Overview: motion estimation

- Differential methods
- Blockmatching
- Fast algorithms for blockmatching
- Sub-pel accuracy
- Rate-constrained motion estimation

Differential motion estimation

- Assume small displacements (d_x, d_y):

$$FD(x,y) \approx -\frac{\partial S(x,y)}{\partial x} d_x - \frac{\partial S(x,y)}{\partial y} d_y$$

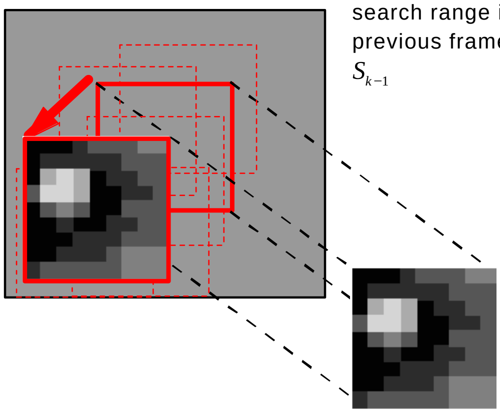
frame-to-frame difference

horizontal, vertical gradient of image signal S

- Aperture problem: 1 equation, but 2 unknowns per pixel. At least 2 (in practice: several) coupled observations required.
- Linearization inaccurate for displacements > 0.5 pel

$\Rightarrow$ multigrid methods, iteration

Principle of blockmatching



- Subdivide every image into square blocks.
- Find one displacement vector for each block.
- Within a search range, find a best „match" that minimizes an error measure.
- Intelligent search strategies can reduce computation.

Blockmatching: error measure

- Mean squared error (sum of squared errors)

$$SSE(d_x, d_y) = \sum_{\text{block}} \left[S_k(x,y) - S_{k-1}(x+d_x, y+d_y) \right]^2$$

- Sum of absolute differences

$$SAD(d_x, d_y) = \sum_{\text{block}} \left| S_k(x,y) - S_{k-1}(x+d_x, y+d_y) \right|$$

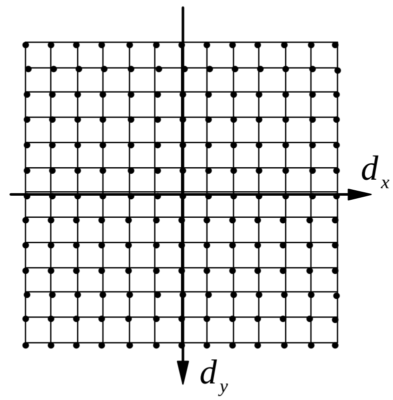
- Approximately same performance

$\Rightarrow$ SAD less complex for some architectures

Blockmatching: search strategies I

Full search

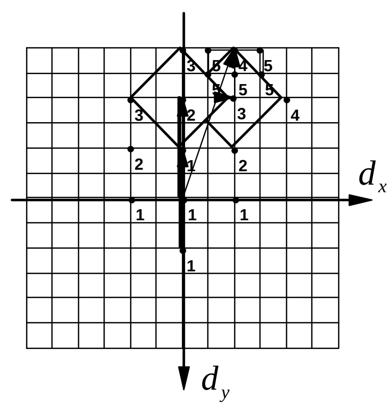
- All possible displacements within the search range are compared.
- Computationally expensive
- Highly regular, parallelizable



Blockmatching: search strategies II

2D logarithmic search (Jain + Jain, 1981)

- Iterative comparison of error measure values at 5 neighboring points
- Logarithmic refinement of the search pattern if
  - best match is in the center of the 5-point pattern
  - center of search pattern touches the border of the search range



Blockmatching: search strategies III

Computational complexity

- Example: max. horizontal, vertical displacement = 6, integer-pel accuracy:

	Block comparisons a	b
2D logarithmic	18	21
full search	169	169

a - for special vector (2,6)
b - worst case

Block comparison speed-ups

- Triangle inequalities for SAD and SSE

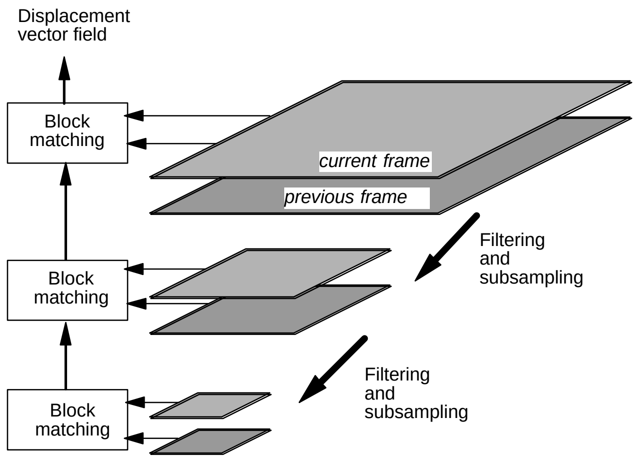
$$\sum_{\text{block}} |S_k - S_{k-1}| \geq \left| \sum_{\text{block}} S_k - S_{k-1} \right| = \left| \sum_{\text{block}} S_k - \sum_{\text{block}} S_{k-1} \right|$$

$$\sum_{\text{block}} |S_k - S_{k-1}|^2 \geq \frac{1}{N} \left| \sum_{\text{block}} S_k - S_{k-1} \right|^2 = \frac{1}{N} \left| \sum_{\text{block}} S_k - \sum_{\text{block}} S_{k-1} \right|^2$$

