Deinterlacing/interpolation of TV signals

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Outline

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- Converting from NTSC to HDTV; What changes need to be considered?
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  - Comparison of intraframe methods
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Terminology: Frame vs Sequence

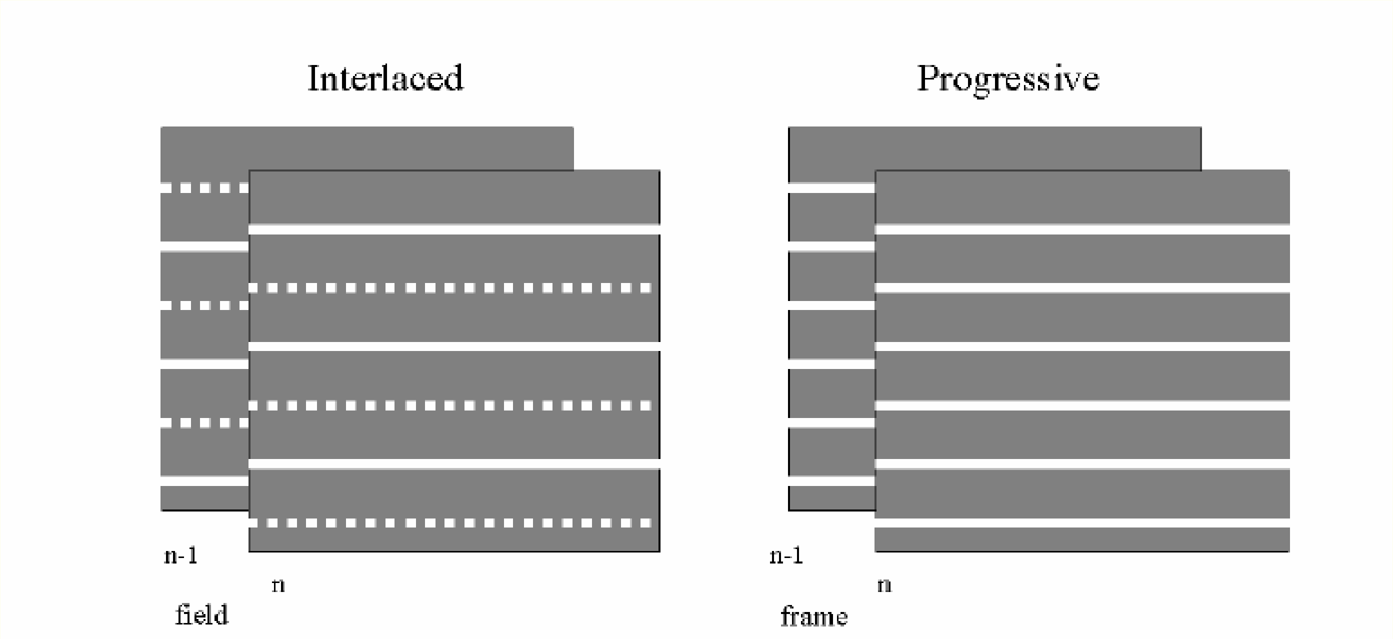
- A video *frame* is a picture made up of a 2D discrete grid of *pixels*.
- A video *sequence* is a collection of frames, with equal dimensions, displayed at fixed time intervals.

Terminology: Mathematical Definition of a sequence

- A video sequence is a three-dimensional array of data in the vertical, horizontal, and temporal dimensions. Let $F[x, y, z]$ denote the pixel in this three-dimensional sequence:
  - Then, for a progressive scan sequence $F[x, y, z]$ is defined for all integers *x, y, z* within the valid height, width, and time duration of the sequence.
  - If $F_i[x, y, z]$ is an interlaced source generated form the same progressive source:

$$F_i[x, y, n] = \begin{cases} F[x, y, n] & \mathrm{mod}(y, 2) = \mathrm{mod}(n, 2) \\ \phi & otherwise \end{cases}$$

Terminology; Scan Mode



- In interlaced fields either the even or the odd lines are scanned.
- In progressively scanned frames all lines are scanned in each frame.

