Research Institute for Future Media Computing 未来媒体技术与研究所 Institute of Computer Vision 计算机视觉研究所

视频压缩技术
Basic Video Compression Techniques

Outline of Lecture 10

- Introduction to Video Compression
- Video Compression with Motion Compensation
- Motion Compensation
- Sequential Search
- Logarithmic Search
- Hierarchical Search
- Reference reading
  - Chapter 10

Introduction to Video Compression

- A video consists of a time-ordered sequence of frames → images

- An obvious solution to video compression would be predictive coding based on previous frames
  - Compression proceeds by subtracting images: subtract in time order and code the residual error

Introduction to Video Compression

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Introduction to Video Compression

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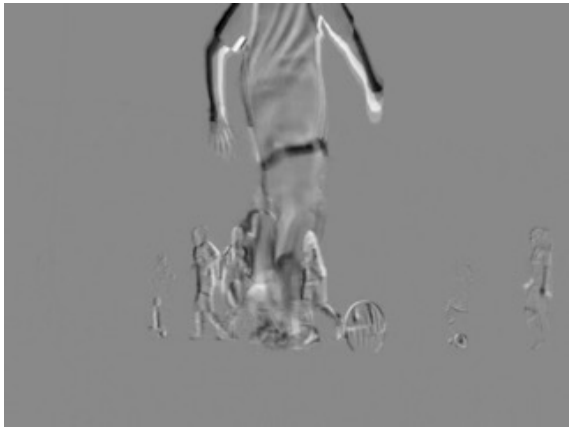
Introduction to Video Compression

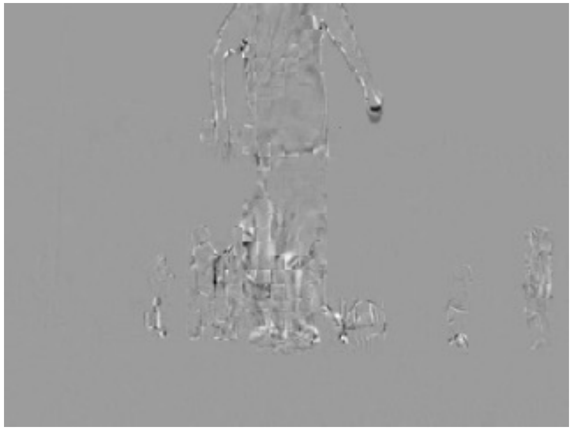
- It can be done even better by searching for just the right parts of the image to subtract from the previous frame

Reference

Target



prediction without MC



MC prediction

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Video Compression with Motion Compensation (运动补偿)

- Temporal redundancy (时间冗余) exists between consecutive (连续的) frames
  - Not every frame of the video needs to be coded independently (独立的) as a new image
  - The difference between the current frame and other frame(s) in the sequence will be coded.
- Steps of video compression based motion compensation (MC)
  - Motion estimation
  - MC-based prediction
  - Derivation of the prediction error

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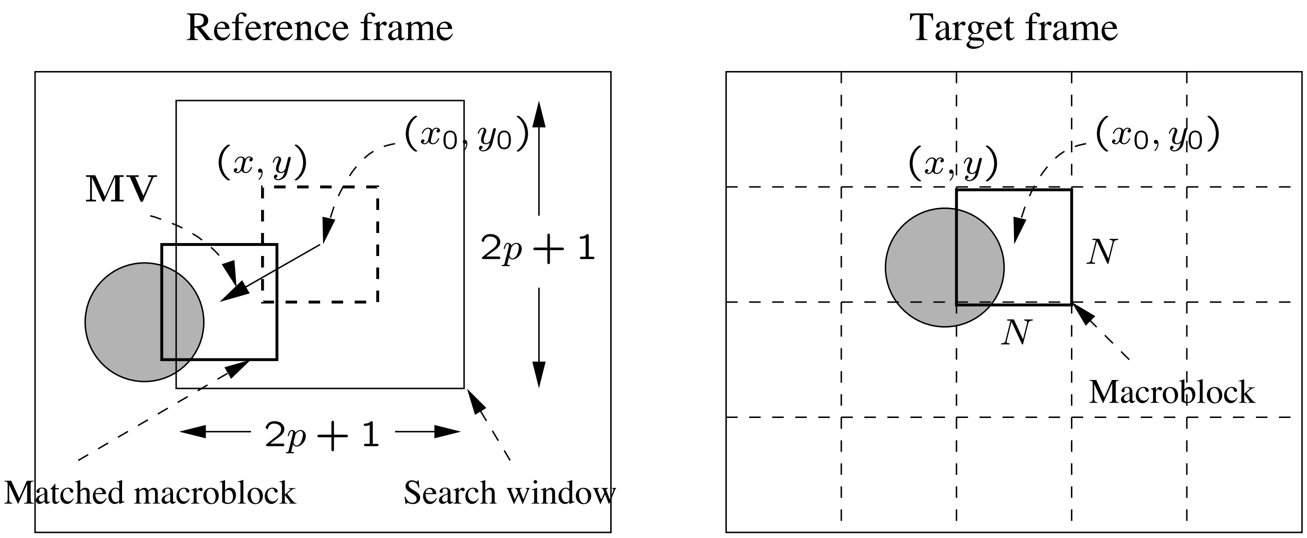
Motion Compensation

