2-Dimensional Motion Estimation

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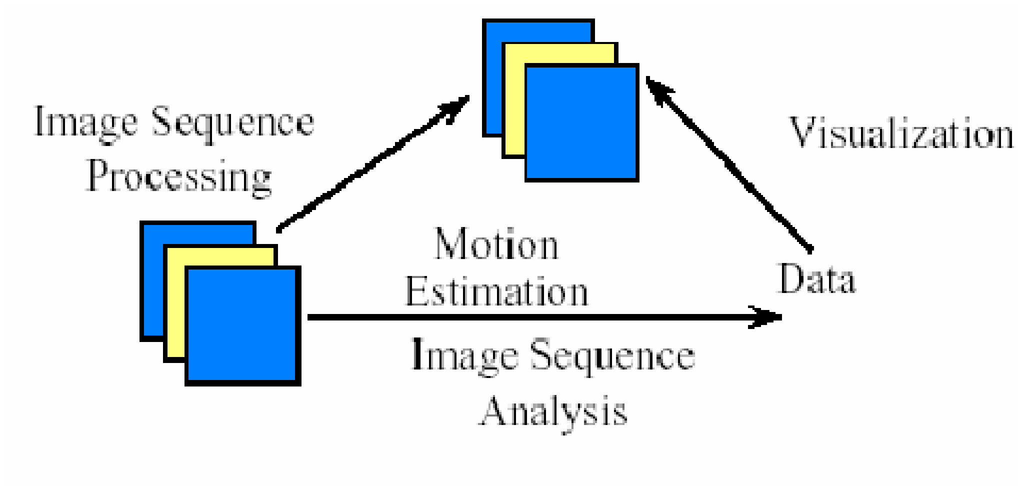
Outline

- Introduction
- 2D Motion and Optical flow
- Optical Flow Equation
- General Methodologies of Motion Estimation Algorithms
  - Parameterization of the motion field ➔ motion representation
  - Formulation of the optimization criteria➔ optimization criteria
  - Searching for the optimal parameters ➔ optimization method
- Pixel Based Motion Estimation
- Block Based Motion Estimation
- Multiresolution Motion Estimation
- Summary

Introduction

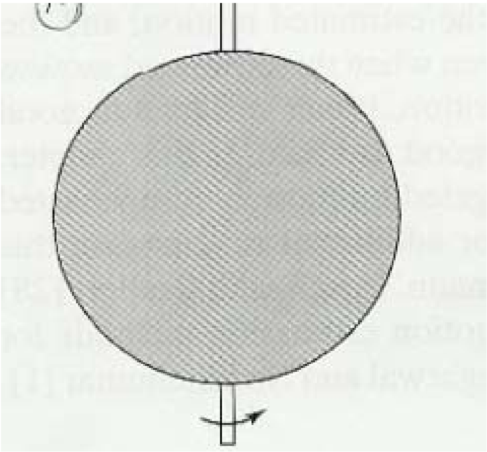


- Applications:
  - Preprocessing step for 3D structure extraction and motion estimation
  - Video Coding: efficient transmission and storage
  - Sampling rate conversion: de-interlacing, frame rate conversion
  - Filtering: noise suppression, de-blurring

2D Motion and Optical flow

- Human eye perceives motion by identifying corresponding points at different times
- Difference between observed 2D motion and the actual projected 2D motion
  - Example one:

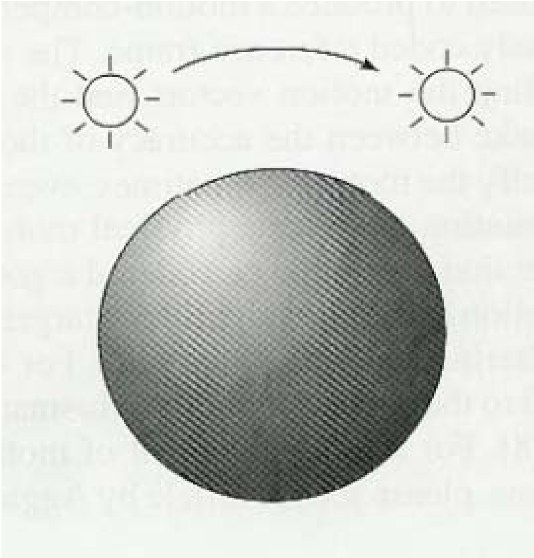
    A uniform flat surface sphere rotating under a constant ambient light



2D Motion and Optical flow

Example 2:

A stationary sphere, illuminated by a point light source rotating around the sphere



- So, Observed motion may not be the same as the true 2D motion
- Observed or apparent 2D motion is referred to as Optical flow
- Optical flow can be caused by
  - Object motion
  - Camera movements
  - Illumination condition changes

