Visual Computing:
Advanced Optical Flow & Video Compression

Prof. Marc Pollefeys

ETH

inf | Informatik Computer Science

Last lecture: Optical Flow

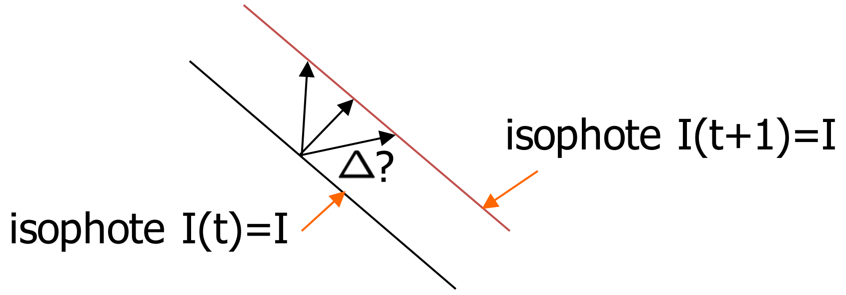
- Brightness constancy equation

$$\boxed{I_x u + I_y v + I_t = 0}$$

- Aperture problem

$I_x u + I_y v + I_t = 0$ (1 constraint)

u, v (2 unknowns)

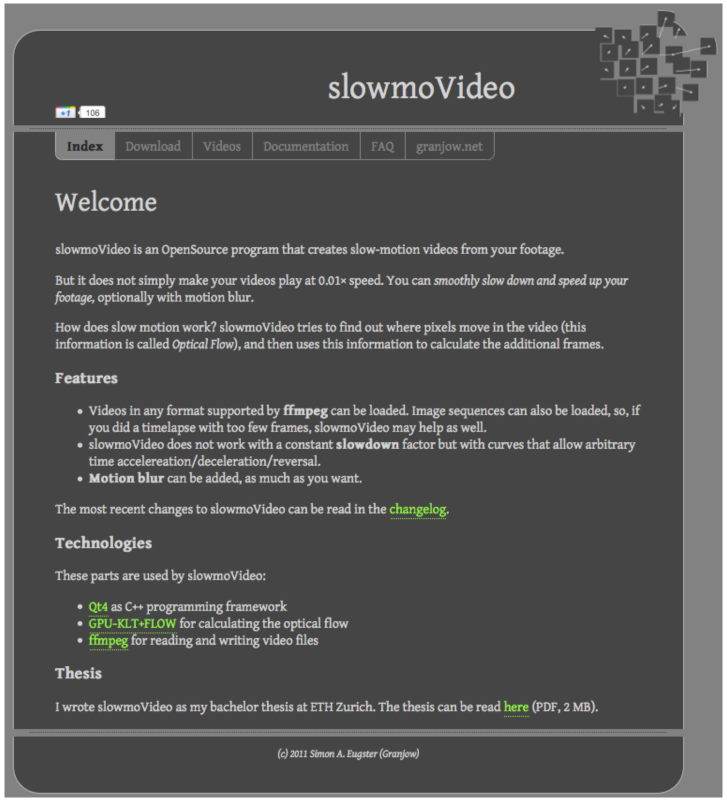


- Solution:
  - regularize (trade-off brightness constancy and smoothness)
  - And many more (***today***)

$$E(\mathbf{h}) = \sum_{\mathbf{x} \in R} [I(\mathbf{x}+\mathbf{h}) - I_0(\mathbf{x})]^2$$

SlowMoVideo

Bachelor thesis Simon Eugster



slowmoVideo

+1 106

Index | Download | Videos | Documentation | FAQ | granjow.net

Welcome

slowmoVideo is an OpenSource program that creates slow-motion videos from your footage.

But it does not simply make your videos play at 0.01× speed. You can *smoothly slow down and speed up your footage*, optionally with motion blur.

How does slow motion work? slowmoVideo tries to find out where pixels move in the video (this information is called *Optical Flow*), and then uses this information to calculate the additional frames.

Features

- Videos in any format supported by **ffmpeg** can be loaded. Image sequences can also be loaded, so, if you did a timelapse with too few frames, slowmoVideo may help as well.
- slowmoVideo does not work with a constant **slowdown** factor but with curves that allow arbitrary time acceleration/deceleration/reversal.
- **Motion blur** can be added, as much as you want.

The most recent changes to slowmoVideo can be read in the changelog.

Technologies

These parts are used by slowmoVideo:

- Qt4 as C++ programming framework
- GPU-KLT+FLOW for calculating the optical flow
- ffmpeg for reading and writing video files

Thesis

I wrote slowmoVideo as my bachelor thesis at ETH Zurich. The thesis can be read here (PDF, 2 MB).

(c) 2011 Simon A. Eugster (Granjow)

http://slowmovideo.granjow.net/

Optical Flow

- Brightness Constancy
- The Aperture problem
- Regularization
- Lucas-Kanade
- Coarse-to-fine
- Parametric motion models
- SSD tracking
- Bayesian flow

Parametric (Global) Motion Models

Global motion models offer

- more constrained solutions than smoothness (Horn-Schunck)
- integration over a larger area than a translation-only model can accommodate (Lucas-Kanade)

Parametric (Global) Motion Models

2D Models:

(Translation)

Affine

Quadratic

Planar projective transform (Homography)

3D Models:

Instantaneous camera motion models

Homography+epipole

Plane+Parallax

$$E(\mathbf{h}) = \sum_{\mathbf{x} \in R} \left[I(\mathbf{x} + \mathbf{h}) - I_0(\mathbf{x}) \right]^2$$

- Transformations/warping of image

$$E(\mathbf{h}) = \sum_{\mathbf{x} \in R} \left[I(\mathbf{x} + \mathbf{h}) - I_0(\mathbf{x}) \right]^2$$

Translations:

$$\mathbf{h} = \begin{bmatrix} \delta x \\ \delta y \end{bmatrix}$$

What about other types of motion?

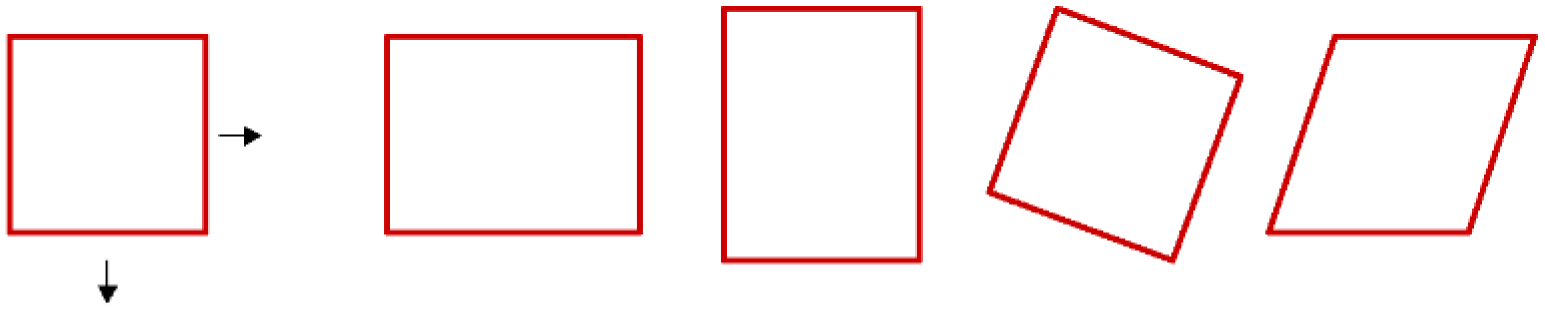
Generalization

- Transformations/warping of image

$$E(\mathbf{A}, \mathbf{h}) = \sum_{\mathbf{x} \in R} \left[I(\mathbf{A}\mathbf{x} + \mathbf{h}) - I_0(\mathbf{x}) \right]^2$$

Affine: $\mathbf{A} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \quad \mathbf{h} = \begin{bmatrix} \delta x \\ \delta y \end{bmatrix}$

Generalization



Affine: $\mathbf{A} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \quad \mathbf{h} = \begin{bmatrix} \delta x \\ \delta y \end{bmatrix}$

Example: Affine Motion

$$\boxed{\begin{aligned} u(x,y) &= a_1 + a_2 x + a_3 y \\ v(x,y) &= a_4 + a_5 x + a_6 y \end{aligned}}$$

Substituting into the B.C. Equation:

$$I_x \cdot u + I_y \cdot v + I_t \approx 0$$

$$\boxed{I_x (a_1 + a_2 x + a_3 y) + I_y (a_4 + a_5 x + a_6 y) + I_t \approx 0}$$

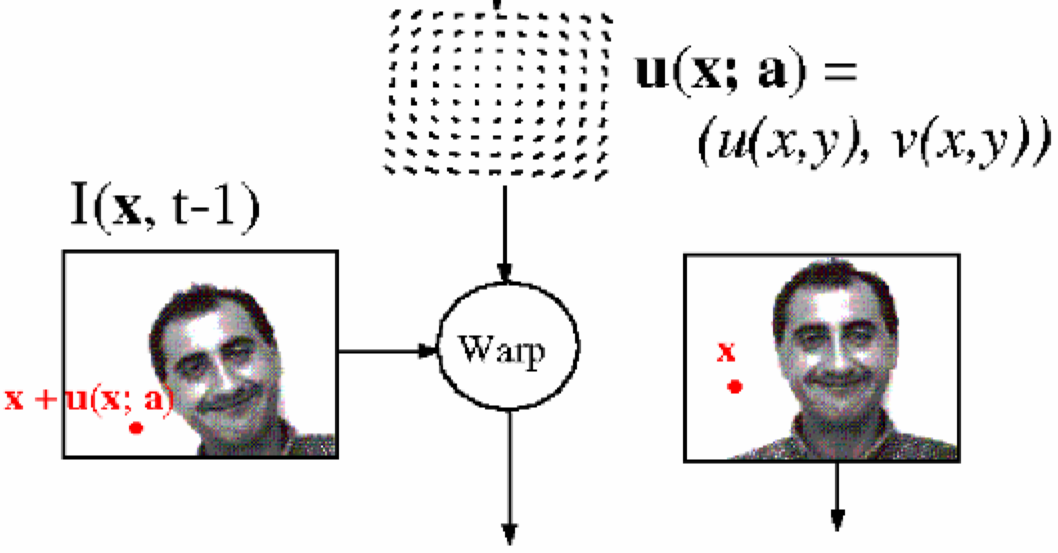
Each pixel provides 1 linear constraint in 6 *global* unknowns
(minimum 6 pixels necessary)

Least Square Minimization (over all pixels):

$$Err(\vec{a}) = \sum \left[I_x (a_1 + a_2 x + a_3 y) + I_y (a_4 + a_5 x + a_6 y) + I_t \right]^2$$

$$u(x, y) = a_0 + a_1 x + a_2 y$$

$$v(x, y) = a_3 + a_4 x + a_5 y$$


$\mathbf{u}(\mathbf{x};\, \mathbf{a}) =$
$(u(x,y),\, v(x,y))$
$I(\mathbf{x}, t\text{-}1)$
$\mathbf{x} + \mathbf{u}(\mathbf{x};\, \mathbf{a})$
Warp
$\mathbf{x}$

$$I(\mathbf{x}+\mathbf{u}(\mathbf{x};\, \mathbf{a}),\, t-1) = I(\mathbf{x}, t)$$

(Brightness Constancy Assumption)

KLT: Good features to keep tracking

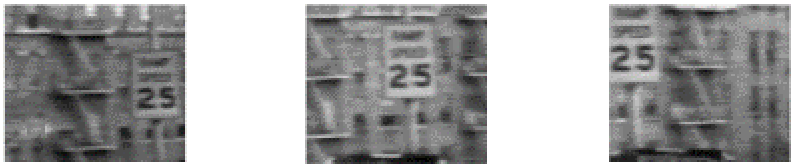
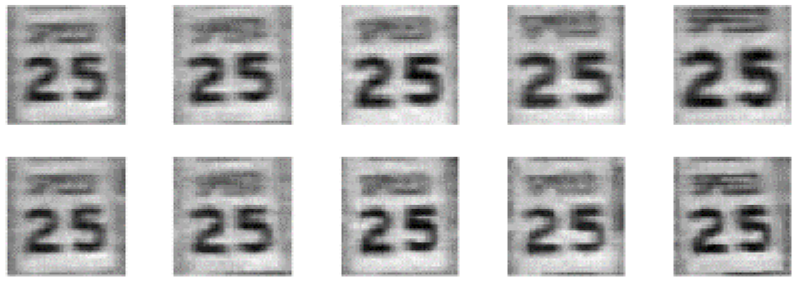
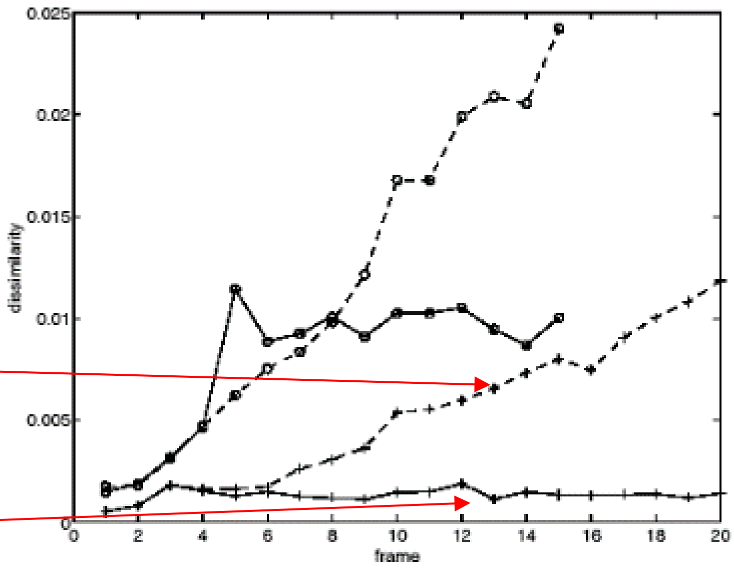


Figure 1: Three frame details from Woody Allen's *Manhattan*. The details are from the 1st, 11th, and 21st frames of a subsequence from the movie.





Simple displacement is sufficient between consecutive frames, but not to compare to reference template

Generalization

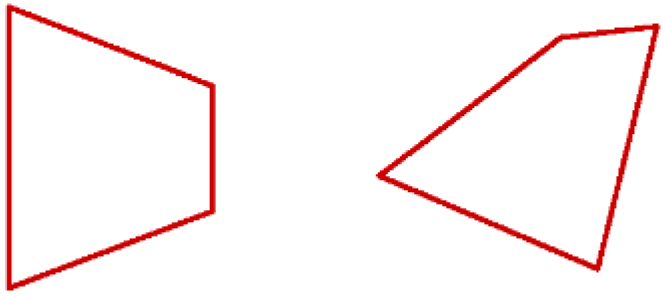
- Transformations/warping of image

$$E(\mathbf{A}) = \sum_{\mathbf{x} \in R} [I(\mathbf{A}\mathbf{x}) - I_0(\mathbf{x})]^2$$

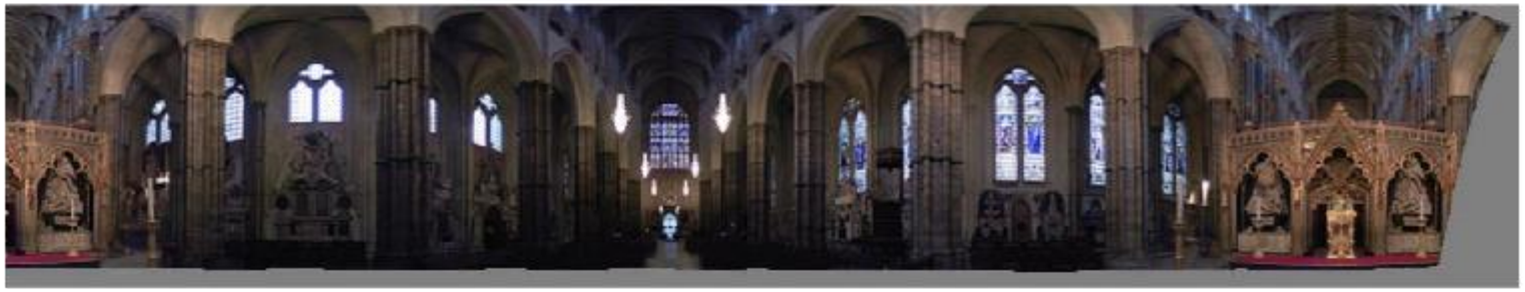
Planar perspective: $\mathbf{A} = \begin{bmatrix} a_1 & a_2 & a_3 \\ a_4 & a_5 & a_6 \\ a_7 & a_8 & 1 \end{bmatrix}$

Generalization

Affine $+$



Planar perspective: $\mathbf{A} = \begin{bmatrix} a_1 & a_2 & a_3 \\ a_4 & a_5 & a_6 \\ a_7 & a_8 & 1 \end{bmatrix}$



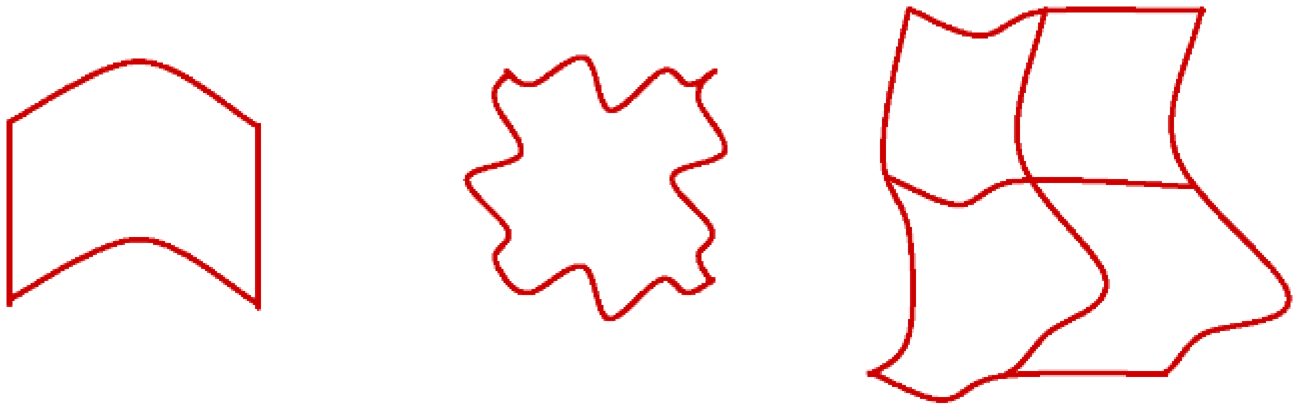
Generalization

- Transformations/warping of image

$$E(\mathbf{h}) = \sum_{\mathbf{x} \in R} \left[I(\mathbf{f}(\mathbf{x}, \mathbf{h})) - I_0(\mathbf{x}) \right]^2$$

Other parametrized transformations

Generalization



Other parametrized transformations

2D Motion Models summary

Quadratic – instantaneous approximation to planar motion

$$u = q_1 + q_2 x + q_3 y + q_7 x^2 + q_8 xy$$
$$v = q_4 + q_5 x + q_6 y + q_7 xy + q_8 y^2$$

Projective – exact planar motion

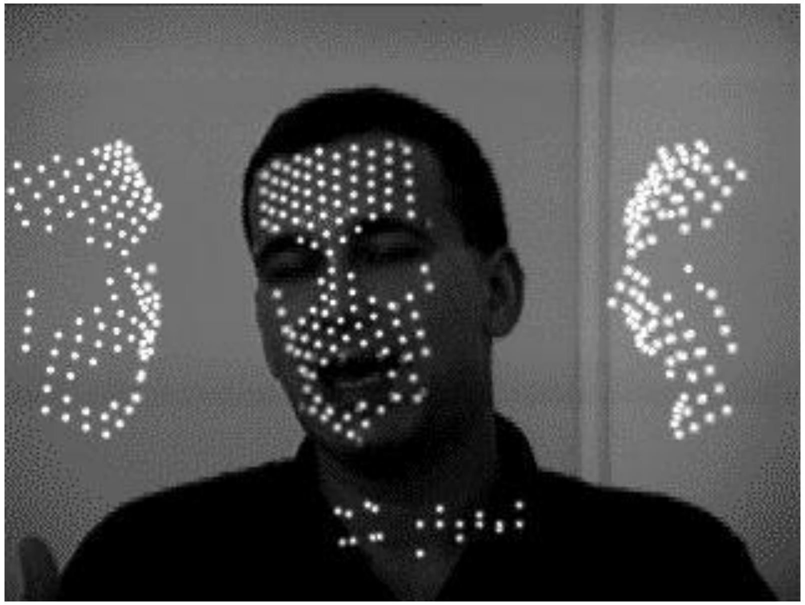
$$x' = \frac{h_1 + h_2 x + h_3 y}{h_7 + h_8 x + h_9 y}$$
$$y' = \frac{h_4 + h_5 x + h_6 y}{h_7 + h_8 x + h_9 y}$$

and

$$u = x' - x, \quad v = y' - y$$

Advanced parametric model

- Optical flow constrained by non-rigid face model



Flexible flow for 3D nonrigid tracking and shape recovery,
Brand and Bhotika, CVPR2001.