- Each image is divided into macroblocks（宏块）of size N × N .
  - By default, N = 16 for luminance images.
  - For chrominance images, N = 8 if 4:2:0 chroma subsampling is adopted.
- Motion compensation is performed at the macroblock level.
  - The current image frame is referred to as ***Target Frame***.
  - A match is sought between the macroblock in the Target Frame and the most similar macroblock in previous and/or future frame(s) (referred to as ***Reference frame***(*s*)).
  - The displacement of the reference macroblock to the target macroblock is called a *motion vector* **MV**.

Macroblocks and Motion Vector in Video Compression



- MV search is usually limited to a small immediate neighborhood — both horizontal and vertical displacements in the range $[-p, p]$.

This makes a search window of size $(2p + 1) \times (2p + 1)$.

Search for Motion Vectors

- Calculating the displacement of the reference macroblock to the target macroblock

Reference image

Target image

Search for Motion Vectors

- The difference between two macroblocks can be measured by Mean Absolute Difference (MAD)，平均绝对误差

$$MAD(i,j) = \frac{1}{N^2} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} |C(x+k, y+l) - R(x+i+k, y+j+l)|$$

N – size of the macroblock,

k and l – indices for pixels in the macroblock,

i and j – horizontal and vertical displacements,

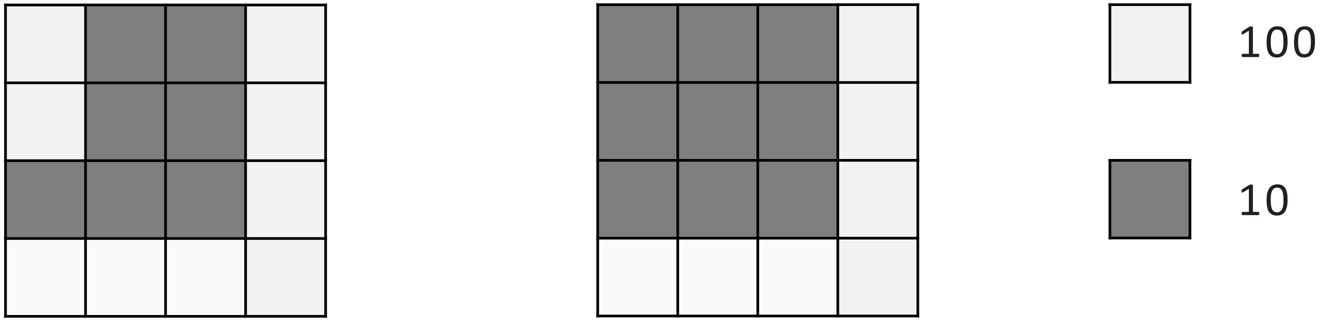
$C(x+k, y+l)$ – pixels in macroblock in Target frame,

$R(x+i+k, y+j+l)$ – pixels in macroblock in Reference frame.

