Video Algorithms and Architectures

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- Context of TV systems
- Video Format Conversion
- De-interlacing and Up-Conversion
- Motion Estimation and Motion Compensation
- Several Architectures
- Conclusion

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Context of TV systems

- Consumer electronics: price for electronics $50 - 100
- Real-time performance: no loss of data, garanteed response
- Embedded systems, certainly for the display processing
- Image quality is important

Context of TV systems

Frequencies for standard resolution TV:

- PAL: 864 pixels, 625/2=312 lines, 50 fields /sec, interlace
- NTSC: 864 pixels, 525/2=262 lines, 60 fields/sec, interlace
  In total:
  13.5 million samples per second,
  luminance (y) and chrominance (u and v, subsampled),
  typically 8-10 bits data for luminance and 8 bits for color

System signal processing: 100 - 1000 operations per pixel:
1.35 - 13.5 **Billion** operations per second,
1.35 - 13.5 Gbyte per second internal bandwidth

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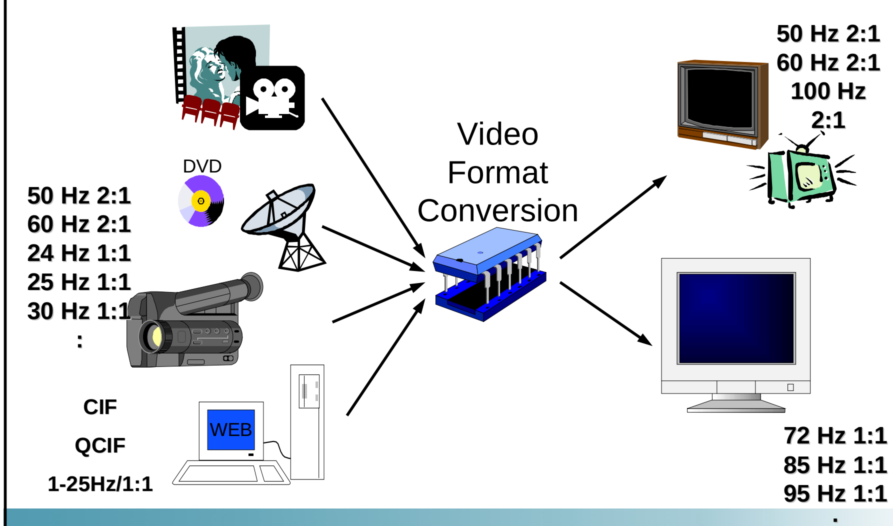
Context of TV systems

Algorithms for picture quality improvements:

- Sharpness "improvement"
- Noise Reduction
- De-interlace
- Up-conversion

Increasing demand for conversion



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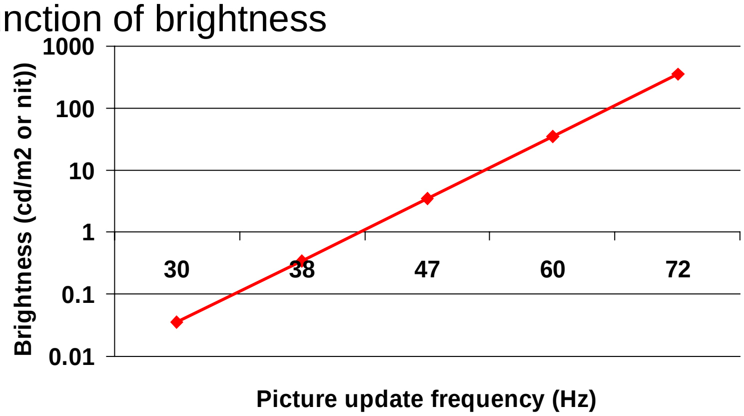
Good reasons for different formats

Standardization is no option

- Channel capacity differs
- Viewing distance differs
- History may be different
- Screen brightness differs
- Resolution requirements differ
- Motion portrayal of different importance