Optical Flow Equation

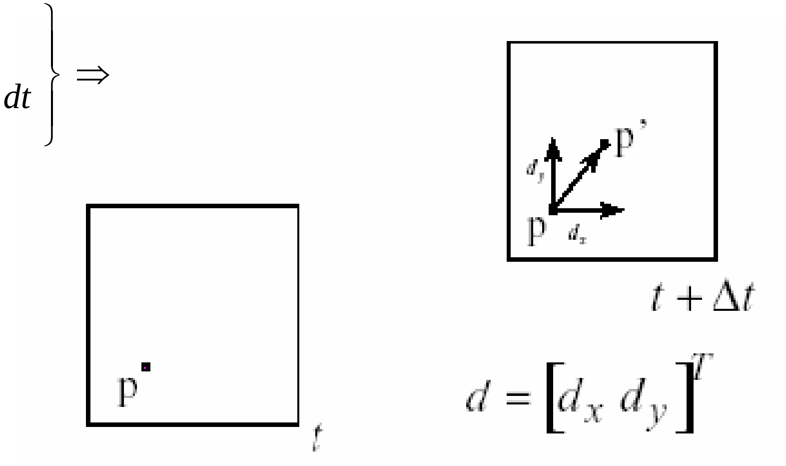
Under the constant intensity assumption:

$$\left.\begin{aligned}&\psi(x+dx,\, y+dy,\, t+dt) = \psi(x,y,t)\\ &\psi(x+dx,\, y+dy,\, t+dt) = \psi(x,y,t) + \frac{\partial\psi}{\partial x}dx + \frac{\partial\psi}{\partial y}dy + \frac{\partial\psi}{\partial t}dt\end{aligned}\right\} \Rightarrow$$

$$\frac{\partial\psi}{\partial x}dx + \frac{\partial\psi}{\partial y}dy + \frac{\partial\psi}{\partial t}dt = 0$$

$$\frac{\partial\psi}{\partial x}v_x + \frac{\partial\psi}{\partial y}v_y + \frac{\partial\psi}{\partial t} = 0$$

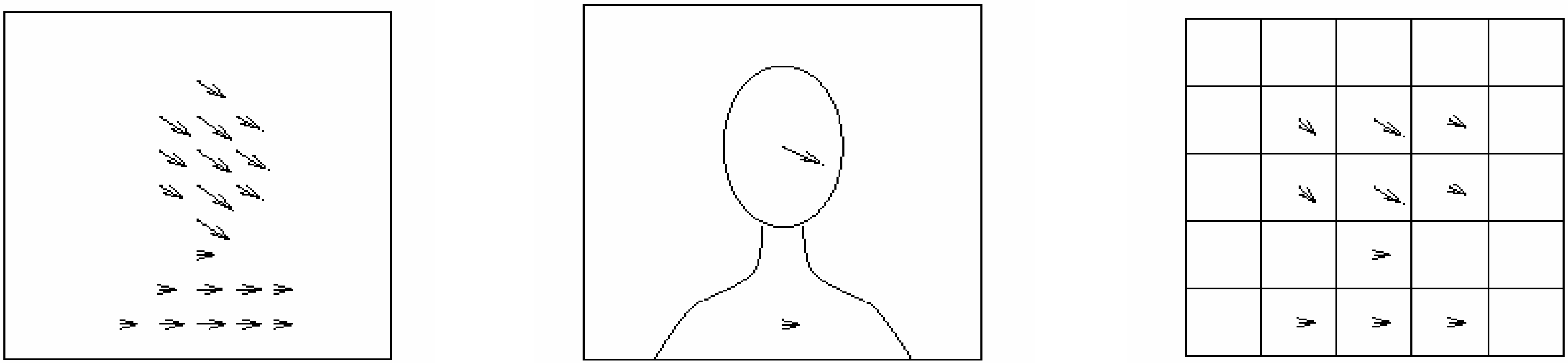
$$\nabla\psi^T V + \frac{\partial\psi}{\partial t} = 0$$



General Methodologies of Motion Estimation Algorithms

- The problem of motion estimation can be converted to an optimization problem
- Solving the problem involves:
  - Parameterization of the motion field ➔ motion representation
  - Formulation of the optimization criteria➔ optimization criteria
  - Searching for the optimal parameters ➔ optimization method

Motion Representation



(1) (2) (3)

(1) Pixel Based Representation
(2) Region Based Representation
(3) Block Based Representation

Motion Representation

- Pixel Based Representation
  - Large number of unknowns for estimation (twice the number of pixels)
  - The solution can be physically incorrect unless proper constraints are imposed

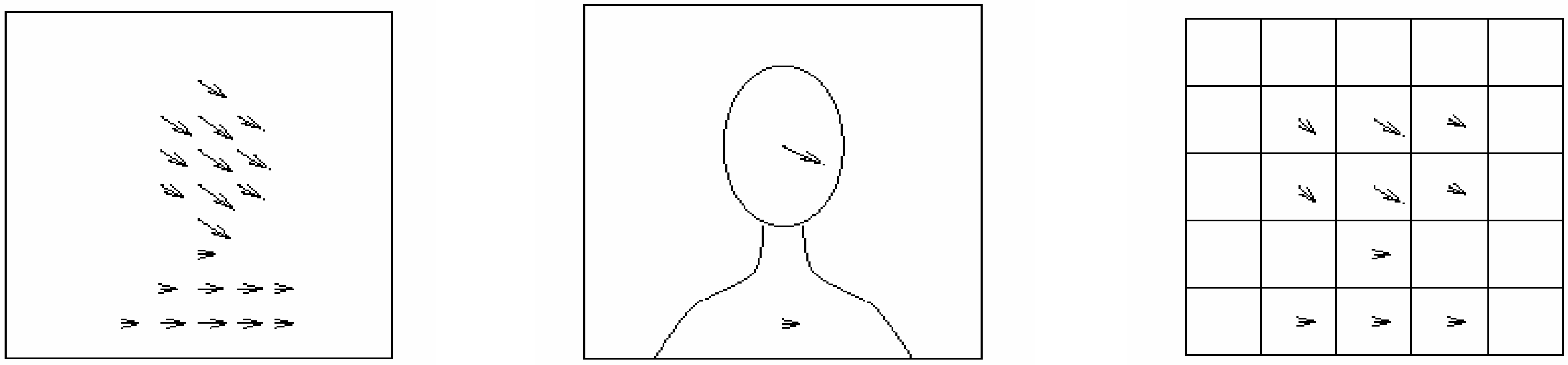
- Region Based Representation
  - Suitable for scenes with multiple moving objects
  - Consists of
    - Segmentation map
    - Several sets of motion parameters
  - Iterative Segmentation and estimation must be used
    - Intensive computation

