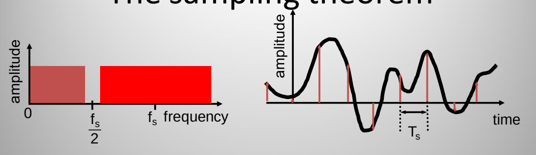
2D sampling grids

The sampling theorem

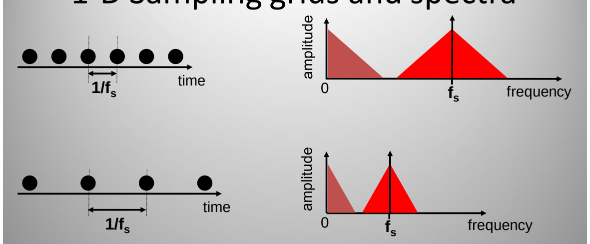


We have a continuous signal

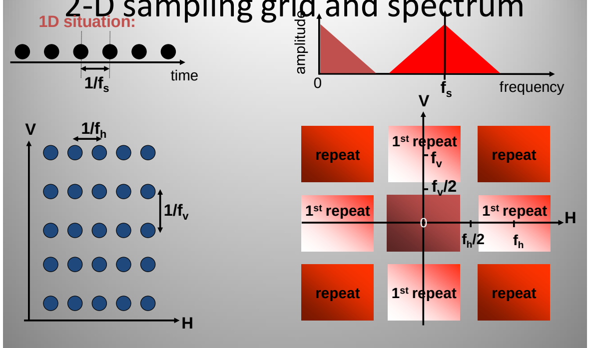
We sample it to obtain a discrete representation

Sampling theorem: we can reconstruct the continuous signal from its discrete representation, provided it contained no frequencies above half the sampling frequency

1-D Sampling grids and spectra

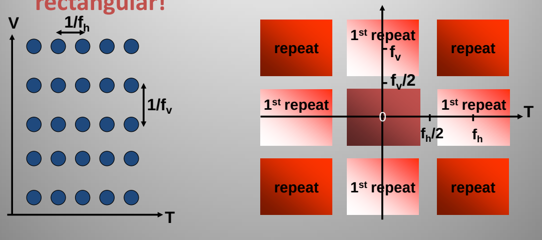


2-D sampling grid and spectrum

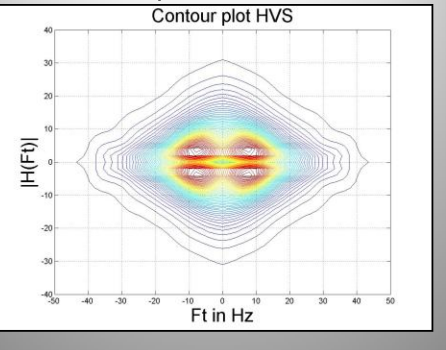


2-D sampling grid and spectrum

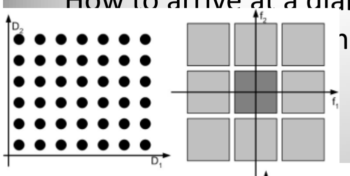
- The space-time sampling grid is also rectangular!



However, the HVS suggest a diamond shaped base-band

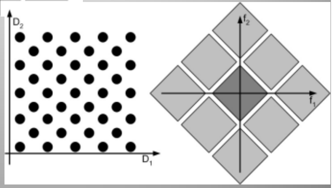


How to arrive at a diamond shaped …n?

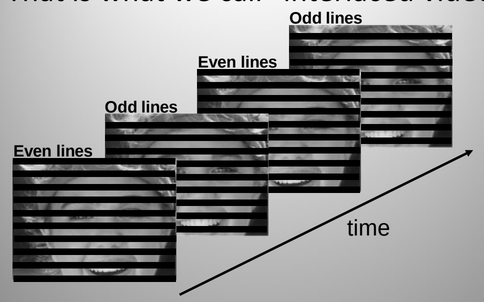


Consequence: not all pixels are transmitted in every image

The odd pixels (lines) in odd pictures, the even pixels (lines) in the even pictures



That is what we call "interlaced video"



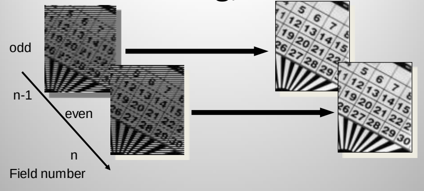
Why interlace?

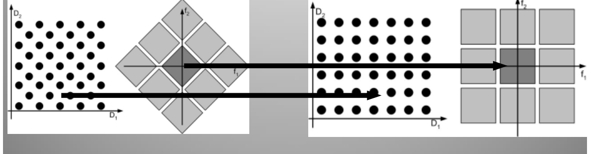
large area	detail
circle LAF	circle INT

- The human visual system (HVS) is less sensitive to flickering detail than to large area flicker (flicker perception threshold depends on viewing angle)
- Interlacing displays profit from this fact
- In the past, around 1935!, transmission format and display format had to be equal to prevent complex processing in the receivers

De-interlacing

De-interlacing; what is it?