Large Area Flicker on TV

Perception threshold for large area flicker as a function of brightness



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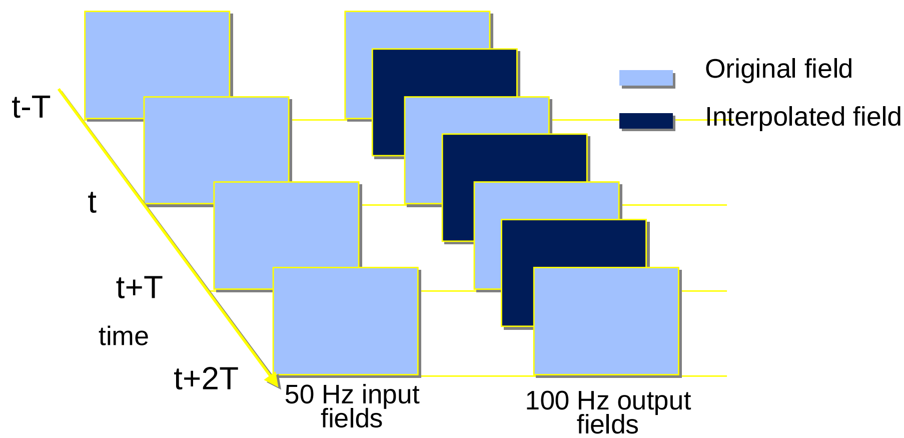
Field Rate Conversion from 50 Hz to 100Hz



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Video format conversion problem

- Video contains time-discrete information:
  - In the temporal domain (discrete number of pict/s)
  - In the vertical domain (discrete number of lines)
  - Often in the horizontal domain (number of pels/line)
- Why not use interpolating and decimating low-pass filters to achieve our goal?
  - TV does not fulfill demands of sampling theorem in V and T domains
  - Tracking viewers transform temporal frequencies

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Field rate conversion

First **De-interlace**:

- vertical temporal filter
- motion estimation, followed by motion compensated techniques

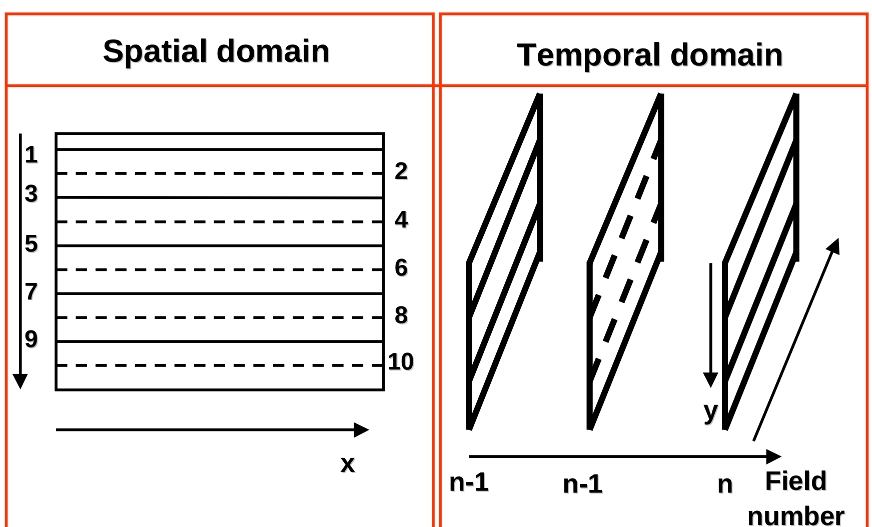
Next perform **Up-conversion**:

- motion estimation, followed by motion compensated techniques

In the end:

- Motion compensated processing in any algorithm that uses previous fields or frames: intra-field noise reduction etc.

What is interlace



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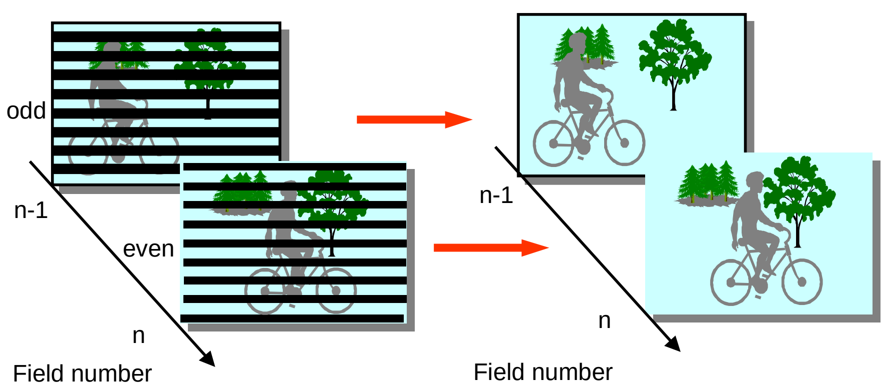
Why de-interlace

