Applications in Communications: Joint Source-Channel Coding

Separation principle

- source coding
- channel coding
- interaction of compression and transmission

Joint source-channel coding

- broadcast
- browsing
- multicast

Source Coding: A Rate-Distortion Primer...

Compression: rate-distortion is fundamental trade-off

- more bitrate $\Rightarrow$ less distortion
- less bitrate $\Rightarrow$ **more** distortion

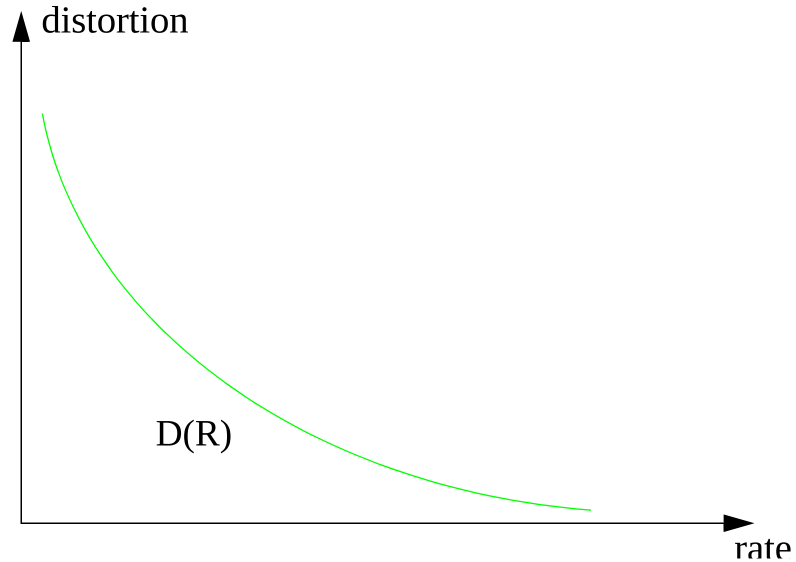
Standard image coder

- operates at one particular point on D(R) curve

Multiresolution coder (layered, scalable)

- travels rate-distortion curve (successive approximation)
- computation scalability (less powerful computer gets approximation)

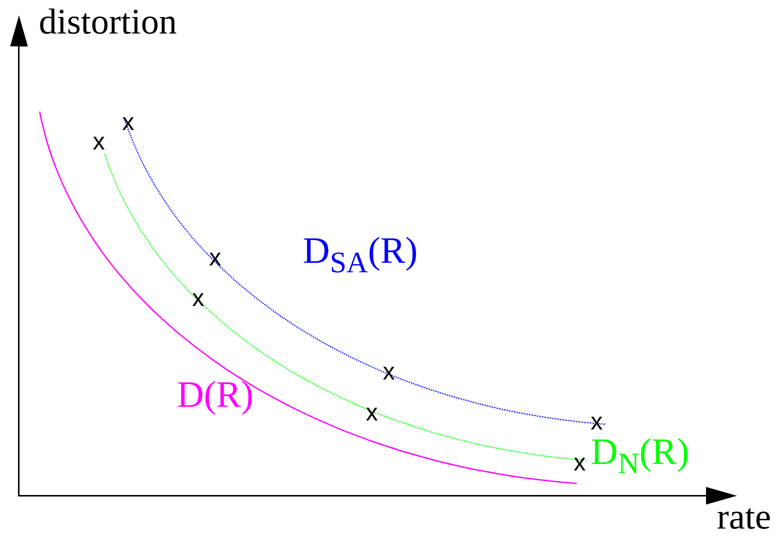
Source Coding: Distortion-Rate Functions



Given a statistical description of a discrete-time source, the distortion rate function gives the minimum distortion achievable at a given rate R:

- ‘‘true’’ D(R): assumes infinite block size
- operational $D_N(R)$ for block size N: minimum distortion achievable for blocks of size N

- successive approximation $D_{SA}(R)$: refinable $D(R)$ function where more bits refine the approximation



Successive approximation source coding

Theoretical foundation [Equitz/Cover]**:**

- certain sources can be refined without loss (but not all...)

Practice of source coding: many schemes can be seen as successive approximation

- pyramid coding
- wavelet and subband coding
- tree-structured vector quantization

Standard coding schemes are not successively refinable (at least not efficiently)

- JPEG
- MPEG

The most successful current image compression schemes are refinable (lucky coincidence?)