Converting from NTSC to HDTV; What changes need to be considered?

vertical_size_value	horizontal_size_value	aspect_ratio_information	frame_rate_code	progressive_sequence
1080[2]	1920	1,3	1,2,4,5	1
			4,5	0
720	1280	1,3	1,2,4,5,7,8	1
480	704	2,3	1,2,4,5,7,8	1
			4,5	0
	640	1,2	1,2,4,5,7,8	1
			4,5	0

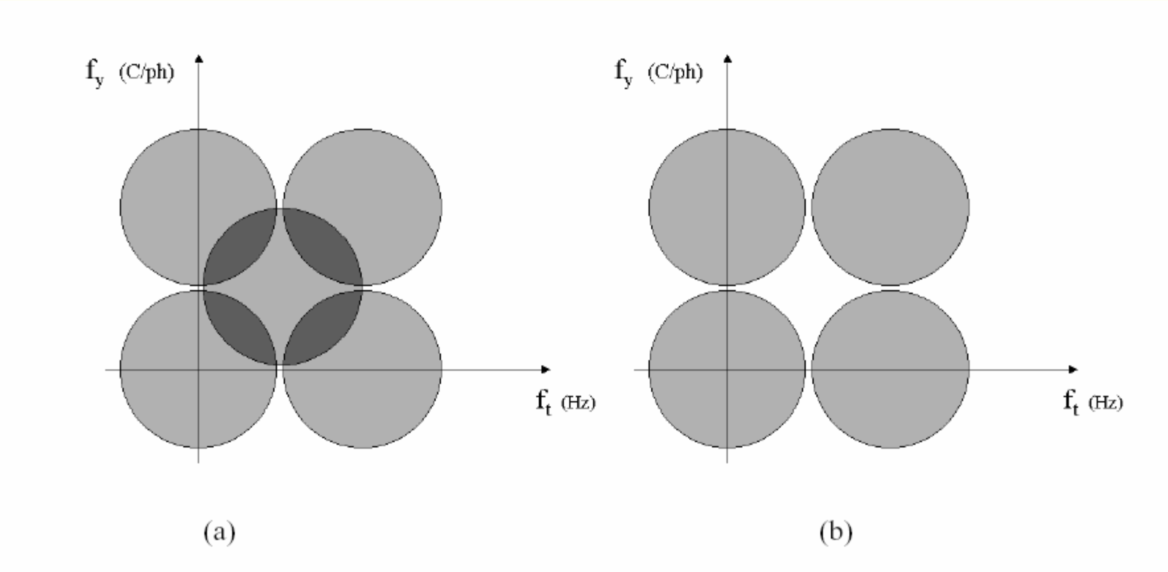
Legend for MPEG-2 coded values:
aspect_ratio_information: 1 = square samples, 2 = 4:3 display aspect ratio, 3 = 16:9 display aspect ratio
frame_rate_code: 1 = 23.976 Hz, 2 = 24 Hz, 4 = 29.97 Hz, 5 = 30 Hz, 7 = 59.94 Hz, 8 = 60 Hz
progressive_sequence: 0 = interlaced scan, 1 = progressive scan

Deinterlacing

- Deinterlacing a video sequence involves converting the interlaced fields into progressively scanned frames.
- Ideal deinterlacing would double the vertical-temporal sampling rate and remove aliasing.
- For a given interlaced input , the output of deinterlacing, can then be defined as

$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & \text{mod}(y,2) = \text{mod}(n,2) \\ \hat{F}[x,y,n] & \textit{othewise} \end{cases}$$

Vertical-temporal spectrum of interlaced scan video signal



(a) Frequency spectrum of an interlaced signal along the vertical-temporal plane.

(b) Ideal Output of deinterlacing algorithm

- The aliasing is due to the interlaced sampling.
- The areas of overlap in (a) cannot be perfectly recovered by any deinterlacing algorithm, so the result in (b) is not possible in general.

Interframe and Intraframe Methods for deinterlacing/interpolation

- These reconstruction methods can be segmented into two categories:
  - *intraframe*

    Intraframe methods only use the current frame for reconstruction
  - *interframe*.

    Interframe methods make use of the previous and or subsequent frames as well.

Intra-frame Methods

- Intraframe methods are also called spatial methods.
- They do not require any additional frame storage.
- Their performance is independent of
  - the amount of motion present in the sequence.
  - the frame-recording rate.

  So, Robustness to motion is one their characteristic.
- Considering only the information in the present field greatly limits their performance, due to the large temporal correlation that typically exists between successive frames.