- Some displays require progressive video (matrix type of displays)
- Eliminate line flicker, resolution loss with motion, and alias
- Basic requirement for all scan conversion (even when converting from interlaced to interlaced format)
  - e.g. field rate doubling preventing odd-odd-even-even field sequence

De-interlacing, what is it?



Calculate picture data at TV-lines not transmitted in the current field

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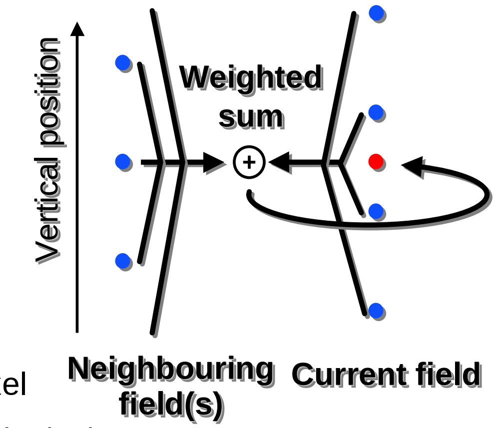
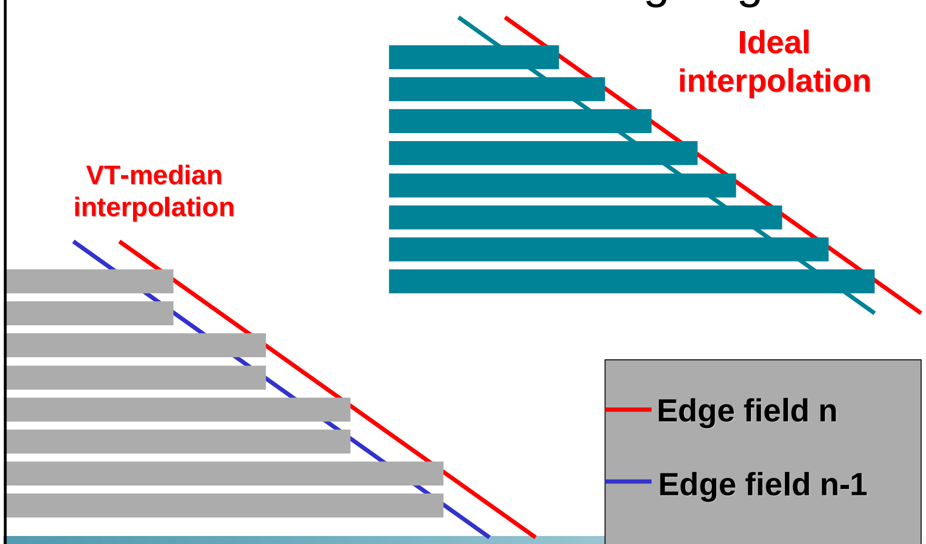
Vertical Temporal Filter (VT)



- Original pixel
- Interpolated pixel

VT Median and moving edge



De-interlacing moving images

- The problem with motion is fundamental for all methods without motion compensation

Since

- information of successive fields cannot be combined because of motion, while single fields cannot provide full vertical detail
- Motion compensation aims at achieving the same quality for moving image parts as for stationary parts

De-interlacing summary

- For stationary images many methods perform well.
- For moving images, only motion compensated methods perform reasonably good.
- Motion compensated methods have been introduced in consumer products already.

Reference articles:

- G. de Haan and E.B. Bellers, "De-interlacing of Video data", *IEEE Tr. On Consumer Electronics*, Vol. 43, No. 3, August 1997, pp. 819-825.
- G. de Haan and E.B. Bellers, "De-interlacing-An overview, Overview article accepted for publication in the *Proceedings of the IEEE* .