- for example, wavelet compression using EZW

Channel Coding

Reliable communication over unreliable channels

Physical channels

- telephone, cable, wireless, radio, terrestrial broadcast
- modulation
- error correction codes

Packet channels

- LAN, WAN, internet (physical layer hidden)
- protocols
- erasure correction codes

Unequal error protection codes (UEP)

- product codes or direct designs

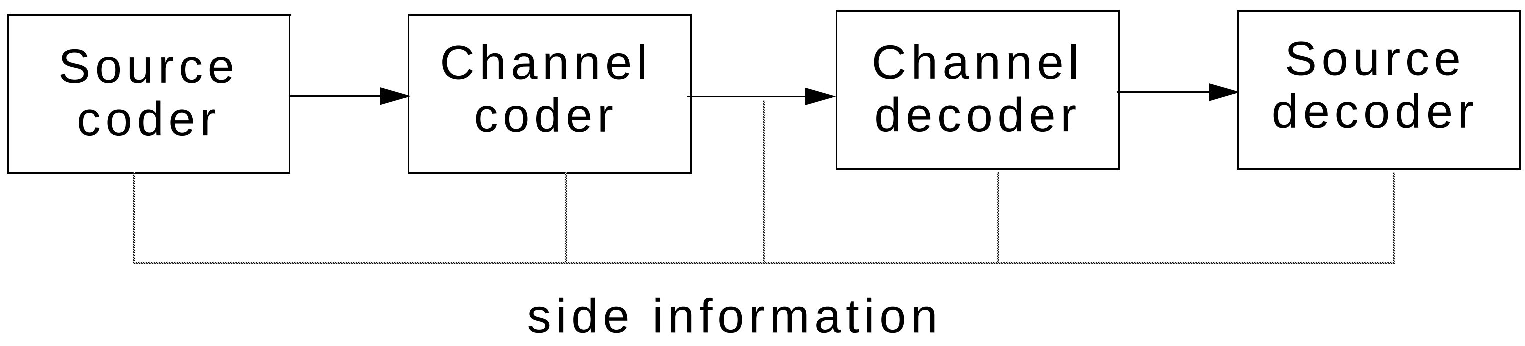
Channels with side information

Channel status available, four cases

- informed transmitter
- informed receiver
- informed transmitter and receiver
- classic noninformed case

Examples

- packet networks with side information
- wireless channels with side information



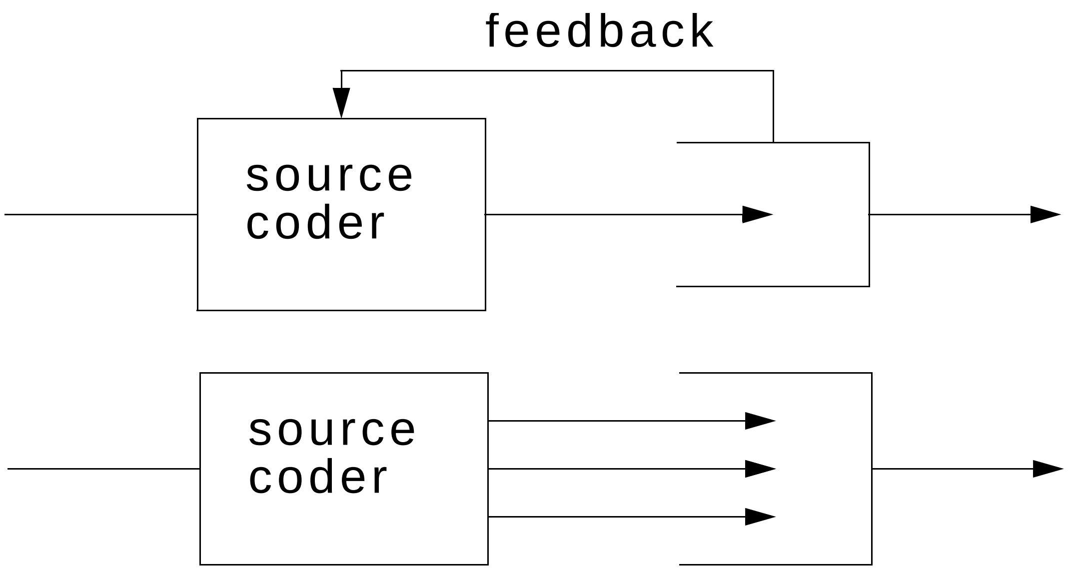
Channel Coding: Quality of Service

In practical situations, and in certain theoretical set-ups, it is necessary to adjust the rate of the source coder:

- buffer control
- time-varying channels (packet, wireless)
- multicast

A. feedback control on rate

B. layered coder



Point-to-point ⇔ broadcast/multicast

Separation principle

''To separate or not to separate, that is the question''
C.E.Shannon

Guiding principle in communication systems design

- channel coding to get close to capacity C
- communication at $C - \varepsilon$ is possible with high reliability
- source coding to reach $D(C - \varepsilon) + d$
- end to end quality is given by $D(C - \varepsilon) + d$

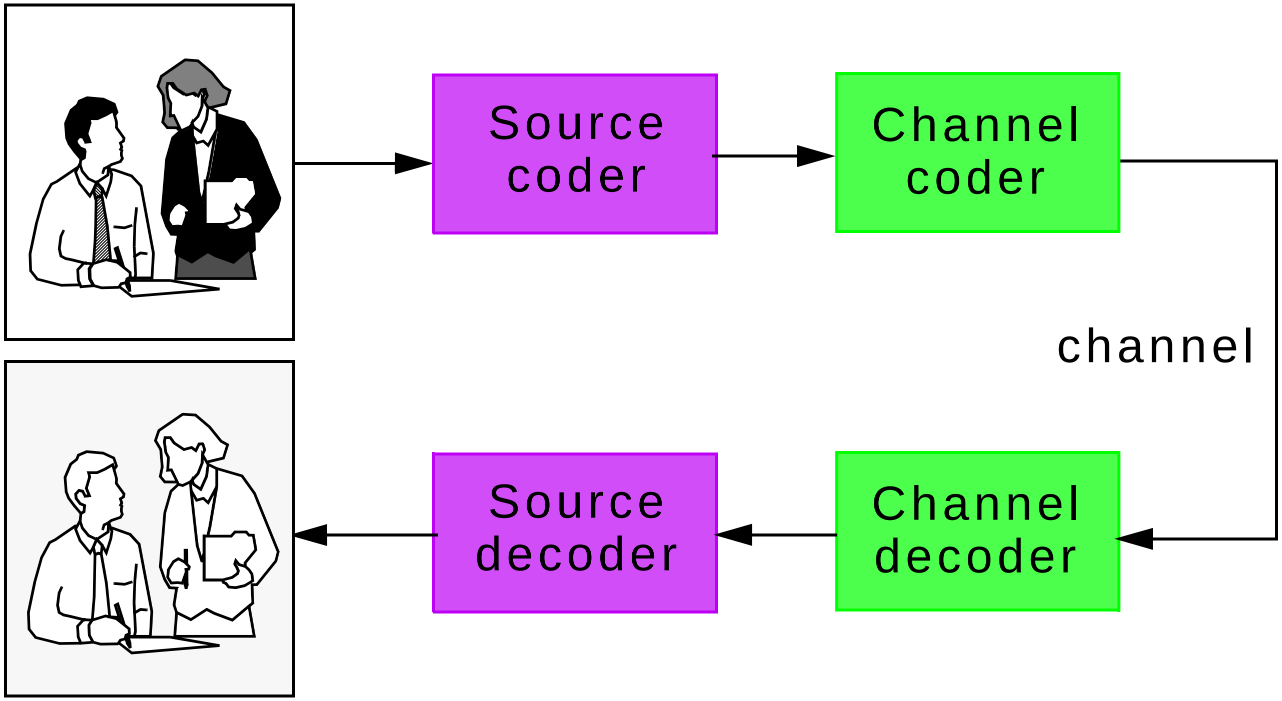
Note

- maximizing capacity minimizes distortion
- typical requirements: stationarity and ergodicity

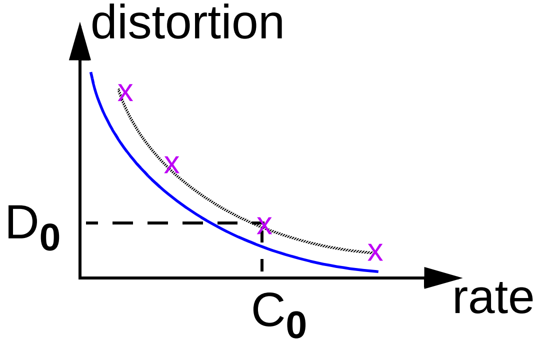
However: practice quite different!