Motion Representation

- Block Based Representation
  - Simple case of region based representation
    - Regions are well defined
  - A simple model characterize the motion within a block
  - Good compromise between accuracy and complexity
  - No constraint on the motion transition between adjacent blocks

- Mesh Based Representation

Motion Representation



(1) (2) (3)

(1) Pixel Based Representation
(2) Region Based Representation
(3) Block Based Representation

Motion Estimation Criteria

- Displaced Frame Difference (DFD) Based criteria

$$E_{DED}(dt) = \sum \left| \psi(x+dx, t+dt) - \psi(x,t) \right|^{p}$$

P=1: Mean Absolute Error

P=2: Mean Square Error

- Frequency domain Criteria

$$\frac{F\{\psi(x+dx, t+dt)\}}{F\{\psi(x,t)\}} = \exp\left(j2\pi\, f\, dx\right) \qquad f = (f_x, f_y)$$

- Regularization

Optimization Methods

- Exhaustive Search Method
  - Generally use MAE
    - Computational complexity
  - Reaching the global minimum is guaranteed
  - Unfeasible for large number of unknown parameters or large range of parameters variation
  - Various fast algorithms can be developed

- Gradient Based Methods
  - Generally use MSE
    - Mathematical tractability
  - Only reaching to a local minimum is guaranteed
  - Gradient calculation methods accuracy influence the algorithm performance

Optimization Methods

- Phase correlation Methods

- Multiresolution Search Methods
  - Any of the previous methods may take advantage of multiresolution implementation to:
    - Decrease computation amount
    - Defeat local minima problem

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Pixel Based Motion Estimation

- Based on calculation of a Motion Vector (MV) for each pixel
  - The problem is ill-defined under constant intensity assumption
    - Could have any number of solutions
  - The problem is indeterminate using optical flow equation
    - Two unknown and one equation for each pixel

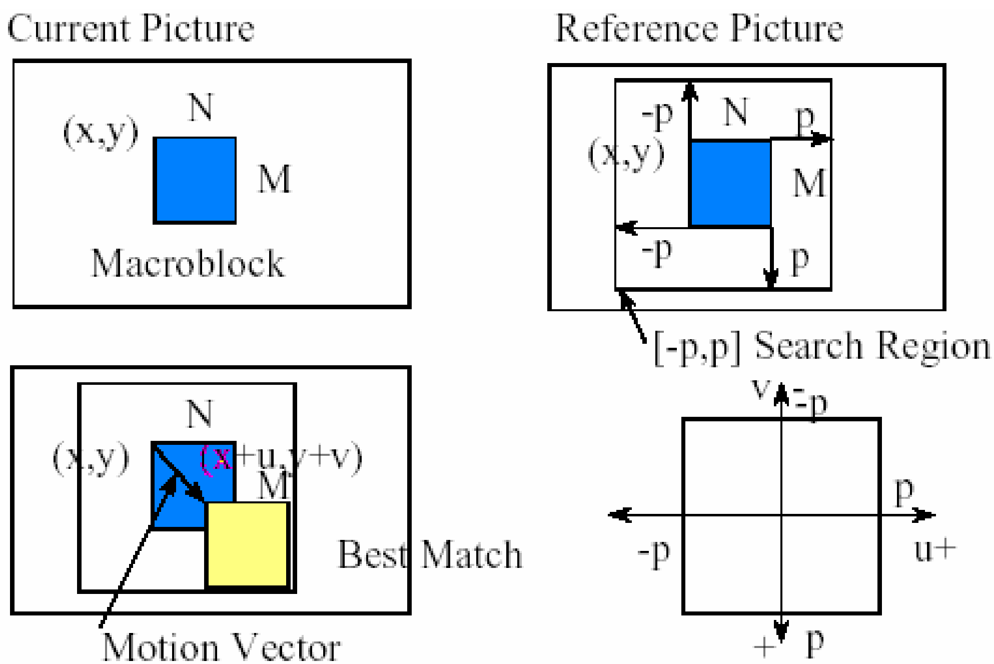
- Three general approaches are available
  - Using multipoint neighborhood MV to solve optical flow equations
  - Pel recursive methods
    - Simple algorithms
    - Prediction error is large
    - Error propagation problem