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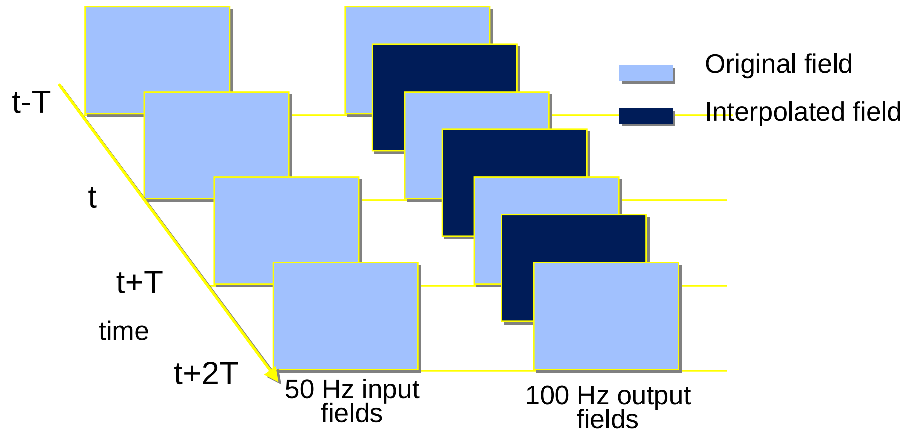
Up-conversion



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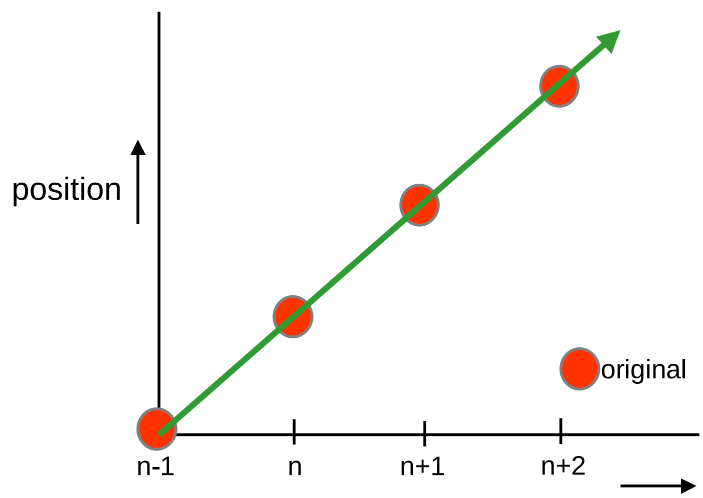
Picture rate conversion

moving object at picture rate



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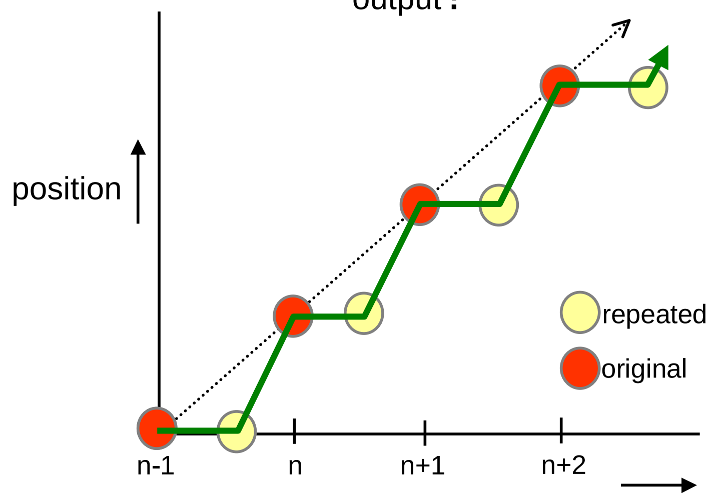
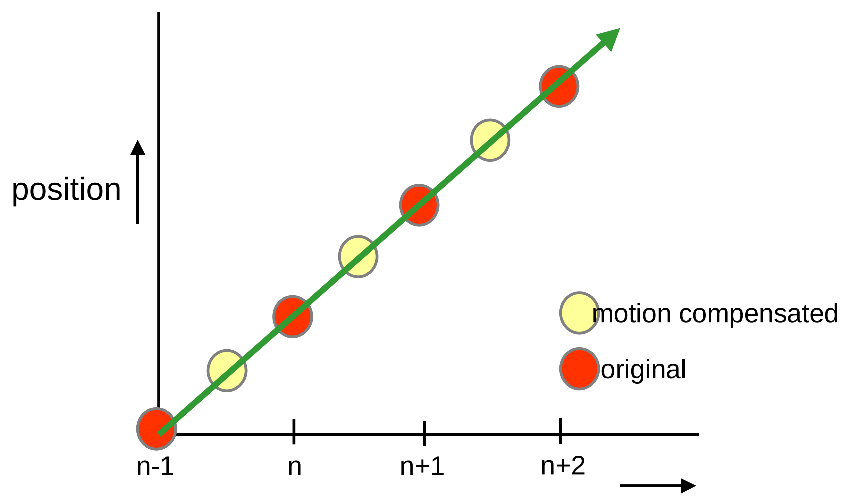
Picture rate conversion,