- The goal of the search is to find a vector (i, j) as the motion vector MV = (u,v), such that MAD(i, j) is minimum

$$(u, v) = [\ (i, j)\ \mid MAD(i, j) \text{ is minimum}, i \in [-p, p],\ j \in [-p, p]\ ]$$

Mean Absolute Difference (MAD)



Reference

Target

Calculate MAD：
MAD=(|10-100|+|10-100|+7* |10-10|+7* |100-100|)/16=180/16

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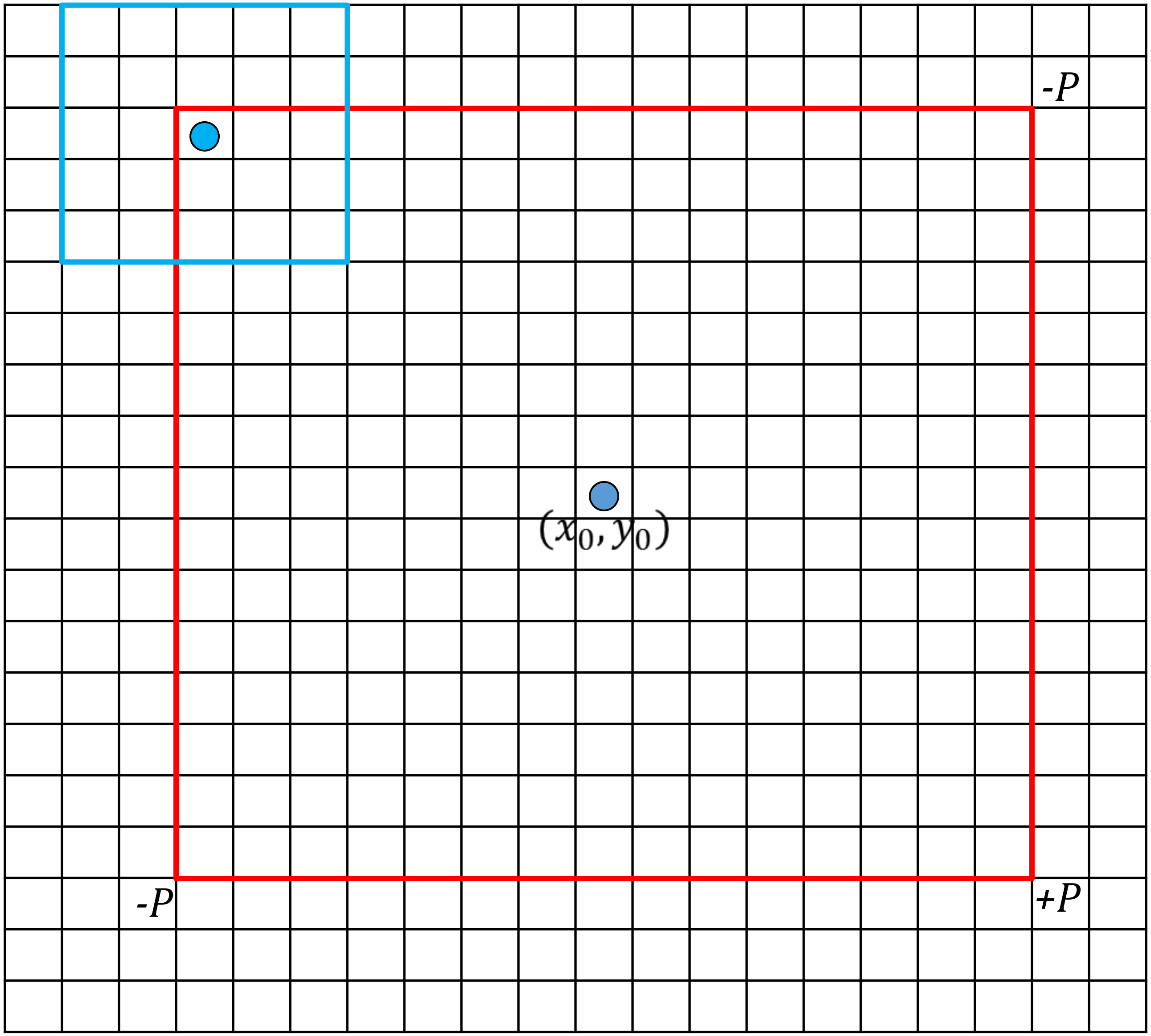
Sequential Search（顺序搜索）



