
Compression for 3DTV - with special focus on MPEG standards

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Image Processing Department

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Overview

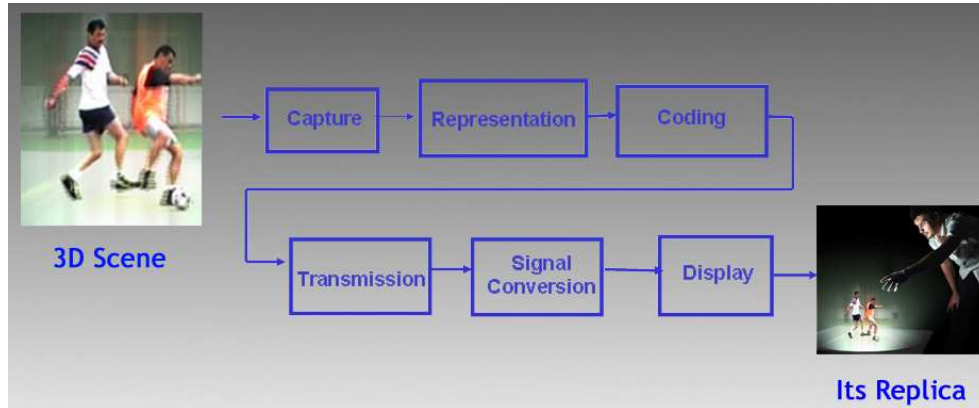
- Introduction, terms, market and standards
- 3D scene representation
- Conventional stereo video coding
- Video plus depth coding
- Multi-view video coding (MVC)
- Multi-view video plus depth (MVD) coding
- (3D mesh compression)
- Summary & Conclusions

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3DV/FVV Processing Chain



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3DV and FVV as Functionalities

- 3D Video (3DV, also known as stereo) and Free Viewpoint Video (FVV) describe **functionalities**
- Expand the user's sensation beyond what is offered by classical 2D video
- They **do not exclude each other**, can be combined in a single system

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Free Navigation

- Arbitrary selection of **viewpoint and direction** within **real world** audio-visual scenes
- Well-known from **computer graphics**, virtual reality, computer games
- **Synthetic** scenes, objects or static views of real objects, 2D video
- Or restricted to **predefined** viewpoints (Formula 1 on Premiere)

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Free Navigation in Real Scenes

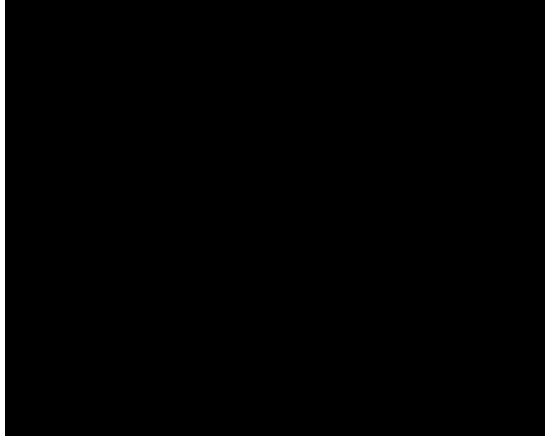
- New technology allows generation of intermediate views in between real existing camera view
 - **Image-Based rendering, 3D reconstruction**
- Allows e.g. viewing sports or theatre from **arbitrary viewpoints**
- New technology for the **whole chain**:
 - Acquisition, signal processing, modelling, representation, compression, transmission, rendering, display

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Free Viewpoint Video



- **Same functionality as CG objects**
 - free navigation, can be viewed from any viewpoint/direction
 - Integration into complete scenes (virtual/augmented/real)
- **But:** depict appearance, motion, deformation of **real world objects**

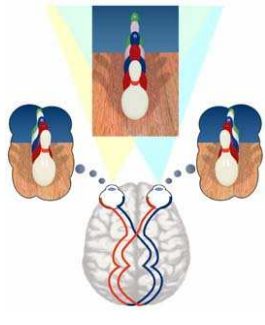
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3DV / Stereo Video

- Generation of a 3D depth impression from separate views for each eye
- Well-known e.g. from IMAX



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3DV / Stereo Video

- Demo

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Applications

- **3DV: Extension of 2D video to 3D with depth impression**
 - DVD, broadcast, cinema, mobile, specific applications (medicine, military, etc.)
 - Buy a DVD of a Hollywood movie in 3D
- **FVV: Extension for interactive viewpoint selection**
 - Production, special effects
 - DVD, broadcast, cinema, mobile, specific applications (medicine, military, etc.)
 - Buy a DVD of a concert, opera, theatre, sports event in FVV
 - E.g. final of FIFA worldcup

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Market Potential

- **3DV and FVV will create huge markets for equipment (production and consumer side) and content in the near future**
- 3D displays
- Set-top boxes, SW
- Content
- Equipment for acquisition
- Equipment/SW for content creation
- ...