Block Based Motion Estimation

- The problem is to determine a matching block in the target frame

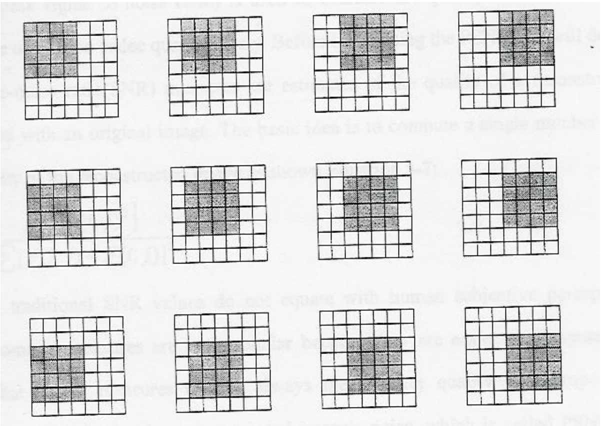
$$E(dx) = \sum_{x \in \beta_m} \left| \psi(X + dX, t + dt) - \psi(X, t) \right|^p$$

- The displacement vector between these two blocks is the MV of the block pixels



Block Based Motion Estimation: Exhaustive Search

- Determines the optimal matching block by comparing the original block with all candidate blocks



- Total number of candidates is $(2p+1)^2$ for a 512x512 frame with N=P=16 the number of operation per frame is 2.85x10^8 so with a frame rate of 30fps the number will be 8.55x10^9 per minute

Fast Algorithms for Block-Based Motion Estimation

- The key to speed up the EBMA is reducing the number of search candidates
- Various Fast algorithms have been developed
- They differ in the way of skipping candidates unlikely to have small error
- The most popular ones are:
  - Three-step search algorithm
  - 2D-log search algorithm
  - Four-step search algorithm
  - Orthogonal search algorithm
  - One at a time algorithm
  - Cross search algorithm

Three-Step Search Algorithm

- Step 1

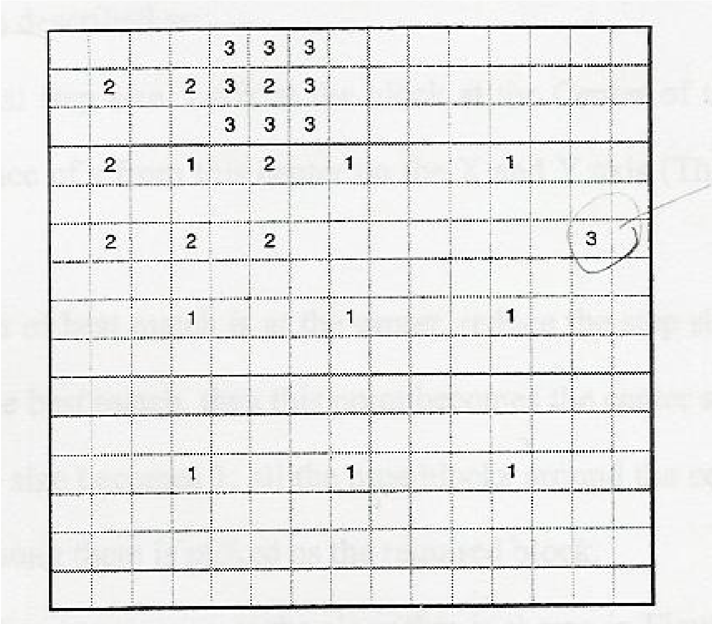
1. Select an initial step size (s) equal or slightly larger than half of the maximum search range
2. Calculate the error for the block at the center of search area and 8 square neighborhood point at the distance of s from center

- Step 2

1. Move the center to the point with minimum distortion
2. Reduce step size by a factor of two
3. If the step size is greater than one, repeat the step 1, otherwise go to step 3