P=7

N=5

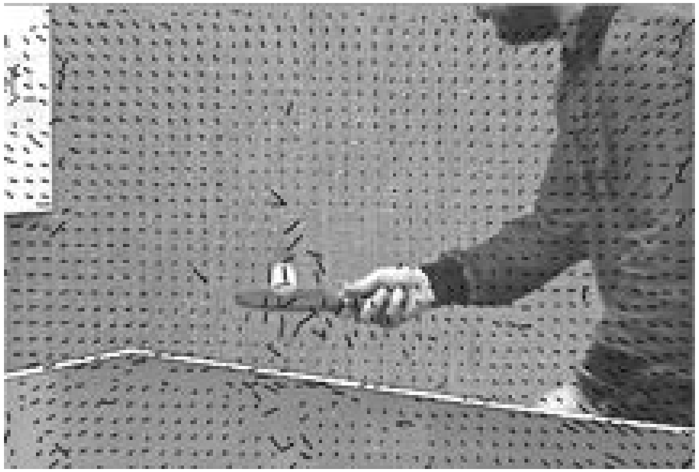
Sequential Search（顺序搜索）

- Sequential search: sequentially search the whole $(2p+1) \times (2p+1)$ window in the Reference frame

  - The vector (i, j) that offers the least M AD is designated as the MV (u, v) for the macroblock in the Target frame.
  - This method is costly — assuming each pixel comparison requires three operations (subtraction, absolute value, addition), the cost for obtaining a motion vector for a single macroblock is

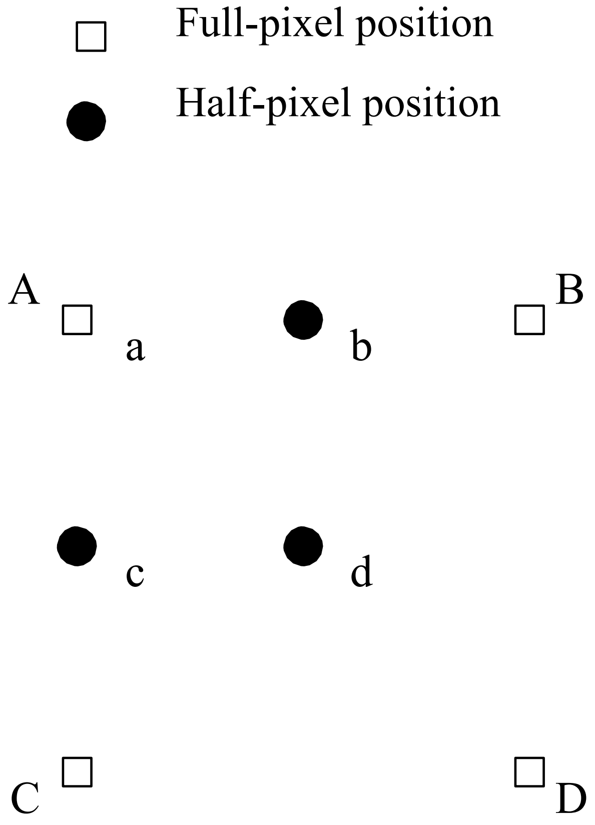
$$(2p+1)\cdot(2p+1)\cdot N^2\cdot 3 \Rightarrow \mathrm{O}(p^2N^2)$$