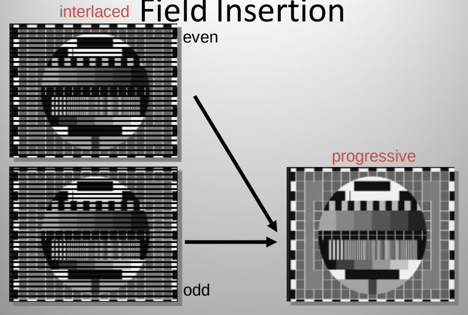




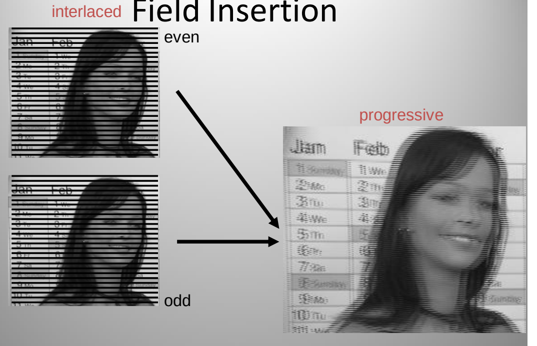
11

Naïve methods

Field Insertion



Field Insertion



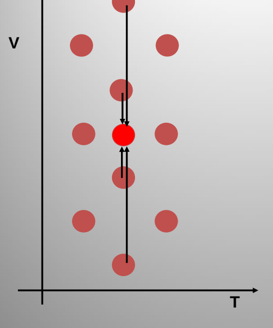
Ideal de-interlacing

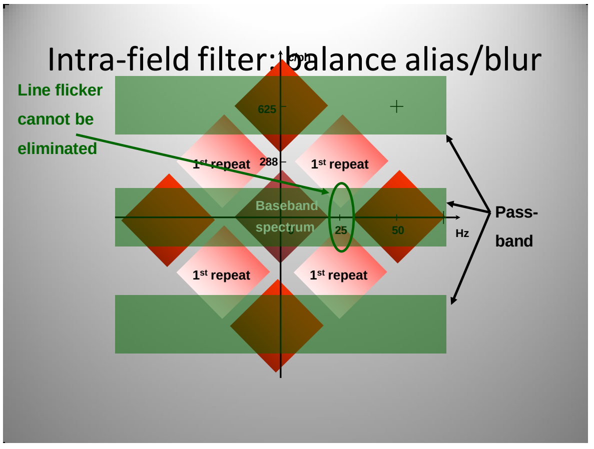
Categories in de-interlacing

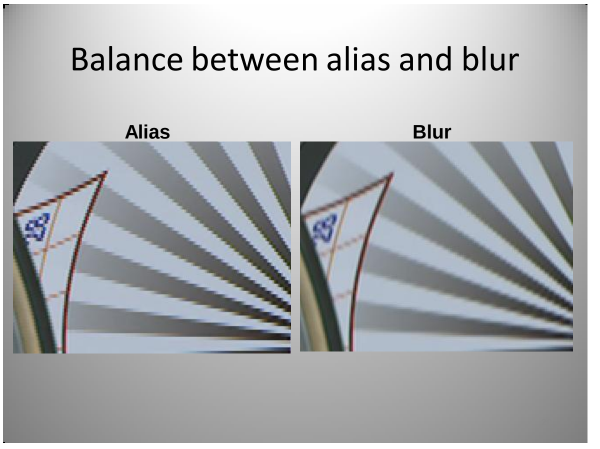
- Intra-field methods
  - 1D linear filtering
  - 2D directional interpolation
- Inter-field methods
  - Motion adaptive de-interlacing
  - 2D linear filtering
  - 2D non-linear filtering
  - Motion compensated methods
  - Useful hybrids

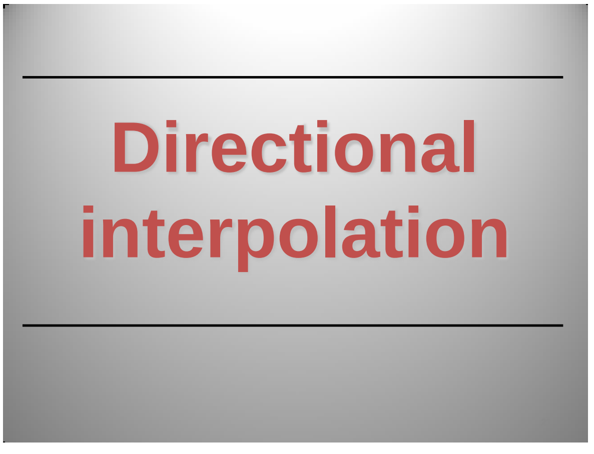
1D intra-field interpolation

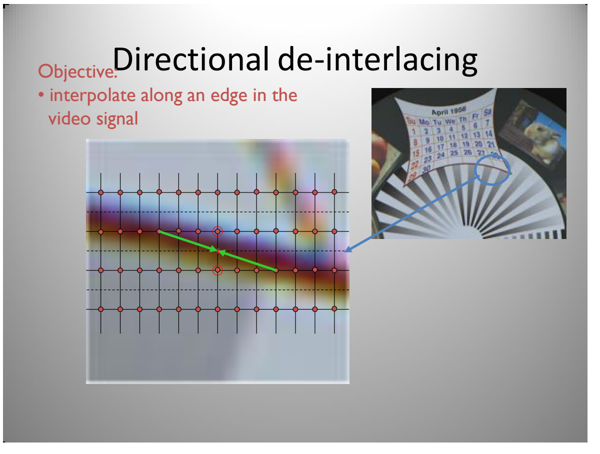
Linear intra-field de-interlacing

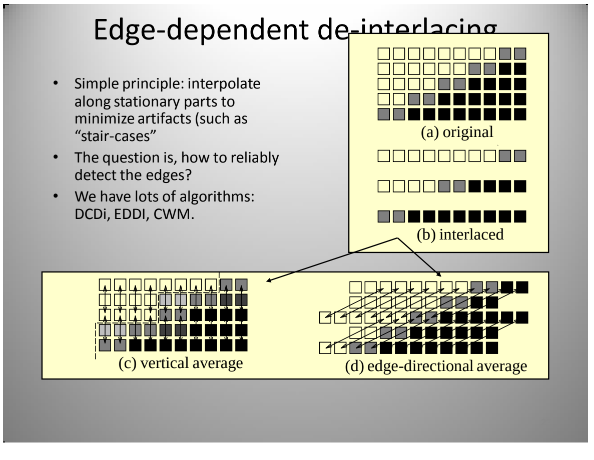


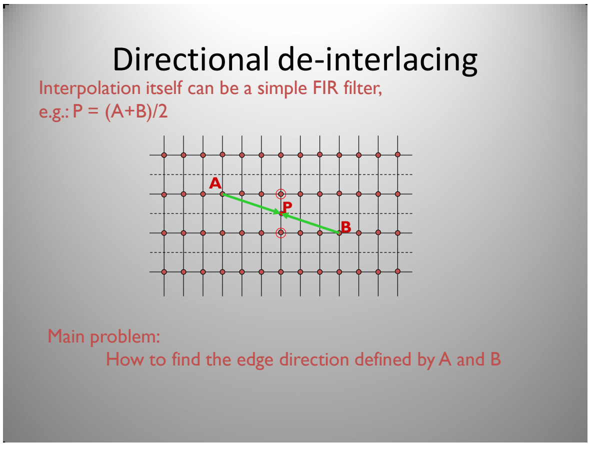

Intra-field filter: balance alias/blur
Line flicker
cannot be
eliminated
625
1st repeat
288
1st repeat
Baseband
spectrum
25
50
Hz
Pass-
band
1st repeat
1st repeat