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Standards

- Development of consumer markets (esp.) requires **interoperability** of systems and equipment from different providers
- This means **standard formats** for content
- Consider impact of **MPEG-2 video** and **mp3** on media related industry and society
- Note: these are “just” digital and compressed formats of their analog counterparts, basically nothing new
- FVV and 3DV expand the sensation

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MPEG/VCEG Standards for FVV and 3DV

- **Standards are necessary** to make 3DV and FVV happen
- **MPEG investigated** the needs for related standards in a sub-group called **3DAV**
- Work continues in the **JVT** of MPEG and VCEG

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MPEG/VCEG Standards for FVV and 3DV

- A lot of things are already possible with MPEG-4, which is a rich multimedia framework
- Additions have been made to the computer graphics specifications (MPEG-4 AFX) to support specific FVV systems
- 2 new standards are finalized or being created
 - Auxiliary Video Data Representation
 - Multi-view Video Coding (MVC)
- More to come, e.g. MVD

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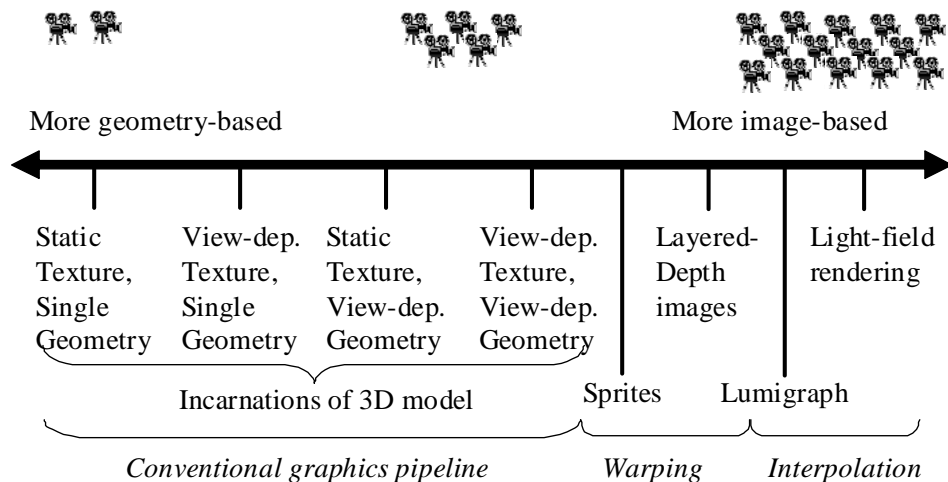
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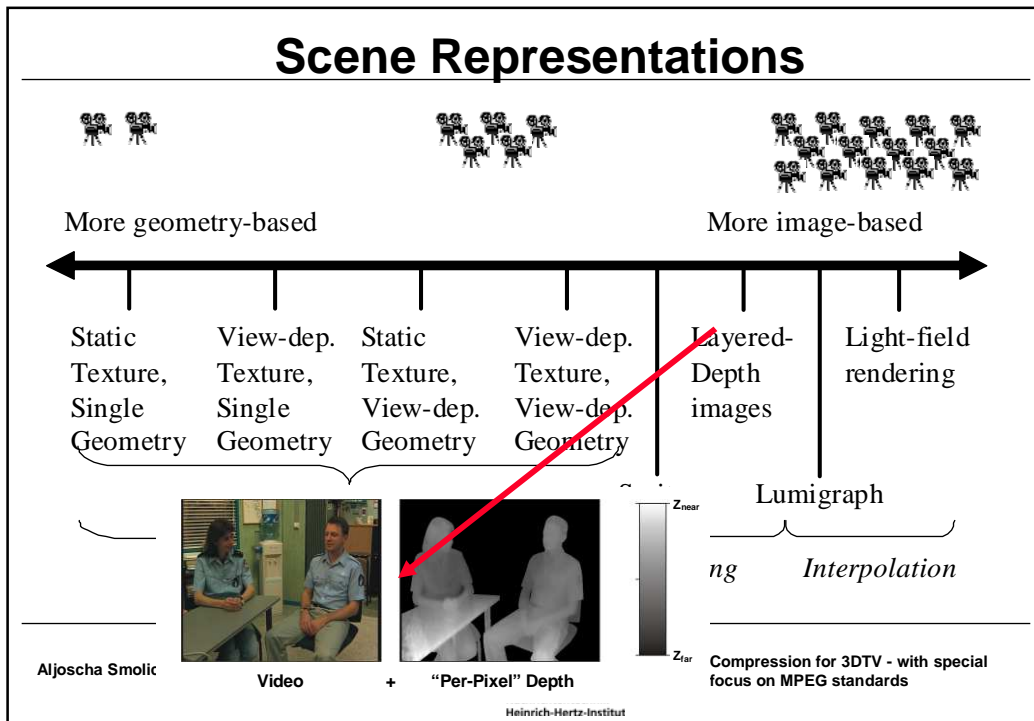
Scene Representations