Sequential Search（顺序搜索）



- See demo ***predictionMC.m***

思考：MV（u，v）只能为整数吗？


□ Full-pixel position

● Half-pixel position

Half-pixel Prediction by Bilinear Interpolation in H.263

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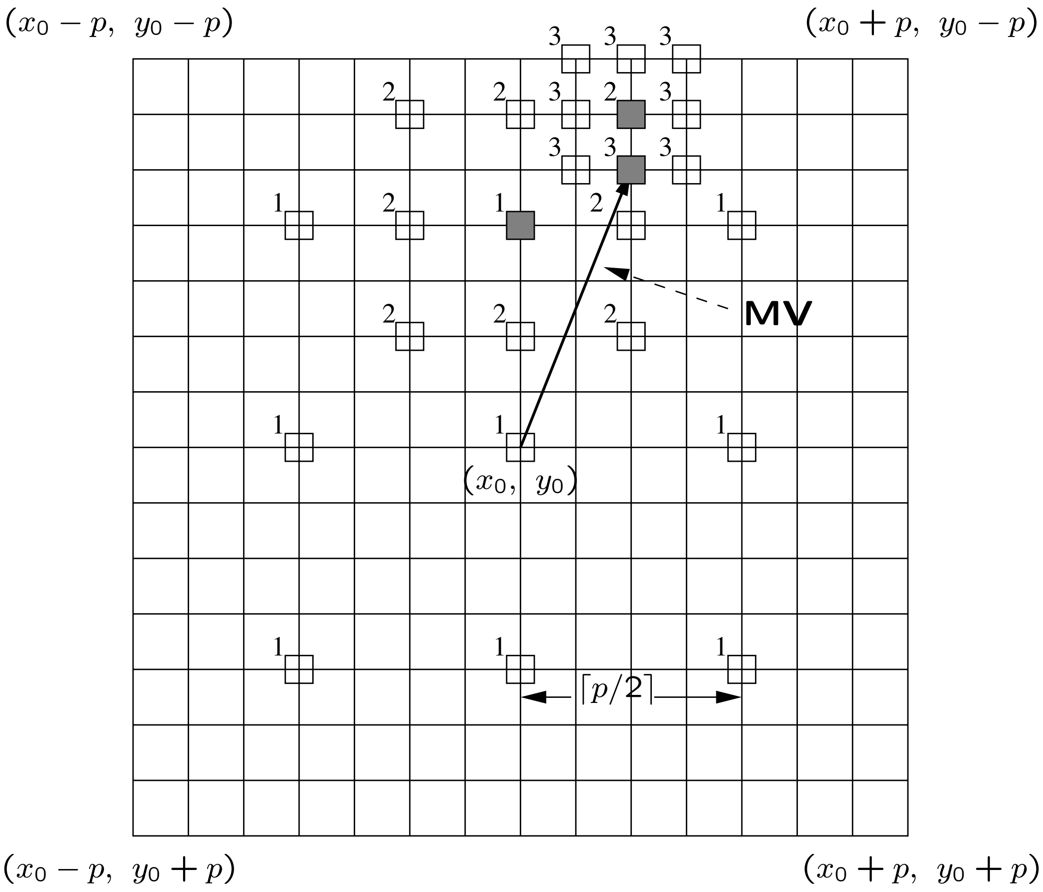
2D Logarithmic Search

- Logarithmic search: a cheaper version, which is suboptimal but usually effective
- The procedure for 2D Logarithmic search takes several iterations (迭代) and is akin to a binary search
  - Initially only nine locations in the search window are used as seeds for a MAD-based search
  - After the one that yields the minimum *MAD* is located, the center of the new search region is moved to it and the step-size ("offset") is reduced to half
  - In the next iteration, the nine new locations are marked as '2', and so on.