Balance between alias and blur
Alias
Blur


Directional
interpolation

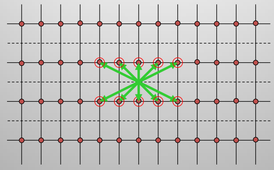

Directional de-interlacing
Objective:
• interpolate along an edge in the
video signal


Edge-dependent de-interlacing
• Simple principle: interpolate along stationary parts to minimize artifacts (such as "stair-cases"
• The question is, how to reliably detect the edges?
• We have lots of algorithms: DCDi, EDDI, CWM.
(a) original
(b) interlaced
(c) vertical average
(d) edge-directional average


Directional de-interlacing
Interpolation itself can be a simple FIR filter,
e.g.: P = (A+B)/2
A
P
B
Main problem:
How to find the edge direction defined by A and B

Dominant edge direction detection

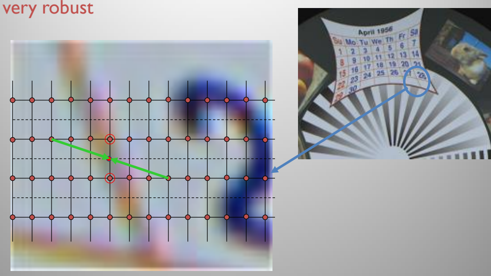
Compare pixel-wise differences, i.e. calculate error functions



Dominant edge direction defined by direction yielding smallest error

Dominant edge direction detection

Not very robust



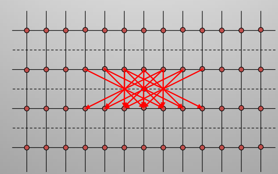
Aperture to determine dominant edge direction is too small

Problems with directional interpolation

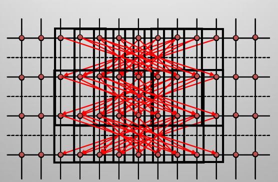
Improved robustness with match-error between more than two pixels (DCDi)

Line averaging in the direction with the highest spatial correlation

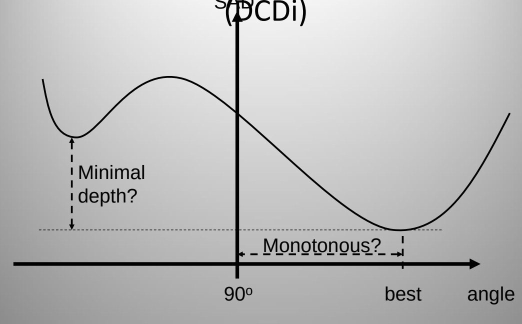
Highest correlation indicated by smallest SUM of absolute pixel difference

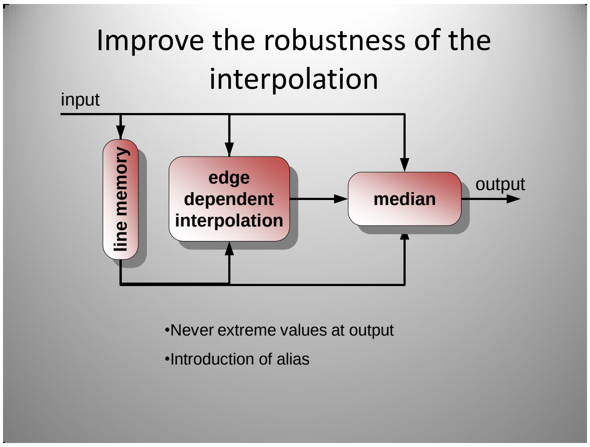


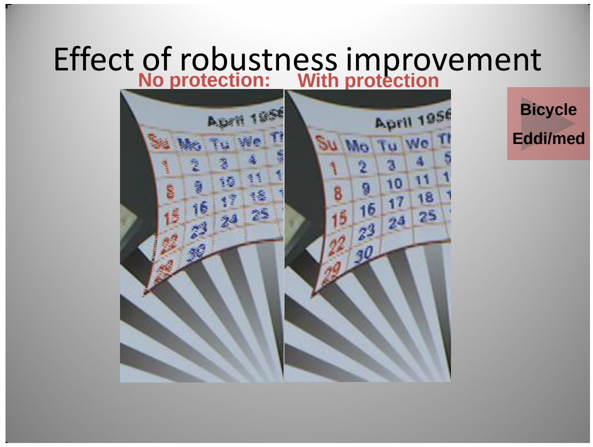
Edge Block Matching

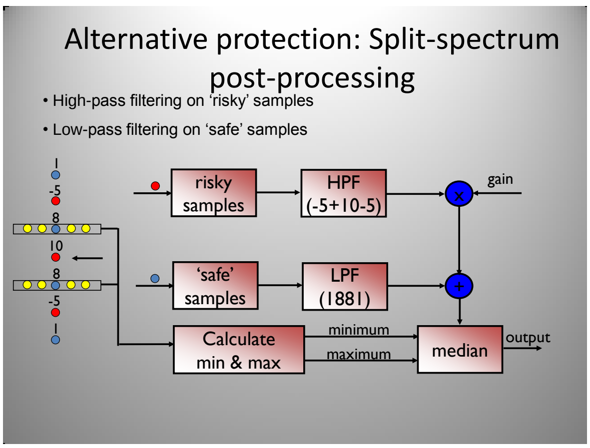


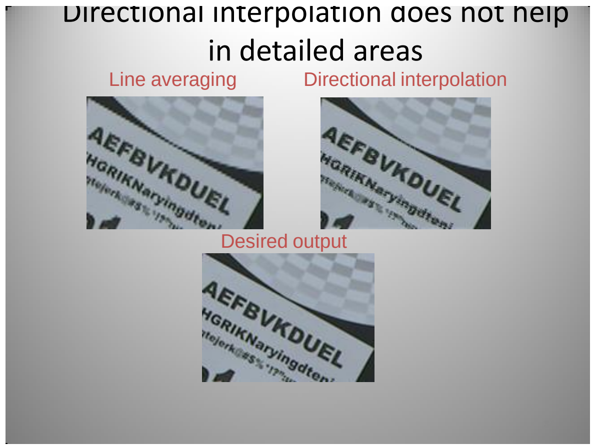
Further refinements of robustness (DCDi)