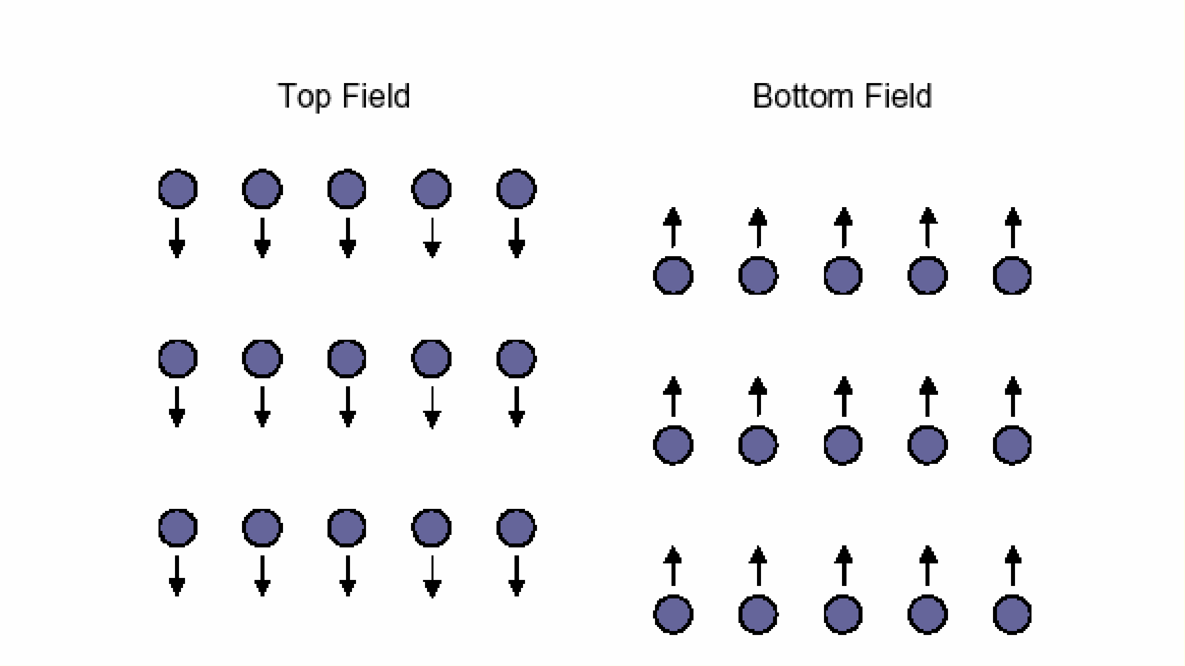
Intra-frame Methods

- Well-known intraframe methods:
  - Line/pixel repetition
  - Linear interpolation
  - Parametric Image Modeling

Intra-frame Methods: Line/Pixel Repetition

- This method is one of the simplest algorithms, and thus, of the first ones to be considered.
- In this method, the missing lines/pixels are generated by repeating the nearest available line/pixel on their top/left neighborhood

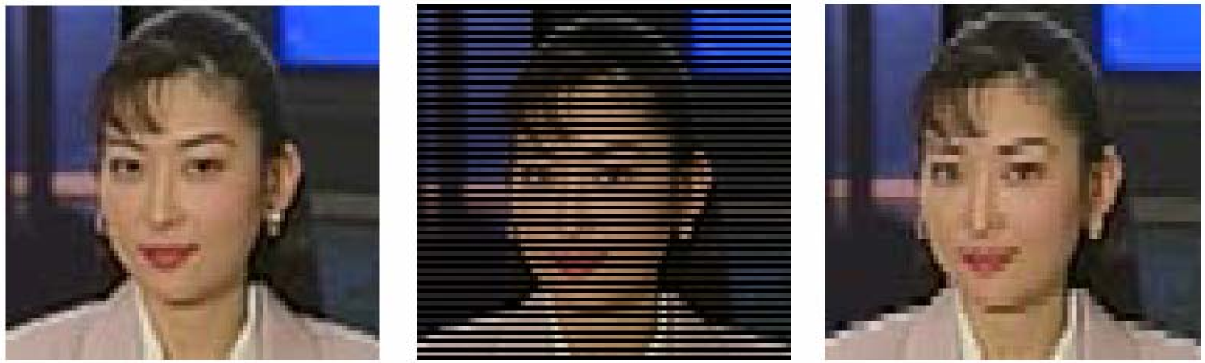
Intra-frame Methods: Line Repetition for Deinterlacing



$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & y \text{ even} \\ F_i[x,y-1,n] & \text{otherwise} \end{cases}$$

$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & y \text{ odd} \\ F_i[x,y+1,n] & \text{otherwise} \end{cases}$$