- finite delay
- different channels (broadcast, side info, ...)
- practical coding schemes
- not all bits are equal

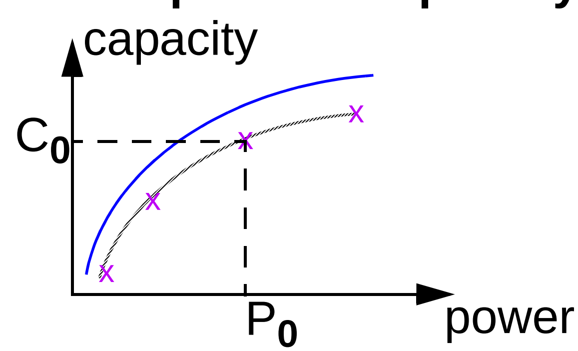
Separation principle



Source: distortion-rate



Channel: power-capacity



Separation principle...
... and reality

Finite delay (real-time communication)

- finite transmission error probability
- selective protection of information for robustness
- buffer control for variable rate sources

Nonergodic channels (e.g. class of channels)

- unknown capacity
- source coder adapts to particular channel

Channels with side information

- time-varying channels with informed transmitters or receivers

Practical coding scheme

- do not operate at $D(R)$
- side information in data (error sensitive)

Joint source channel coding principles

Not all bits are equal!

- design source codes so that errors are less harmful (VQ designs for robustness to errors)
- protect more important bits more (unequal error protection, modulation)