2D Logarithmic Search for Motion Vectors

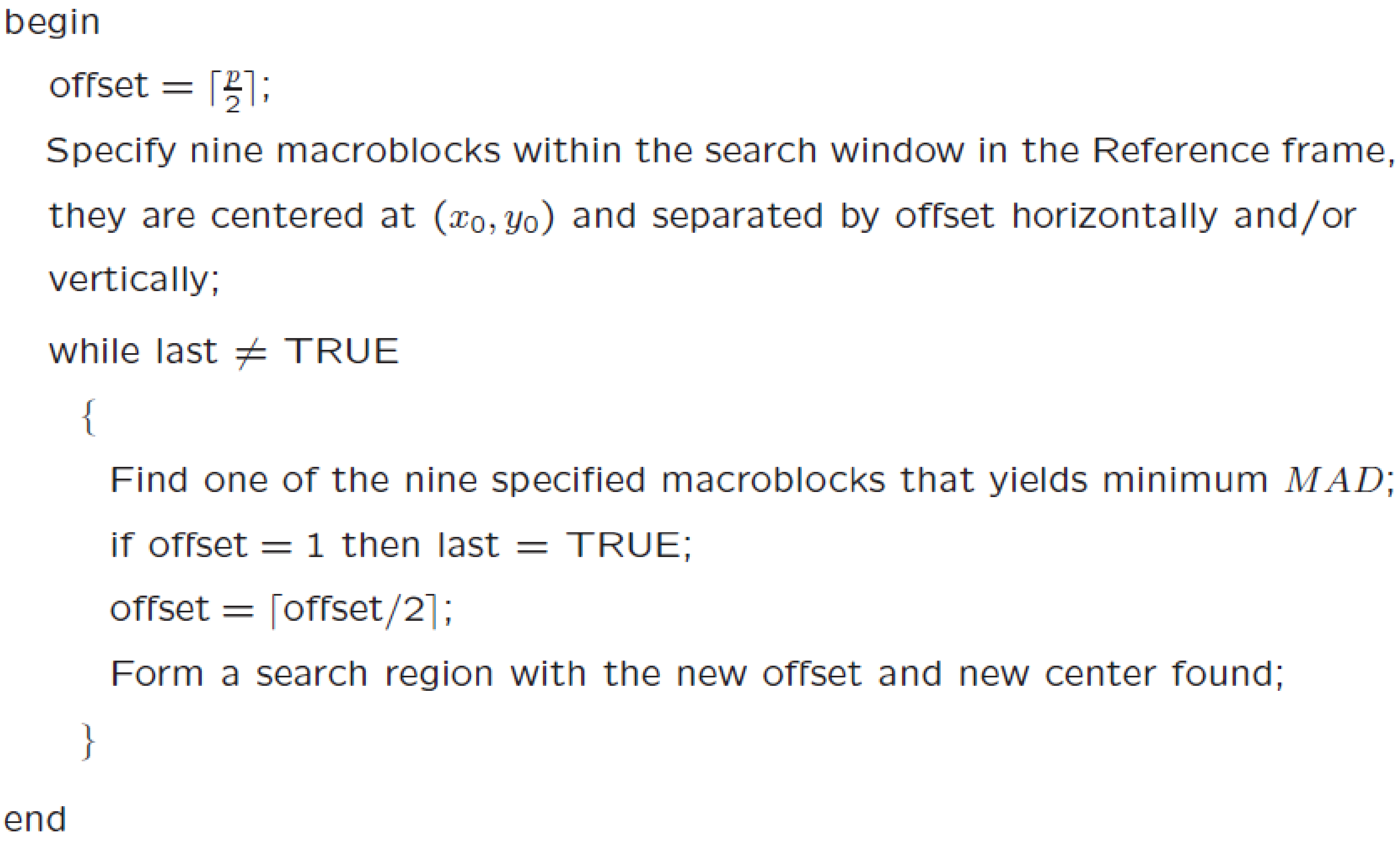


The total operations per second is dropped to:

$$O(\log p^{*} N^{2})$$

每一步搜索：步长=$\left\lceil \frac{p}{2} \right\rceil$, 最优MV，MAD

Algorithm of 2D-Logarithmic Search



```
begin
    offset = $\lceil \frac{p}{2} \rceil$;
    Specify nine macroblocks within the search window in the Reference frame,
    they are centered at $(x_0, y_0)$ and separated by offset horizontally and/or
    vertically;
    while last $\neq$ TRUE
      {
        Find one of the nine specified macroblocks that yields minimum $MAD$;
        if offset = 1 then last = TRUE;
        offset = $\lceil$offset/2$\rceil$;
        Form a search region with the new offset and new center found;
      }
end
```

