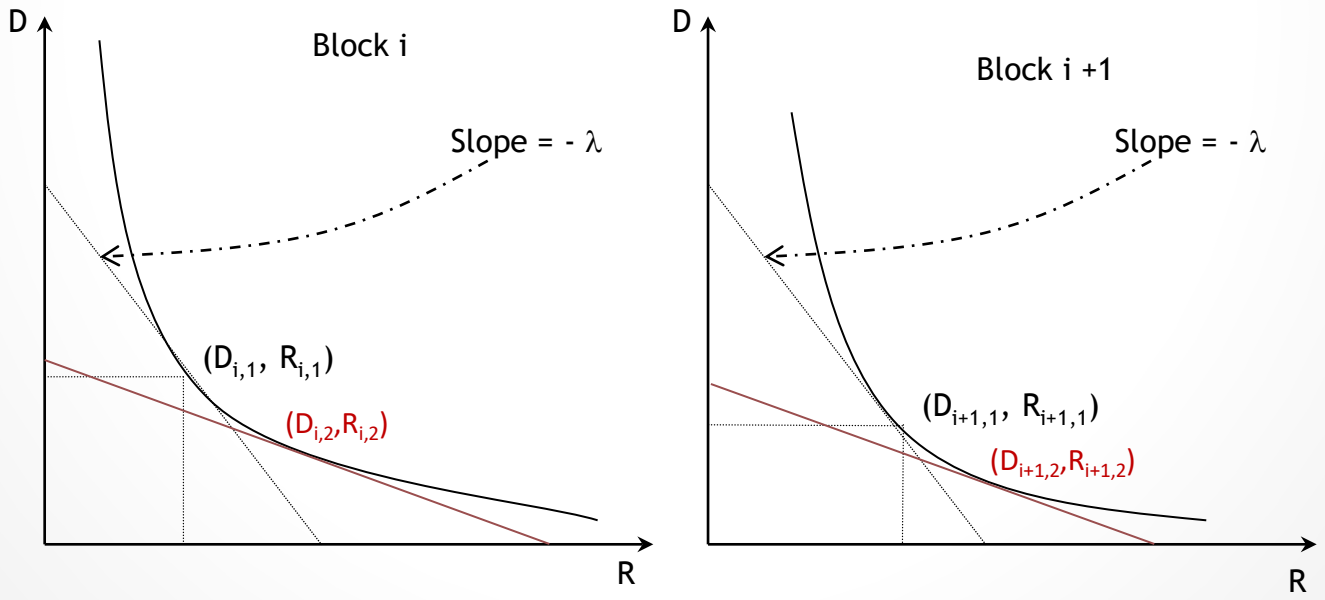
Rate - distortion (R-D) model

- The optimal R - D point is where the line of slope λ first hits at when moving from left hand side to right hand side, which give the minimum value of $J_{i,2}$.
- Note that for each macroblock i, the point on the R-D curve that minimizes $J_{i,j}$. The line at the point j of slope $-\lambda$ is tangent to the R-D curve.
- The choice of λ will affect the operating point. The larger the value λ, the lower the quality can be obtained.



Rate - distortion (R-D) model

- Since λ is the same for each macroblock in the video data, this algorithm also refers to constant slope optimization.
- With the constant slope λ, different blocks may have different operating points that give the minimum value of J.



Rate - distortion (R-D) model

- Find the best value λ, such that the total distortion is minimum and total bitrate is within the constraint.
- The value λ is fixed for entire video sequence, and minimize J(λ) in the following

$$J(\lambda) = \sum_{i=1}^{N} \left(D_{i,j} + \lambda R_{i,j} \right)$$

- and we also need to satisfy the following requirements

$$D_{total}(\lambda) = \sum_{i=1}^{N} D_{i,j} \Big|_{\lambda}$$

$$R_{total}(\lambda) = \sum_{i=1}^{N} R_{i,j} \Big|_{\lambda} \le R_{target}$$