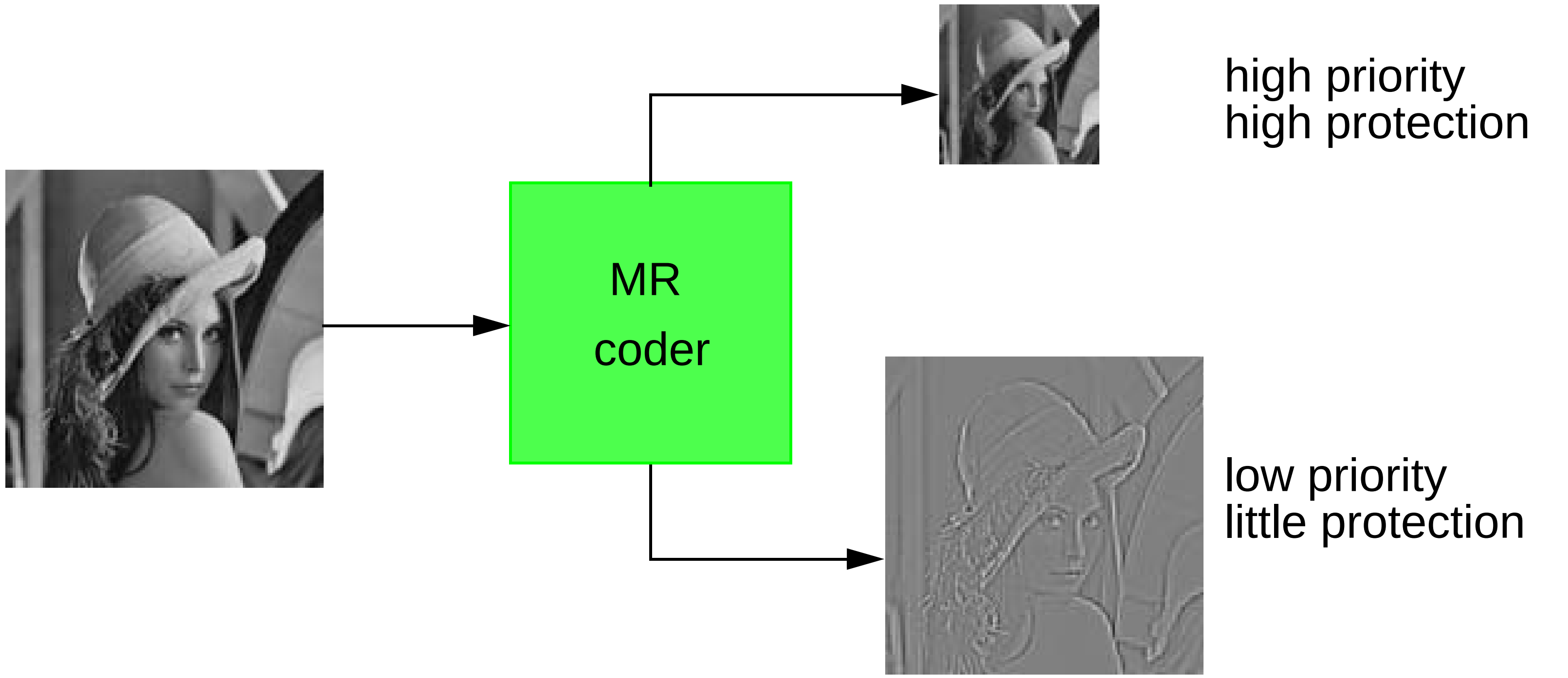
Layered source and channel coding

- split source coding bits into important base layer and additional enhancement layers
- favor base layer through protection or modulation

Multiple description source coding

- several description, independently good
- sum description better

Interaction of source and channel coding

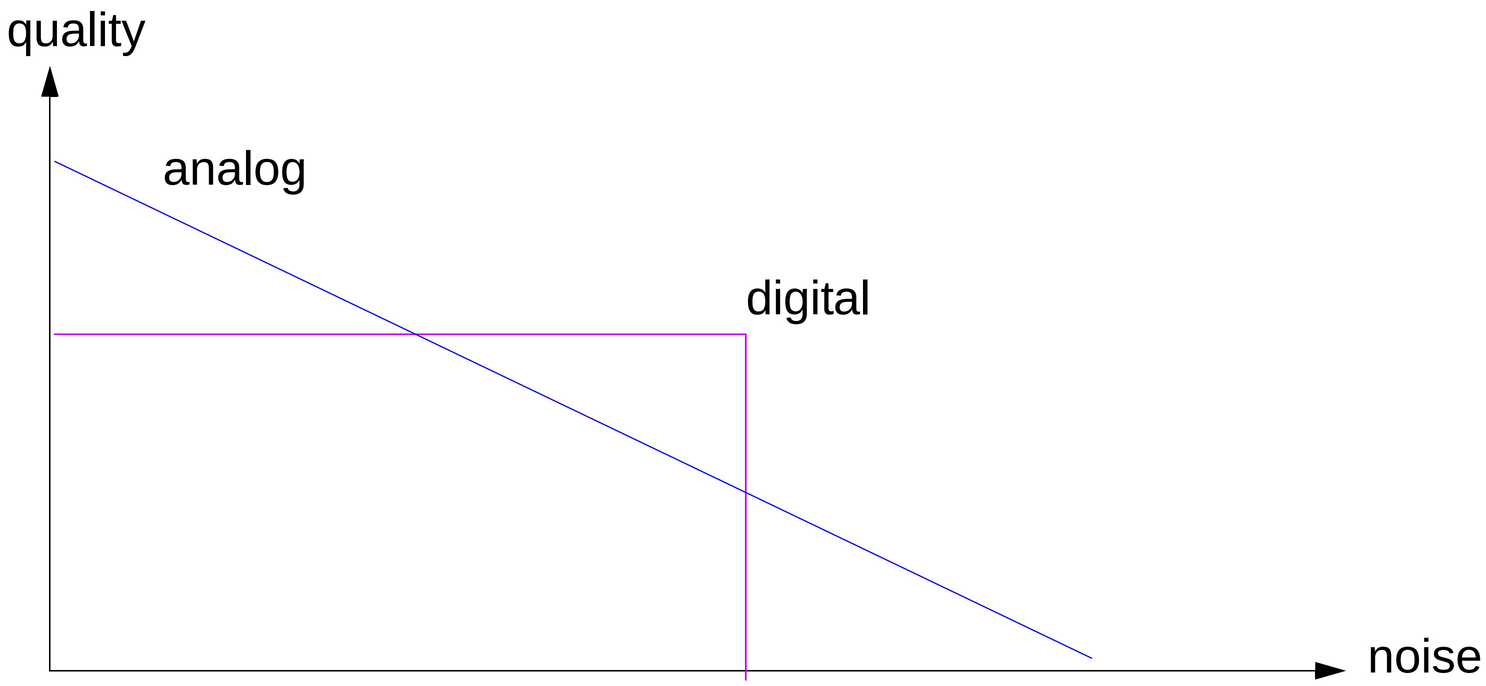


full reconstruction

coarse reconstruction

Digital is great... until it breaks!

