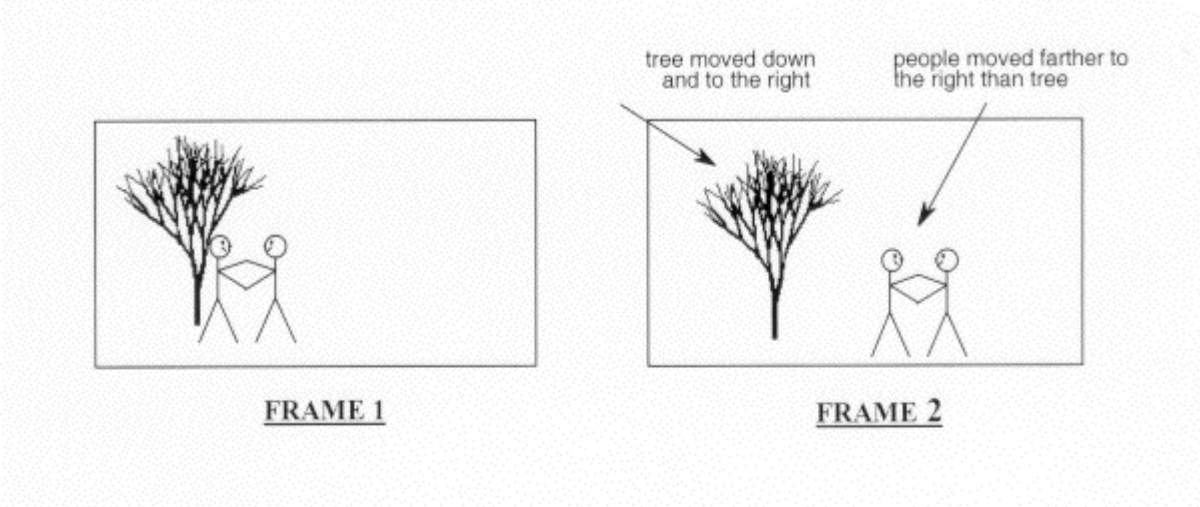
Motion Estimation

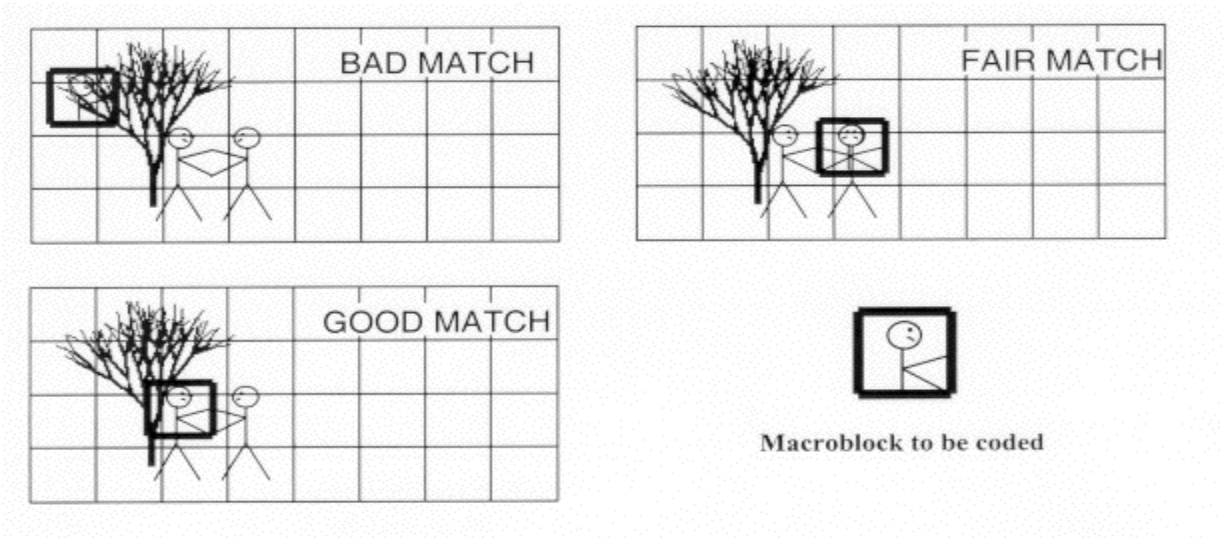
The temporal prediction technique used in MPEG video is based on motion estimation. The basic premise of motion estimation is that in most cases, consecutive video frames will be similar except for changes induced by objects moving within the frames. In the trivial case of zero motion between frames (and no other differences caused by noise, etc.), it is easy for the encoder to efficiently predict the current frame as a duplicate of the prediction frame. When this is done, the only information necessary to transmit to the decoder becomes the syntactic overhead necessary to reconstruct the picture from the original reference frame. When there is motion in the images, the situation is not as simple. Figure Below shows an example of a frame with 2 stick figures and a tree. The second half of this figure is an example of a possible next frame, where panning has resulted in the tree moving down and to the right, and the figures have moved farther to the right because of their own movement outside of the panning. The problem for motion estimation to solve is how to adequately represent the changes, or differences, between these two video frames.