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Scene Representations

- Suitable for FVV and 3DV
- Pure FVV: rendering of one view from the representation
- 3DV: rendering of a stereo pair corresponding to eye positions
- **A lot of very different data types are used for FVV and 3DV**

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Conventional Stereo Video

- Generation of a 3D depth impression from separate views for each eye
- Well-known e.g. from IMAX
- 2 video signals are used



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pecial

Conventional Stereo Video

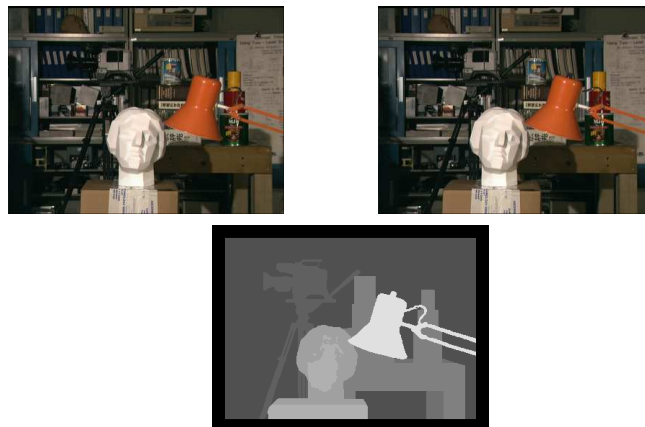
- Stereo images are very similar
- Images are related through scene geometry and camera properties
- Predict one view from the other
- Displacement of a pixel with respect to other image: disparity

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Disparity



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Conventional Stereo Video

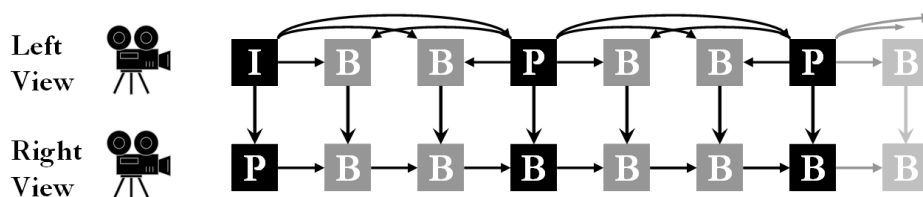
- Analogy: dense motion field
 - Use principles of motion estimation/compensation for prediction
- Specific differences:
 - Different statistics of disparity and motion vectors
 - Disparities can be very large
 - Adjustments of entropy coding
 - Temporal adjacent images are more similar
 - Disocclusion more evident
 - Problems of white & color balancing
 - Scene lighting, surface reflections

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Inter-view Prediction



- Algorithms well known, standards available (MPEG-2 MV Profile)
- Limited gain, temporal prediction works well
- Significant gain only for I frames
- No commercial relevance

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Downsampling



- Downsample one view
- Does not degrade 3D impression significantly
- Toggle between left/right

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Limitations of Conventional Stereo Video

- Problem of conventional stereo video (2 fixed views):
 - head motion parallax viewing is not supported
- Viewer expects occlusions/dis-occlusions when watching 3D scenery
- Unnatural impression when moving head (impression that whole scene moves)
- Can be overcome adding **free viewpoint functionality**:
 - View is adapted to user motion
 - Tracking
 - Multi-view displays

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Depth-Based Rendering



Image



Depth

3D Warp



Virtual view

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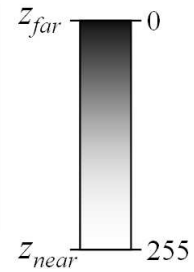
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MPEG-C Part 3

Video



Depth



- Depth: monochromatic 8 bit video signal

We would like to thank the Image Based Realities Group of Microsoft Research for providing the Breakdancers and Ballroom data sets.