what if we just repeat the most recent image at the output?



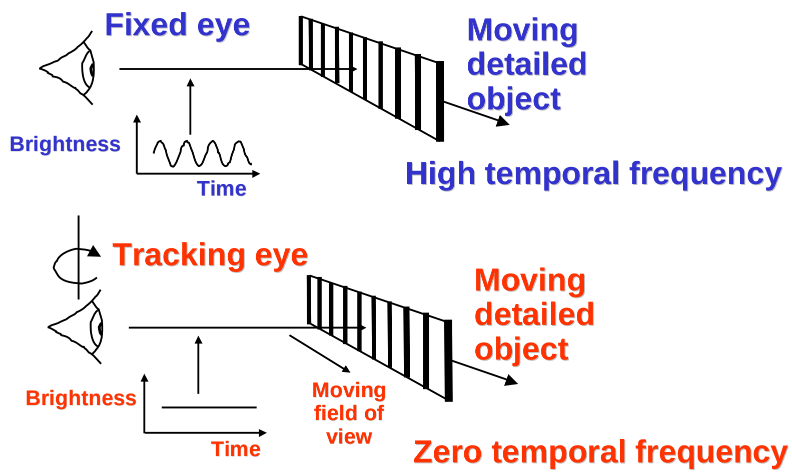
Picture rate conversion

this is what we hoped for

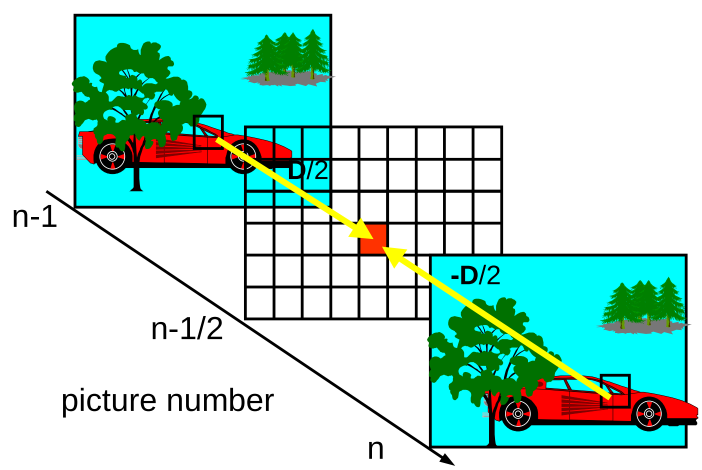


Tracking by viewer

so moving images need to be sharp



Motion Compensated picture rate up-conversion



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Picture rate conversion,

can we notice the improvement?

Non - Motion Compensated **Motion Compensated**

Motion Estimation

So this is what we need:

- Is there any motion?
- How fast?
- into which direction?