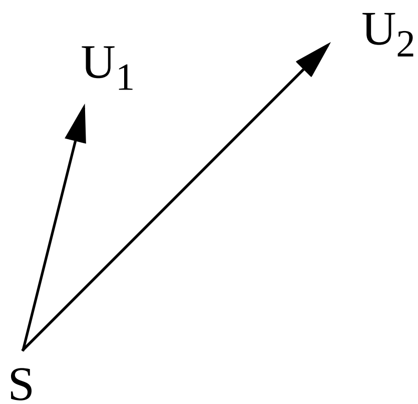
- error sensitivity
- single target rate
- cliff effect

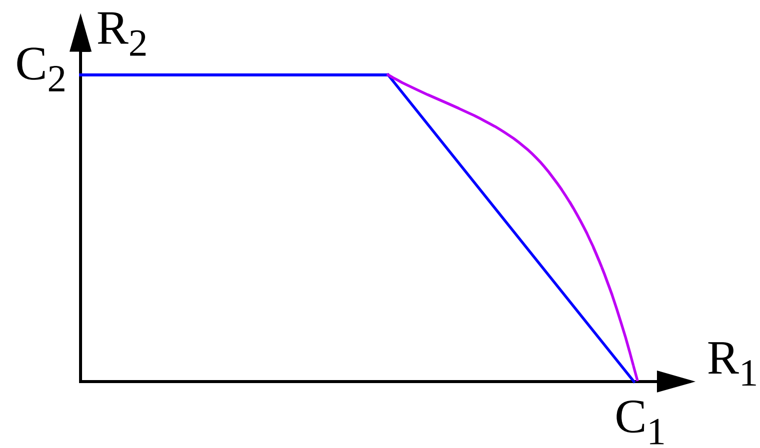


MR transmission for digital broadcast ...
... broadcast channel

Broadcast à la Cover

- one source, two receivers with capacities C_1 and C_2 where $C_2 < C_1$
- consider multiplexing only: α to user 1, $1 - \alpha$ to user 2
- optimal multiplexing for maximum rate: α_r
- optimal multiplexing for minimum distortion: α_r
  if $\alpha_r \neq \alpha_r$: no separation