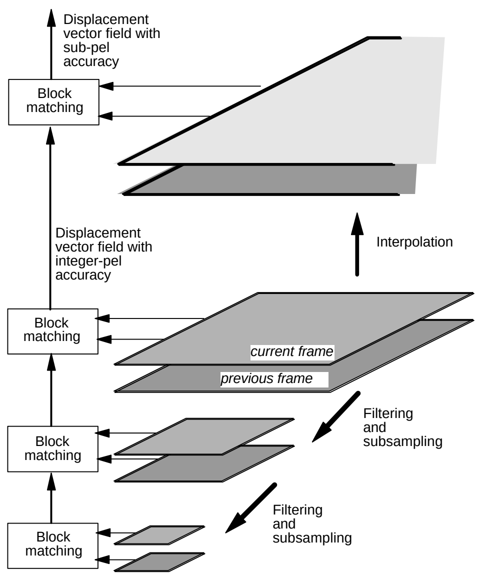
(N: number of terms in sum)

- Strategy:
  - Compute partial sums for blocks in current and previous frame
  - Compare blocks based on partial sums
  - Omit full block comparison, if partial sums indicate worse error measure than previous best result
- Performance: > 20x speed-up of full search block matching reported by employing (Lin + Tai, IEEE Tr. Commun., May 97)
  - Sum over 16x16 block
  - Row wise block projection
  - Column wise block projection

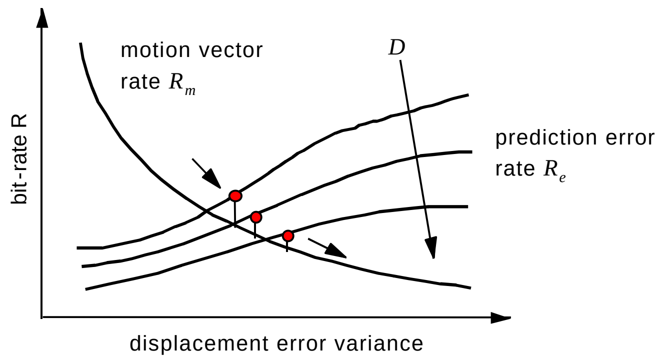
Hierarchical blockmatching



Sub-pel accuracy



Rate-constrained motion estimation I



optimum trade-off: $$\frac{\partial D}{\partial R_m} = \frac{\partial D}{\partial R_e}$$

Rate-constrained motion estimation II

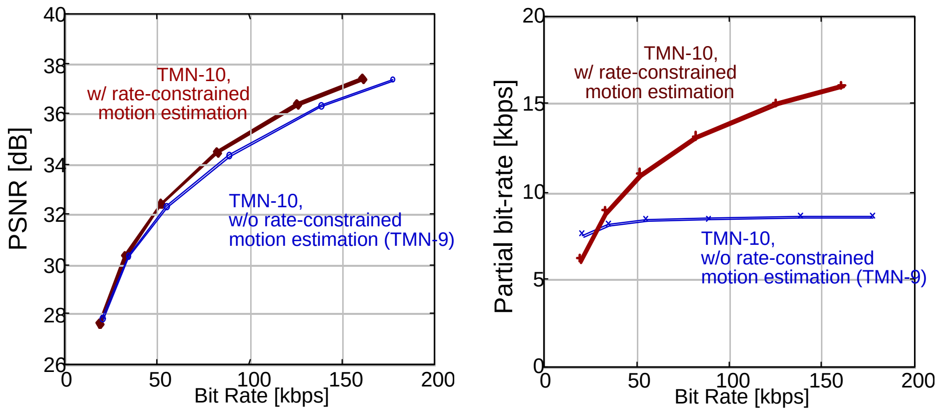
- How to find best motion vector subject to rate constraint?
- Lagrangian cost function: solve unconstrained problem rather than constrained problem

$$\min\left(D + l R_m\right)$$

error measure · motion vector rate

$\Rightarrow$ Interpret motion search as ECVQ problem.

Rate-constrained Motion Estimation in H.263 Reference Model TMN-10



Simulation details:

Foreman, QCIF, SKIP=2
Q=4,5,7,10,15,25
Annexes D+F

Summary: motion estimation

- Differential methods calculate displacement from spatial and temporal differences in the image signal.
- Aperture problem: measurement window required.
- Differential methods require several iterations.
- Blockmatching computes error measure for candidate displacements and finds best match.
- Speed up blockmatching by search methods and by clever application of triangle inequality.
- Hierarchical blockmatching employs resolution pyramid.
- Blockmatching with sub-pel accuracy by interpolation of the image signal.
- Rate-constrained motion estimation using Lagrangian cost function.