3D Motion Models summary

Instantaneous camera motion:

Global parameters: $\Omega_X, \Omega_Y, \Omega_Z, T_X, T_Y, T_Z$

Local Parameter: $Z(x,y)$

$$u = -xy\Omega_X + (1+x^2)\Omega_Y - y\Omega_Z + (T_X - T_Z x)/Z$$
$$v = -(1+y^2)\Omega_X + xy\Omega_Y - x\Omega_Z + (T_Y - T_Z x)/Z$$

Homography+Epipole

Global parameters: $h_1, \ldots, h_9, t_1, t_2, t_3$

Local Parameter: $\gamma(x,y)$

$$x' = \frac{h_1 x + h_2 y + h_3 + \gamma t_1}{h_7 x + h_8 y + h_9 + \gamma t_3}$$
$$y' = \frac{h_4 x + h_5 y + h_6 + \gamma t_1}{h_7 x + h_8 y + h_9 + \gamma t_3}$$
and : $u = x' - x, \quad v = y' - y$

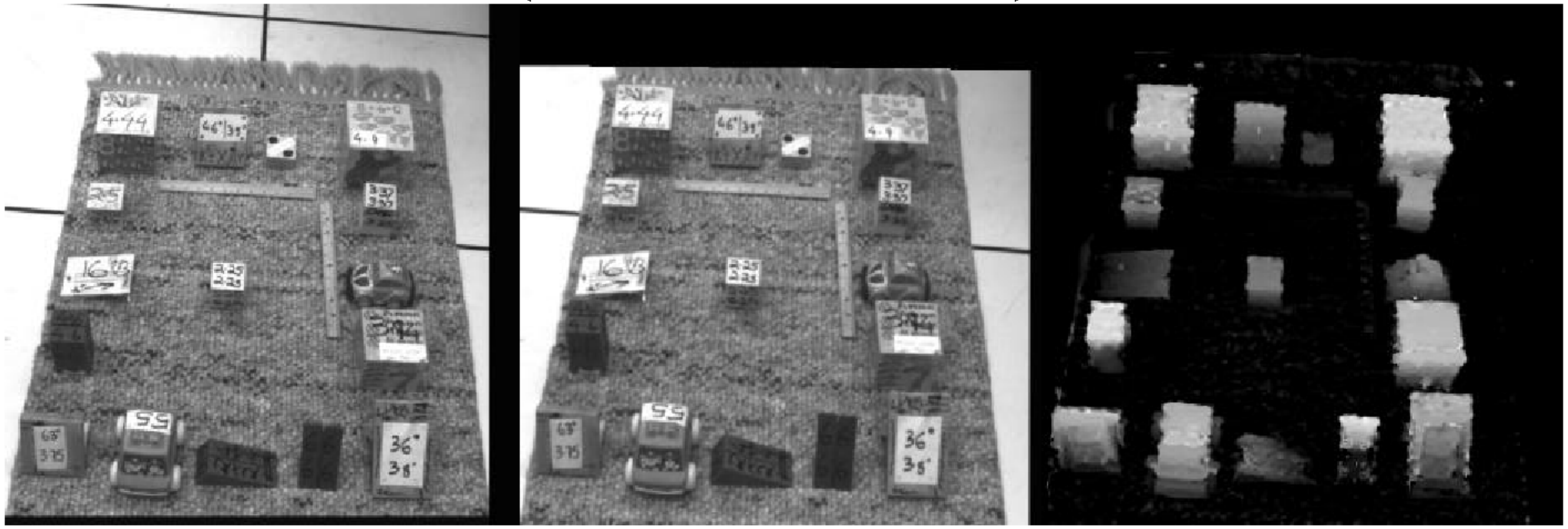
Residual Planar Parallax Motion

Global parameters: t_1, t_2, t_3

Local Parameter: $\gamma(x,y)$

$$u = x^w - x = \frac{\gamma}{1+\gamma t_3}(t_3 x - t_1)$$
$$v = y^w - x = \frac{\gamma}{1+\gamma t_3}(t_3 y - t_2)$$

Residual Planar Parallax Motion (Plane+Parallax)

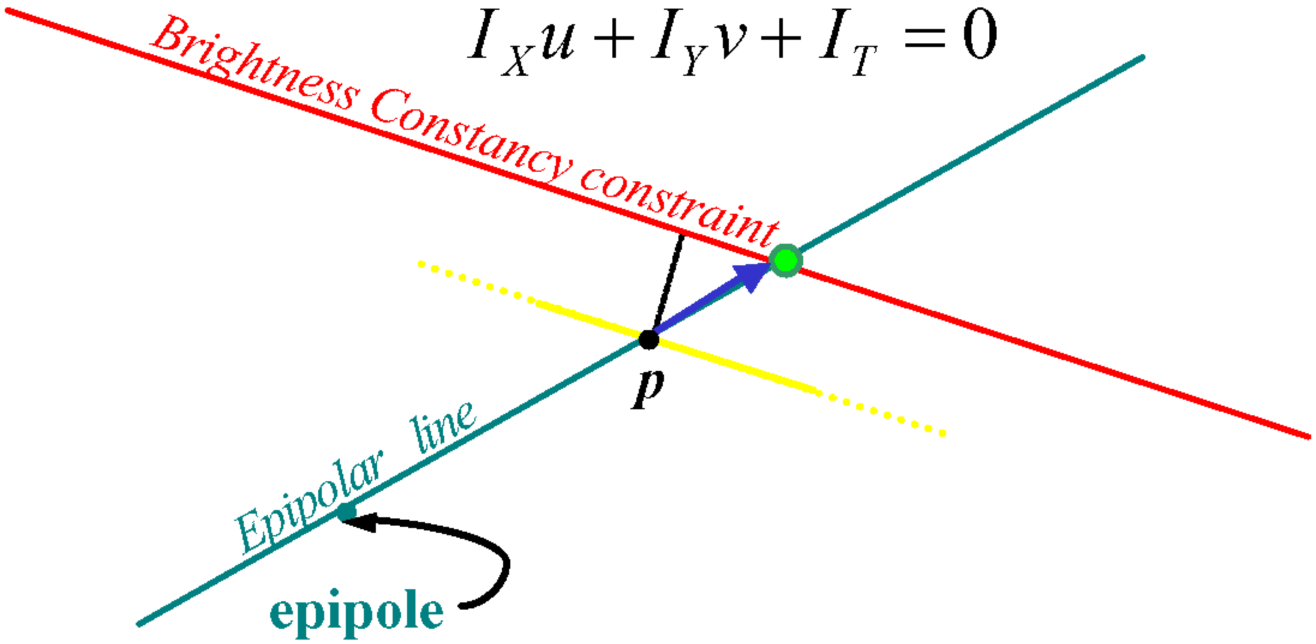


Original sequence **Plane-aligned sequence** **Recovered shape**

Block sequence from [Kumar-Anandan-Hanna'94]

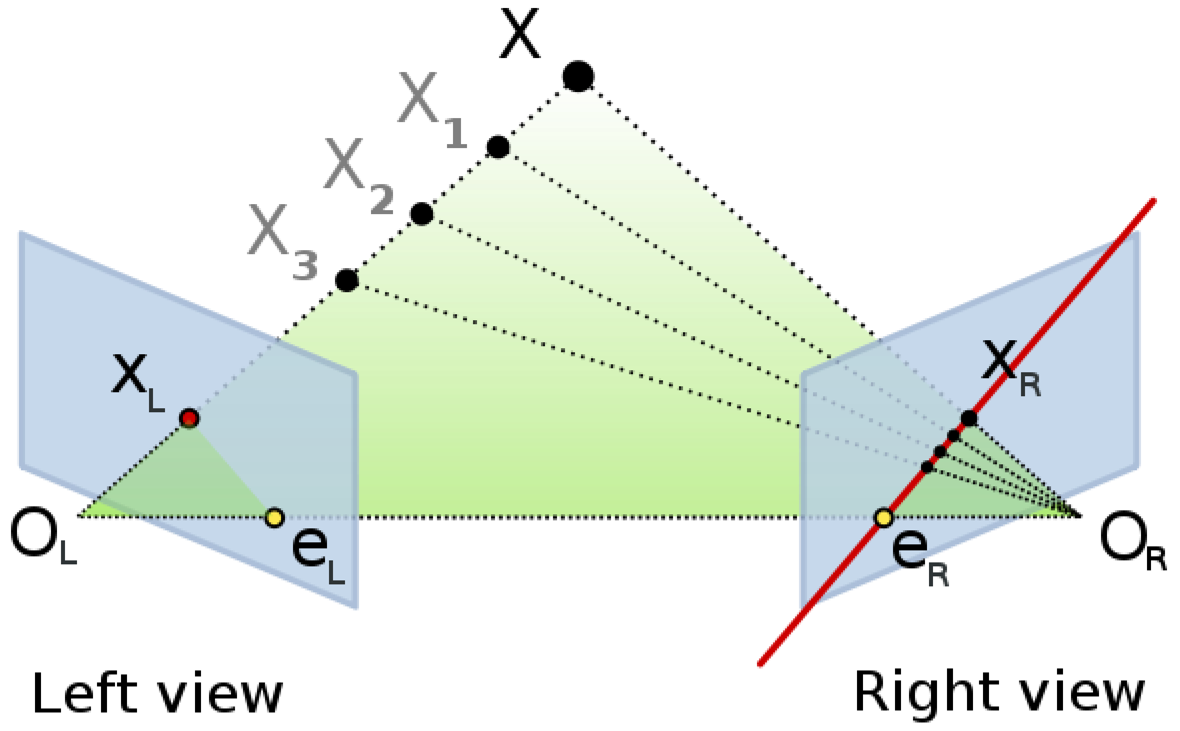
"Given two views where motion of points on a parametric surface has been compensated, the residual parallax is an epipolar field"

Residual Planar Parallax Motion

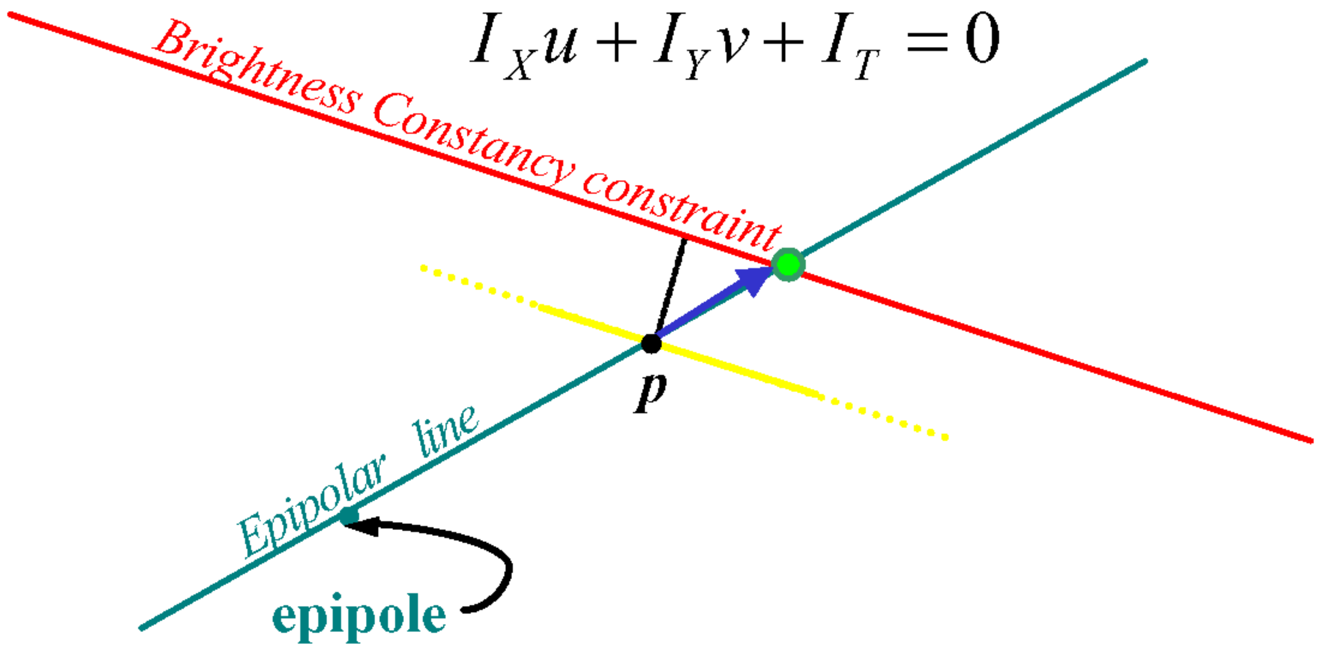


The intersection of the two line constraints <u>uniquely</u> defines the displacement.

Epipolar Geometry



Residual Planar Parallax Motion



The intersection of the two line constraints <u>uniquely</u> defines the displacement.

Optical Flow

- Brightness Constancy
- The Aperture problem
- Regularization
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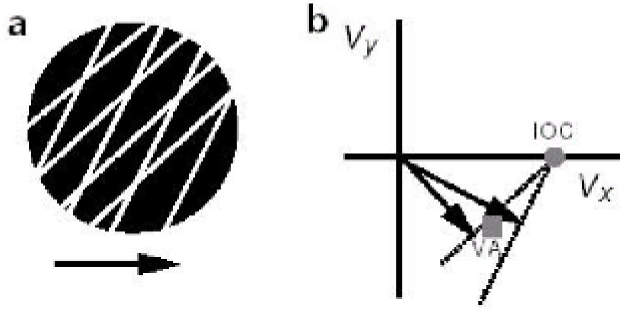
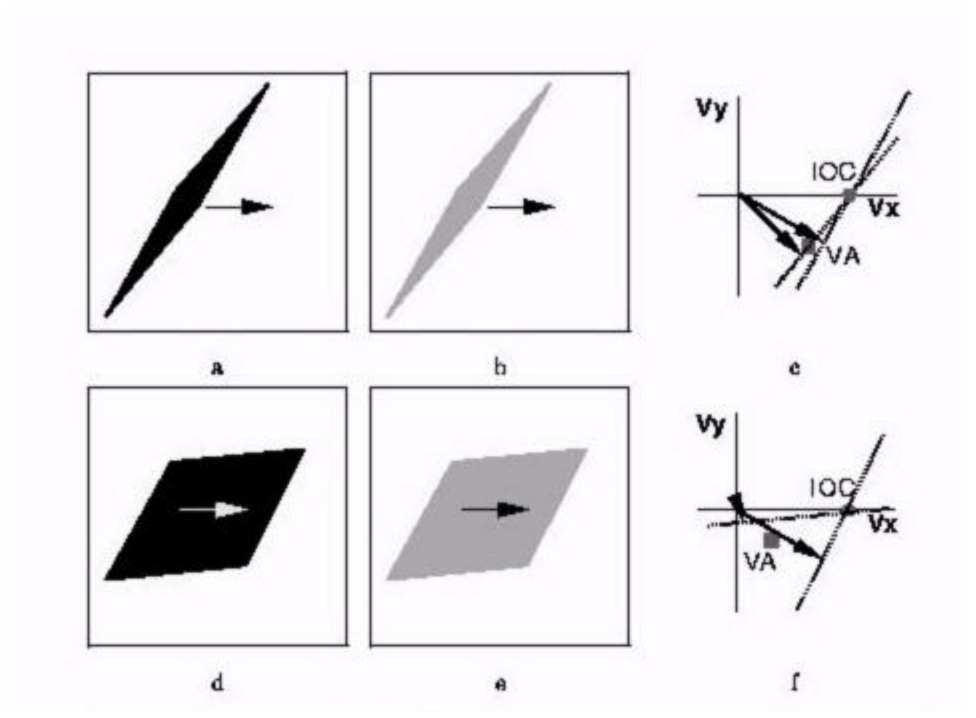
- SSD tracking
- Bayesian flow

Bayesian Optic Flow

- Some low-level human motion illusions can be explained by adding an uncertianty model to Lucas-Kanade tracking
- Theories from Psychology about normal flow fusion:
  - (VA) vector average (of normal motions)
  - (IOC) intersection of constraints (e.g., Lucas-Kanade):



Rhombus Displays



http://www.cs.huji.ac.il/~yweiss/Rhombus/

Brightness constancy with noise:

$$I(x,y,t) = I(x + v_x\Delta t,\ y + v_y\Delta t,\ t + \Delta t) + \eta$$

Assume Gaussian noise, smooth surfaces, locally constant; take first order linear approximation:

$$P(I(x_i,y_i,t)|v_i) \propto$$

$$\exp\left(-\frac{1}{2\sigma^2} \int_{x,y} w_i(x,y)\ (I_x(x,y,t)v_x + I_y(x,y,t)v_y + I_t(x,y,t))^2\, dx\, dy \right)$$

Prior favoring slow speeds:

$$P(v) \propto \exp(-\|v\|^2/2\sigma_p^{\ 2}).$$

Assume noise is independent across location; apply Bayes:

$$P(v|I) \propto P(v) \prod_i P(I(x_i,y_i,t)\ |v),$$

With constant window w=1,

$$P(v|I) \propto \exp\left(-\|v\|^2/2\sigma_p^{\ 2} - \frac{1}{2\sigma^2} \int_{x,y} (I(x,y)\ v_x + I_y(x,y)v_y + I_t)^2\, dx\, dy \right)$$

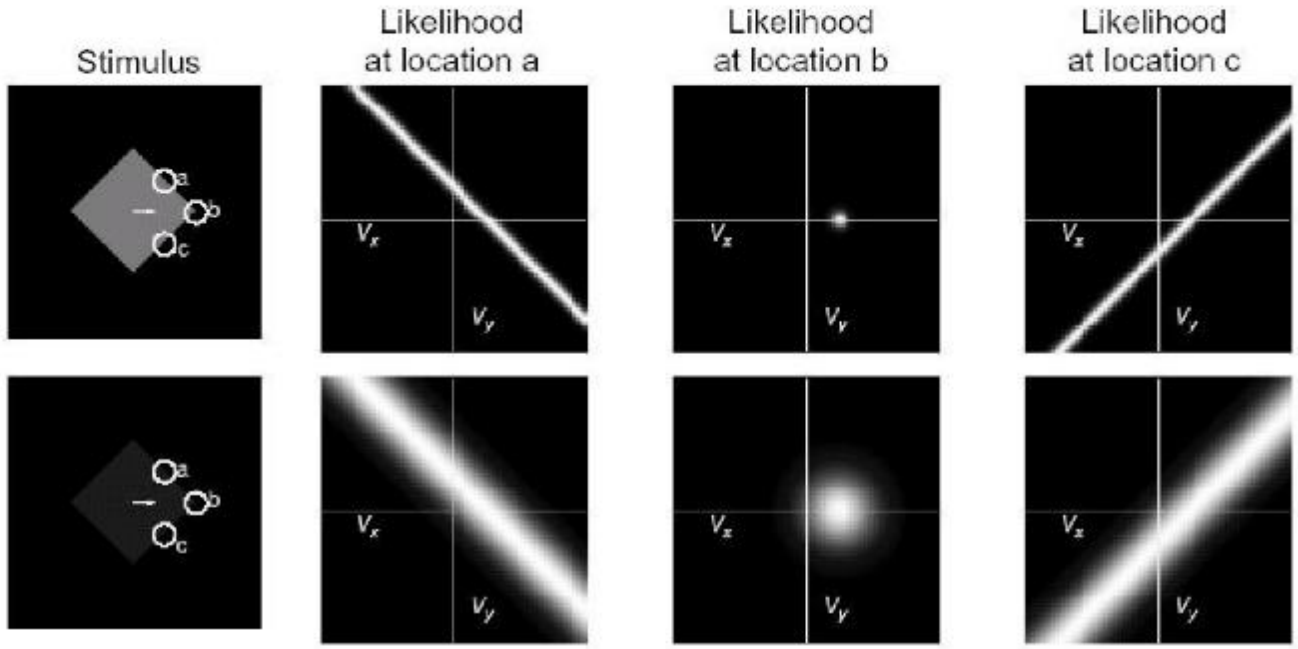
Form ‘normal equations’ to arrive at….