Motion Estimation Example

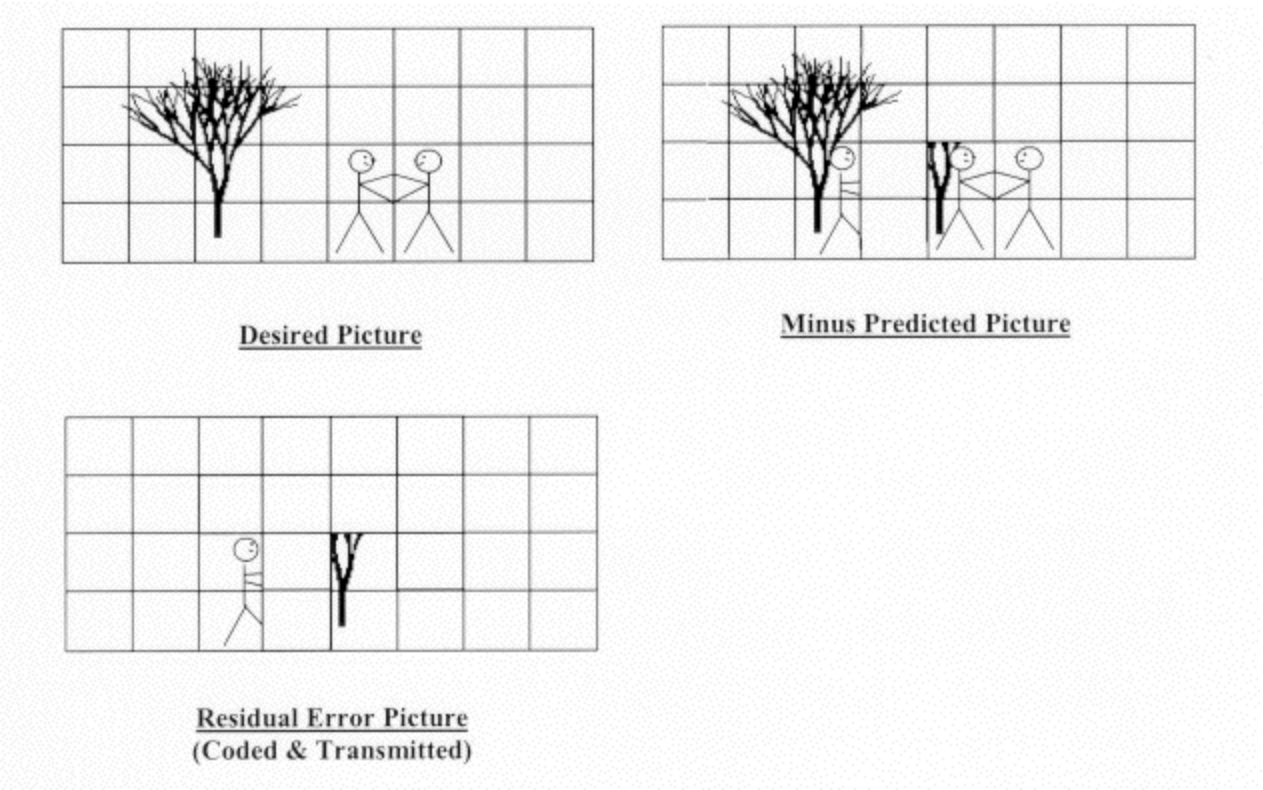
The way that motion estimation goes about solving this problem is that a comprehensive 2-dimensional spatial search is performed for each luminance macroblock. Motion estimation is not applied directly to chrominance in MPEG video, as it is assumed that the color motion can be adequately represented with the same motion information as the luminance. It should be noted at this point that MPEG does not define how this search should be performed. This is a detail that the system designer can choose to implement in one of many possible ways. This is similar to the bit-rate control algorithms discussed previously, in the respect that complexity vs. quality issues need to be addressed relative to the individual application. It is well known that a full, exhaustive search over a wide 2-dimensional area yields the best matching results in most cases, but this performance comes at an extreme computational cost to the encoder. As motion estimation usually is the most computationally expensive portion of the video encoder, some lower cost encoders might choose to limit the pixel search range, or use other techniques such as telescopic searches, usually at some cost to the video quality.