MR transmission for digital broadcast

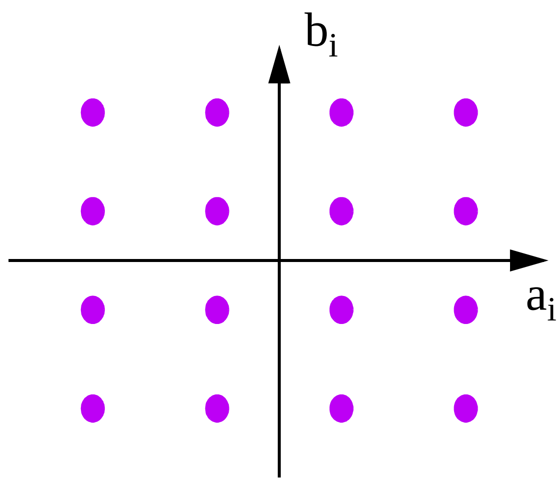
Requirements

- robustness to channel errors
- graceful degradation

Point toward

- hierarchically decomposed data (MR)
- blend MR transmission with MR coding

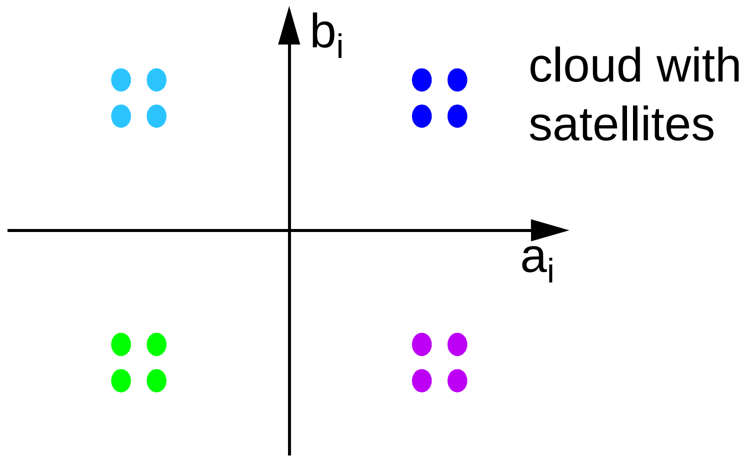
Recall QAM



$$s_i(t) = a_i \cos \omega t + b_i \sin \omega t$$

MR transmission for digital broadcast

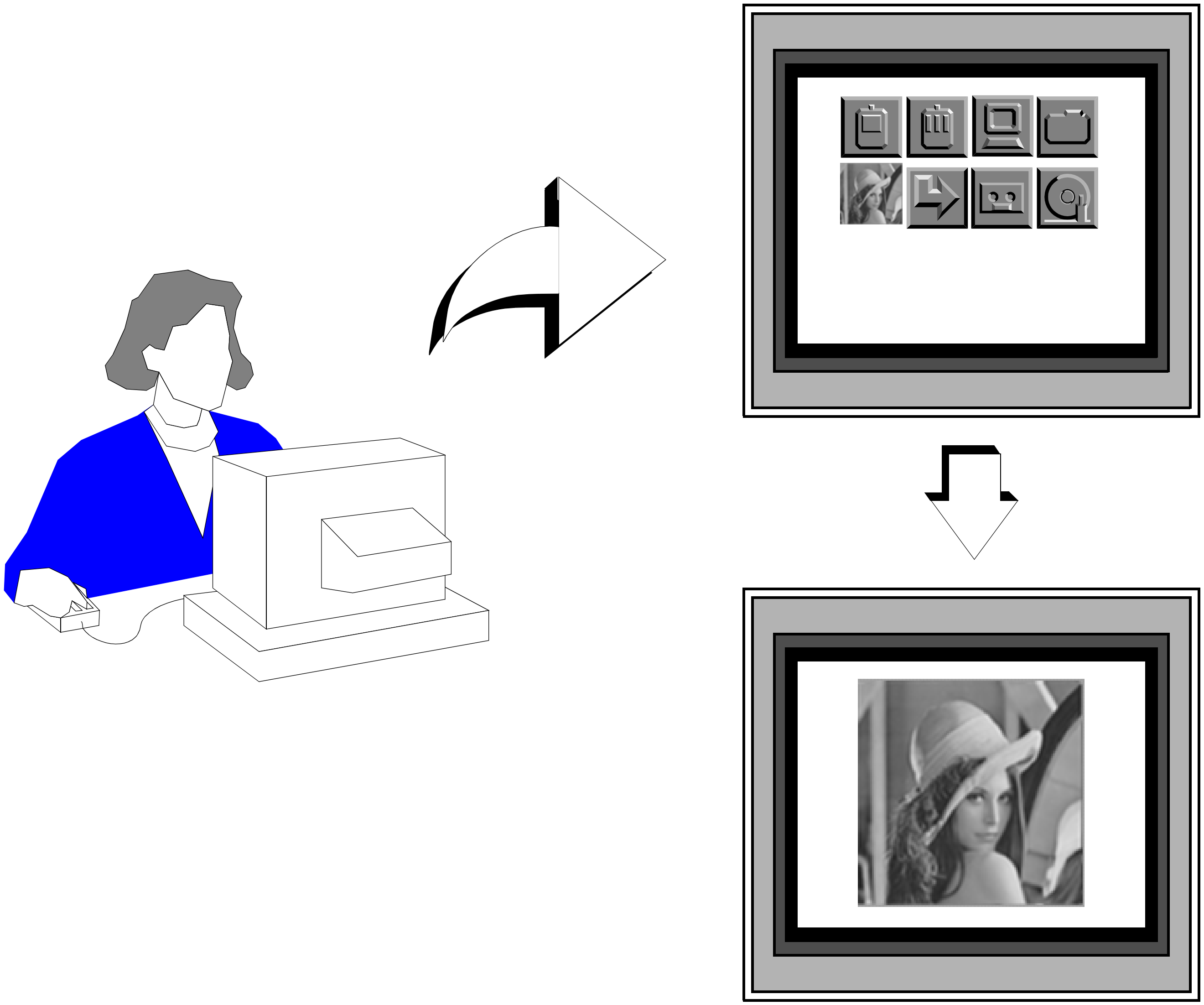
Embedding of coarse information within detail



- cloud: carries coarse info
- satellite: carries detail

Trade-off in broadcast ranges [miles]

MR for remote image databases browsing



MR coding for multicast over the Internet

''I want to say a special welcome to everyone that's climbed into the Internet tonight, and has got into the MBone --- and I hope it doesn't all collapse!''