Lucas-Kanade with uncertainty:

$$v^* = -\begin{pmatrix} \sum I_x^2 + \frac{\sigma^2}{\sigma_p^2} & \sum I_x I_y \\ \sum I_x I_y & \sum I_y^2 + \frac{\sigma^2}{\sigma_p^2} \end{pmatrix}^{-1} \begin{pmatrix} \sum I_x I_t \\ \sum I_y I_t \end{pmatrix}$$

One parameter: ratio of observation and prior gaussian spread.

http://www.cs.huji.ac.il/~yweiss/Rhombus
[Weiss, Simoncelli, Adelson Nature Neuroscience 2002]


Stimulus
Likelihood at location a
Likelihood at location b
Likelihood at location c
a
b
c
V_x
V_y

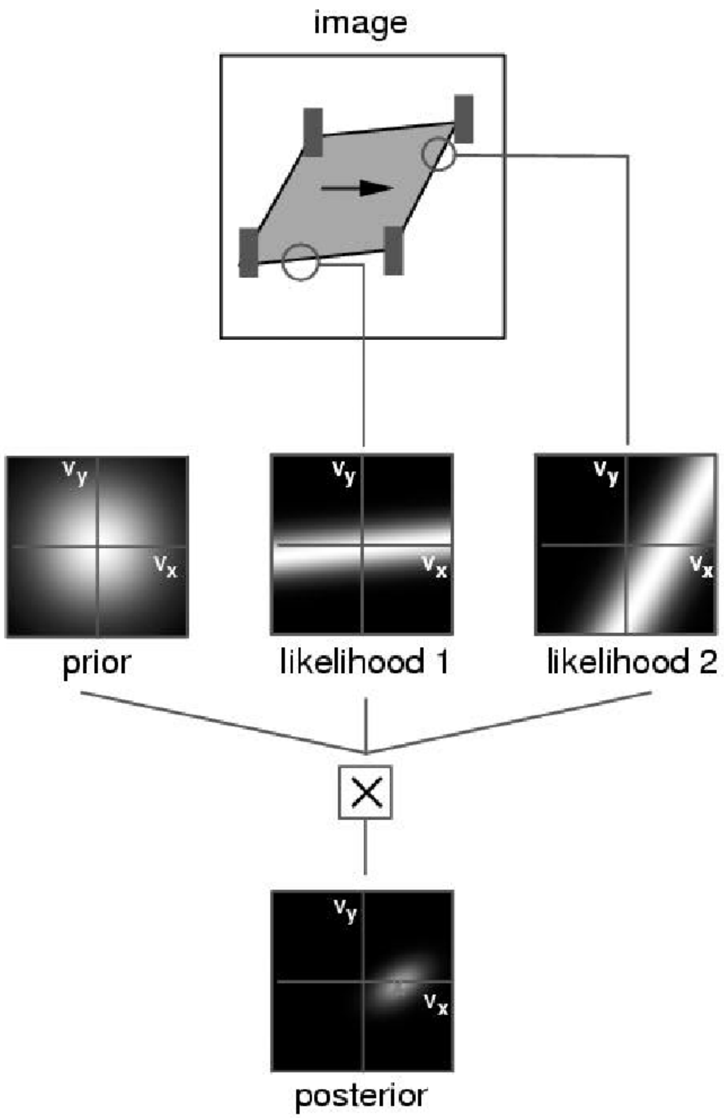


Figure 4: The response of the Bayesian estimator to a fat rhombus. (replotted from Weiss and Adelson 98)

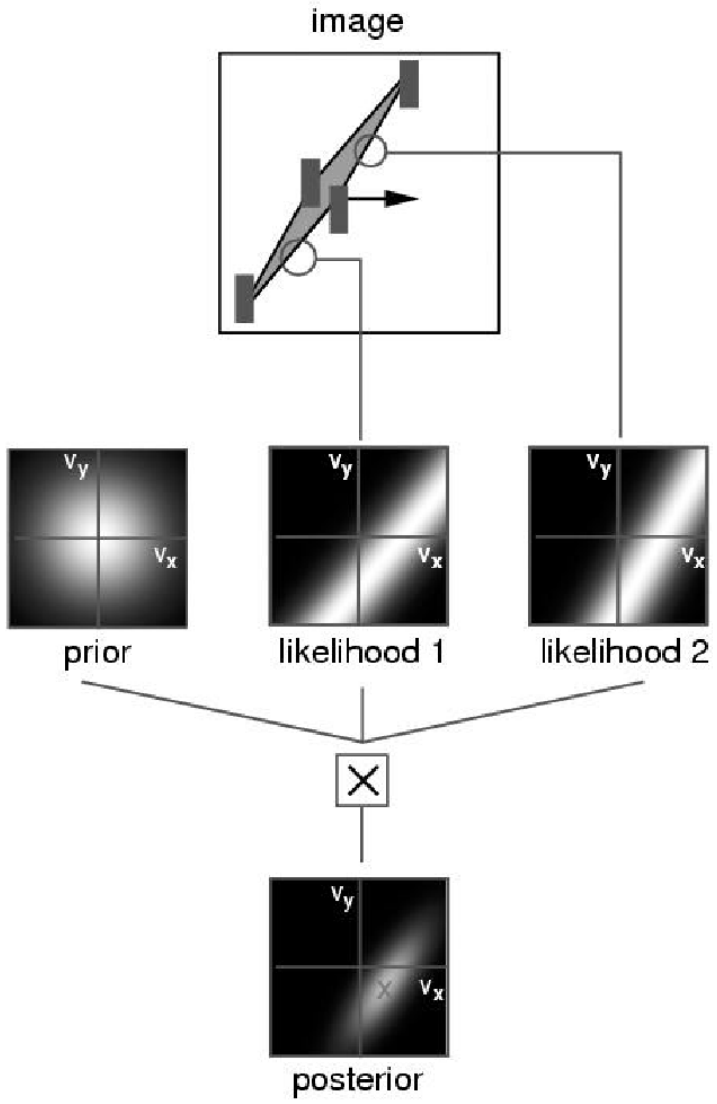
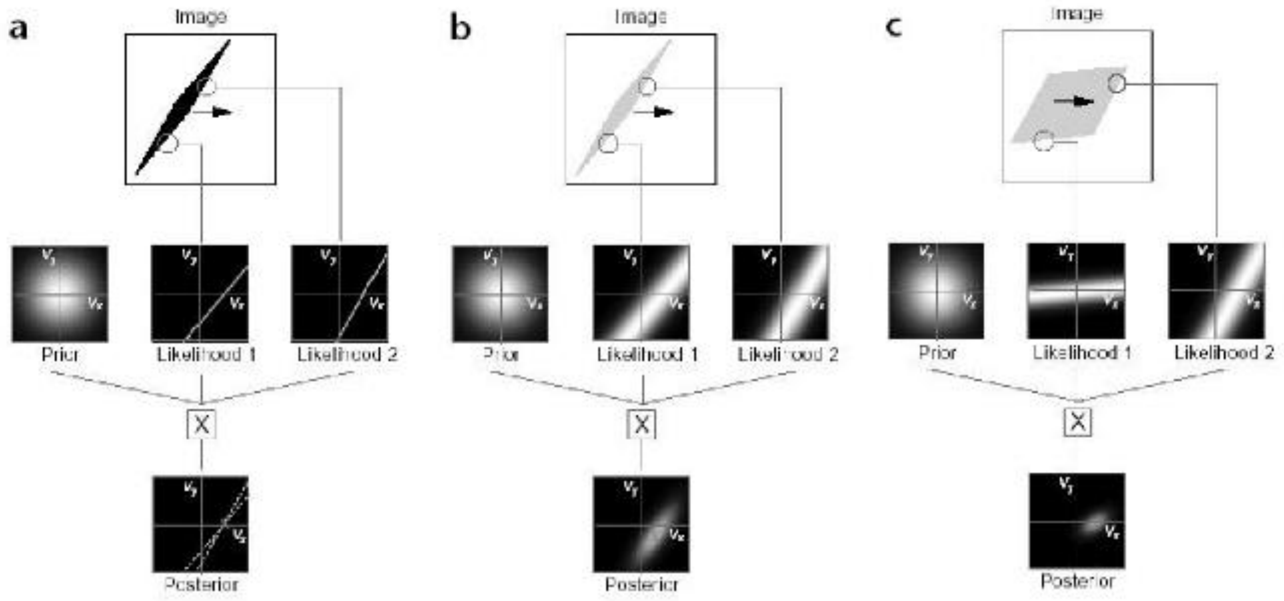


Figure 3: The response of the Bayesian estimator to a narrow rhombus. (replotted from Weiss and Adelson 98)

Effect of contrast



Optical Flow

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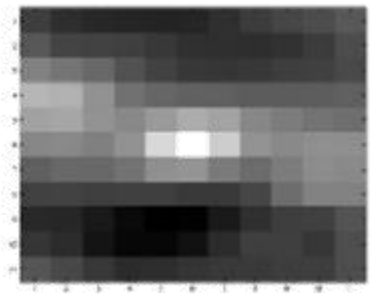
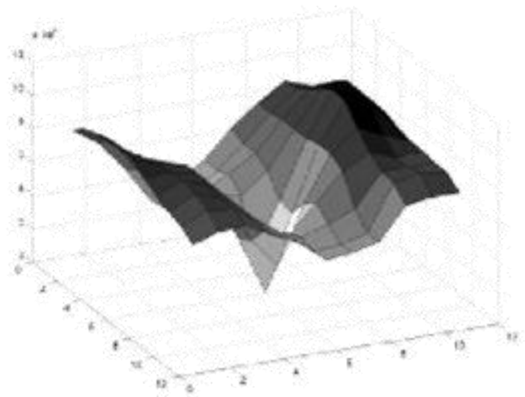
Correlation and SSD

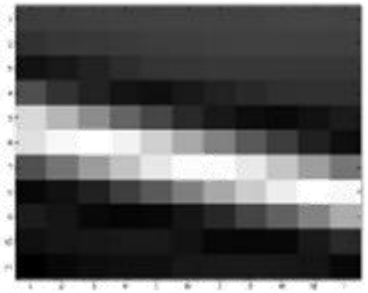
- For large displacements, do template matching as was used in stereo disparity search.
  - Define a small area around a pixel as the template
  - Match the template against each pixel within a search area in next image.
  - Use a match measure such as correlation, normalized correlation, or sum-of-squares difference
  - Choose the maximum (or minimum) as the match
  - Sub-pixel interpolation also possible

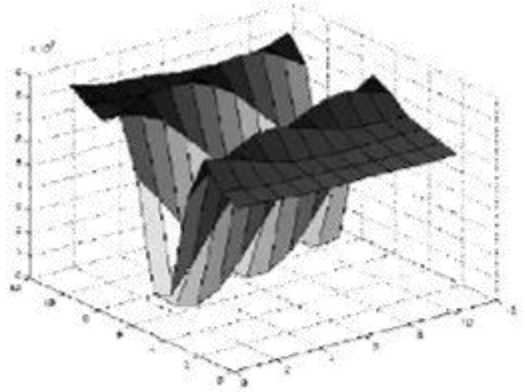
SSD Surface – Textured area



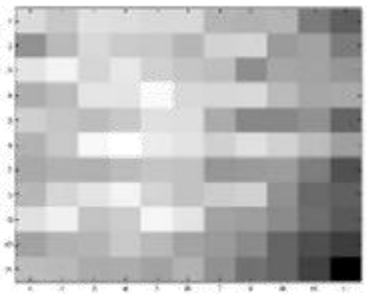


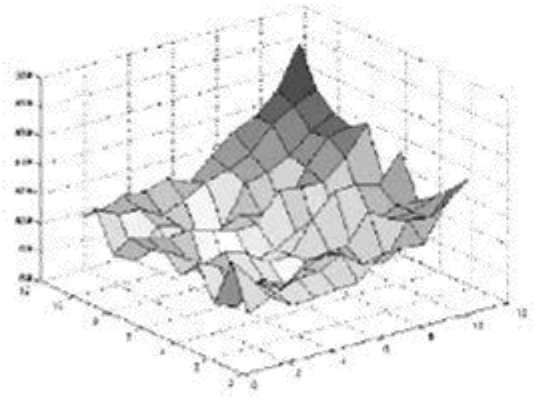
SSD Surface -- Edge





SSD Surface – homogeneous area





Discrete Search vs. Gradient Based Estimation

Consider image I translated by u_0, v_0

$$\boxed{\begin{aligned} I_0(x,y) &= I(x,y) \\ I_1(x+u_0, y+v_0) &= I(x,y) + \eta_1(x,y) \end{aligned}}$$

$$\boxed{\begin{aligned} E(u,v) &= \sum_{x,y} (I(x,y) - I_1(x+u, y+v))^2 \\ &= \sum_{x,y} (I(x,y) - I(x-u_0+u, y-v_0+v) - \eta_1(x,y))^2 \end{aligned}}$$

Discrete search simply searches for the best estimate.
Gradient method linearizes the intensity function and solves for the estimate

Visual Computing: Video Compression

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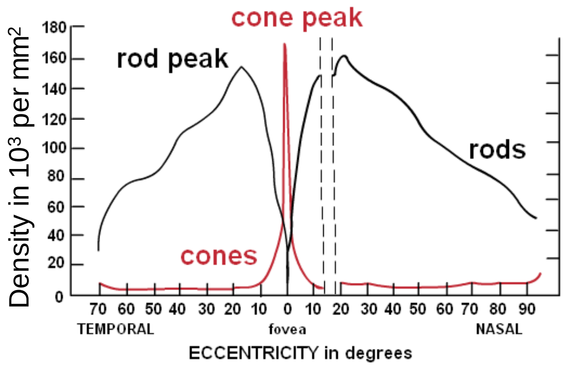
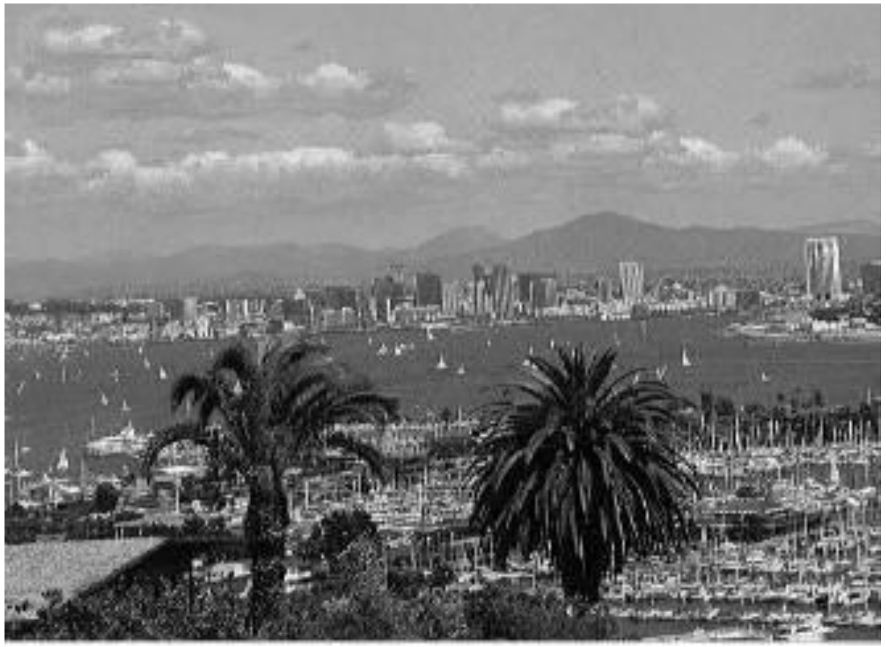
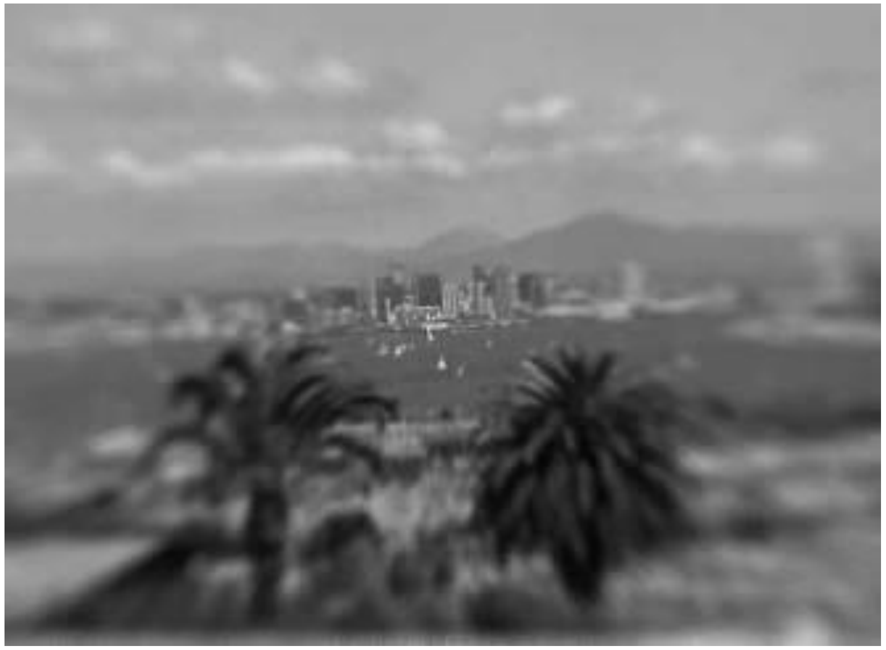
Perception of motion

- Human visual system is specifically sensitive to motion
- Eyes follow motion automatically
- Some distortions are not as perceivable as in image coding (would be if we froze frame)
- No good psycho-visual model available

Acuity of the Visual Field (small digression)



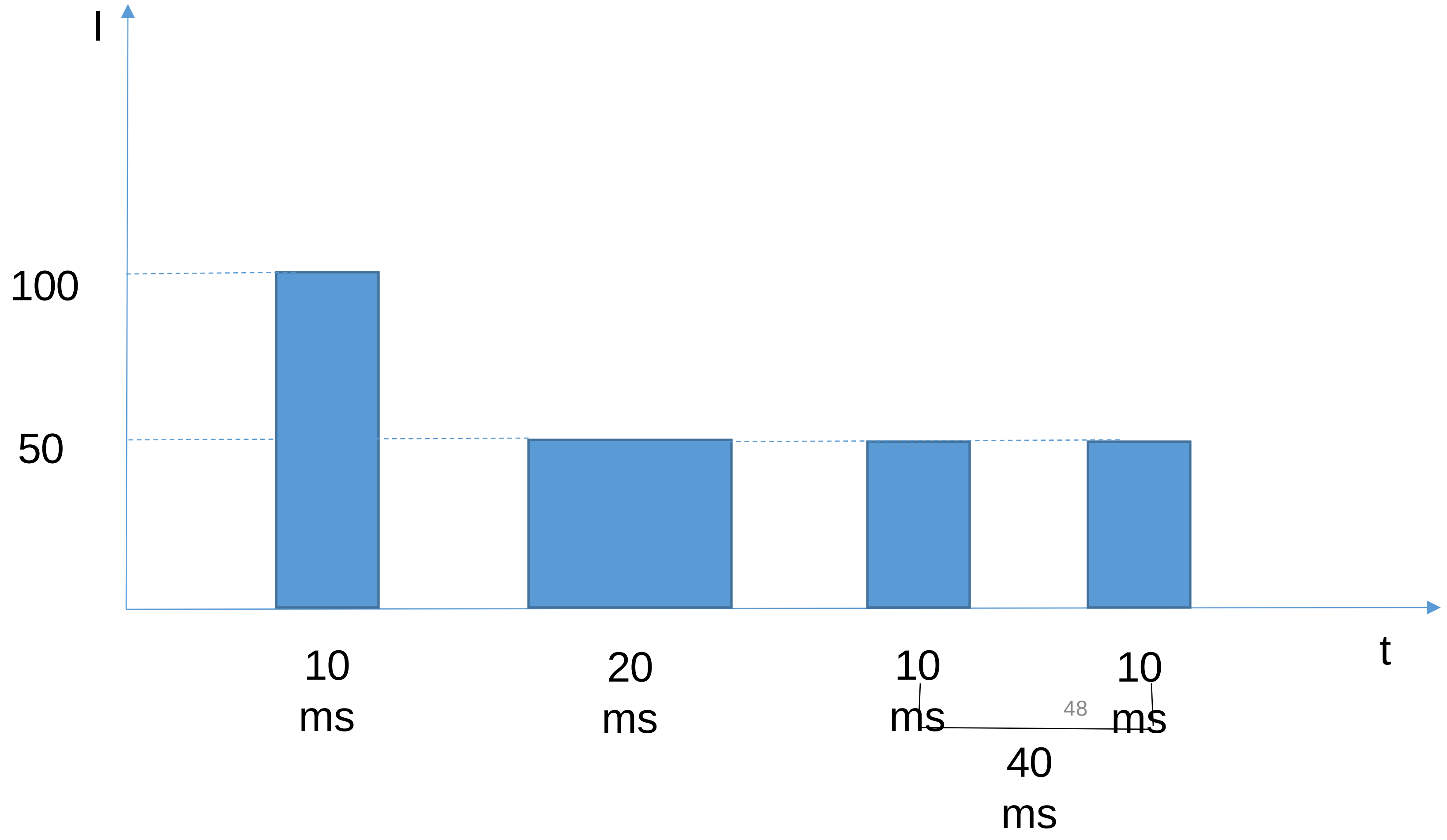




Perception of motion

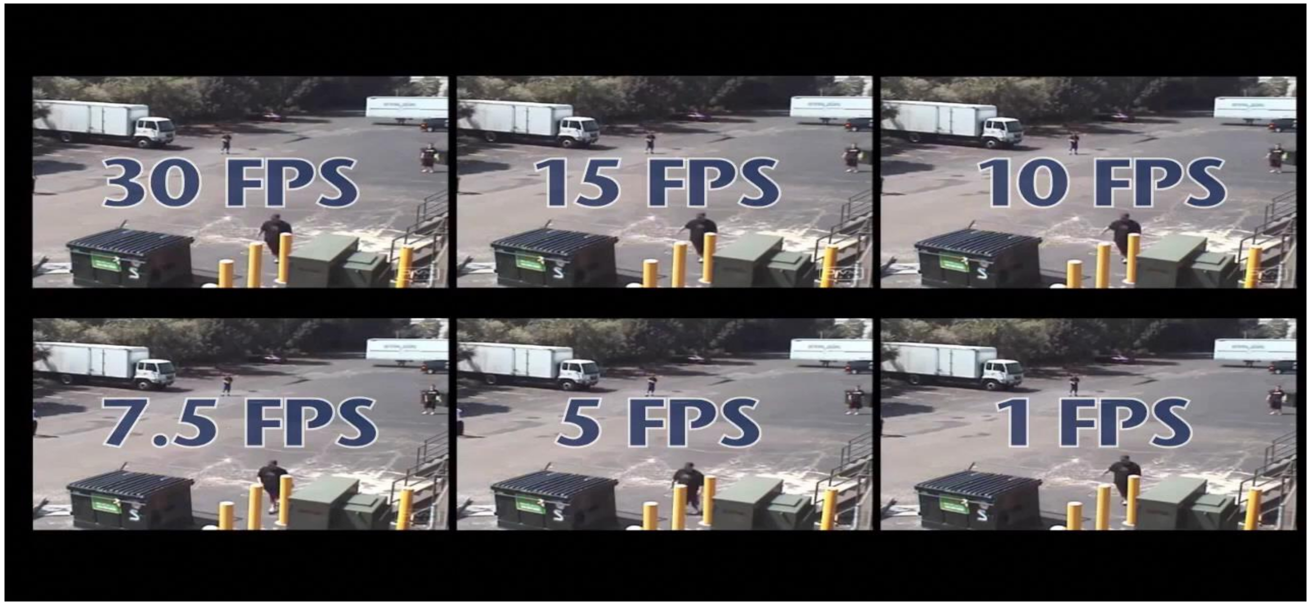
- Visual perception is limited to <24Hz
  - A succession of images will be perceived as continuous if frequency is sufficiently high
  - Cinema 24Hz, TV 25(50) Hz
- Still need to avoid aliasing (wheel effect)
  - High-rendering frame-rates desired in computer games (needed due to absence of motion blur)
- Flicker can be perceived up to >60Hz in particular in periphery
  - Issue addressed by 100Hz TV