Up-conversion summary

- Motion compensated upconversion is required for good quality
- Robust methods are important

- Reference articles:
- G. de Haan et al., “IC for Motion Compensated 100Hz TV, with a Smooth Motion Movie-Mode”, *IEEE Tr. on Consumer Electronics*, May 1996, pp. 165-174.
- G. de Haan et al., “An evolutionary architecture for motion-compensated 100 Hz television”, *IEEE Tr. on Circuits and Systems for Video Technology*, Jun. 1995, pp. 207-217.

Architectural Considerations

Combine:

- Motion estimation: 3D recursive search
- Deinterlace
- Upconversion
- Preferably noise reduction and aspect ratio scaling

Into:

ONE consumer priced IC, or a part of a platform in ONE consumer based platform.

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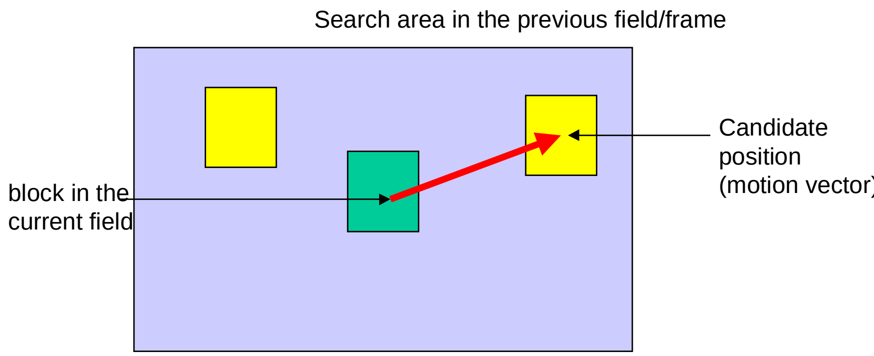
Motion Estimation

The problem: find the best block position at a number of candidate positions, comparing data of the current field/frame with date of the previous field/frame



Motion Estimation Questions:

Find a perceptively **good** ME that requires limited:

- external memory
- internal memory
- computational load.
- What is a good ME? Iterative development loop:
- Propose an algorithm for ME
- Implement de-interlace and or up-conversion with it
- Evaluate the video quality and the cost of implementation!

Trade-offs with very non-linear and implicit cost functions

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Choices for Motion Estimation

Algorithmic choices have a video quality and cost impact:

- Number of previous fields/frames used, e.g one frame (~ 1 Mbyte, external off chip memory)
- search range, typically +/- 12 - 16 in vertical direction, +/- 30-40 in horizontal direction (~ 10-100kByte internal memory)
- Block size for comparison, typically 8x8 to 16x16
- Accuracy of vectors, typically 0.25 pixel!, so 2D interpolation is required inside the motion estimation
- Number of pixels used in the calculation of the Sum of differences: typically a sub-sample of a factor 2-4.

Combination of Motion Estimation, De-interlace and Up-conversion

- Combine the field/frame memories,
- Combine the De-interlacing with Motion Estimation: recursive de-interlacing
- Use motion vectors for De-interlace
- Calculate new motion vectors for Up-conversion at proper temporal location (vector split)

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System Trade-offs, solution 1

Existing IC (SAA 4991), used in high end Philips TVs

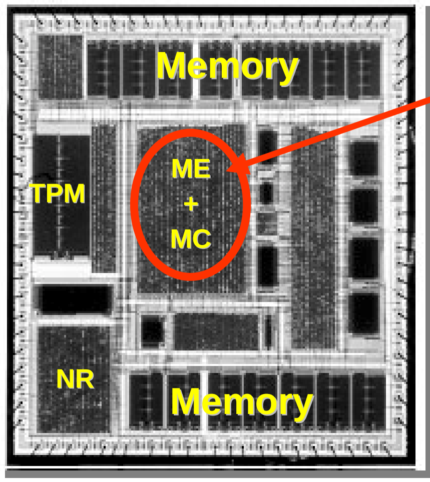
- All pixel processing in dedicated synthesized hardware.
- frame/field memories of chip
- line memories for the search range on-chip.
- Control settings and field level adjustment in a micro-controller (8051)
- Good video quality, implementation tuned for the TV market
- Includes noise reduction and vertical scaling of the image
- Runs synchronous with the video scanning frequency

System Trade-offs, solution 1)

- IC characteristics:

Process	CMOS 0.8 µm
Die Size	97 mm^2
Transistor Count	980.000
Data Clock	27 or 32 MHz
Package	PLCC84
Dissipation	1.8 W
Interface	UART-bus
ME/MC Range	±16 (H), ±9 (V) pixels

System Trade-offs solution 1)

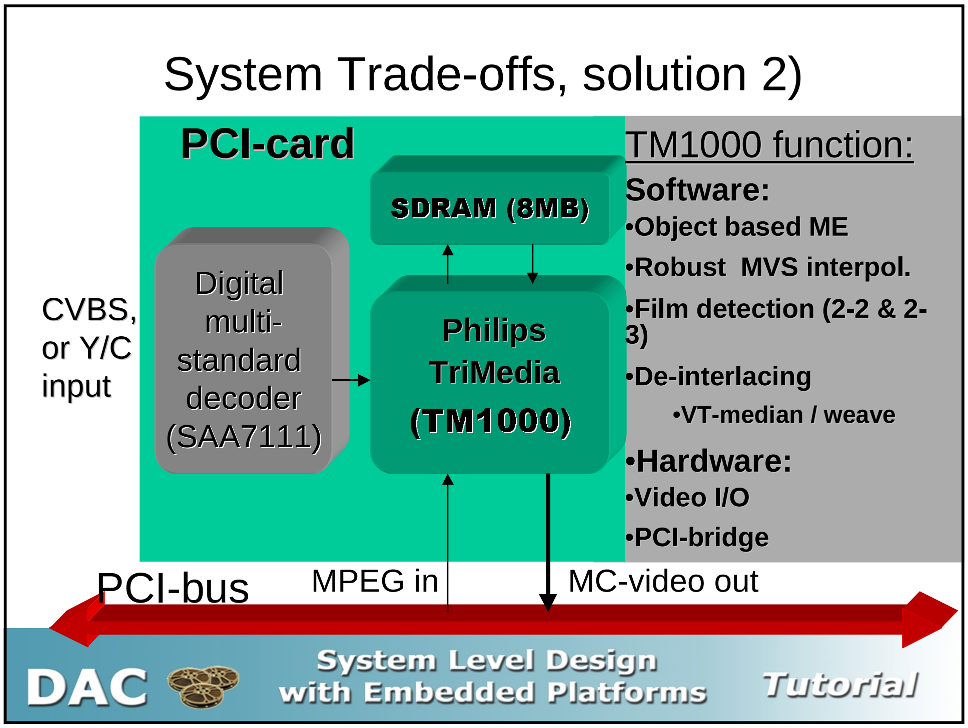


Dedicated, synthesized, tuned solution

System trade-offs, solution 2)

Attempt to implement the de-interlacing and up-conversion completely in software exploiting the opportunities of Philips Trimedia VLIW core:

- Data parallelism 4 bytes in a word in the 32 bit architecture,
- Special Media instructions making SAD calculations and Median calculations very efficient
- Instruction Level Parallelism exploiting: 4.5 out of 5 issueslot effectively used over the complete program
- Some video quality limitations to achieve the software solution