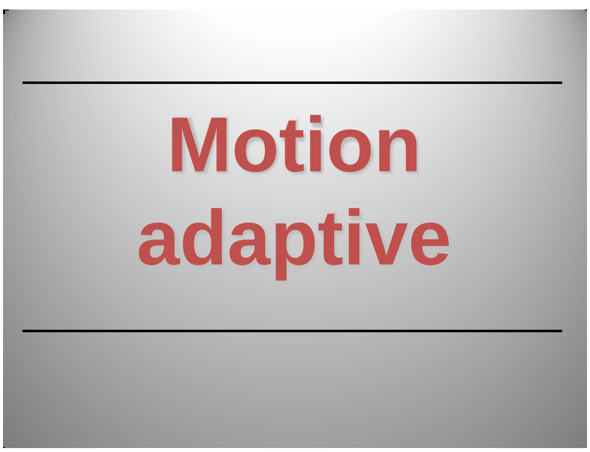


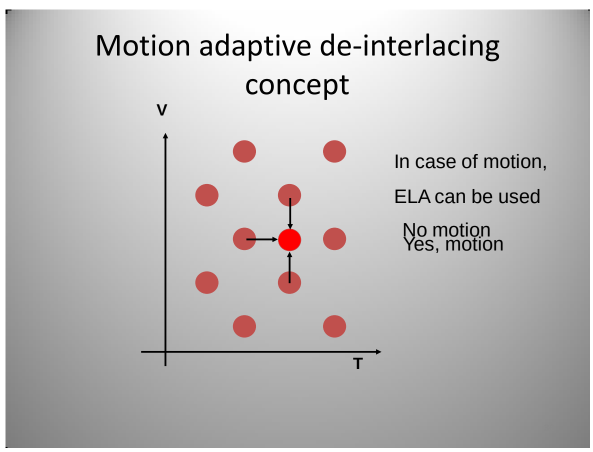

Improve the robustness of the interpolation
input
line memory
edge dependent interpolation
median
output
•Never extreme values at output
•Introduction of alias

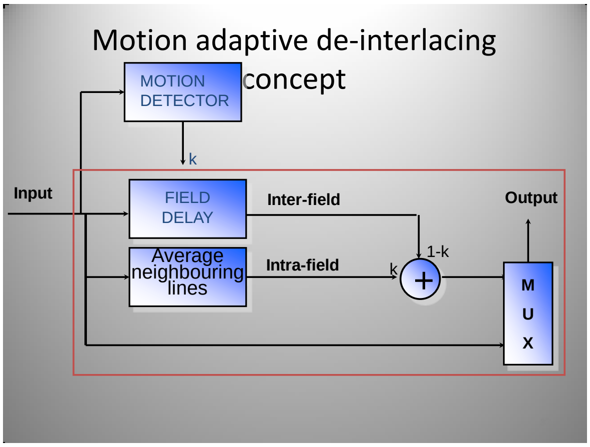

Effect of robustness improvement
No protection:
With protection
Bicycle
Eddi/med

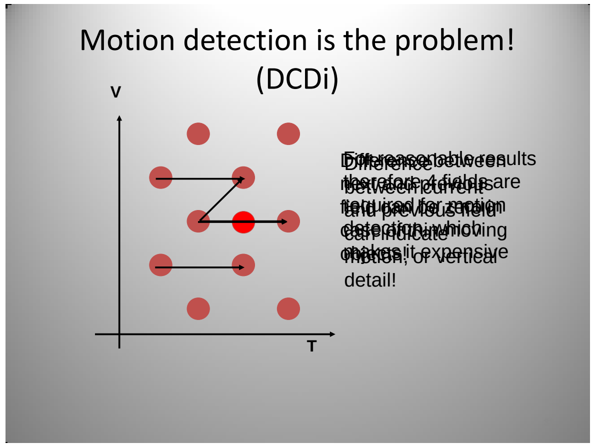

Alternative protection: Split-spectrum post-processing
• High-pass filtering on 'risky' samples
• Low-pass filtering on 'safe' samples
risky samples
HPF (-5+10-5)
gain
'safe' samples
LPF (1881)
Calculate min & max
minimum
maximum
median
output


Directional interpolation does not help in detailed areas
Line averaging
Directional interpolation
Desired output

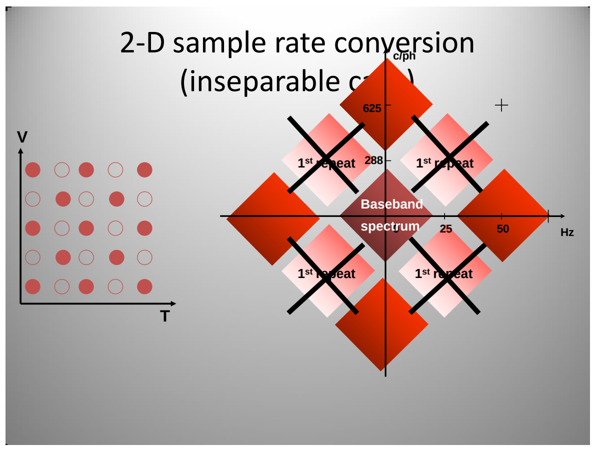

Motion adaptive

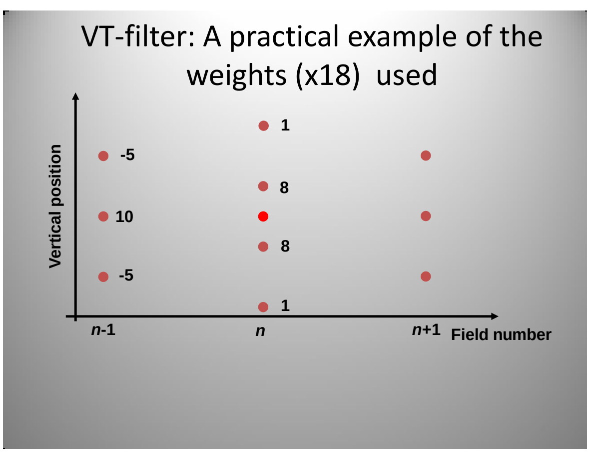

Motion adaptive de-interlacing concept
V
T
In case of motion,
ELA can be used
No motion
Yes, motion

