Motion estimation for video compression

- Blockmatching
- Search strategies for block matching
- Block comparison speedups
- Hierarchical blockmatching
- Sub-pixel accuracy
Block-matching algorithm

- Subdivide current frame into 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.

search range in previous frame $S_{k-1}$

block of current frame $S_k$
Block-matching algorithm

Measurement window is compared with a shifted block of pixels in the other image, to determine the best match.

Block of pixels is selected as a measurement window.
Block-matching algorithm

... process repeated for another block.
Blockmatching: Matching Criterion

- **Sum of Squared Differences** to determine similarity

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

- Alternative matching criteria: SAD (**Sum of Absolute Differences**), cross correlation, . . .
- How about sub-pixel shifts?
SSD Values Resulting from Blockmatching

Estimated displacement
Integer-pixel accuracy
Motion-compensated prediction: example

Previous frame

Current frame

Prediction with displacement vectors

Motion-compensated Prediction error
Interpolation of the SSD Minimum

- Fit parabola through >3 points approximately
- Sub-pixel Accurate Minimum

$SSD$ vs. Horizontal shift $d_x$
2-d Interpolation of SSD Minimum

Paraboloid
- Perfect fit through 6 points
- Approximate fit through >6 points
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

Diamond search [Li, Zeng, Liou, 1994] [Zhu, Ma, 1997]

- Start with large diamond pattern at (0,0)
- If best match lies in the center of large diamond, proceed with small diamond
- If best match does not lie in the center of large diamond, center large diamond pattern at new best match
Most search strategies can be further accelerated by . . .

- **Predictive motion search**
  - Use median of motion vectors in causal neighborhood as starting point for search.
  - Additionally test zero-vector as a starting point

- **Early termination**
  - Interrupt summation to calculate SSD or SAD, if value grows too quickly (relative to previous best match)
  - Stop search, if match is “good enough” (SSD, SAD < threshold)
Block comparison speed-ups

- Triangle and Cauchy-Schwarz inequalities for SAD and SSE

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

\[
\sum_{\text{block}} \left( S_k - S_{k-1} \right)^2 \geq \frac{1}{N} \left( \sum_{\text{block}} S_k - S_{k-1} \right)^2 = \frac{1}{N} \left( \sum_{\text{block}} S_k - \sum_{\text{block}} S_{k-1} \right)^2
\]

- 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

- Sum over 16x16 block
- Row wise block projection
- Column wise block projection
Hierarchical blockmatching

Integer-pixel accuracy

Extension to sub-pixel accuracy
Sub-pixel accuracy

- Interpolate pixel raster of the reference image to desired sub-pixel accuracy (typically by bi-linear interpolation)
- Straightforward extension of displacement vector search to fractional accuracy
- Example: half-pixel accurate displacements

\[
\begin{pmatrix}
d_x \\
d_y
\end{pmatrix} = \begin{pmatrix} 4.5 \\ 4.5 \end{pmatrix}
\]
Bi-linear Interpolation

Interpolated Pixel Value
Reading