Bloch's Law



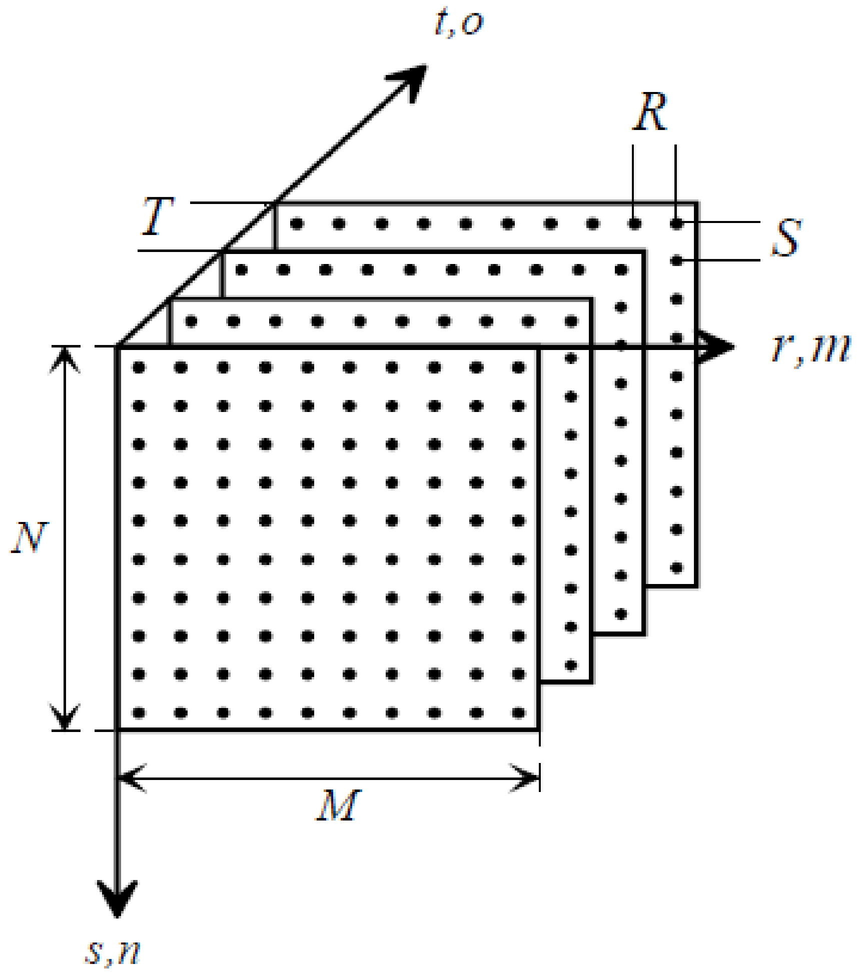
Bloch's Law - Implications

- Enforces limits on framerate for animations and videos (min 10 Hz)

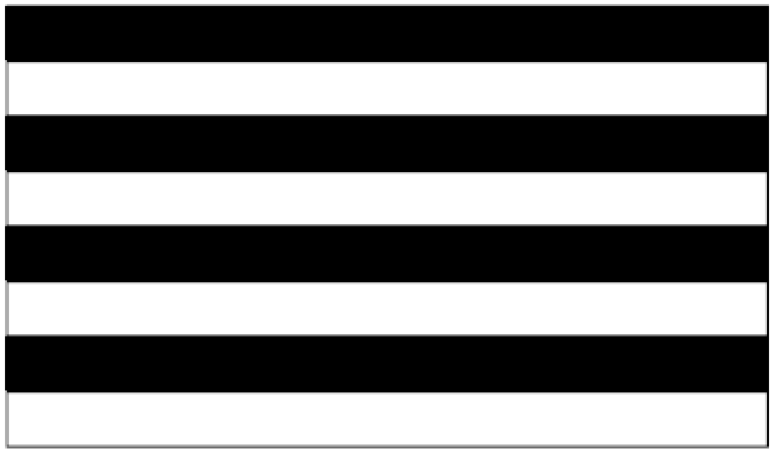


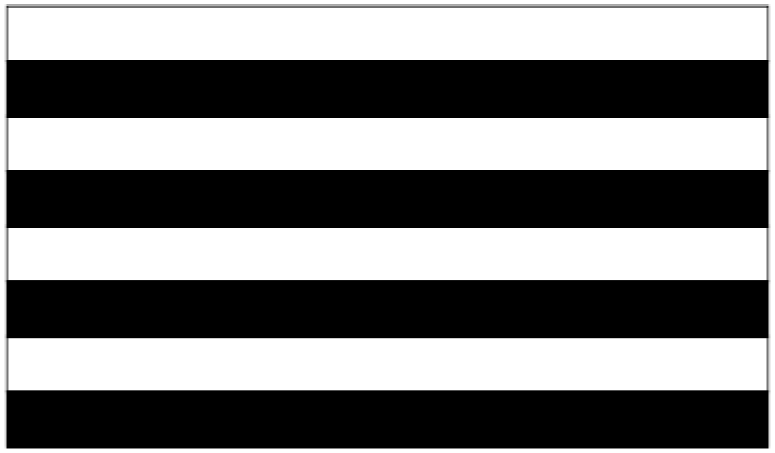
Video Format

- **2D+t :** Video sequence



Interlaced video format


top field


bottom field

- 2 temporally shifted half images, increase of frequency 25 -> 50 Hz
- Reduction of spatial resolution
- Full image representation: progressive

Why compress video?

- Raw HD TV signal 720p@50Hz

  1280x720x50x24bits/s = 1.105.920.000bits/s

  >1Gb/s

(e.g.1920x1080@60Hz>1Gb/s)

Only 20Mb/s HDTV channel bandwidth

Required compression factor of 60

(0.40bits/pixel on average)

Video Compression

XviD Configuration

About

Brightness

Postprocessing
- [✓] Deblocking (Y)
- [✓] Dering (Y)
- [ ] Film Effect
- [✓] Deblocking (UV)
- [✓] Dering (UV)

Output
- [ ] Rip video
- [ ] Compatibility Renderer

Output Colourspace: No Force

FourCC support
- [✓] DIVX
- [✓] DX50
- [✓] mp4v

Aspect Ratio

After restarting player, use this AR: Auto (mpeg-4 firs

Lossy video compression

- Take advantage of redundancy
  - Spatial correlation between neighboring pixels
  - Temporal correlation between frames
- Drop perceptually unimportant details

Temporal Redundancy

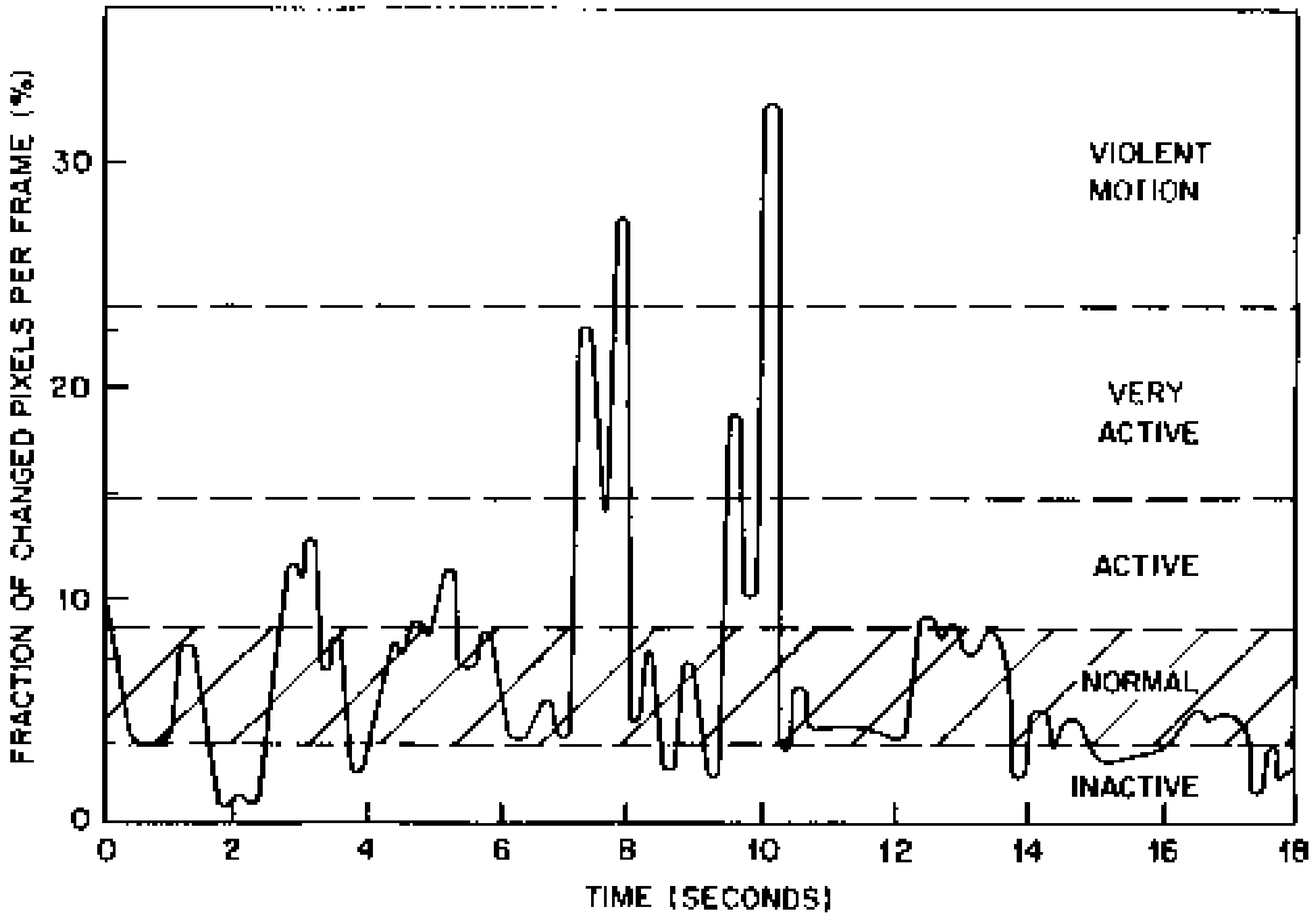
- Take advantage of similarity between successive frames

950

951

952

Temporal Activity



“Talking Head”

Temporal processing

- Usually high frame rate: *Significant temporal redundancy*
- Possible representations along temporal dimension:
  - *Transform/subband methods*
    - Good for textbook case of constant velocity uniform global motion
    - Inefficient for nonuniform motion, I.e. real-world motion
    - Requires large number of frame stores
      - Leads to delay (Memory cost may also be an issue)
  - *Predictive methods*
    - Good performance using only 2 frame stores
    - However, simple frame differencing in not enough…

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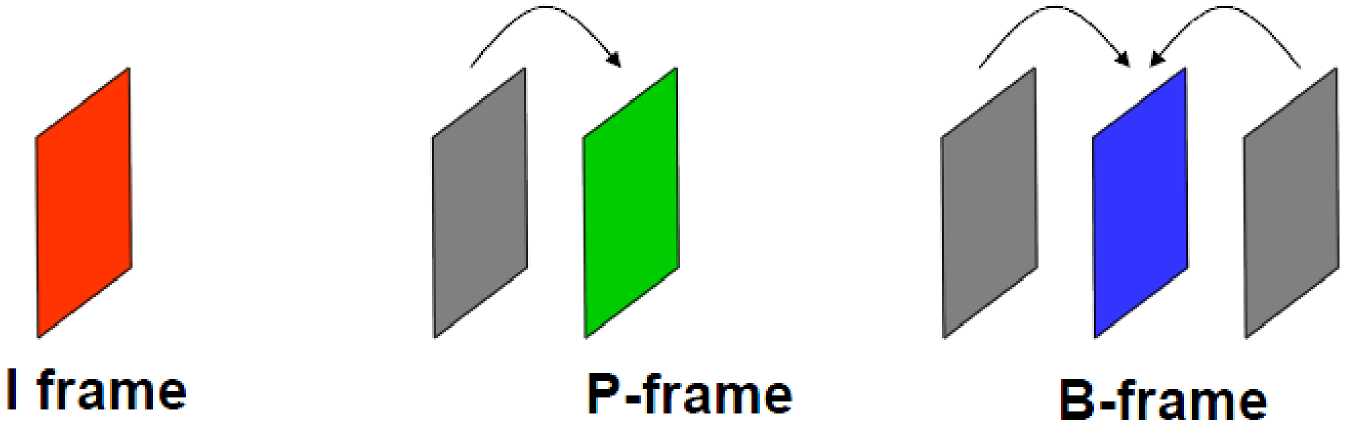
Video Compression

- Goal: Exploit the temporal redundancy
- *Predict current frame* based on previously coded frames
- Three types of coded frames:
  - ***I-frame:*** Intra-coded frame, coded independently of all other frames
  - ***P-frame:*** Predictively coded frame, coded based on previously coded frame
  - ***B-frame:*** Bi-directionally predicted frame, coded based on both previous and future coded frames



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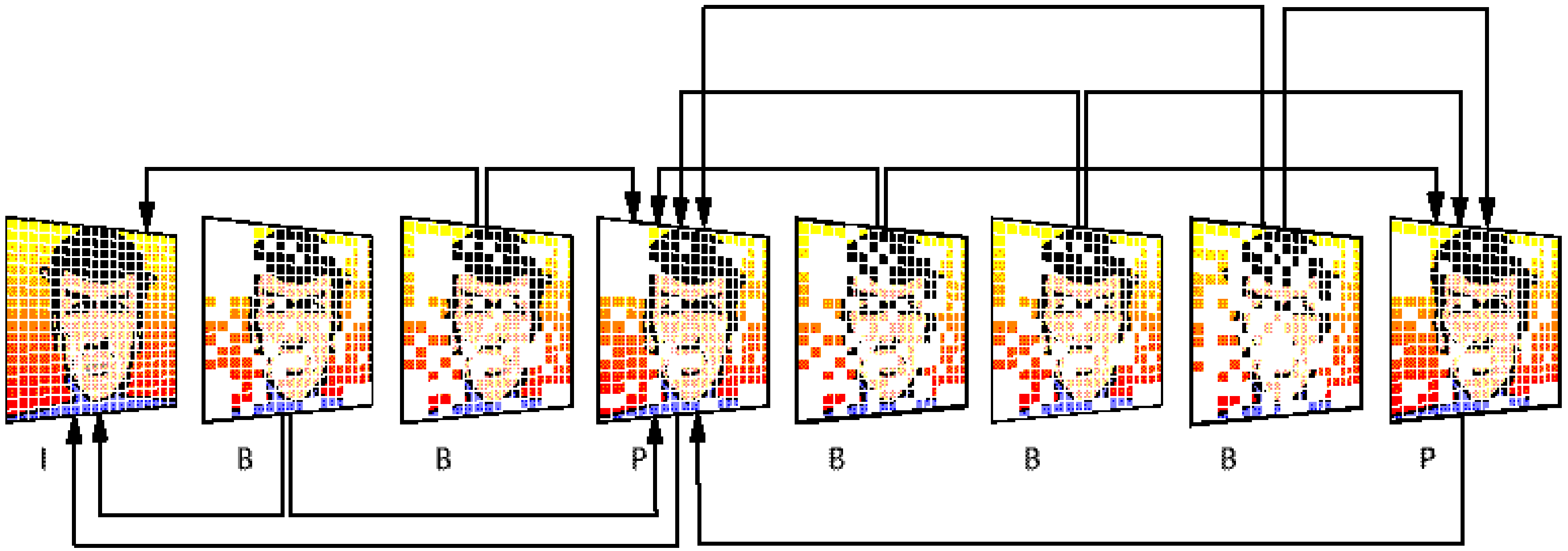
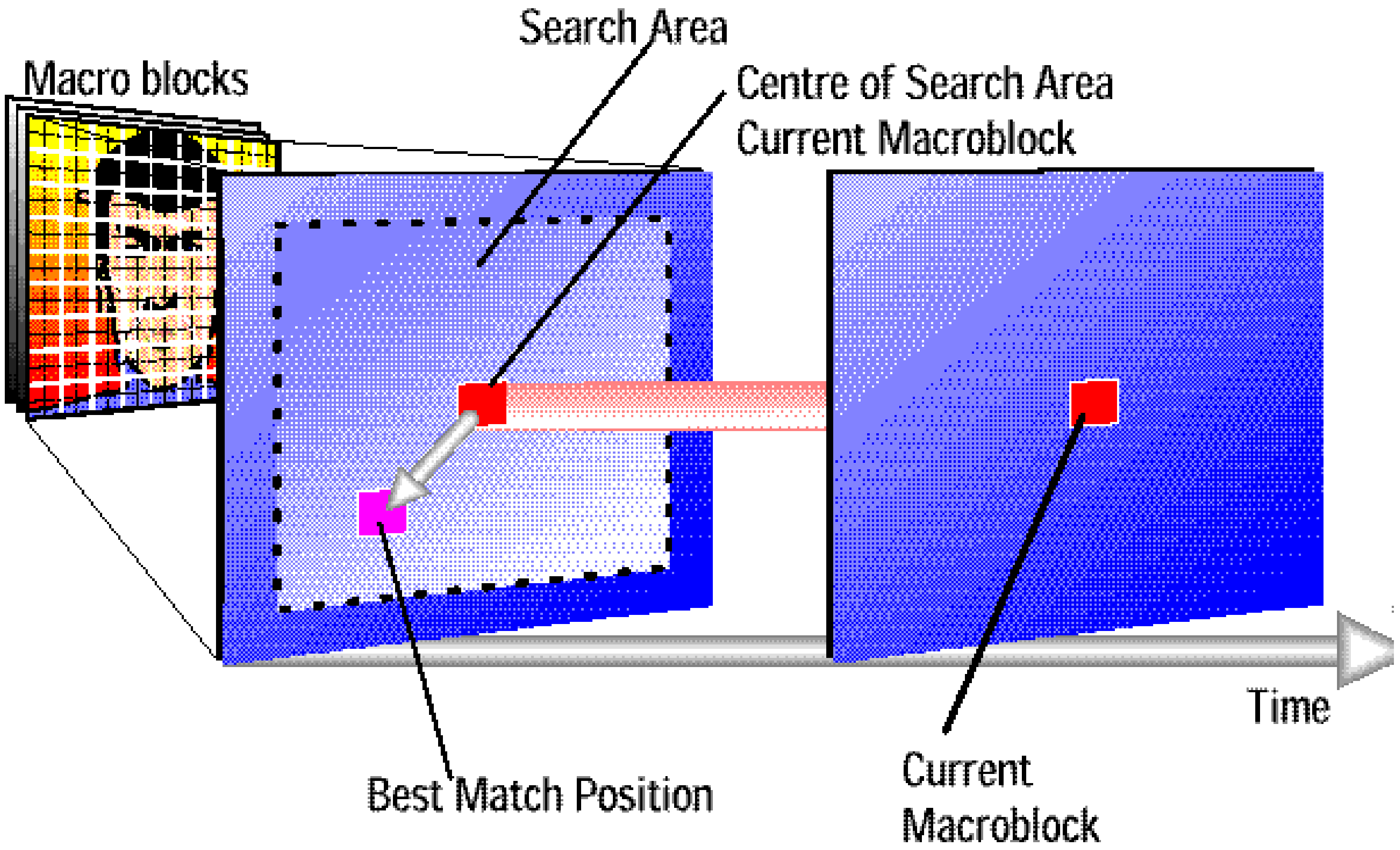
Temporal Redundancy Reduction