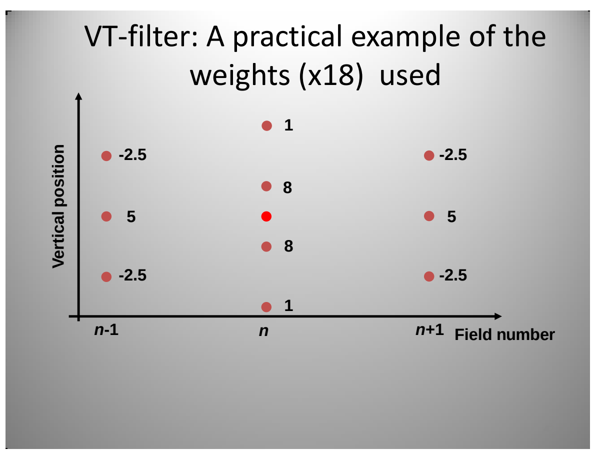


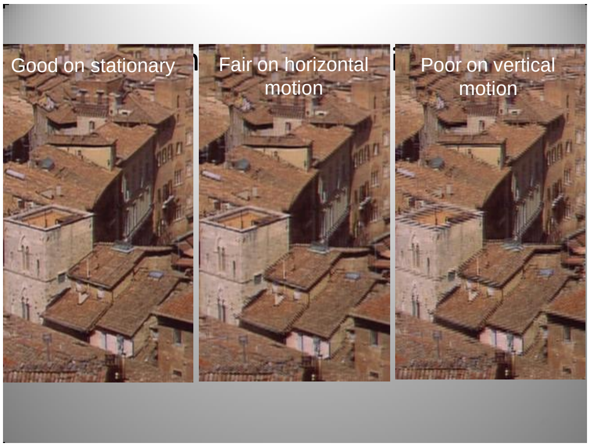


2D linear filtering



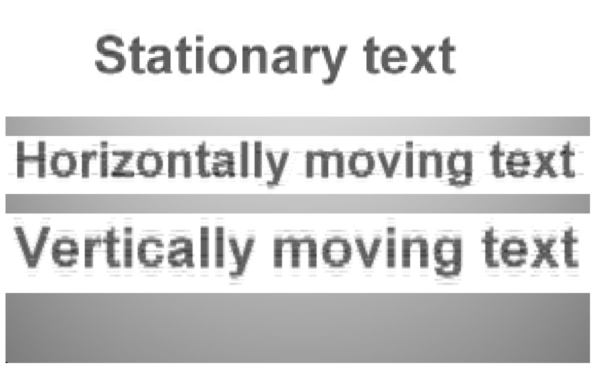




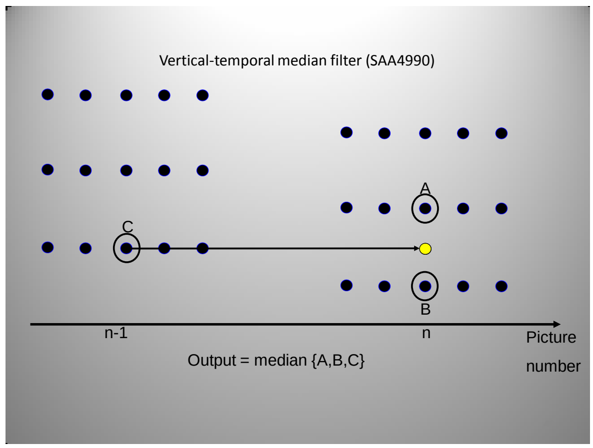


Performance of the VT-linear filter

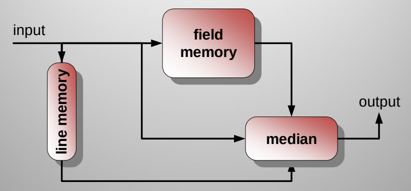
MC vs NMC



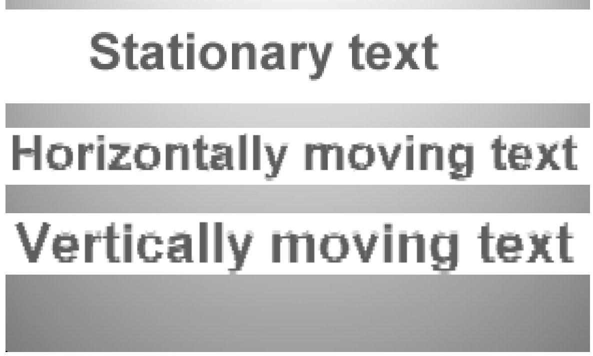
2D non-linear filtering



Median filter de-interlacing; the block diagram

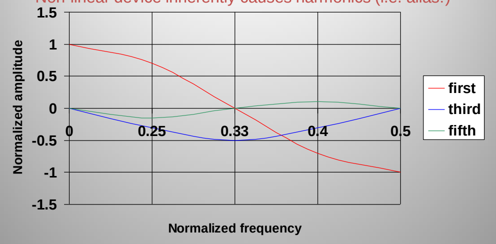


Performance of the VT-median filter



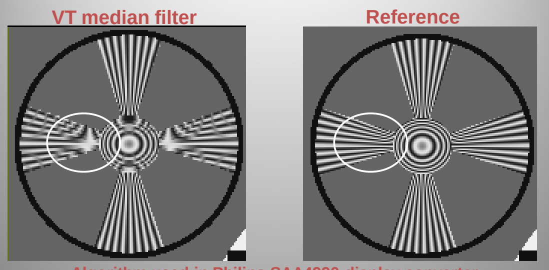
Frequency response VT-median

Non-linear device inherently causes harmonics (i.e. alias!)