System Trade-offs, solution 2)
PCI-card
SDRAM (8MB)
Digital multi-standard decoder (SAA7111)
CVBS, or Y/C input
Philips TriMedia (TM1000)
TM1000 function:
Software:
•Object based ME
•Robust MVS interpol.
•Film detection (2-2 & 2-3)
•De-interlacing
•VT-median / weave
•Hardware:
•Video I/O
•PCI-bridge
PCI-bus
MPEG in
MC-video out
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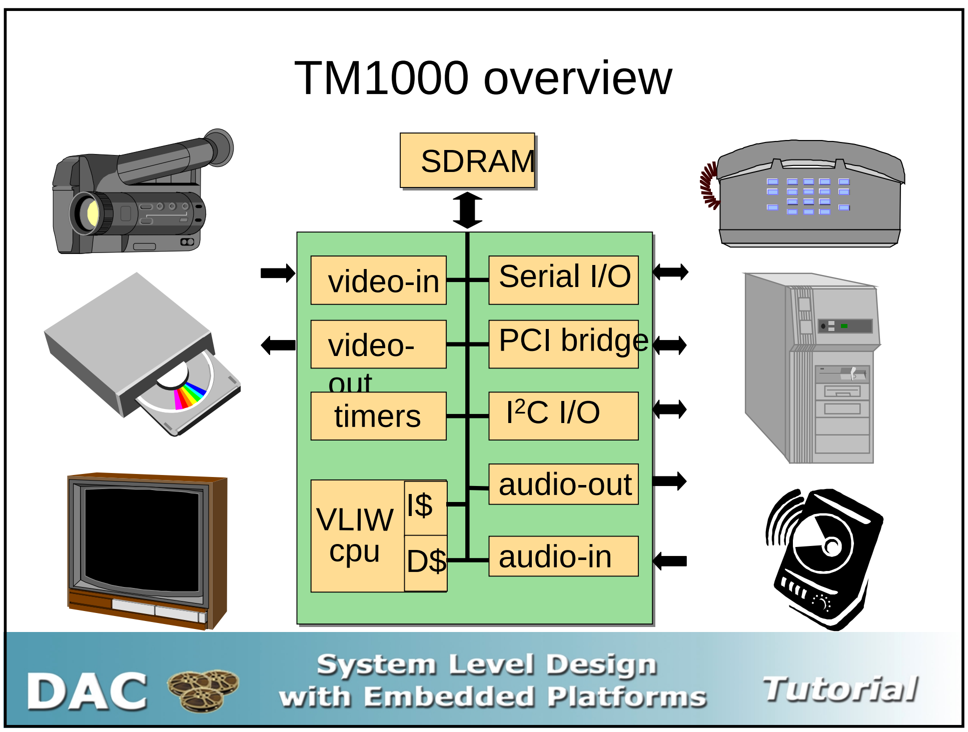
TM1000 overview
SDRAM
video-in
video-out
timers
VLIW cpu
I$
D$
Serial I/O
PCI bridge
I2C I/O
audio-out
audio-in
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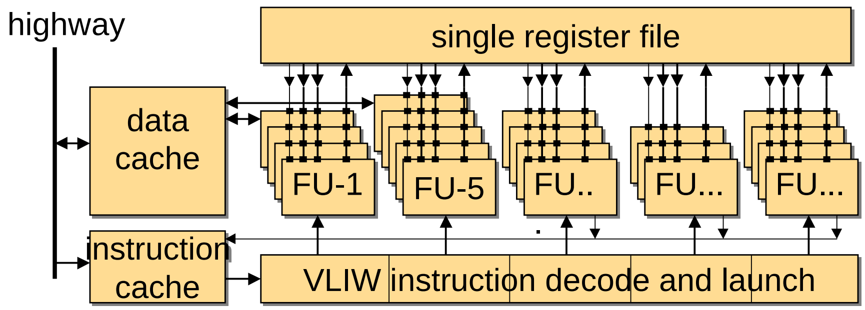
TM1000 VLIW core



32 KB instr cache
16 KB data cache,
quasi dual ported,
8-way set associative

128 words x 32 bits register file
5 ALU, 5 const, 2 shift, 3 branch
2 I/FPmul, 2 FPalu,1 FPdivsqrt, 1 FPcomp
2 loadstore, 2 DSPalu, 2 DSPmul
Pipelined, latency 1 to 3 cycles (except FPdivsqrt)

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System Trade-offs, proposal 3)

- New proposal: joint effort of Philips Research, Philips Trimedia and Philips Semiconductors Business Line Video.
- Best video quality
- Partitioning of total functionality in Software on the TM-core and a dedicated new coprocessor, with on chip internal memory for the search range
- Combined with many other functions and features in the context of TV processing
- Runs completely de-coupled from the video input frequency or the video output frequency, and independent of the video scanning direction.

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Conclusion

- The feasibility of Motion Estimation and Motion Compensated De-interlacing and Up-Conversion has been shown
- Several implementations with a range in video quality have been illustrated.
- Quantifying the system trade-offs for next generation systems is essential.
- The combination of powerful Media processor cores with flexible coprocessors is unique in this field.
- De-coupling of video scanning opens new algorithmic opportunities

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