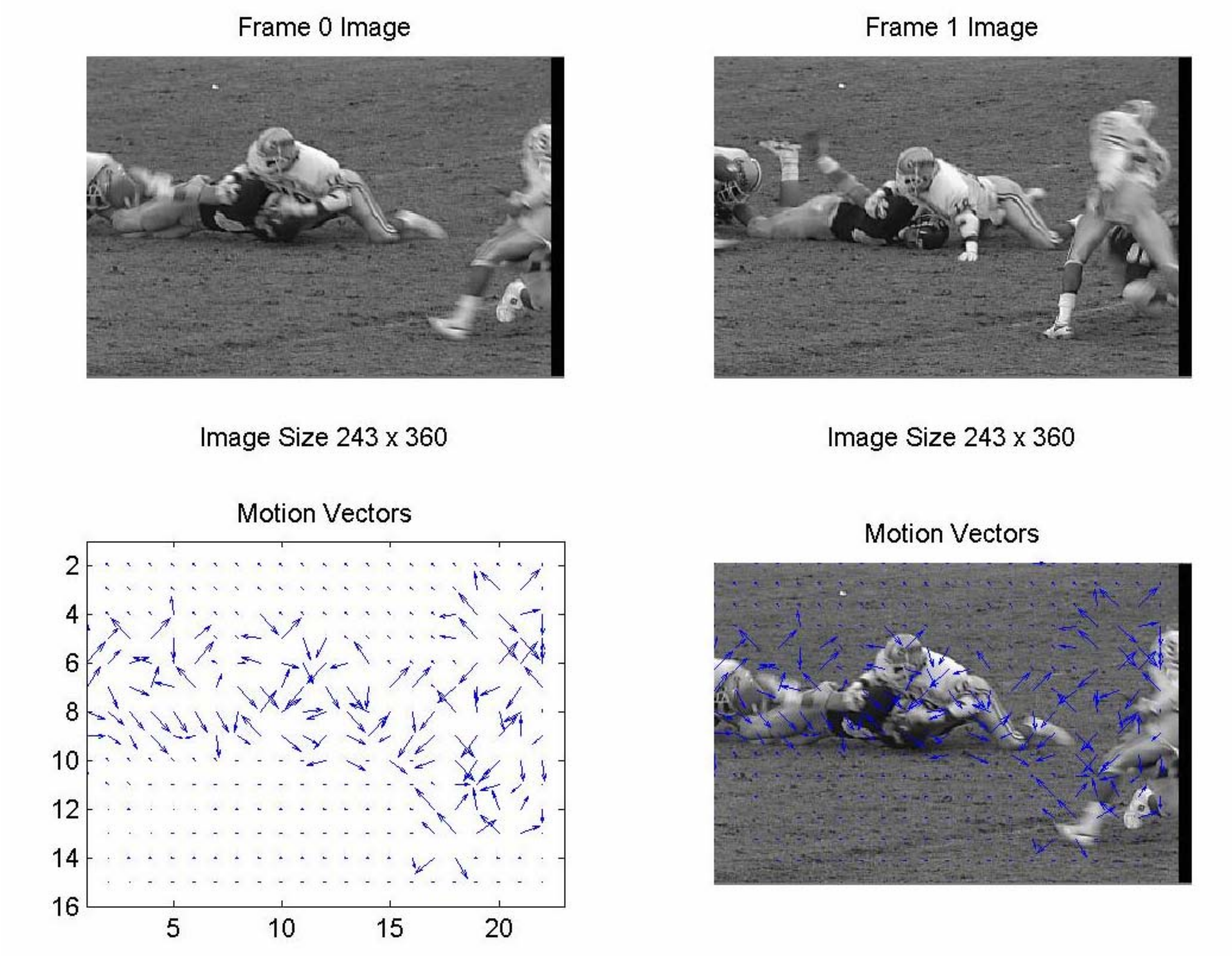
- Step 3

1. Final point with minimum distortion is the result



Three-Step Search Algorithm

Simulation Results



Three-Step Search Algorithm

- Advantages:
  - Low Complexity in terms of selected candidate locations
  - Good regularity in terms of motion vector generation

- Disadvantages:
  - Complexity factor increases with search area size
  - High data bandwidth

2D-Logarithmic Search Algorithm

- Step 1

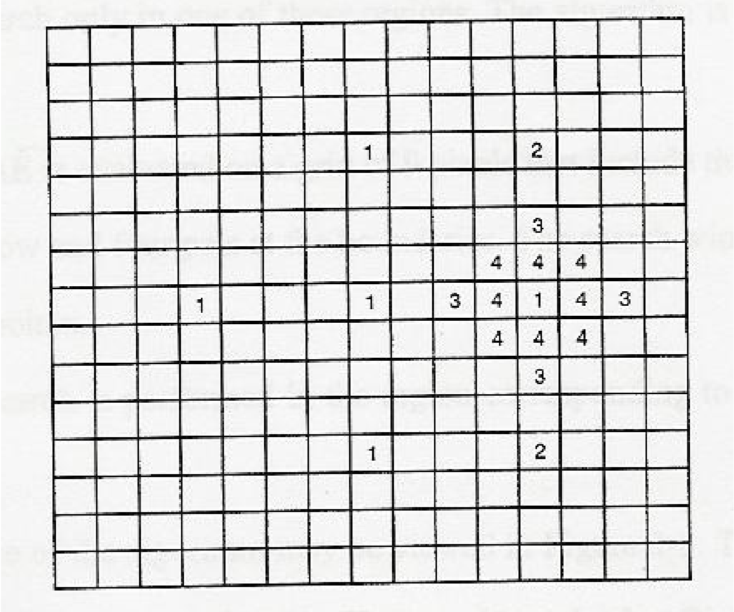
1. Select an initial step size (s)
2. Calculate the error for the block at the center of search area and four point at x and y axis at distance of s from center

- Step 2

1. If the position of best match is at centre keep the centre unchanged and reduce the step size by half, otherwise the best match becomes the center
2. Then step 1 is repeated