VT median filtering (Med)

Alias can occur in highly vertically detailed picture parts due to these harmonics



Algorithm used in Philips SAA4990 display converter

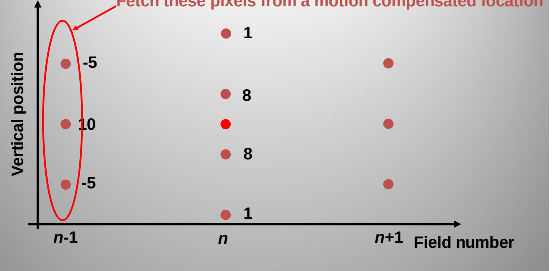
Summary of NMC de-interlacing methods

- Linear methods
  - intra-field
    - compromise alias and blur
  - inter-field
    - poor performance on detailed parts with motion
- Non-linear methods
  - motion adaptive
    - switch between intra and inter-field interpolation
  - median filter
    - good for stationary, fair for moving image parts
  - edge orientation dependent filtering
    - difficult in detailed picture parts
- Now: Motion compensated de-interlacing

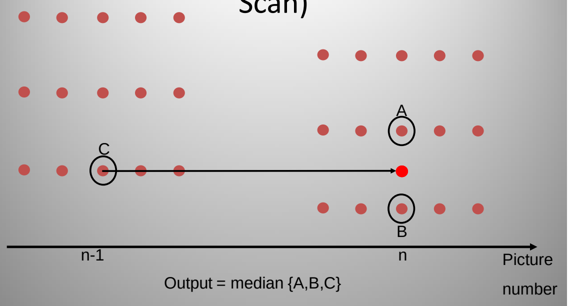
Motion-compensated methods

Every inter-field method improves with MC

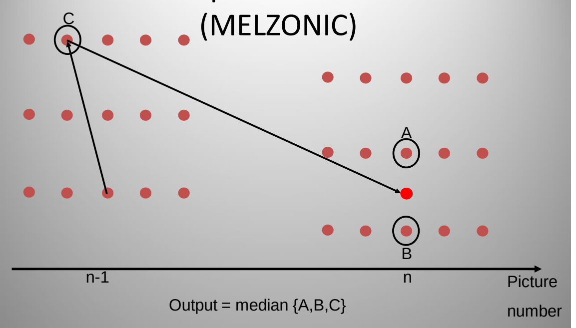
VT-filter: Motion compensation



Vertical-temporal median filter (Digital Scan)

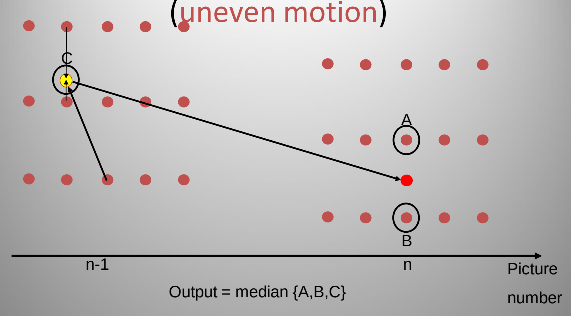


Motion compensated median filter (MELZONIC)

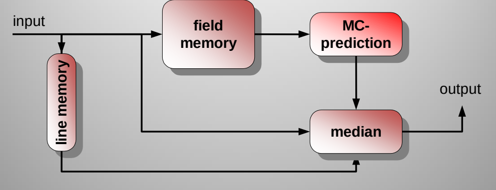


Motion-compensated median

Motion compensated median filter (uneven motion)

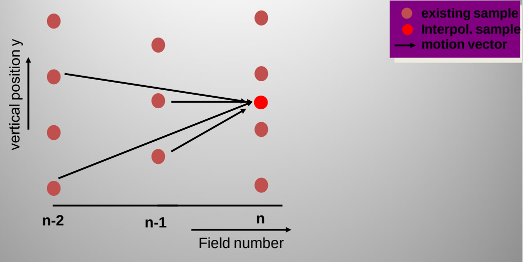


The block diagram of MC-median filtering



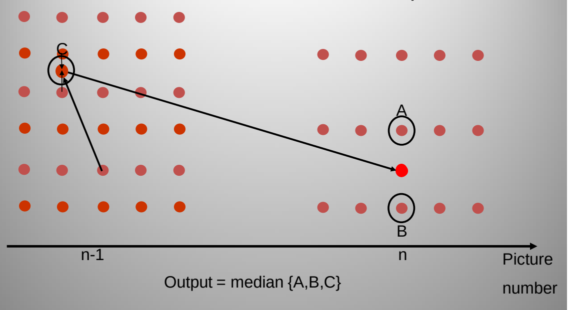
Temporal backward projection

Temporal backward projection(TBP)



Time-recursive de-interlacing

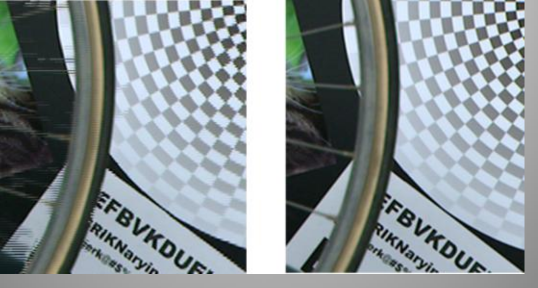
Time recursive de-interlacing (use earlier de-int result)



Error propagation

TR-de-interlacing without median protection

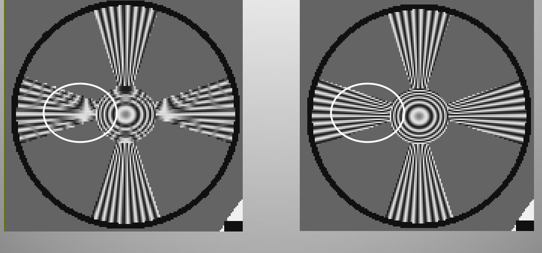
Reference image



VT median protection causes a

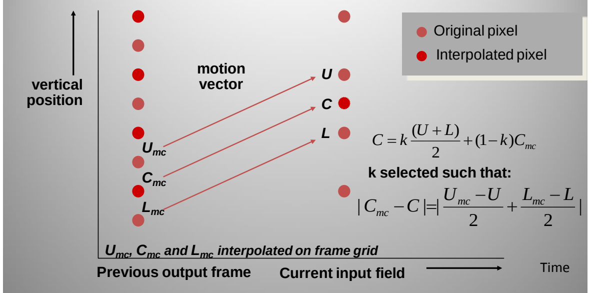
VT median filter

Reference



Adaptive-Recursive de-interlacing

MC AR de-interlacing (AR)



$$C = k\frac{(U+L)}{2} + (1-k)C_{mc}$$

k selected such that:

$$|C_{mc} - C| = |\frac{U_{mc} - U}{2} + \frac{L_{mc} - L}{2}|$$

Derivation of control factor k in AR de-interlacing

- Interpolated pixel results as:

$$C = k\frac{(U+L)}{2} + (1-k)C_{mc}$$

- Prediction quality equivalent for original and interpolated pixels

$$|C_{mc} - C| = |\frac{U_{mc} - U}{2} + \frac{L_{mc} - L}{2}|$$

- Substitution results in:

- Some rewriting:

$$|C_{mc} - (1-k)C_{mc} + k\frac{(U+L)}{2}| = |\frac{U_{mc} - U}{2} + \frac{L_{mc} - L}{2}|$$

$$k = \frac{|(U_{mc} + L_{mc}) - (U+L)| + \delta}{|2C_{mc} - (U+L)| + \delta}$$

Performance MC AR de-interlacing

Stationary text

Horizontally moving text

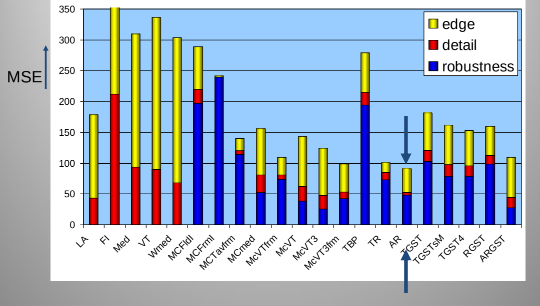
Vertically moving text

Performance MC AR de-interlacing

Majority selection

Strengths & weaknesses

(no single algo best in ALL categories)

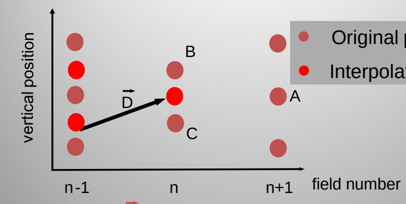


Majority selection (MS)

- Possible strengths:
  - preservation of edges (median, MC field insertion)
  - preservation of texture (VT-filter, MC-field insertion)
  - robustness (median, VT-filter)
- Principle of MS de-interlacing:
  - median selects between individual de-interlacing methods
  - all strengths occur in a majority of de-interlacing methods
  - weaknesses only occur in minority of de-interlacing methods
  - → so output combines strengths of individual methods
- No strict evidence for principle, but results very good

Majority selection

3 field de-interlacing; MC majority selection



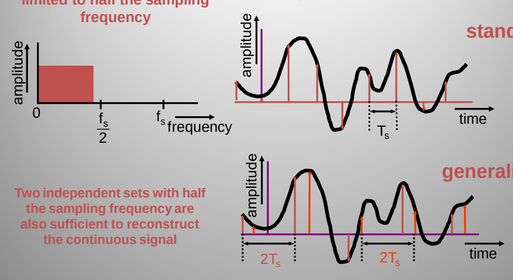
Median ($\vec{D}$, Median (A,B,C), MCVT)

$\vec{D}$ is calculated from the motion compensated previously de-interlaced field
Also the MCVT uses this de-interlaced frame
Only the non-MC median uses the next field

Generalized sampling

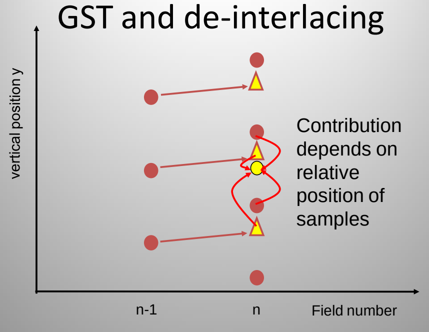
Generalised sampling theorem (1956, Yen)

Spectrum of continuous signal limited to half the sampling frequency



Two independent sets with half the sampling frequency are also sufficient to reconstruct the continuous signal

GST and de-interlacing

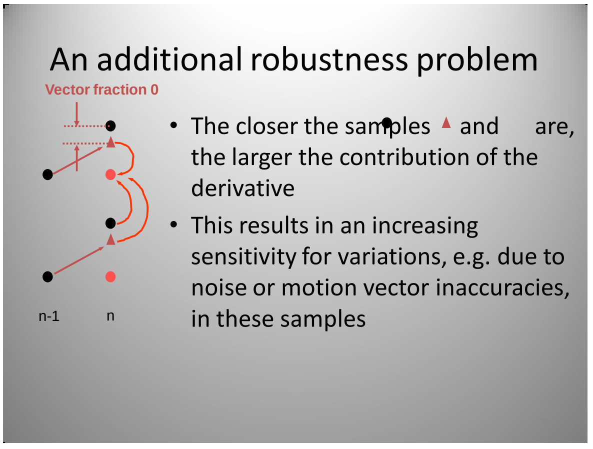


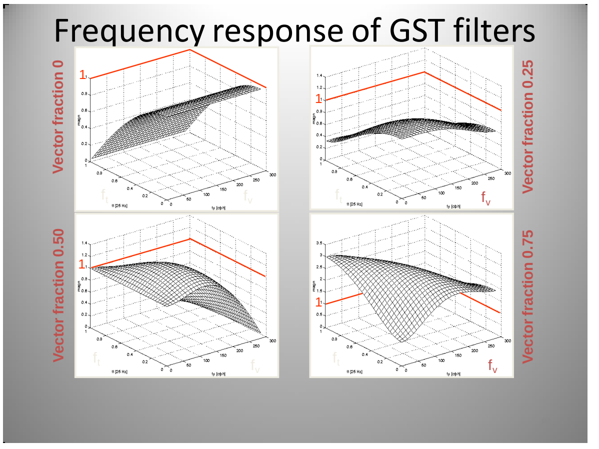
Robustness of GST de-interlacer

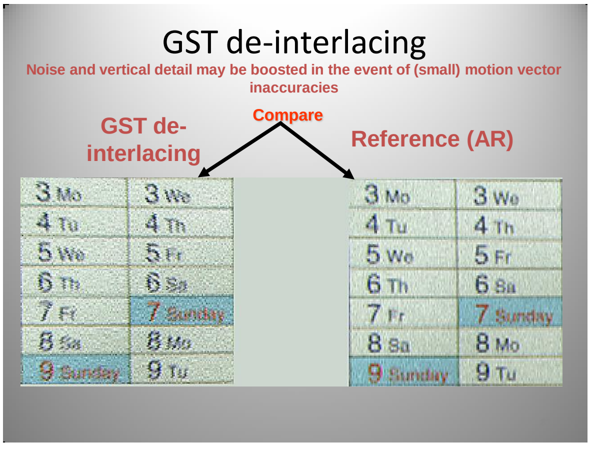
Conclusion: also this method requires additional protection measures in the event of erroneous motion vectors