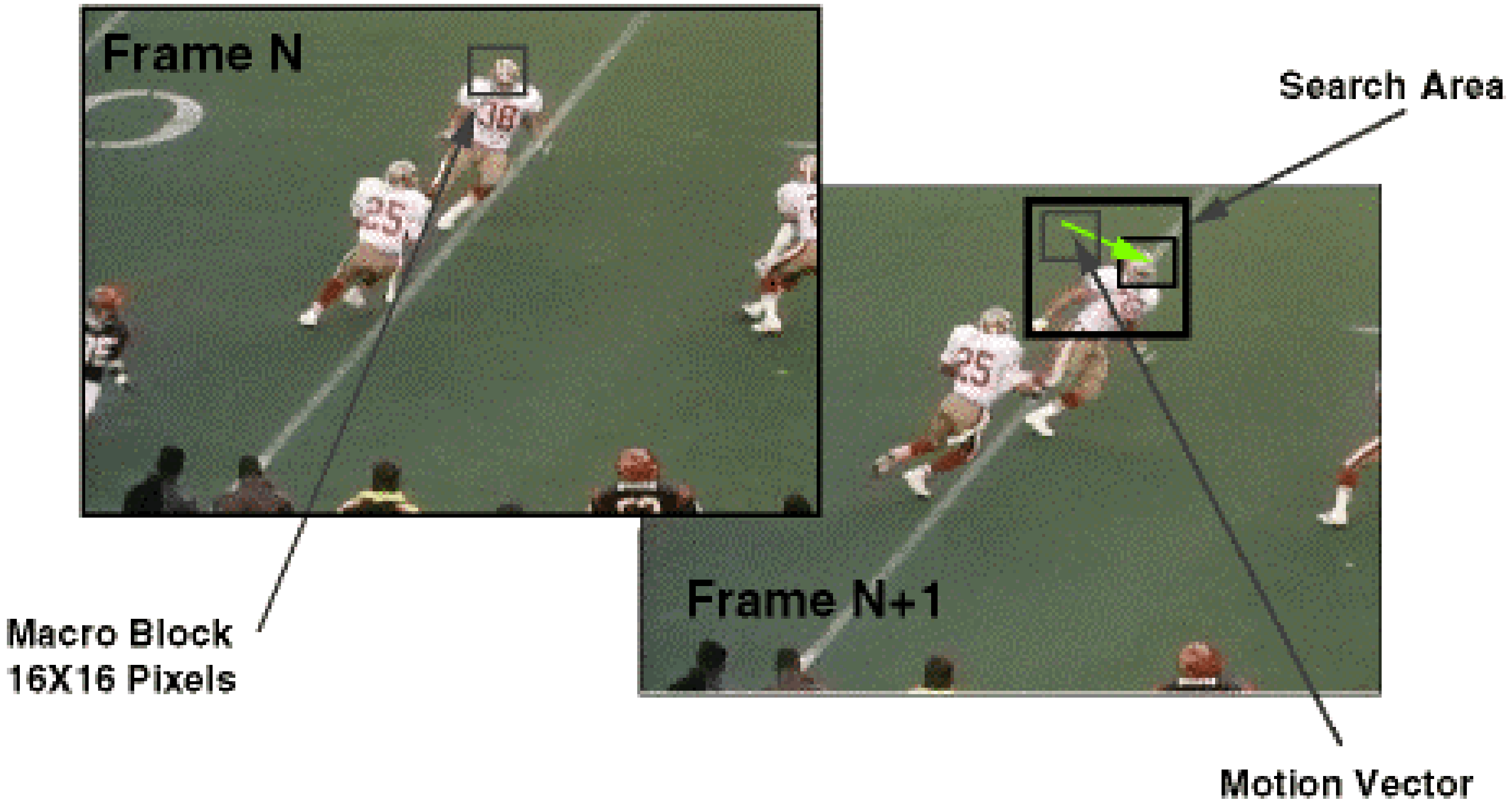


- *I* frames are independently encoded
- *P* frames are based on previous I, P frames
  - Can send motion vector plus changes
- *B* frames are based on previous and following I and P frames
  - In case something is uncovered

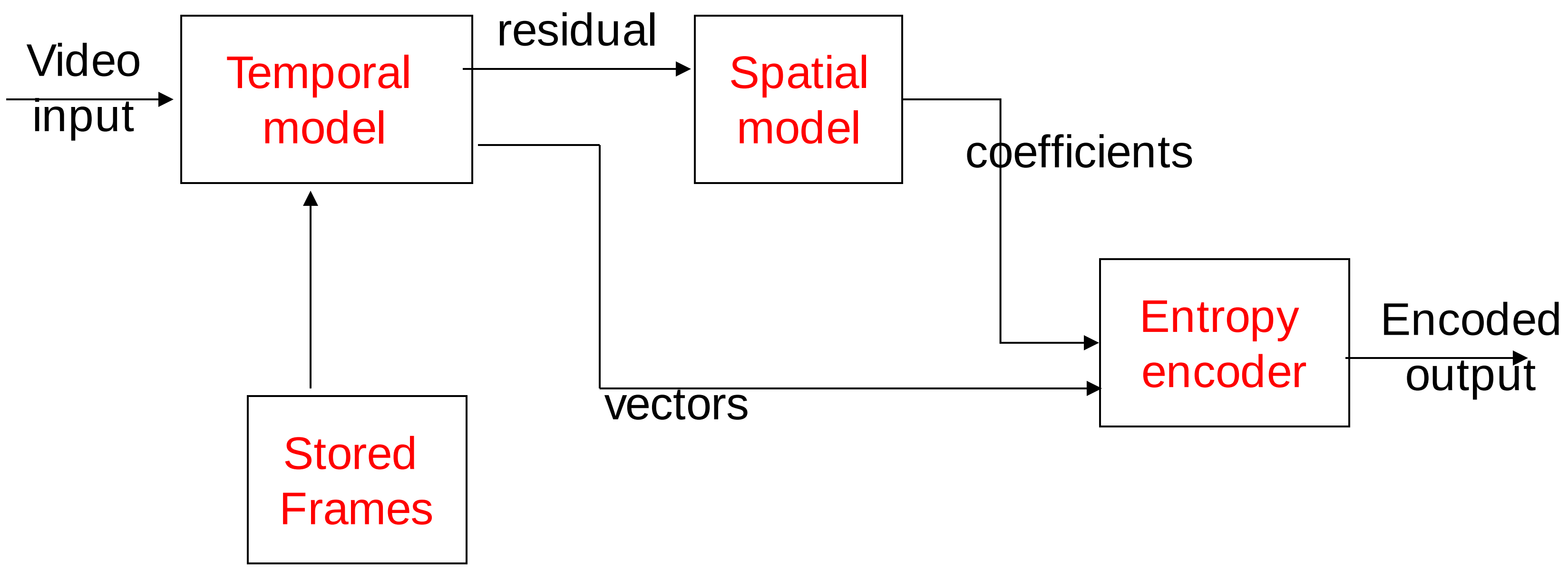
Temporal Redundancy Reduction



Temporal Redundancy Reduction



Video compressor diagram



Question

- When may temporal redundancy reduction be ineffective?

Answer

- *When may temporal redundancy reduction be ineffective?*
  - Many scene changes
  - High motion

Non-Temporal Redundancy

- Many scene changes

Non-Temporal Redundancy

- Sometimes high motion

Temporal processing: Motion-compensated prediction

- Simple frame differencing *fails* when there is motion
- *Must account for motion*

  $\rightarrow$ *Motion-compensated (MC) prediction*
- MC-prediction generally provides significant improvements
- Questions:
  - How can we estimate motion?
  - How can we form MC-prediction?

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Temporal processing: Motion estimation

- Ideal situation:
  - Partition video into moving objects
  - Describe object motion

  → Generally very difficult
- Practical approach: *Block-Matching Motion Estimation*
  - Partition each frame into blocks, e.g. 16x16 pixels
  - Describe motion of each block

  → No object identification required

  → Good, robust performance

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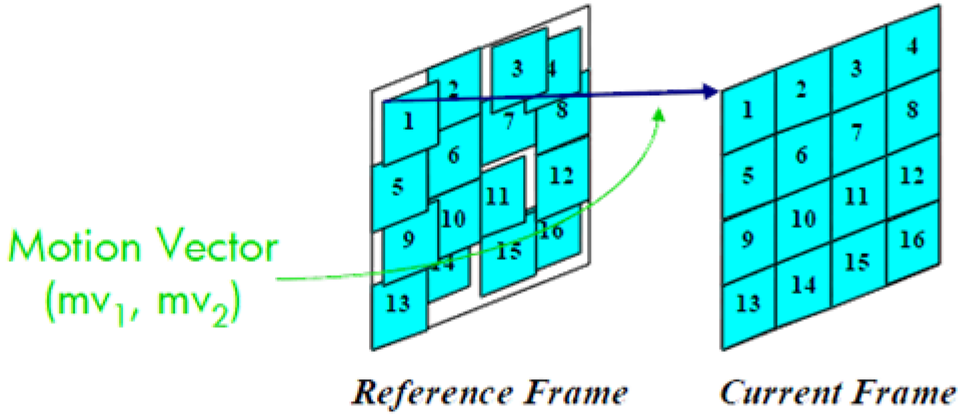
Block-matching motion estimation



- *Assumptions:*
  - Translational motion within block:

$$f(n_1, n_2, k_{cur}) = f(n_1 - mv_1, n_2 - mv_2, k_{ref})$$

  - All pixels within each block have the same motion
- *ME Algorithm:*
  1) Divide current frame into non-overlapping $N_1 x N_2$ blocks
  2) For each block, find the *best matching block* in reference frame
- *MC-Prediction Algorithm:*
  - Use best matching blocks of reference frame as prediction of blocks in current frame

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Block-matching: determining the best matching block

- For each block in the current frame search for best matching block in the reference frame
  - *Metrics* for determining "best match":

$$MSE = \sum_{(n_1,n_2)\in Block} \sum \left[f(n_1, n_2, k_{cur}) - f(n_1 - mv_1, n_2 - mv_2, k_{ref}) \right]^2$$

$$MAE = \sum_{(n_1,n_2)\in Block} \sum \left| f(n_1, n_2, k_{cur}) - f(n_1 - mv_1, n_2 - mv_2, k_{ref}) \right|$$

  - *Candidate blocks*: All blocks in, e.g., $(\pm 32, \pm 32)$ pixel area
  - *Strategies for searching* candidate blocks for best match
    - Full search: Examine all candidate blocks
    - Partial (fast) search: Examine a carefully selected subset
- Estimate of motion for best matching block: *"motion vector"*

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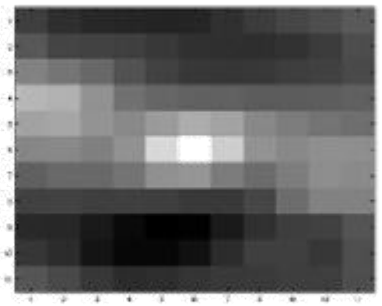
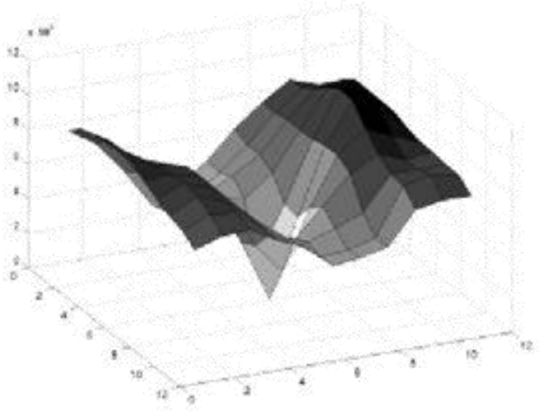
SSD Surface – Textured area





(from last lecture)

Motion vector and motion vector field

- *Motion vector*
  - Expresses the *relative horizontal and vertical offsets* *(mv_1,mv_2)*, or motion, of a given block from one frame to another
  - Each block has its own motion vector
- *Motion vector field*
  - Collection of motion vectors for all the blocks in a frame

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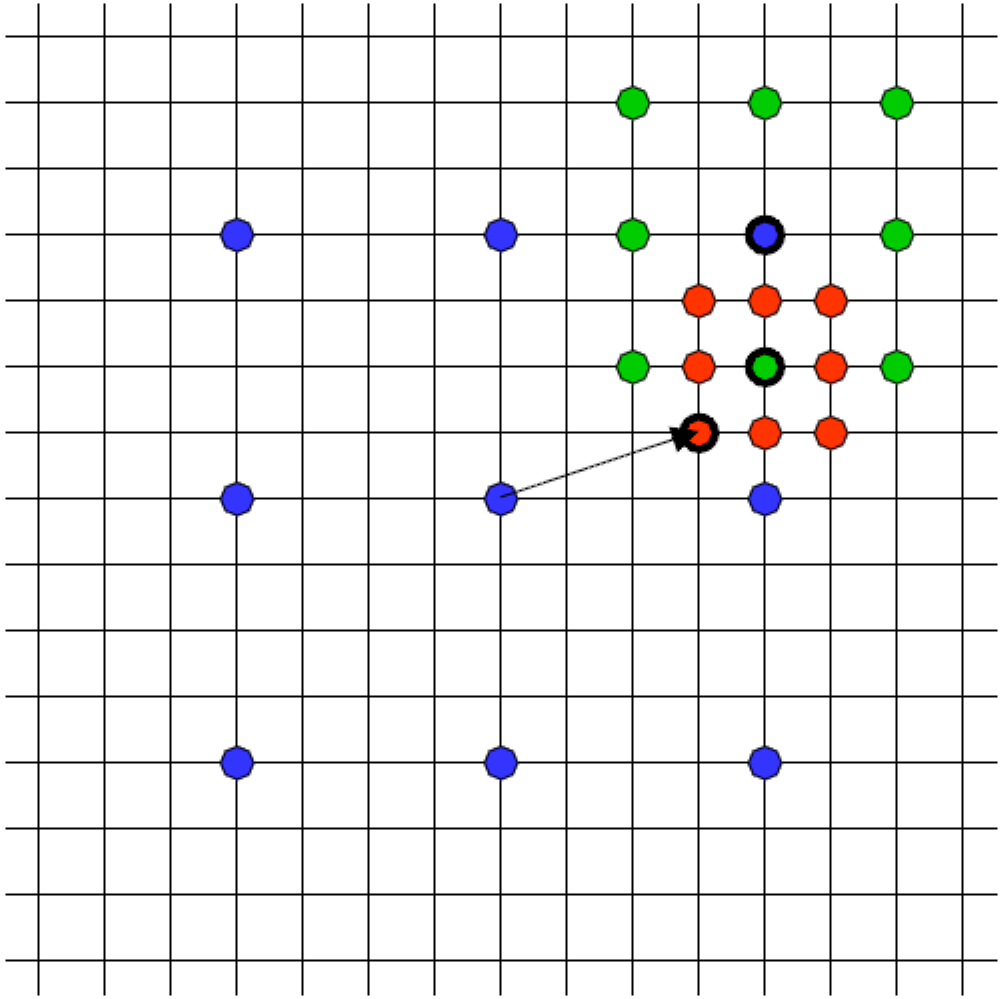
Example of Fast Motion Estimation Search: 3-Step (Log) Search



- *Goal: Reduce number of search points*
- Example: $(\pm 7, \pm 7)$ search area
- Dots represent search points
- Search performed in 3 steps (coarse-to-fine):
  - Step 1: ● $(\pm 4\, pixels)$
  - Step 2: ● $(\pm 2\, pixels)$
  - Step 3: ● $(\pm 1\, pixels)$
- Best match is found at each step
- Next step: Search is centered around the best match of prior step
- Speedup increases for larger search areas

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Motion Vector Precision?

- Motivation:
  - *Motion is not limited to integer-pixel offsets*
  - However, video only known at discrete pixel locations
  - To estimate sub-pixel motion, frames must be *spatially interpolated*
- Fractional MVs are used to represent the sub-pixel motion
- Improved performance (extra complexity is worthwhile)
- Half-pixel ME used in most standards: MPEG-1/2/4
- *Why are half-pixel motion vectors better?*
  - Can capture half-pixel motion
  - Averaging effect (from spatial interpolation) reduces prediction error → Improved prediction
  - For noisy sequences, averaging effect reduces noise → Improved compression

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Practical Half-Pixel Motion Estimation Algorithm

- *Half-pixel ME (coarse-fine) algorithm:*
  1) *Coarse step:* Perform integer motion estimation on blocks; find best integer-pixel MV
  2) *Fine step:* Refine estimate to find best half-pixel MV
     a) Spatially interpolate the selected region in reference frame
     b) Compare current block to interpolated reference frame block
     c) Choose the integer or half-pixel offset that provides best match
- Typically, bilinear interpolation is used for spatial interpolation

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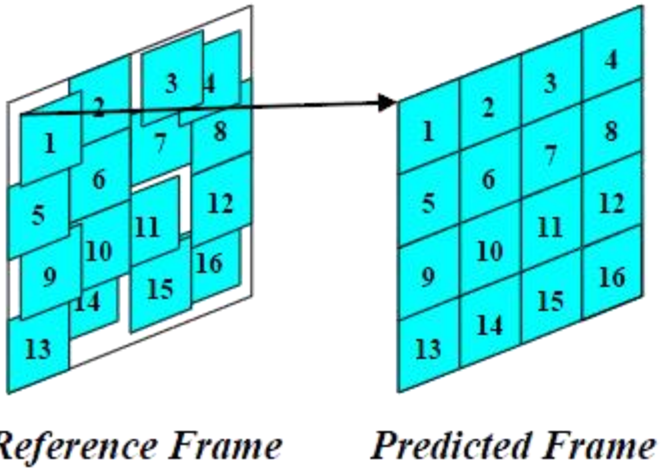
Example: MC-Prediction for Two Consecutive Frames

Previous Frame
(Reference Frame)

Current Frame
(To be Predicted)



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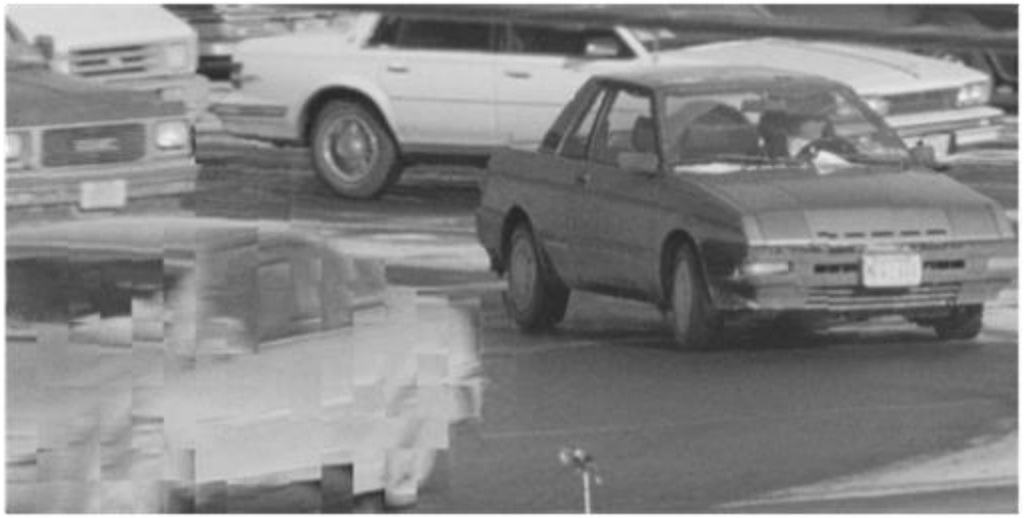
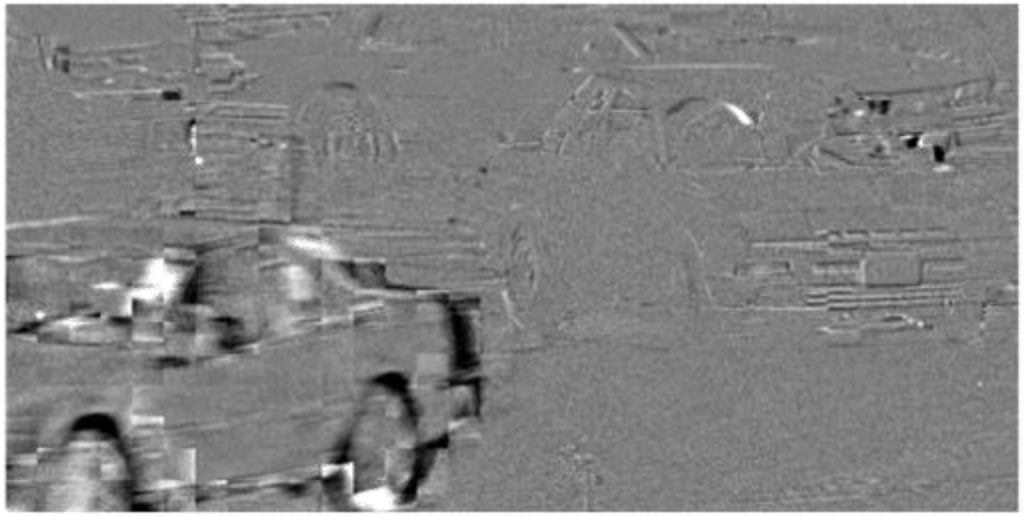
Example: MC-Prediction for Two Consecutive Frames

Prediction of Current Frame



Prediction Error (Residual)



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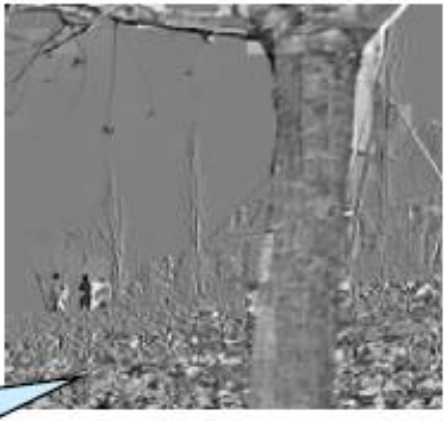
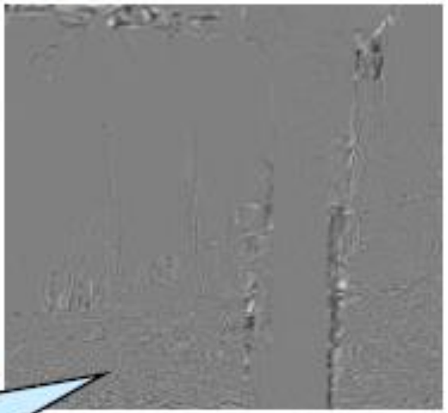
MC-prediction