- Step 3

1. When the step size becomes 1 all the 8 neighbor blocks around the center will be checked for finding the best match



2D-Logarithmic Search Algorithm

Simulation results

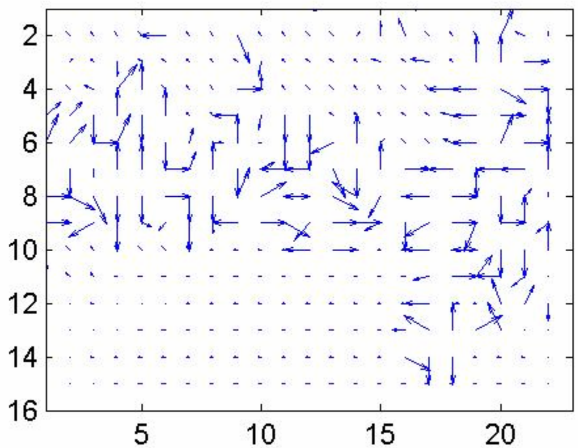
Frame 0 Image

Image Size 243 x 360

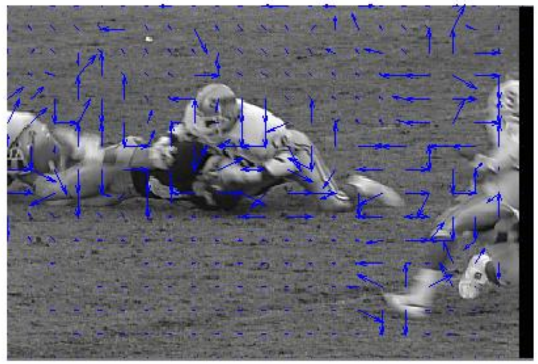
Frame 1 Image

Image Size 243 x 360

Motion Vectors



Motion Vectors

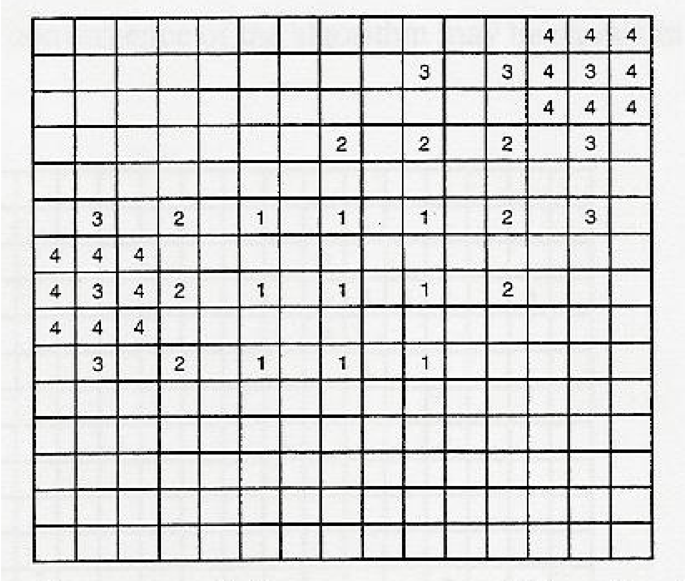


2D-Logarithmic Search Algorithm

- Advantage:
  - It is suitable for sequences with fast motion
- Disadvantage
  - The accuracy of algorithm is low when the motion vector is at an angle to x-y axis

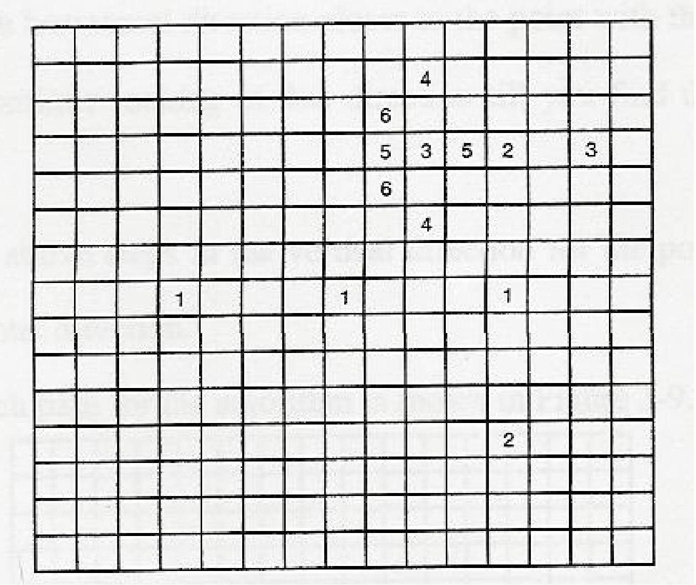
Four Step Search Algorithm

- Advantage:
  - Very Low complexity in terms of selected candidate locations
  - More accurate than three-step search
  - Memory bandwidth saving
  - For small motions, fewer steps calculation are needed
- Disadvantage:
  - Risk of local minima if motion is far away from center



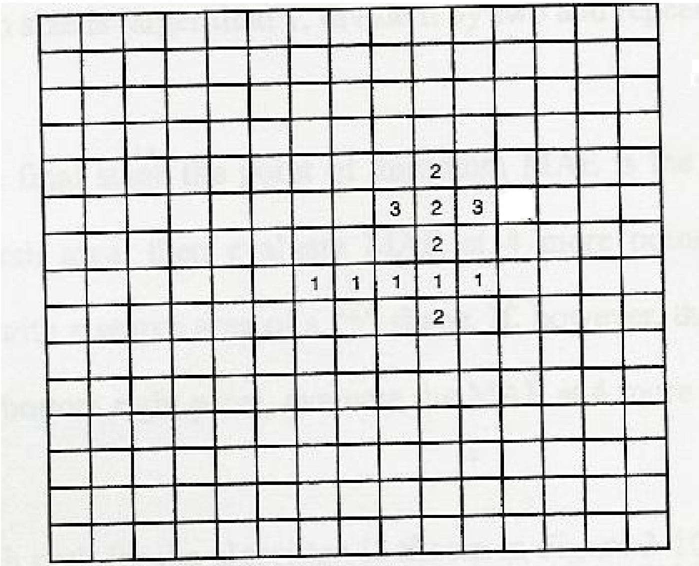
Orthogonal Search Algorithm

- Advantage:
  - Very quick for small motions
- Disadvantage:
  - Local minima may stop the search very soon