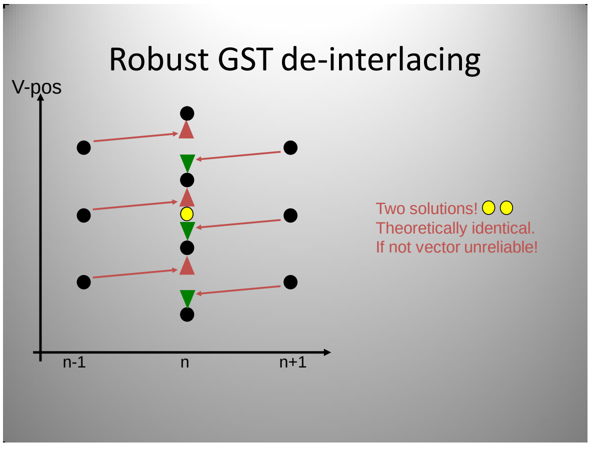
Generalized sampling

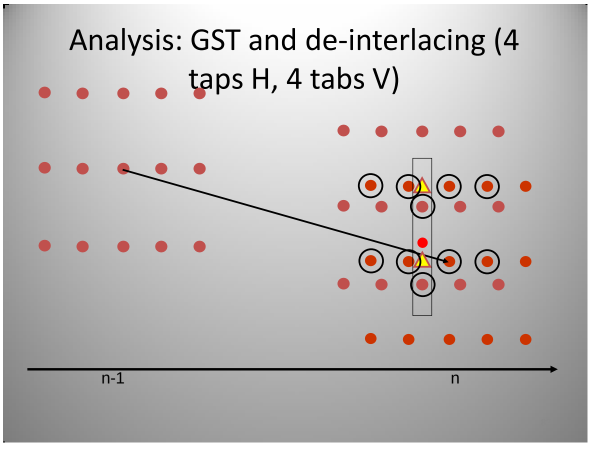
Reference (AR)

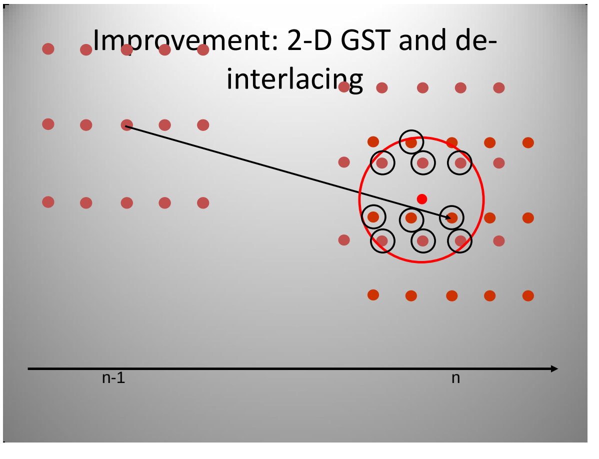

An additional robustness problem
Vector fraction 0
The closer the samples and are, the larger the contribution of the derivative
This results in an increasing sensitivity for variations, e.g. due to noise or motion vector inaccuracies, in these samples
n-1
n


Frequency response of GST filters
Vector fraction 0
Vector fraction 0.25
Vector fraction 0.50
Vector fraction 0.75


GST de-interlacing
Noise and vertical detail may be boosted in the event of (small) motion vector inaccuracies
Compare
GST de-interlacing
Reference (AR)


Robust GST de-interlacing
V-pos
Two solutions!
Theoretically identical.
If not vector unreliable!
n-1
n
n+1


Analysis: GST and de-interlacing (4 taps H, 4 tabs V)
n-1
n


Improvement: 2-D GST and de-interlacing
n-1
n

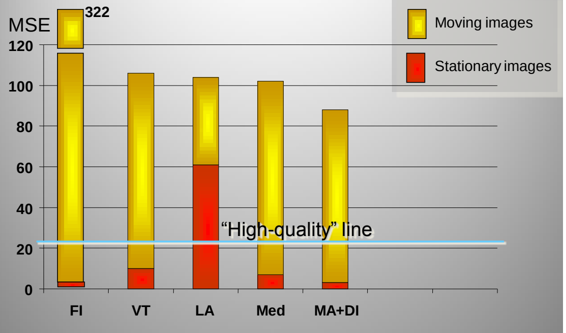
Some results (MSE)

DEMO
AR vs. 2-D RobGST

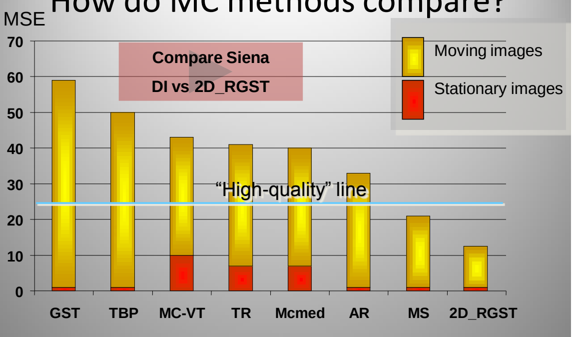
Algorithm/ Sequence	Adaptive Recursive	Original GST	Original GST (Robust)	2-D GST (Robust)
Siena	12.16	9.19	7.68	2.70
Kielp	84.73	109.15	87.25	60.73
Football	27.28	50.12	30.67	27.34
Renata	23.29	13.58	7.03	6.97
Bicycle	32.28	65.97	31.14	21.39

Quality comparison of methods

How do non-MC methods compare?



How do MC methods compare?



Combined MC & directional interpolation

Combination of DI and MC (SAA4998)

- MC and DI have orthogonal strengths!
- MC: poor on long edges (aperture problem), strong on details
- DI: strong on long edges, poor in detailed areas
- What is more logical than combining the two?

DI MC Combined