Image of a video sequence

Difference to previous image



Without Motion compensation



With Motion compensation

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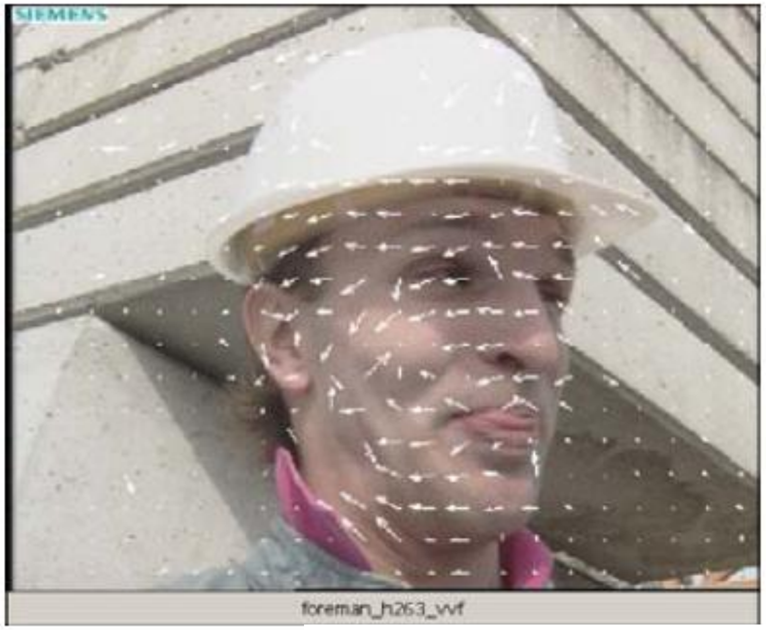
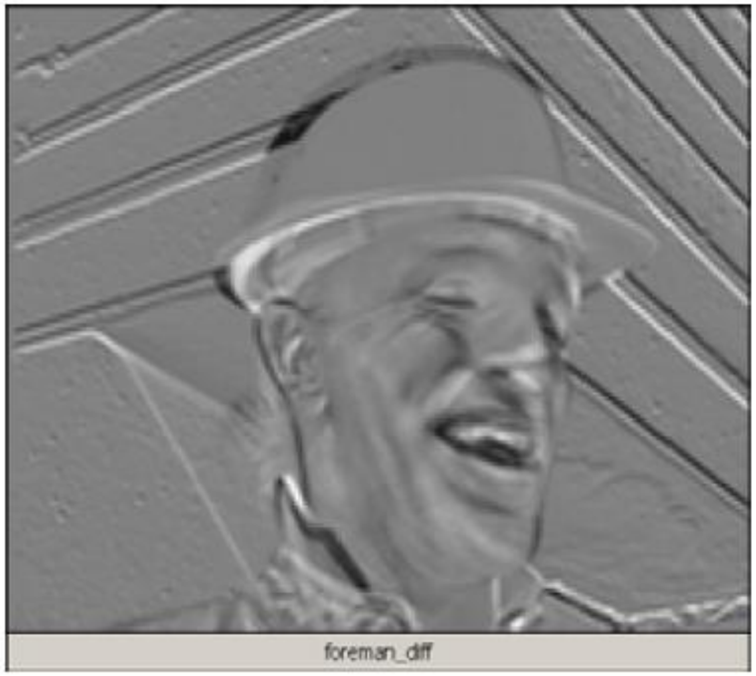
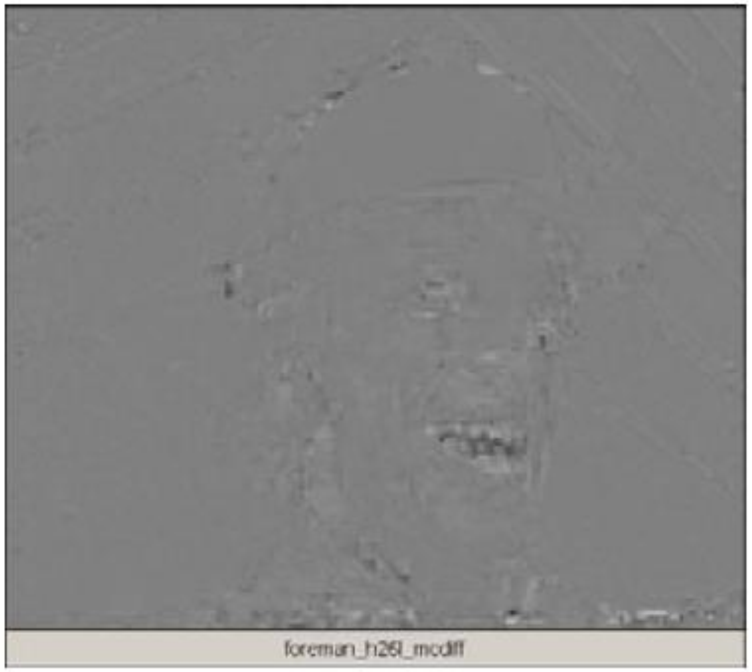
Example MC





Without motion compensation



With motion compensation

CIF Format (352x288)

ETH

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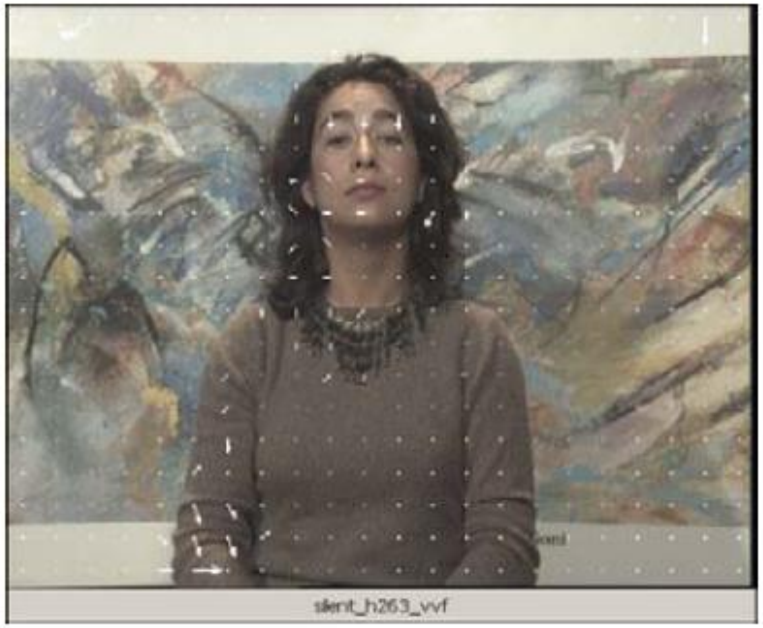
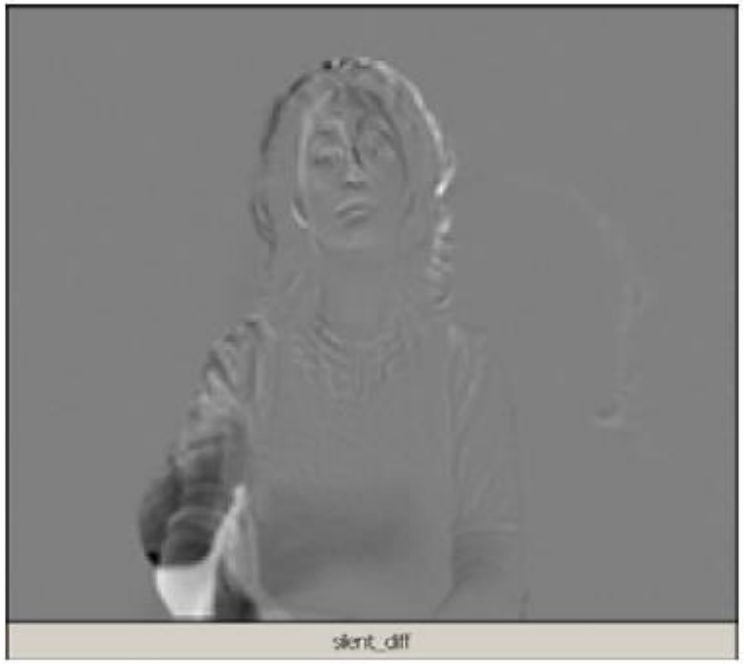
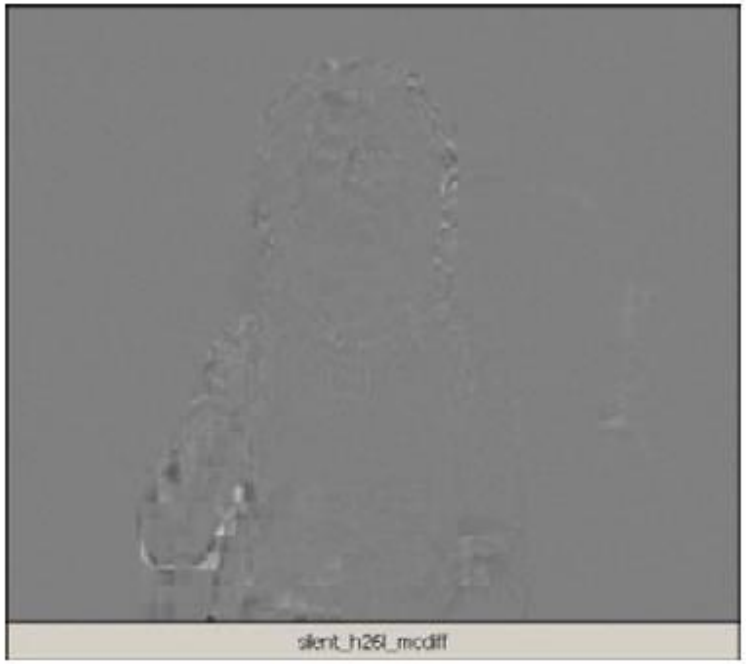
Example MC





Without motion compensation



With motion compensation

QCIF Format
(176x144)

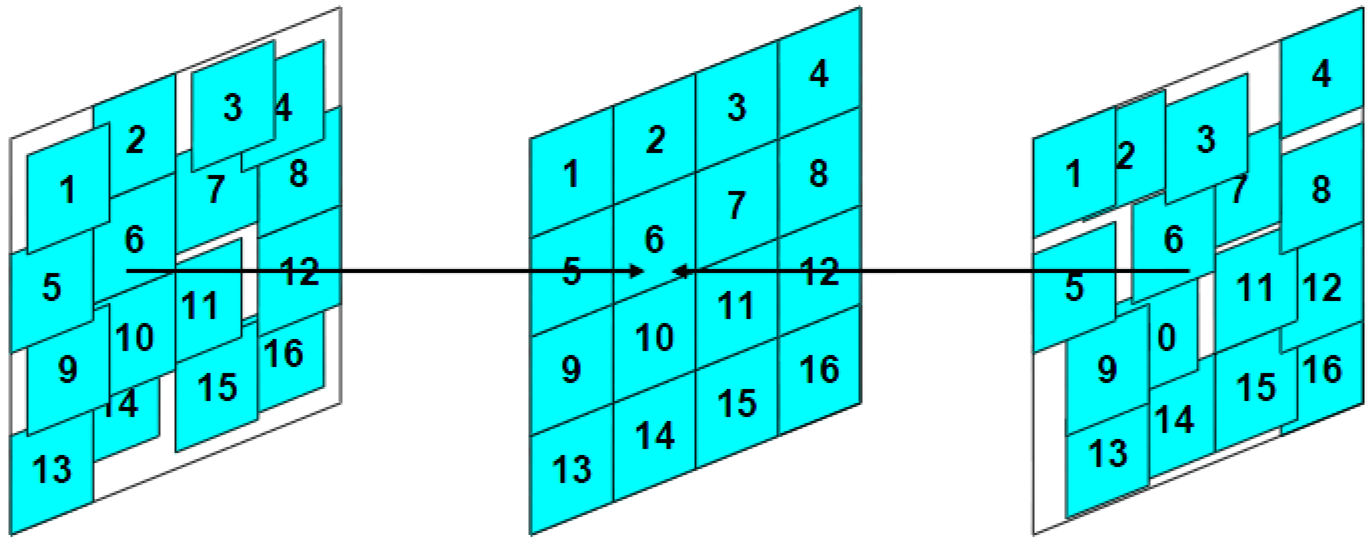
Slide from
Aljoscha Smolic

Block Matching Algorithm: Summary

- *Issues:*
  - Block size?
  - Search range?
  - Motion vector accuracy?
- Motion typically estimated only from luminance
- *Advantages:*
  - Good, robust performance for compression
  - Resulting motion vector field is easy to represent (one MV per block) and useful for compression
  - Simple, periodic structure, easy VLSI implementations
- *Disadvantages:*
  - Assumes translational motion model $\rightarrow$ Breaks down for more complex motion
  - Often produces blocking artifacts (OK for coding with Block DCT)

Slide from John G. Apostolopoulos

Bidirectional MC prediction



Previous Frame ***Current Frame*** ***Future Frame***

- *Bi-Directional MC-Prediction* is used to estimate a block in the current frame from a block in:
  1) Previous frame
  2) Future frame
  3) Average of a block from the previous frame and a block from the future frame
  4) Neither, i.e. code current block without prediction

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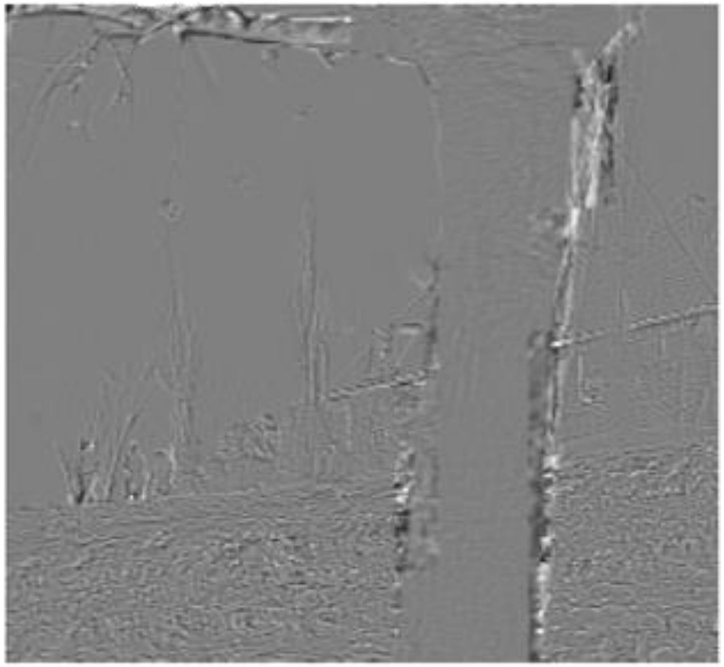
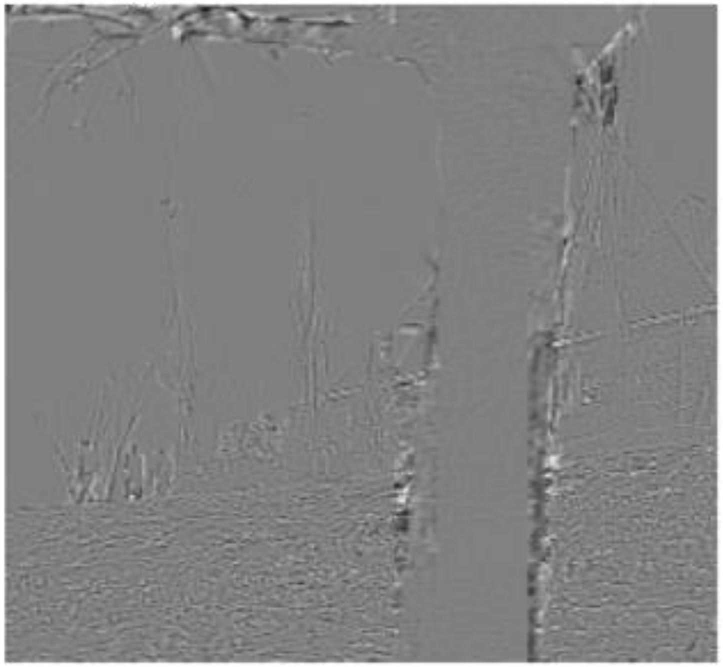
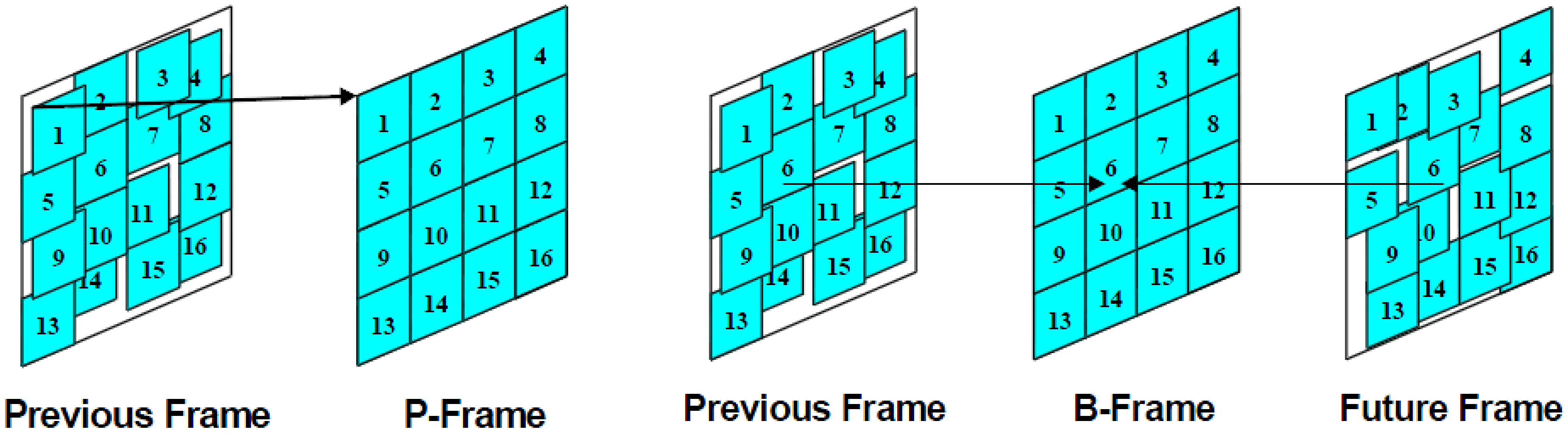
Example bidirectional prediction

- Prediction error with unidirectional (left) and bidirectional (right) prediction

MC-Prediction and Bi-Directional MC-Prediction (P-and B-frames)

- Motion compensated prediction: Predict the current frame based on reference frame(s) while compensating for the motion
- Examples of block-based motion-compensated prediction (*P-frame*) and bi-directional prediction (*B-frame*):



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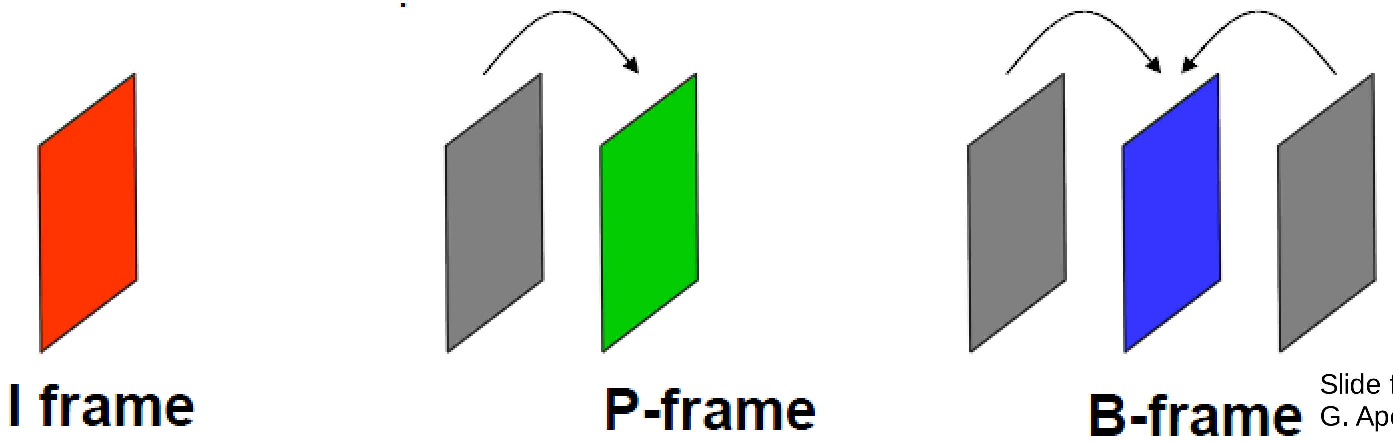
Video compression