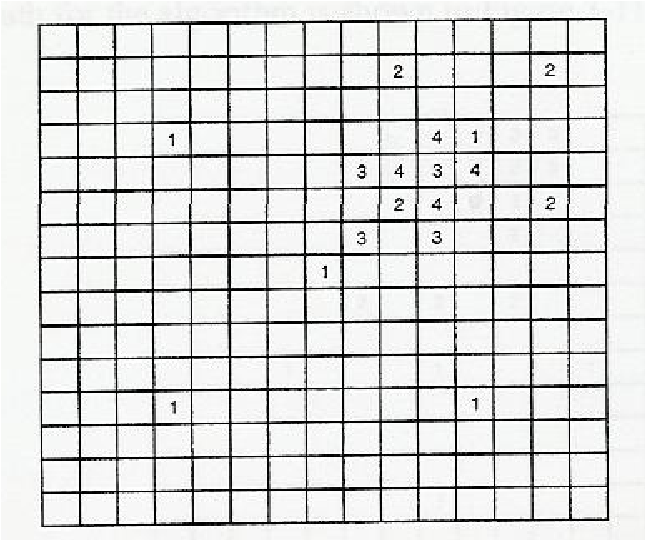
One at a time Algorithm

- Advantage:
  - The procedure can be stopped at any step to ensure low computational cost
- Disadvantage:
  - Local minima



Cross Search Algorithm

- Advantage:
  - Low computational cost
- Disadvantage:
  - Performance is worse than Three-step search



Comparison of Fast Block-Based Algorithms

- The algorithms with more regular structure have a fixed number of computations
- The ones with less regularity have very different best-case and worse-case computation
- Structural regularity is important for VLSI implementation
- Average case complexity is important for software implementation
- To achieve half-pel accuracy a final step can be added to any fast algorithm

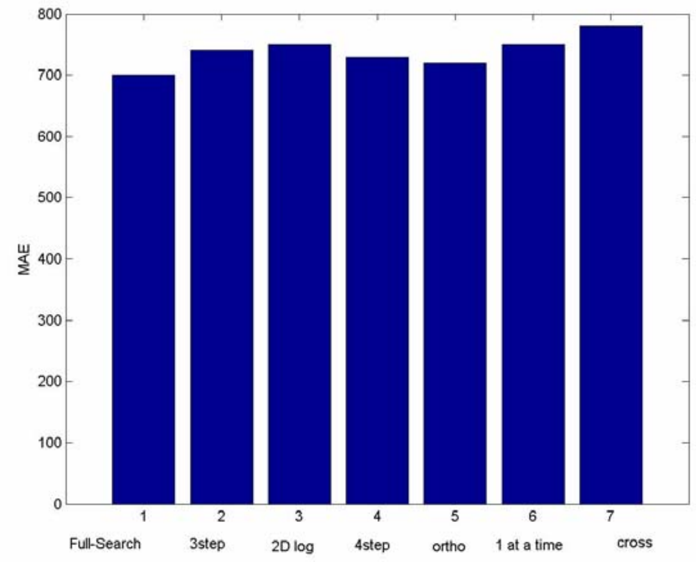
Comparison of Fast Block-Based Algorithms

Image size: 243x360

Block size: 16x16

Search range: 32x32

For 20frames per sequence and 3 different sequences



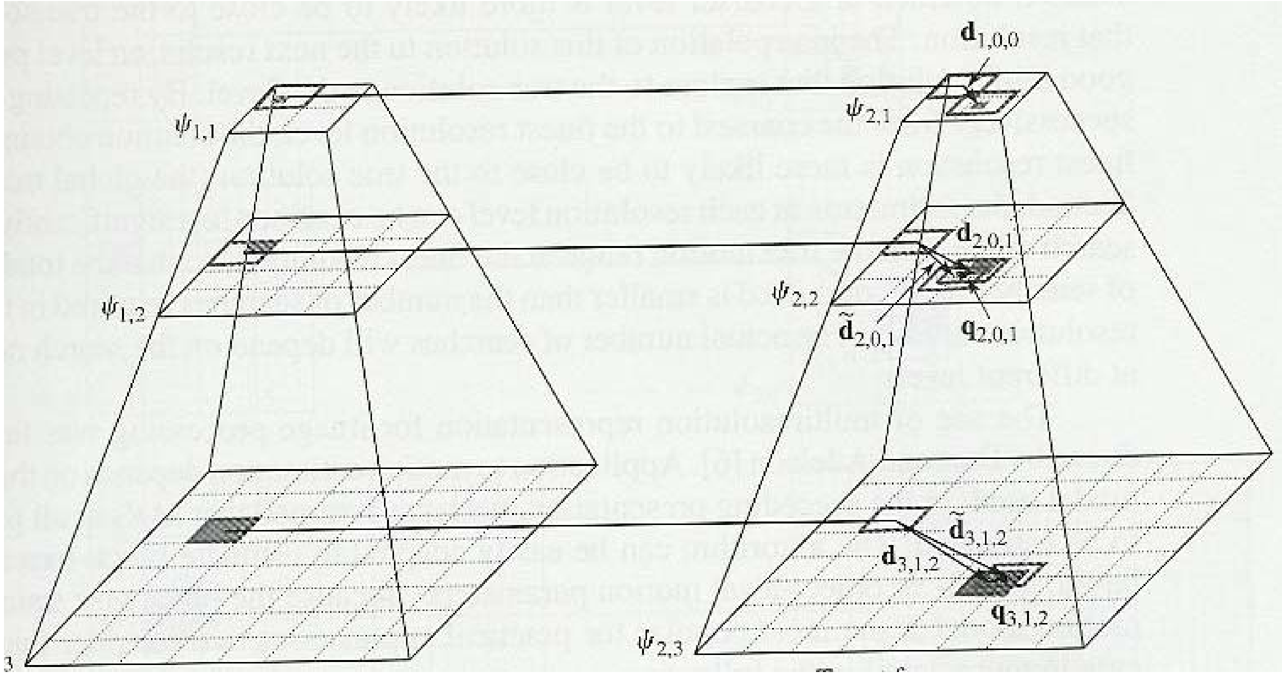
$$MAE = \frac{\sum \left| \psi(X) - \Psi(X) \right|}{N^2}$$