Mick Jagger, Rollings Stones on Internet,11/18/94

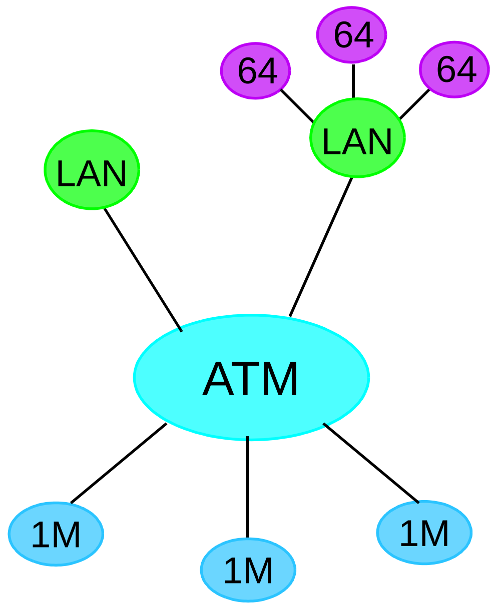
Motivation: Internet is a heterogeneous mess!

Video multicast over Mbone

- video by VIC
- software encoder/decoder
- learning experience (seminars ...)

Heterogeneous user population

On-going experience



MR coding for multicast over the Internet

Fact: different users receive bit rates

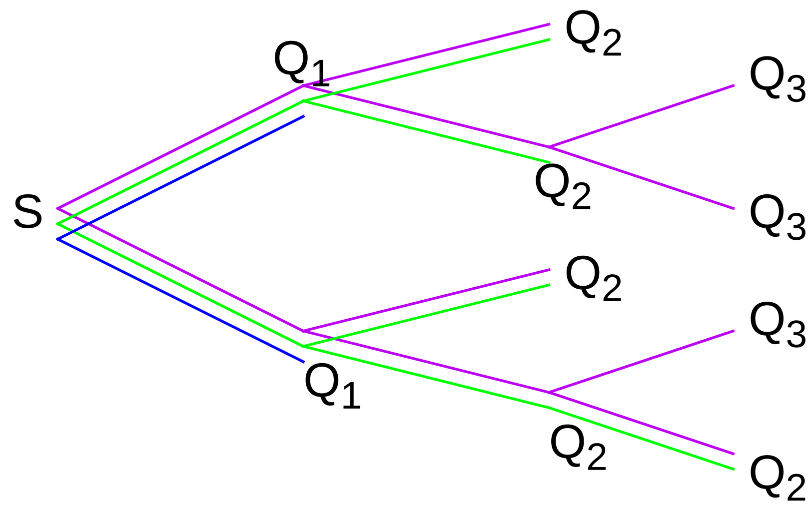
- transmission heterogeneity

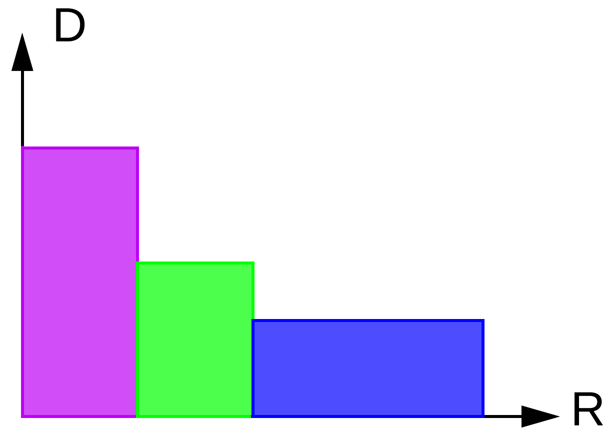
Different users absorb different bit rates

- computation heterogeneity

Solution: layered multicast trees

- different layers are transmitted over independent trees
- automatic subscribe/unsubscribe
- dynamic quality management





MR coding for multicast over the Internet

Video coder

- robust to packet loss: conditional replenishment
- layered: wavelet based (local CR with SBC)
- computationally efficient: software encoding/decoding in real-time on standard workstation

Networking

- multiple multicast sessions
- pruning and joining algorithms

Interaction of source and channel coding

- tight coupling between source coding and networking infrastructure

Lesson

- communications systems require tight coupling between key elements