- Main addition over image compression:
  - Exploit the temporal redundancy
- Predict current frame based on previously coded frames
- Three types of coded frames:
  - ***I-frame:*** Intra-coded frame, coded independently of all other frames
  - ***P-frame:*** Predictively coded frame, coded based on previously coded frame
  - ***B-frame:*** Bi-directionally predicted frame, coded based on both previous and future coded frames



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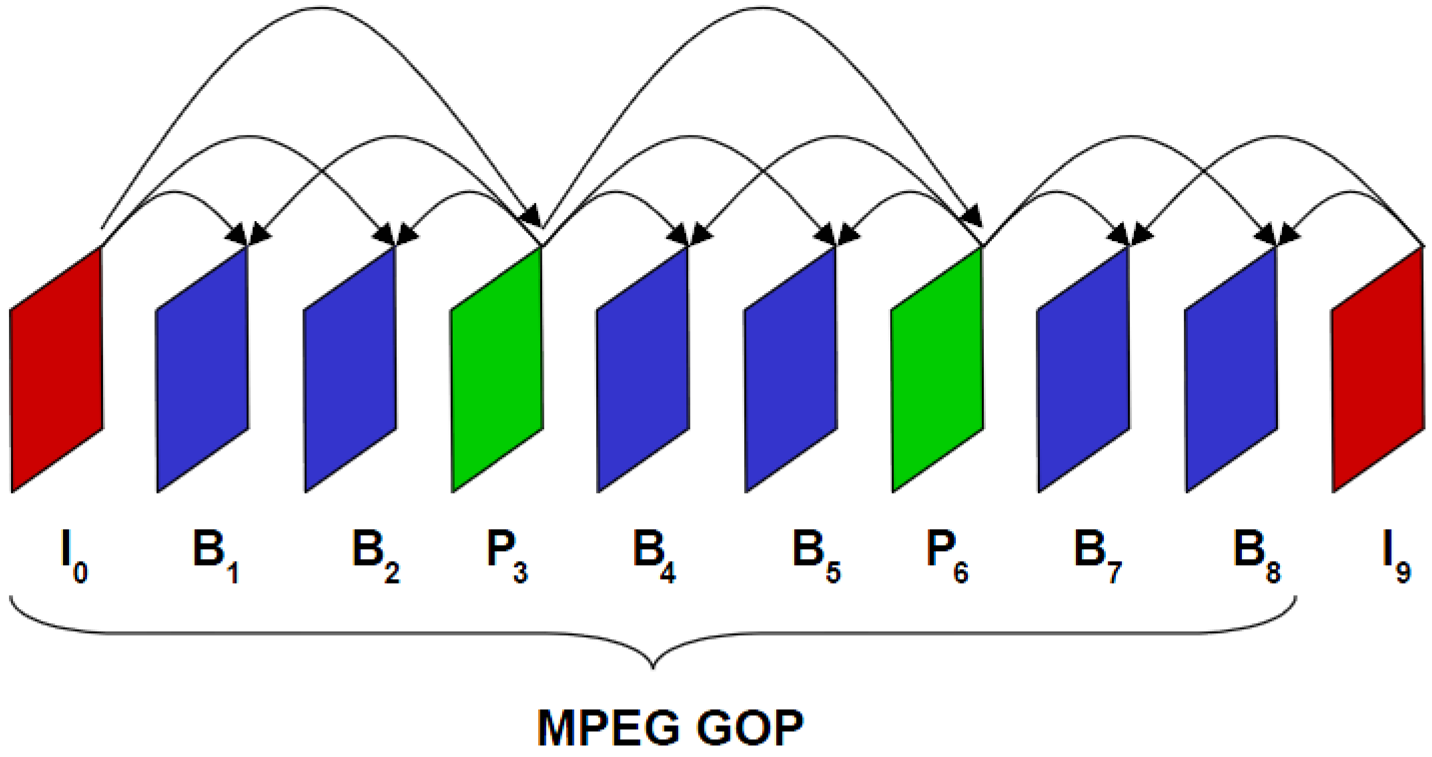
Example Use of I-,P-,B-frames: MPEG Group of Pictures (GOP)

- Arrows show prediction dependencies between frames



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Group of Pictures (GOP)

- Starts with an I-frame
- Ends with frame right before next I-frame
- "Open" ends in B-frame, "Closed" in P-frame
  - (What is the difference?)
- MPEG Encoding a parameter, but 'typical':
  - I B B P B B P B B I
  - I B B P B B P B B P B B I
- *Why not have all P and B frames after initial I?*

Example Compress. Performance

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

Note, results are Variable Bit Rate, even if frame rate is constant

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Summary of Temporal Processing

- Use MC-prediction (P and B frames) to reduce temporal redundancy
- MC-prediction usually performs well; In compression have a second chance to recover when it performs badly
- *MC-prediction yields:*
  - *Motion vectors*
  - *MC-prediction error or residual* $\rightarrow$ *Code error with conventional image coder*
- Sometimes MC-prediction may *perform badly*
  - Examples: Complex motion, new imagery (occlusions)
  - Approach:
    1. Identify frame or individual blocks where prediction fails
    2. Code *without prediction*

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Basic Video Compression Architecture

- Exploiting the redundancies:
  - Temporal: MC-prediction (P and B frames)
  - Spatial: Block DCT
  - Color: Color space conversion
- Scalar quantization of DCT coefficients
- Zigzag scanning, runlength and Huffman coding of the nonzero quantized DCT coefficients

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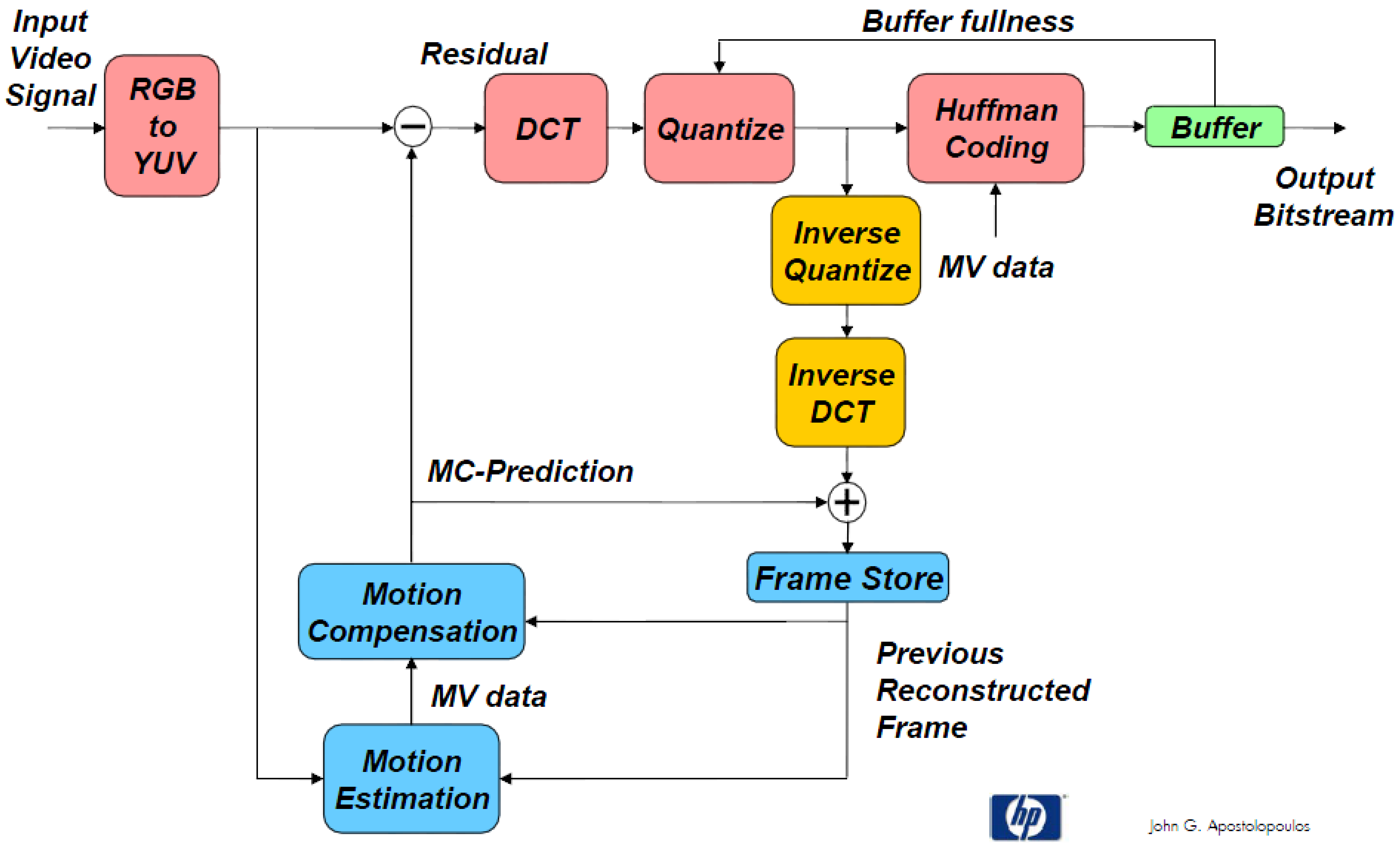
Example Video Encoder



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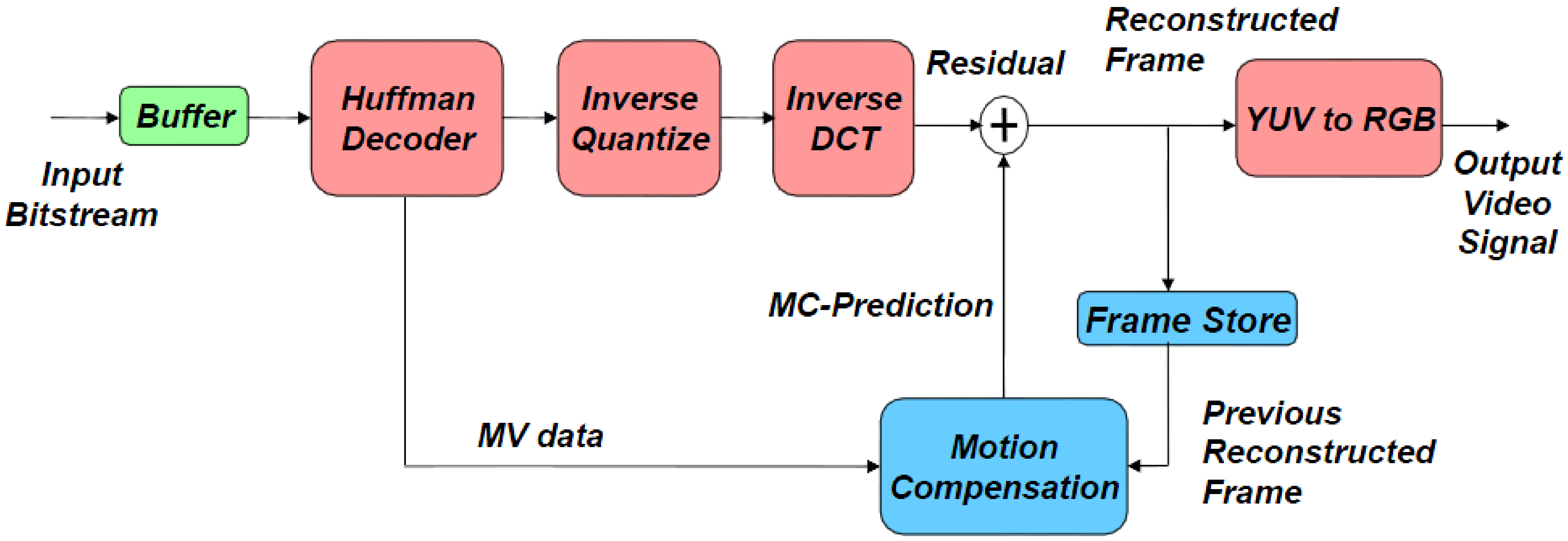
Example Video Decoder



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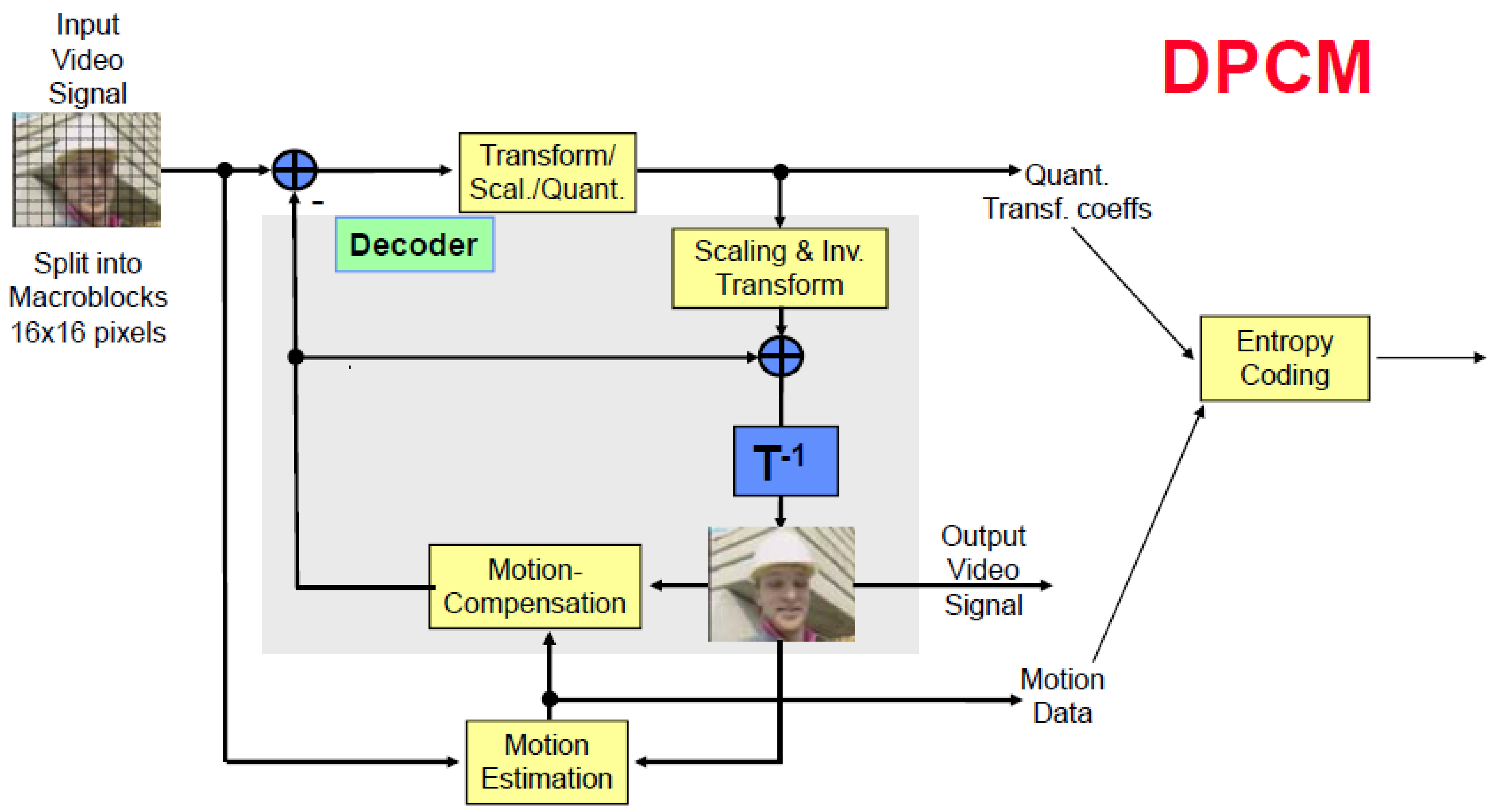
Hybrid Coding (MC+DCT)



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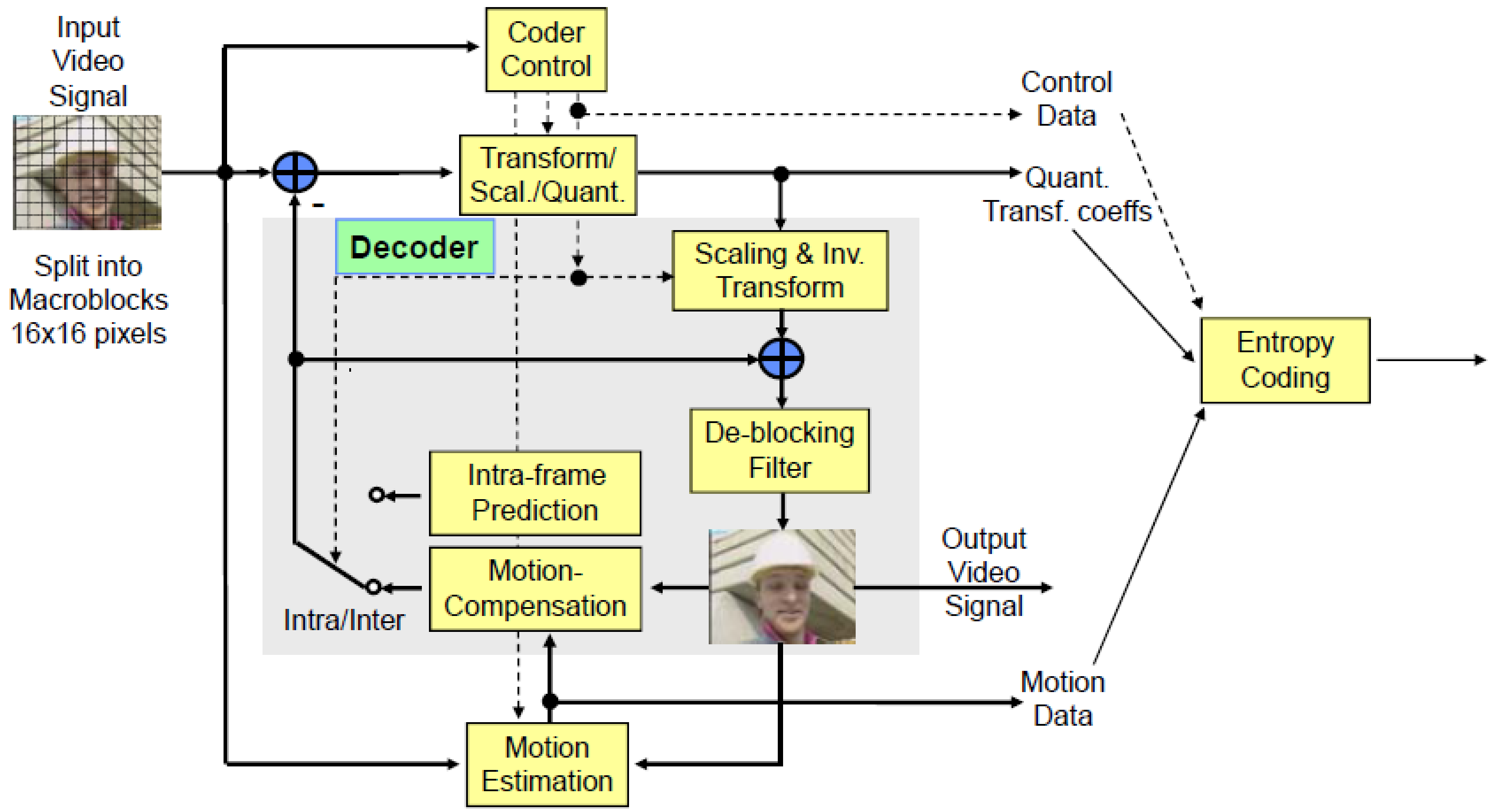
MPEG-4 part 10 aka H.264



Current Video Compression Standards

- International Telecommunication Union (ITU-T)
  - H.261 : 1991
  - H.262 : 1994
  - H.263 : 1995 Version 1, versch. Erweiterungen "H.263+/++"
  - H.264 : Ende 2002

- International Standardization Organization (ISO) : Moving Picture Experts Group (MPEG)
  - MPEG-1 : ISO 11572 : 1992
  - MPEG-2 : ISO 13818 : 1994 (identisch mit H.262)
  - MPEG-4 : ISO 14496 : 1999 (teilweise identisch mit H.263 V1)
  - MPEG-4 Part 10 (AVC): 2003 (identisch mit H.264)

"Joint Video Team" (JVT)

Actual Standard H.264/AVC

- Still hybrid video codec (MC-DCT) as other standards before
- Significant over all improvement by improvement of all parts
  - Motion compensation
    - Variable block sizes (16x16, 16x8, 8x8, 8x4, 4x4)
    - ¼ pixel motion compensation
    - Multiple reference frames
    - Intra prediction
  - Integer 4x4 transform
  - In-loop deblockingfilter
  - Entropycoding
    - Arithmetic coding CABAC

Objective quality measure: PSNR

- Error for one pixel, difference between original and decoded value

$$e(v,h) = \tilde{x}(v,h) - x(v,h)$$

- Mean-Squared-Error, MSE e.g. over an image

$$e_{\text{mse}} = \sqrt{\frac{1}{N \cdot M} \sum_{v=1}^{N} \sum_{h=1}^{M} e^2(v,h)}$$

- Peak-Signal-to-Noise-Ratio

$$\text{PSNR} = \frac{[\text{maximum value of } x]^2}{e_{\text{mse}}^2}$$

$$\text{PSNR} = 10 \cdot \log_{10}\left(\frac{[2^K]^2}{e_{\text{mse}}^2}\right) \text{dB}$$

$$\text{PSNR} = 10 \cdot \log_{10}\left(\frac{255^2}{e_{\text{mse}}^2}\right) \text{dB}$$

Slides Aljoscha Smolic

Subjective evaluation

- MOS: Mean opinion score

5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

- Subjective Tests with many participants and statistical evaluation
- Representative test material
- Careful selection of test conditions (display, light, disturbances, ...)