Multiresolution Motion Estimation

- Common difficulties with motion estimation algorithms
  - Local minima; difficulty in finding the global minimum unless it is close to the initial solution
  - High computation amount of minimization process

- Multiresolution approach is a solution for both of these difficulties
  - By searching the solution in a successively finer resolutions
    - Local minima: by first searching the solution in a coarse resolution
    - High computation cost: by limiting the search in each resolution to a small area using the previous level results

Multiresolution Motion Estimation



$$\tilde{d}_l(X) = \mathrm{I}(d_{l+1}(X))$$

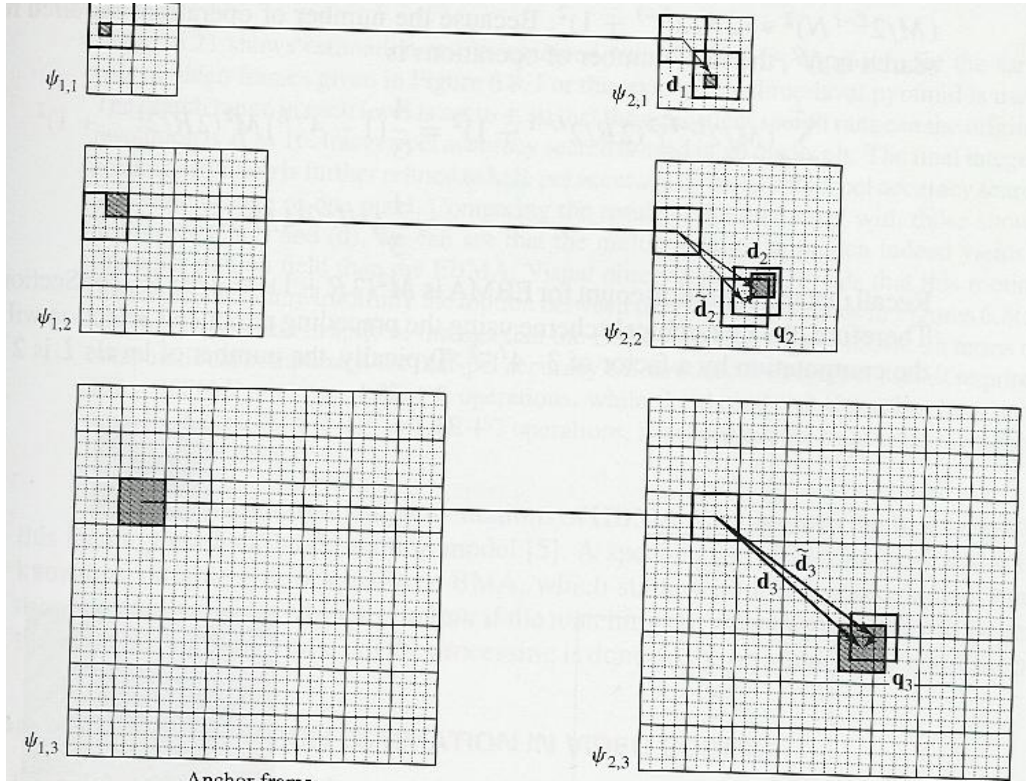
I represent the interpolation operator

$$\sum_{X \in \Lambda_l} \left| \psi_{2,l}(X + \tilde{d}_l(X) + q_l(X)) - \psi_{1,l}(X) \right|^p$$

$$d(X) = q_L(X) + I(q_{L-1}(X) + I(q_{L-2}(X) + \dots I(q_1(X) + d_0(X))\dots))$$

Multiresolution Motion Estimation

As the original level view shows the final MV is (13,11)



Multiresolution estimation:

$$q_1 = (3,3) \Rightarrow d_1 = q_1 + I(d_0) = (3,3)$$

$$q_2 = (1,-1) \Rightarrow d_2 = q_2 + I(d_1) = (7,5)$$

$$q_3 = (-1,1) \Rightarrow d_3 = q_3 + I(d_2) = (13,11)$$

Multiresolution Motion Estimation

- Lower level representations are obtained by spatial low-pass filtering and subsampling
- The most common pyramid structure is one in which resolution is reduced by half
- Any of the block matching algorithms could be used at each resolution
- The benefits of the multiresolution approach are:
  - Minimization problem at a coarse resolution is better-posed than at a finer resolution, so more likely to be the true solution
  - The estimation at each resolution can be done using a smaller search range so the, so we have less number of computation

Summary

- Relation between Image Intensity and Motion
  - Almost all motion estimation algorithms are based on the constant intensity assumption and optical flow equation
- Key Component in Motion Estimation
  - Motion Representation
    - Depends on the way we divide a frame: pixel-based, block-based, region-based, mesh-based
    - Motion model used for each region of the partition (block, region …)
    - Different motion representation led to different motion estimation methods

Summary

- Motion Estimation Criterion
  - Motion estimation problem is usually converted to an optimization problem
  - To speed up the search and avoid being trapped in local minim, a multiresolotion procedure can be used

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Thanks for your Attention☺