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Hierarchical Search （分层搜索）

- Sequential search method is very costly

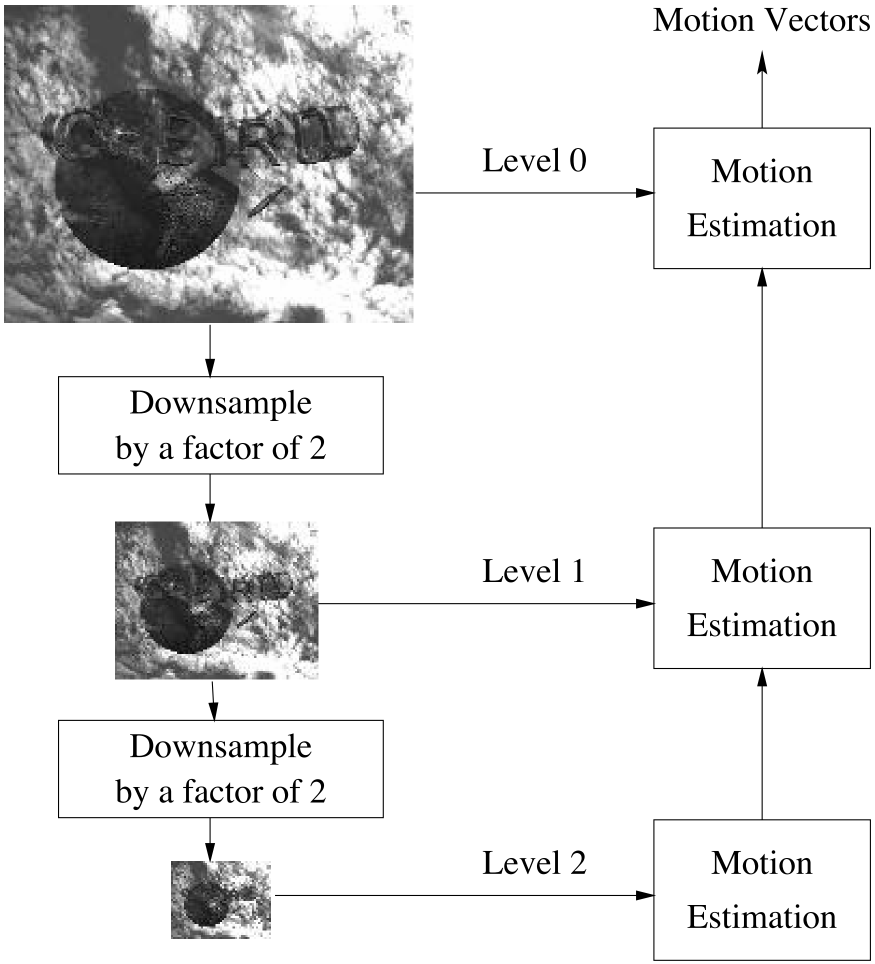
$$(2p+1)\cdot(2p+1)\cdot N^2\cdot 3 \Rightarrow O(p^2N^2)$$

- Reduce p and N, could reduce the cost.
- The search can benefit from a hierarchical (multiresolution) approach in which initial estimation of the motion vector can be obtained from images with a significantly reduced resolution.

A Three-level Hierarchical Search for Motion Vectors

Original image is at Level 0, images at Levels 1 and 2 are obtained by down-sampling from the previous levels by a factor of 2, and the initial search is conducted at Level 2.

Since the size of the macroblock is smaller and p can also be proportionally reduced, the number of operations required is greatly reduced.



Comparison of Computational Cost

Search Method	OPS_per_second for 720 × 480 at 30 fps	
	p = 15	p = 7
Sequential search	29.89×10^9	7.00×10^9
2D Logarithmic search	1.25×10^9	0.78×10^9
3-level Hierarchical search	0.51×10^9	0.40×10^9

练习题

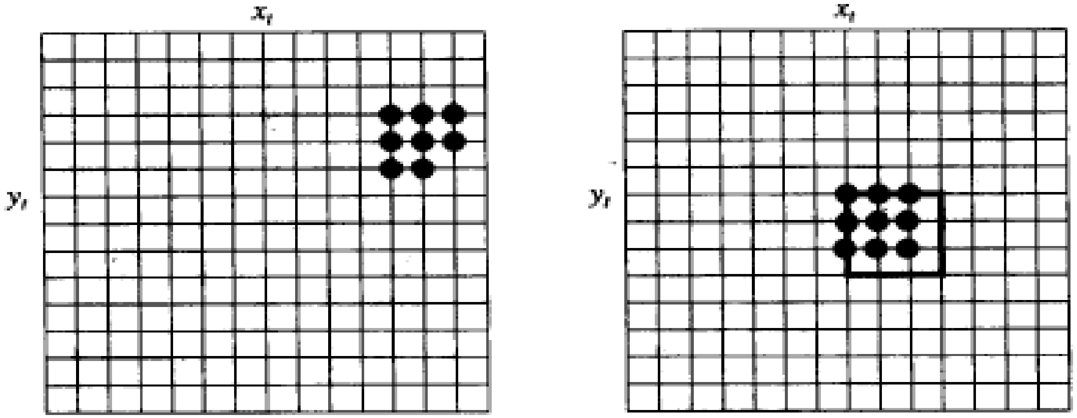
4. 回答下面用于运动向量的 2D 对数搜索的问题（见图 10-14）。

目标（当前）帧为 P 帧。宏块的大小为 4×4。运动向量是 $MV(\Delta x, \Delta y)$，其中 $\Delta x \in [-p, p]$，$\Delta y \in [-p, p]$。在这个问题中，假设 $p = 5$。