Intra-frame Methods: Line Repetition for Deinterlacing

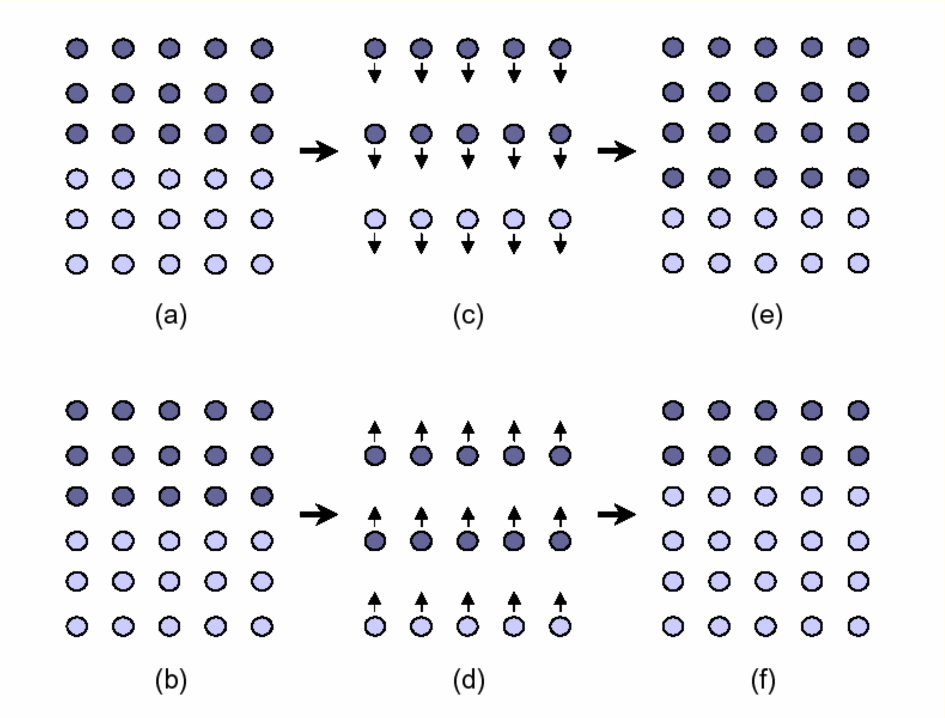


Original (a) | Interlaced (b) | Line Repetition (c)

- Output of line repetition shows a poor performance.
- It introduce severe jagged edge and jitter artifacts.

Line Repetition for Deinterlacing

- Comparing the deinterlaced frames, this method has incorrect reconstruction of the horizontal edges
- This will make the output sequence appear to shake.
- The rate of the resulted vibration corresponds directly to the frame rate of the video sequence.
  - At high frame rates, this shaking may become unnoticeable to the human eye.
  - At lower frame rates this effect becomes very noticeable and extremely annoying.



(a) (b) Consecutive progressive frames of a stationary image with a horizontal edge.
(c) (d) Corresponding interlaced fields.
(e) (f) Result of reconstruction.

Intra-frame Methods: Linear Interpolation

- Linear interpolation is slightly more advanced than line/pixel repetition.
- In linear interpolation the missing line/pixels are reconstructed by averaging the line/pixels directly above and below.
- It results in a slightly smoother picture than line/pixel repetition, but still has fairly poor performance.
- It has the same problems as line/pixel repetition, such as aliasing and jitter.

Intra-frame Methods: Parametric Image Modeling

- These are a more advanced form of spatial methods which utilizes image modeling.
- They attempt to model a small region of an image through a set of parameters and basis equations.
- Missing line/pixels are then reconstructed using linear interpolation.
- They attempt to determine the contours of a shape in an image and interpolates along this direction to reduce interpolation errors.
- They are some optimized suggested models, which can be used to spatially interpolate, interlaced video fields, for e.g.
  - Martinez suggests a Line Shift Model in which small segments of adjacent scan lines are assumed to be related to each other through a horizontal shift
  - Ayazifar similarly suggests a generalization of the Line Shift Model through a Concentric Circular Shift Model in which small segments of concentric arcs of an image are related to adjacent arcs by an angular shift.

Intra-frame Methods: Parametric Image Modeling

- These methods tend to be less susceptible to noise.
- They require more computations.
- Depending on the order of model selected, the complexity of these algorithms can be greater than other methods.

Comparison of intraframe methods

(a) Line repetition.

(b) Linear interpolation.

(c) Martinez-Lim algorithm.