Figure 7.18 shows an example of a particular macroblock from Frame 2 of Figure 7.17, relative to various macroblocks of Frame 1. As can be seen, the top frame has a bad match with the macroblock to be coded. The middle frame has a fair match, as there is some commonality between the 2 macroblocks. The bottom frame has the best match, with only a slight error between the 2 macroblocks. Because a relatively good match has been found, the encoder assigns motion vectors to the macroblock, which indicate how far horizontally and vertically the macroblock must be moved so that a match is made. As such, each forward and backward predicted macroblock may contain 2 motion vectors, so true bidirectionally predicted macroblocks will utilize 4 motion vectors.



Motion Estimation Macroblock Example

Figure 7.19 shows how a potential predicted Frame 2 can be generated from Frame 1 by using motion estimation. In this figure, the predicted frame is subtracted from the desired frame, leaving a (hopefully) less complicated residual error frame that can then be encoded much more efficiently than before motion estimation. It can be seen that the more accurate the motion is estimated and matched, the more likely it will be that the residual error will approach zero, and the coding efficiency will be highest. Further coding efficiency is accomplished by taking advantage of the fact that motion vectors tend to be highly correlated between macroblocks. Because of this, the horizontal component is compared to the previously valid horizontal motion vector and only the difference is coded. This same difference is calculated for the vertical component before coding. These difference codes are then described with a variable length code for maximum compression efficiency.



Final Motion Estimation Prediction

Of course not every macroblock search will result in an acceptable match. If the encoder decides that no acceptable match exists (again, the "acceptable" criterion is not MPEG defined, and is up to the system designer) then it has the option of coding that particular macroblock as an intra macroblock, even though it may be in a P or B frame. In this manner, high quality video is maintained at a slight cost to coding efficiency.

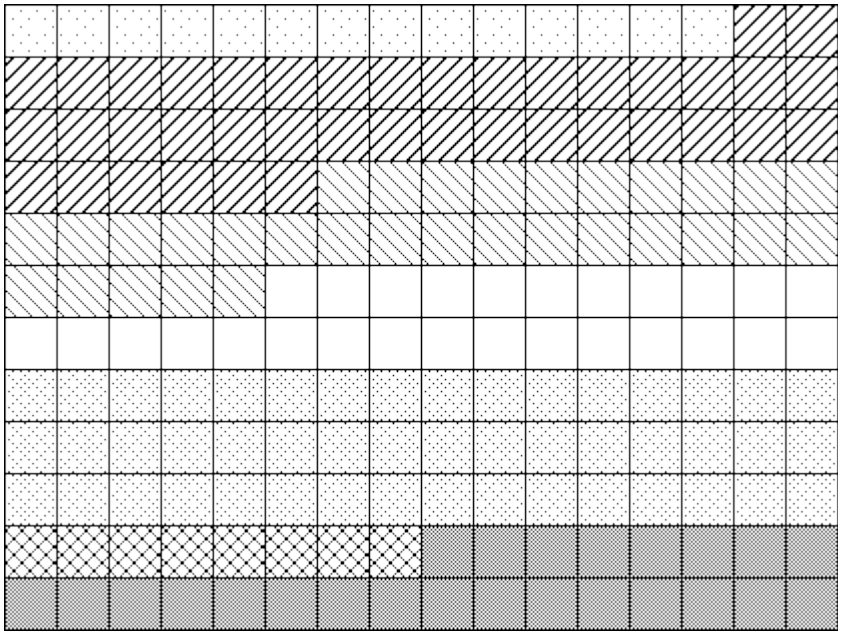
Coding of Predicted Frames: Coding Residual Errors