帧中黑色的宏块左上角的坐标是 (x_t, y_t)。它包含 9 个黑色的像素，每个像素的亮度值为 10；其余 7 个像素点是背景的一部分，统一亮度值为 100。参考帧（前一帧）有 8 个黑色像素点。

（a）求 Δx 、Δy 的最优值，宏块的平均绝对误差（MAE）是多少？

（b）一步步地说明如何进行 2D 对数搜索，包括搜索的位置和通道以及 Δx 、 Δy 和 MAE 的所有中间值。



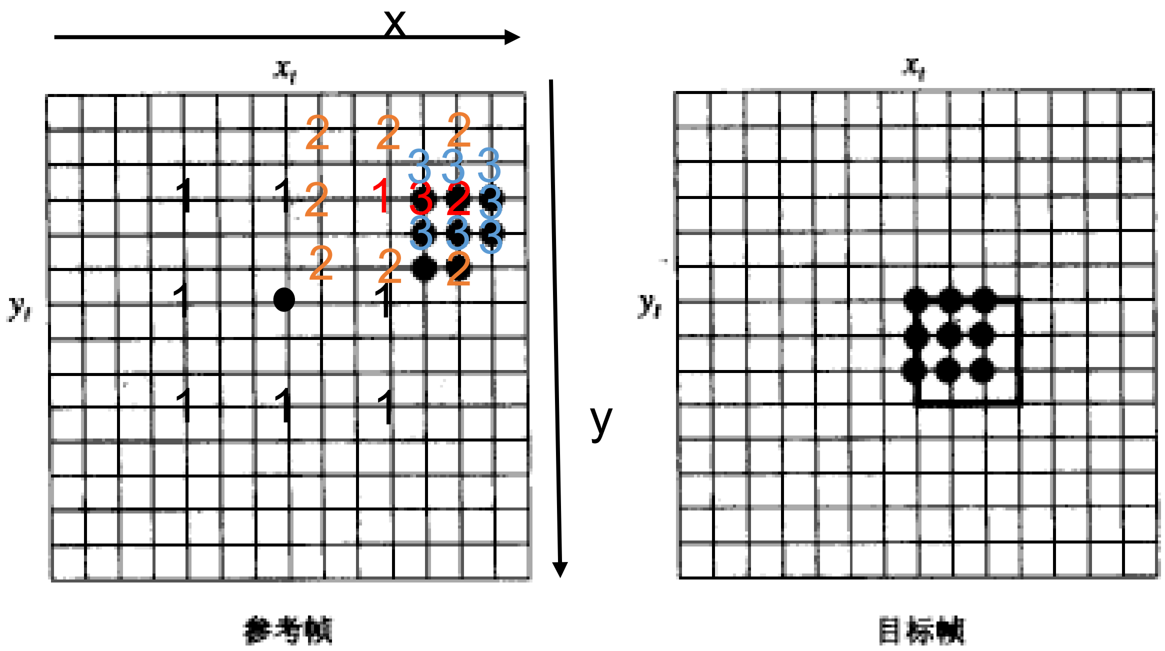
参考帧　　　　目标帧

● 亮度值为 10 的像素

其他是背景（未标识）像素，亮度为 100

图 10-14　运动向量的 2D 对数搜索

练习题



第一步搜索，步长为$\left\lceil \frac{5}{2} \right\rceil$=3，最优MV (3,-3)，MAD为 5*|10-100|/16

第二步搜索，步长为$\left\lceil \frac{3}{2} \right\rceil$=2，最优MV (5,-3)，MAD为 4*|10-100|/16

第三步搜索，步长为$\left\lceil \frac{2}{2} \right\rceil$=1，最优MV (4,-3)，MAD为 |10-100|/16

思考题

- 在基于块的视频编码中，压缩或者解压缩哪个耗费代价高？简要说明原因。

- 答：压缩环节耗费代价高，因为运动向量的获取，需要多次比较计算当前帧中的预测块与参考帧中的待匹配块之间的MAD值；而解码时仅需直接从码流中根据运动向量的值，进行运动补偿即可。