Rate-Distortion Curve

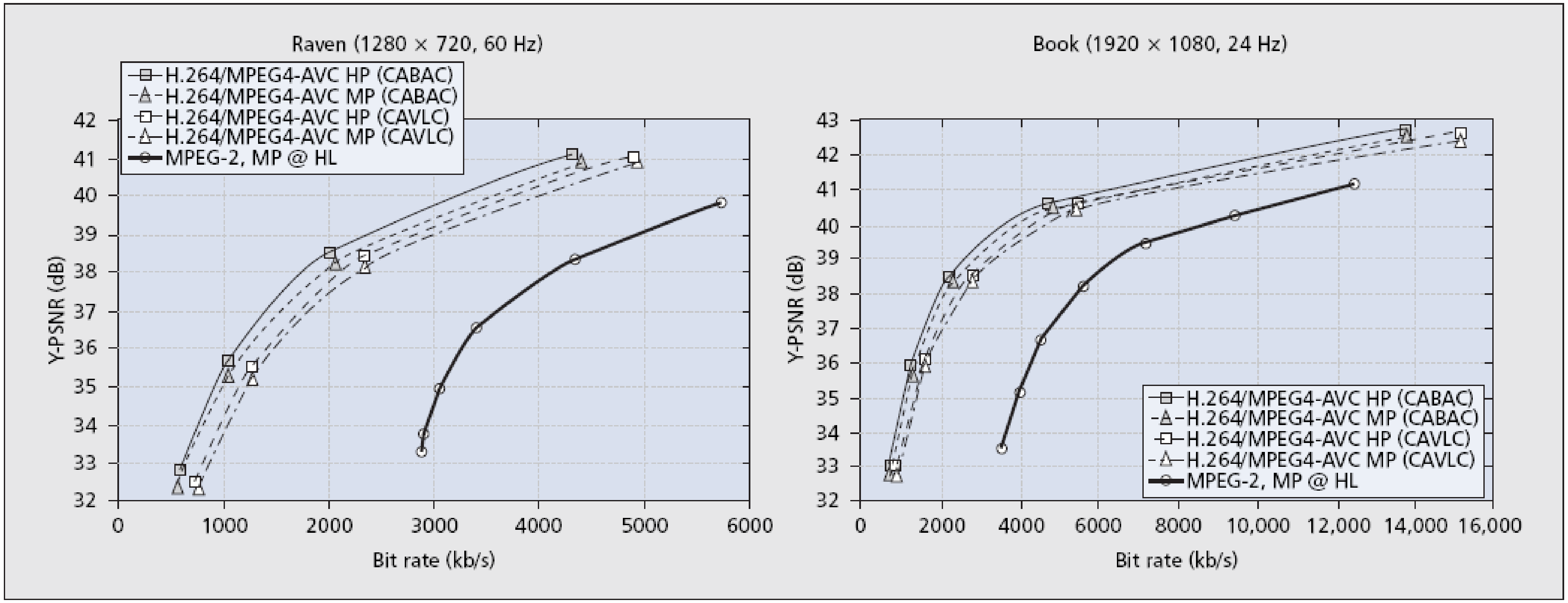


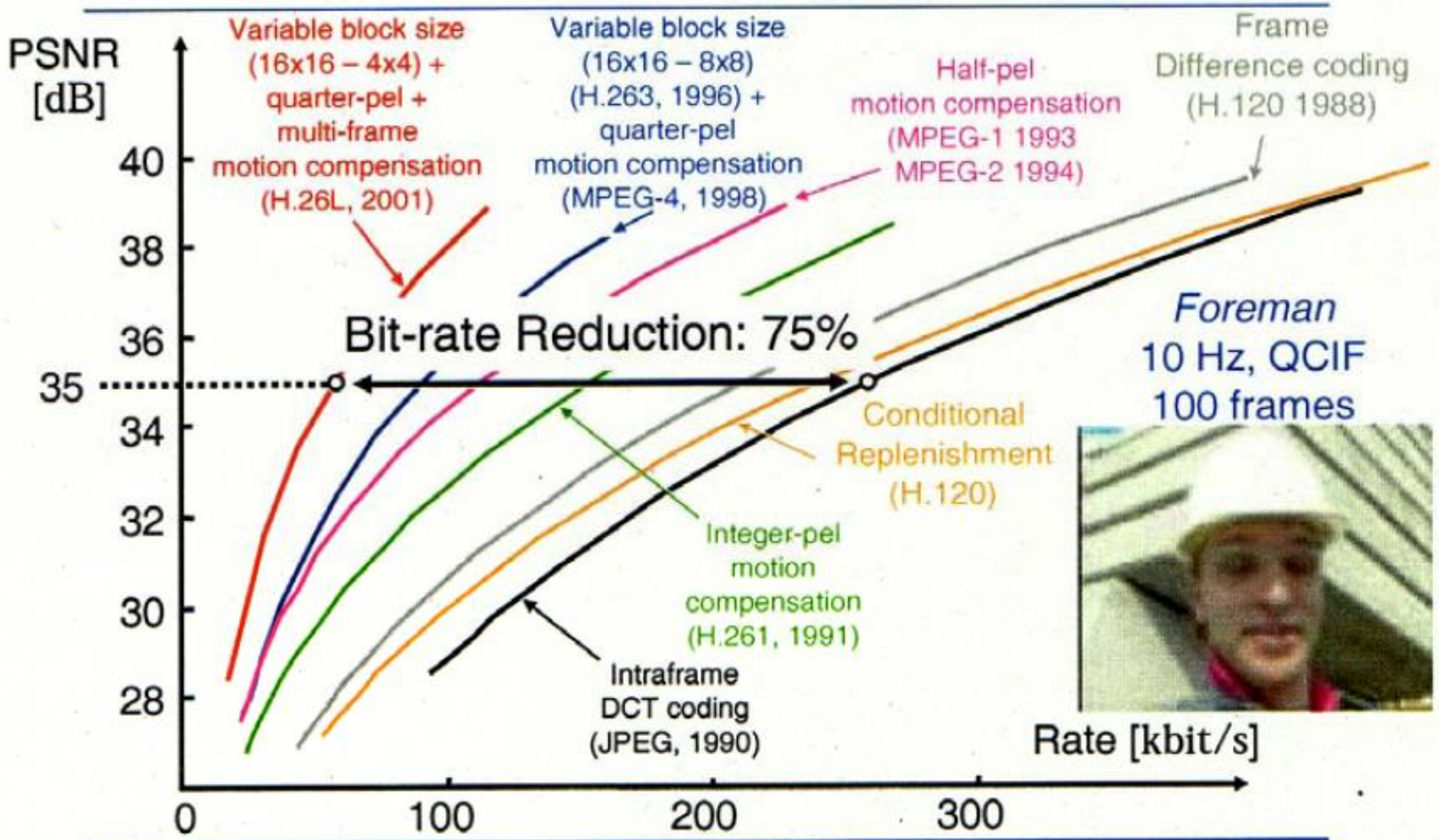
Figure 7. *Left: Objective performance for the "Raven" sequence (left) and "Book" sequence (right) comparing H.264/MPEG4-AVC HP, MP (both using CABAC and CAVLC), and MPEG2 MP@HL.*

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) = 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right)$$

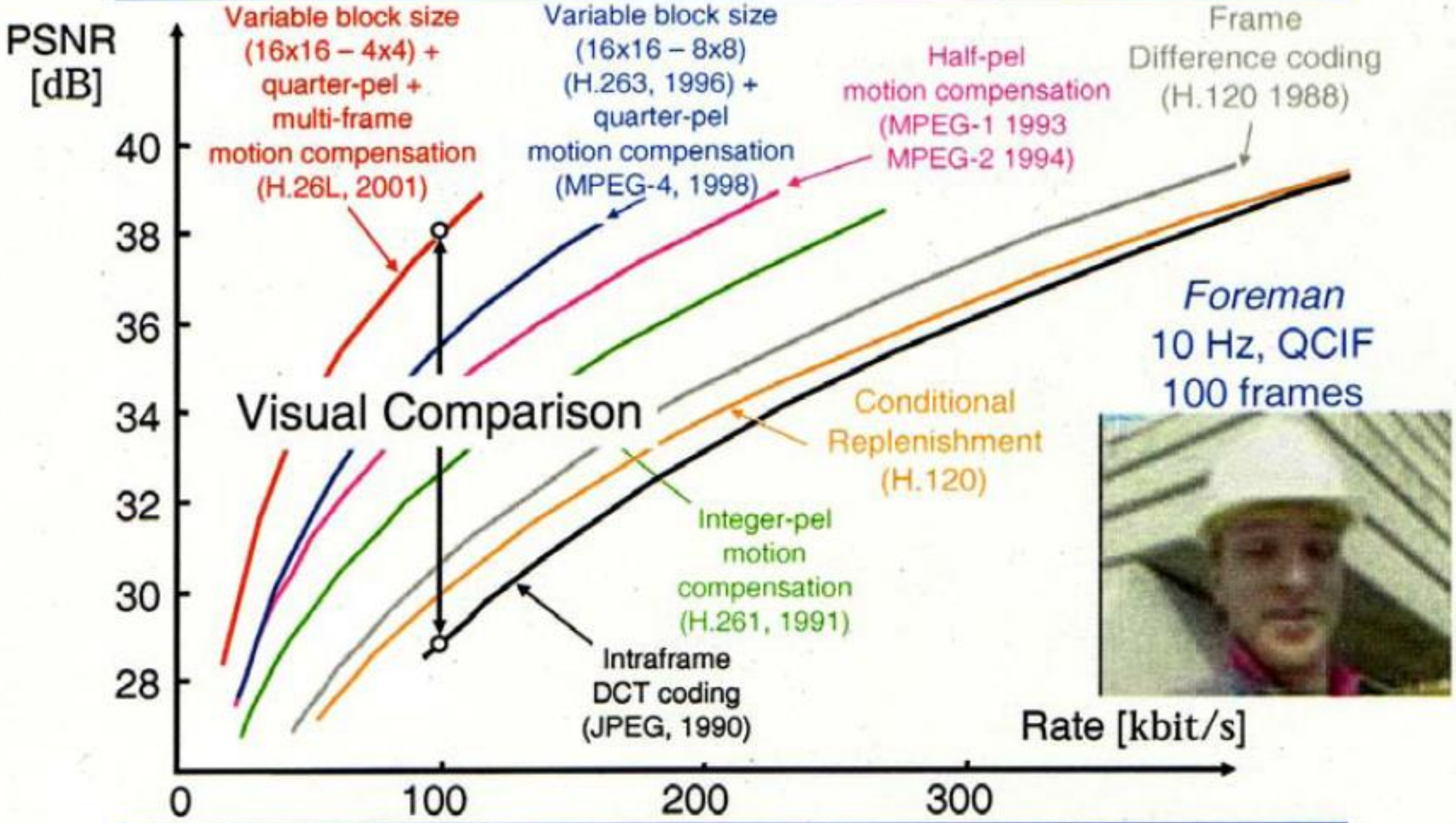
$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}||I(i,j) - K(i,j)||^2$$

($PSNR$ = Peak Signal to Noise Ratio) (MSE = Mean Square Error)

Milestones in Video Coding



Milestones in Video Coding



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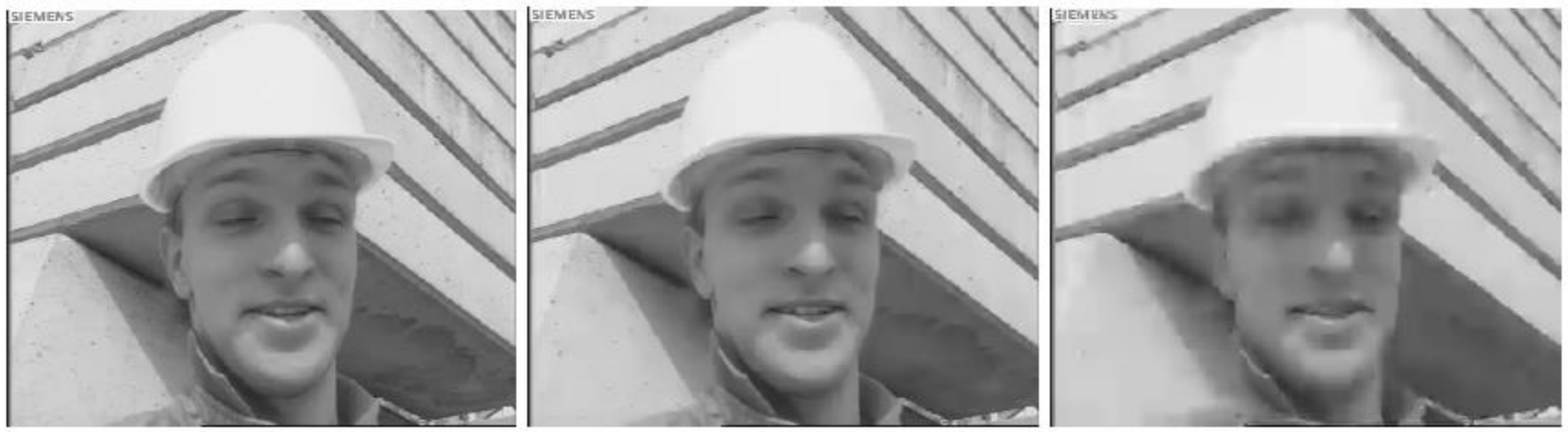
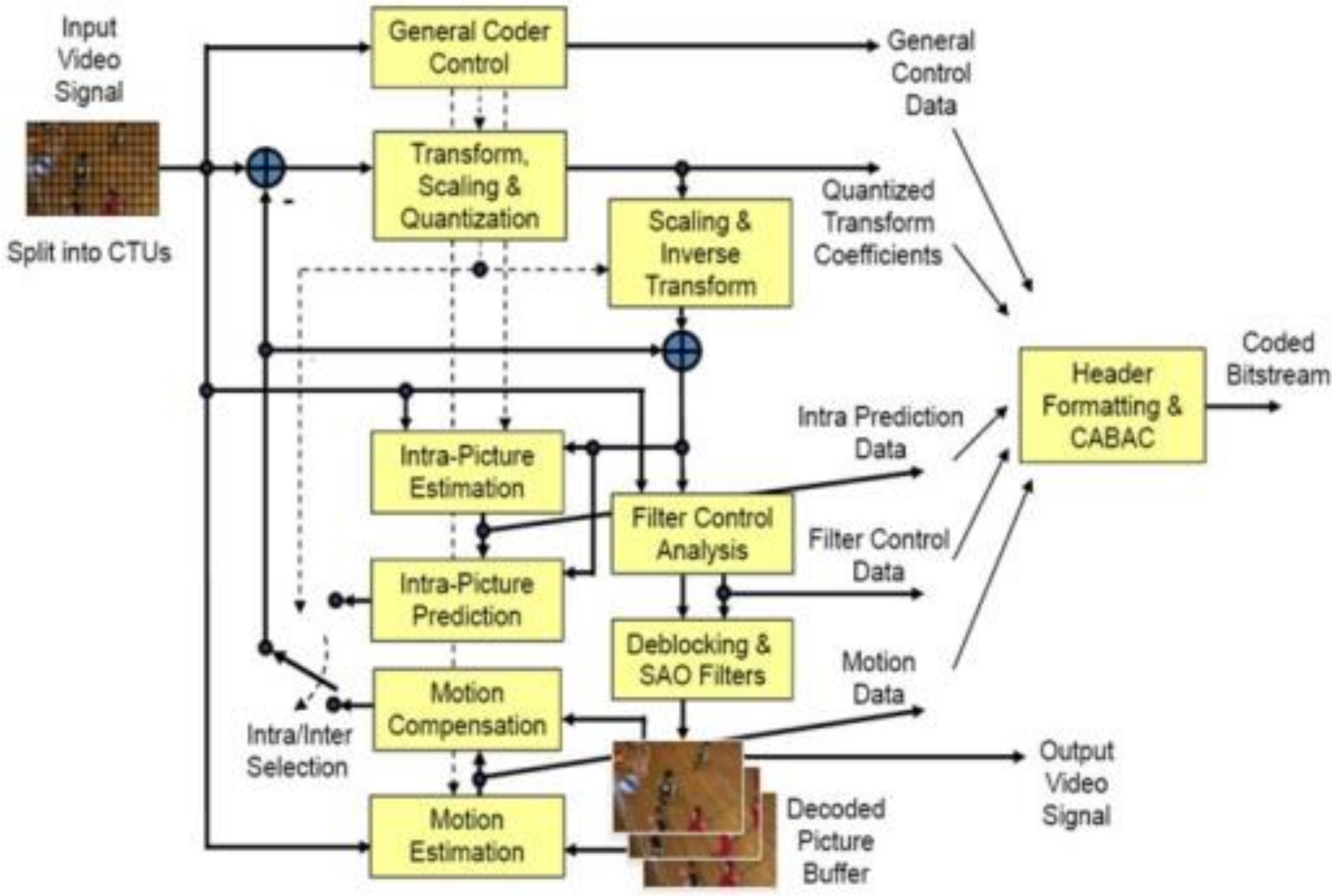
Examples H.264/AVC

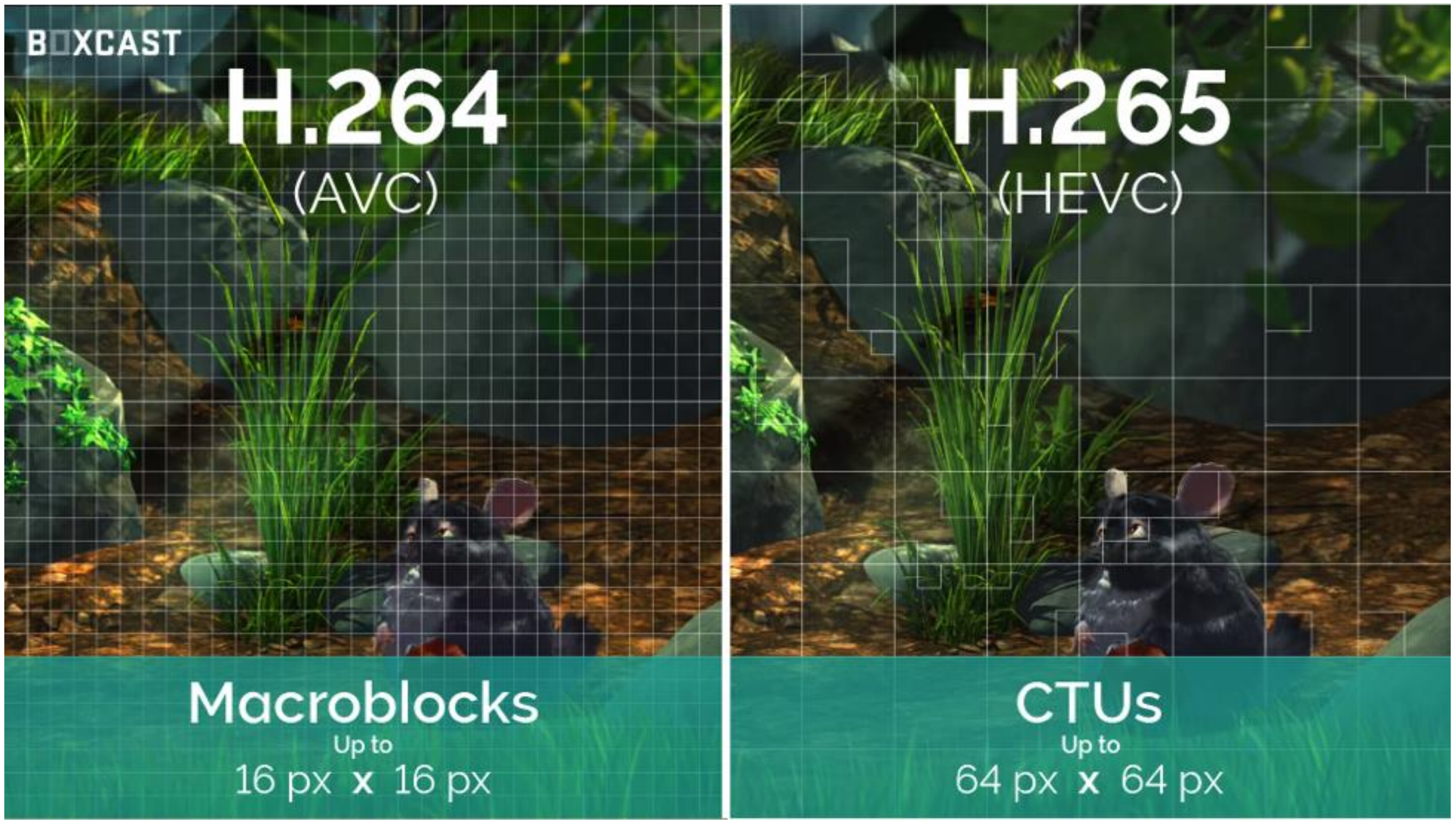


1:47 **1:165** **1:495**

Compression ratio

- http://en.wikipedia.org/wiki/High_Efficiency_Video_Coding





From https://www.thebroadcastbridge.com/content/entry/10029/h.264-versus-hevc-understanding-the-differences#:~:text=265%20is%20more%20advanced%20than,Unlike%20H .

Next week:

Selected topics:
CNN & Radon transform