After a predicted frame is subtracted from its reference and the residual error frame is generated, this information is spatially coded as in I frames, by coding 8x8 blocks with the DCT, DCT coefficient quantization, run-length/amplitude coding, and

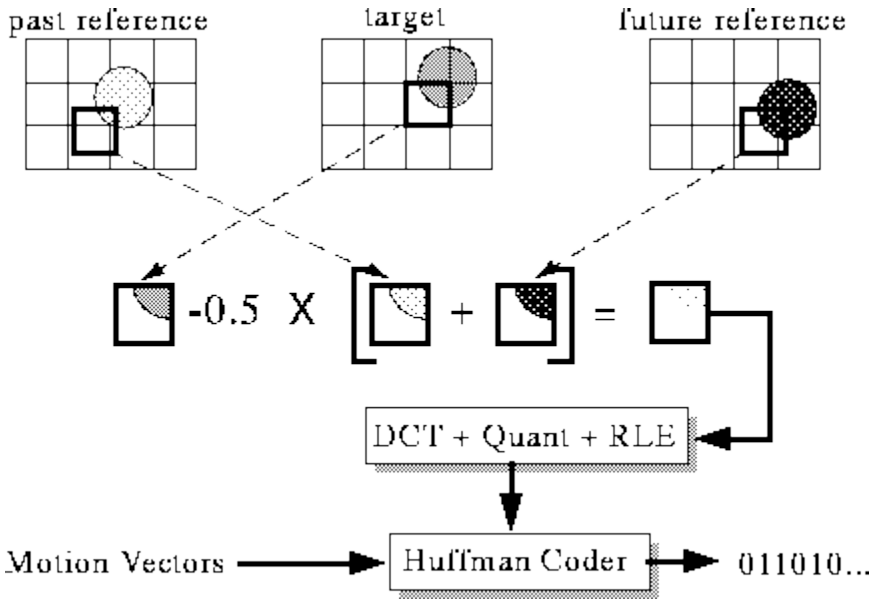
bitstream buffering with rate control feedback. This process is basically the same with some minor differences, the main ones being in the DCT coefficient quantization. The default quantization matrix for non-intra frames is a flat matrix with a constant value of 16 for each of the 64 locations. This is very different from that of the default intra quantization matrix which is tailored for more quantization in direct proportion to higher spatial frequency content. As in the intra case, the encoder may choose to override this default, and utilize another matrix of choice during the encoding process, and download it via the encoded bitstream to the decoder on a picture basis. Also, the non-intra quantization step function contains a dead-zone around zero that is not present in the intra version. This helps eliminate any lone DCT coefficient quantization values that might reduce the run-length amplitude efficiency. Finally, the motion vectors for the residual block information are calculated as differential values and are coded with a variable length code according to their statistical likelihood of occurrence.

Differences from H.261

- Larger gaps between I and P frames, so expand motion vector search range.
- To get better encoding, allow motion vectors to be specified to fraction of a pixel (1/2 pixels).
- Bitstream syntax must allow random access, forward/backward play, etc.
- Added notion of *slice* for synchronization after loss/corrupt data. Example: picture with 7 slices:



- B frame macroblocks can specify *two* motion vectors (one to past and one to future), indicating result is to be averaged.



Compression performance of MPEG 1

Type	Size	Compression

I	18 KB	7:1
P	6 KB	20:1
B	2.5 KB	50:1
Avg	4.8 KB	27:1