(a) (b) (c)

- The Martinez-Lim algorithm tends to generate the smoothest, most realistic images.
- It also suffers from some of the jitter effects although these effects are significantly reduced, compared to the other two methods.

Inter-frame Methods

- Inter-frame or temporal methods consider previous and/or subsequent frames to exploit temporal correlation.
- Well-known inter-frame methods include:
  - Field Repetition
  - Bilinear frame interpolation
  - Vertical-temporal median filtering
  - Motion compensated methods
  - Motion adaptive methods

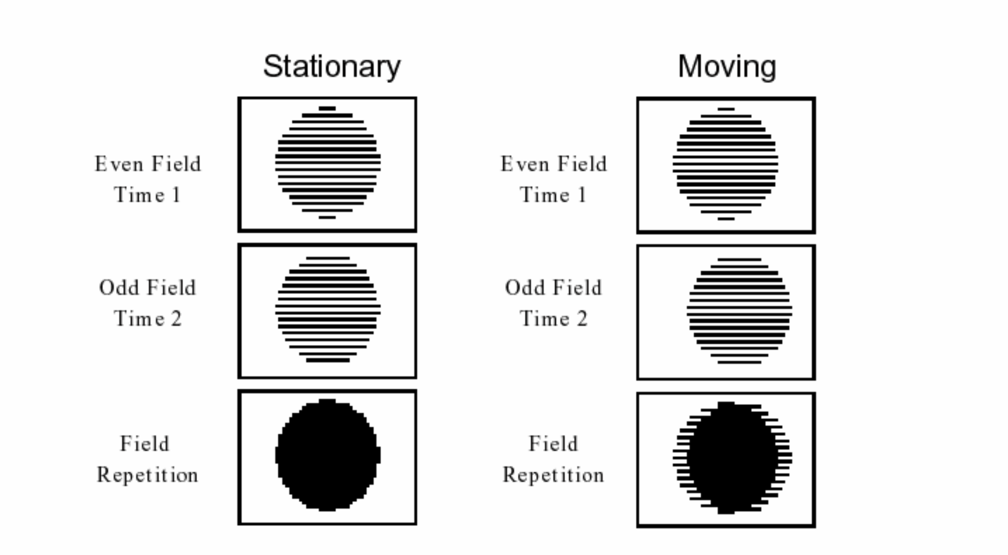
Inter-frame Methods: Field Repetition

Field repetition refers to the generation of missing scan lines by copying lines from the previous frame at the same vertical position.

Field repetition is defined as:

$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & \mathrm{mod}(y,2) = \mathrm{mod}(n,2) \\ F_i[x,y,n-1] & otherwise \end{cases}$$

Inter-frame Methods: Field Repetition



- The stationary circle is perfectly reconstructed by combining the even and odd fields.
- However, for the moving circle, the image is blurred since the even and odd fields are no longer properly aligned due to the motion of the circle between frames.

Inter-frame Methods: Blurred frame caused by field repetition

(a) (b)

(a) Original progressive frame. (b) Frame produced using field repetition.

- Motion of the ballerina causes edges to be distorted resulting in a blurred image.

Bilinear Field Interpolation

- It uses the average of the previous and future frame lines for deinterlacing.
- The definition is $$F_o[x,y,n]=\begin{cases} F_i[x,y,n] & \mathrm{mod}(y,2)=\mathrm{mod}(n,2) \\ (F_i[x,y,n+1]+F_i[x,y,n-1])/2 & otherwise \end{cases}$$
- It has essentially the same benefits and issues as field repetition.
  - Works very well in stationary regions,
  - Works poorly in moving regions.
- It introduces more blurring artifacts in the presence of motion since it blends three frames together rather than just two.

Inter-frame Methods: Bilinear Field Interpolation

- Three separate fields are visible in image (b).
- The result is a “ghostly” image with badly blurred edges.
- In this sense, when compared to field repetition, field interpolation is even more unacceptable.

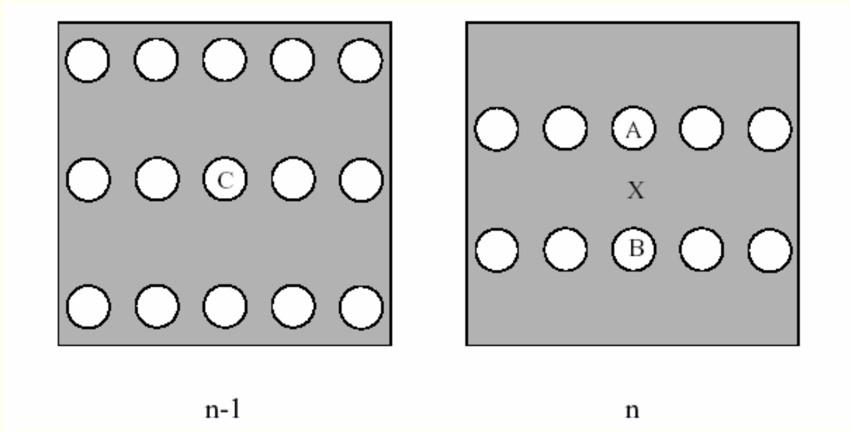
(a) (b)

Inter-frame Methods: Vertical-Temporal Median Filtering

- Vertical-Temporal (VT) filters utilize neighboring pixels in the current and adjacent frames.
- In VT median filtering, a median operation is used rather than a linear combination of the surrounding pixels.
- VT median filtering is popular due to its performance and ease of implementation.
- Deinterlacing VT median filter for a 3-tap median filter is described as:

$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & \mathrm{mod}(y,2) = \mathrm{mod}(n,2) \\ median(F_i[x,y+1,n], F_i[x,y-1,n],\ F_i[x,y,n-1]) & otherwise \end{cases}$$

Inter-frame Methods: Vertical-Temporal Median Filtering



$$\Rightarrow X = med(A, B, C)$$

Median filtering adapts itself to moving and stationary regions on a pixel-by-pixel basis.

- So it will be robust to motion

Inter-frame Methods: Motion Compensated Methods

- The most advanced techniques for deinterlacing generally make use of motion estimation and compensation.
- There are many motion estimation algorithms that can be used to estimate the motion of individual pixels between one field and then next.
- If accurate motion vectors are determined, motion compensation (MC) can basically remove the motion from a video sequence.
- If motion were perfectly removed, temporal interpolation could theoretically restore the original frames.
- In general any non-MC algorithm can be converted to a MC algorithm.
- However, only those techniques that perform better on stationary images will most likely be improved.
- Some straightforward MC methods include field repetition, field interpolation, and VT median filtering.

Inter-frame Methods: Motion Compensated Methods

- The most common method for determining motion vectors is through block matching algorithms.
- The "matching" criterion that is typically used is either mean square error or mean absolute error.
- A number of problems can arise when using block matching motion estimation scheme; for instance
  - when objects pass in front of one another, there are appearing and disappearing regions of the fields, which cannot be accounted for with motion vectors.
  - If an object moves beyond the motion vector search area, the motion vector will not be accurately determined.
  - The pixels may have sub-pixel motion. In this case, the motion vector actually should point between pixels or at missing lines in the previous field.

Inter-frame Methods: Motion Adaptive Methods

- Interlaced sequences can be perfectly reconstructed by:
  - interframe methods in the absence of motion
  - intraframe methods in the presence of motion
- Motion adaptive methods use a motion detector to take advantage of this fact by separating each field into moving and stationary regions.
- The algorithm then fades between a temporal method and a spatial method.
- The output of this type of motion adaptive algorithm can be represented as:

$$F_o[x,y,n] = \begin{cases} F_i[x,y,n] & \mathrm{mod}(y,2) = \mathrm{mod}(n,2) \\ \alpha \,.\, F_{mot}[x,y,n] + (1-\alpha) \,.\, F_{stat}[x,y,n] & otherwise \end{cases}$$

Comparison of inter-frame methods

- Motion adaptive methods had the most potential for using for deinterlacing/interpolation of video frames.
- Motion adaptive methods are designed to take advantage of the varying information that is present in different regions of a video sequence.
  - In stationary images, there exists significant correlation between the present field and the adjacent fields. Temporal methods such as field repetition are designed to benefit from this fact.
  - In moving regions, this temporal correlation does not exist, and more information can be found in adjacent pixels on the current field. Spatial methods take advantage of this fact.
- Motion adaptive methods attempts to combine the benefits of both temporal and spatial methods by segmenting each image into moving and stationary regions.
- In order to segment a video sequence into moving and stationary regions, motion adaptive methods must use some form of motion detection.

Summery and future work

- Considering the fact that, motion adaptive methods had the most potential for using for deinterlacing/interpolation of video frames; there should be some future work done on:
  - Finding an efficient motion detection method
  - Finding efficient temporal and spatial methods which could be used for combined deinterlacing-interpolation opration

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