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Interactive Stereo Video

- Generation of 2 views for each eye from one video and per pixel depth information
- Rendering of a stereo pair at the decoder
- Virtual views can be generated **within a certain operating range** => head motion parallax viewing
- Requires tracking of user



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Interactive Stereo Video



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FhG-HHI Autostereoscopic Display

- 3D impression without glasses
- Automatic gaze tracking with built-in camera sensors
- Automatic adjustment of 3D rendering due to user motion



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Interactive Stereo Video

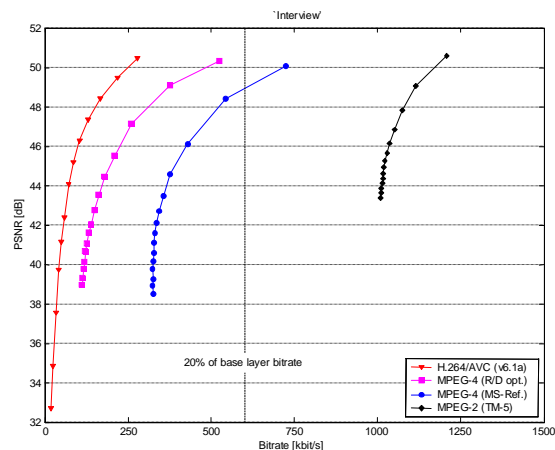
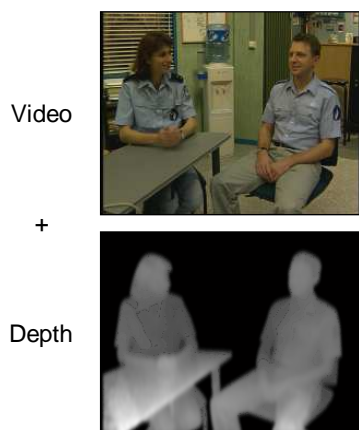
- 3D impression is individually adjustable due to rendering at decoder
 - Strength of depth impression
 - Position in relation to the screen (in front, behind, distance)
- ATTEST:
 - Efficient compression of depth data is possible
 - Only 10% of related rate for video signal without noticeable artifacts

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Coding of „Video plus Depth“

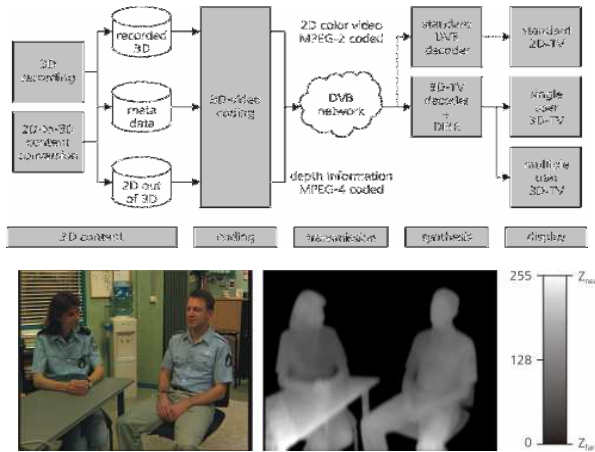


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3D-TV System of the ATTEST Project



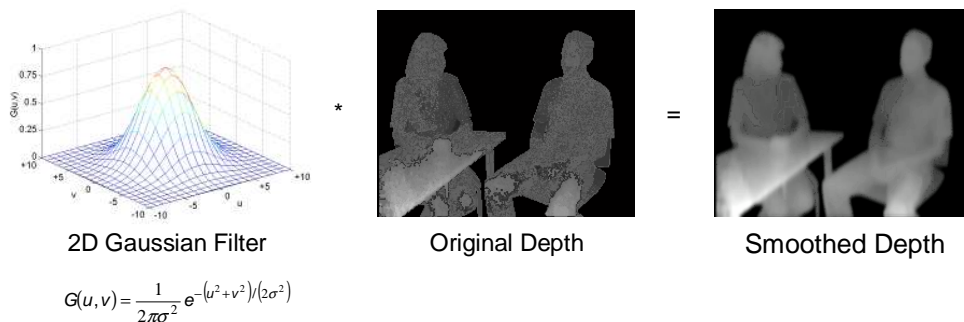
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Handling of Disocclusions

- **Best approach:** Pre-process (smooth) depth-images such that no disocclusions appear !



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Handling of Disocclusions



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Limitations of Single Video plus Depth



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Limitations of Single Video plus Depth

Disocclusion artifacts increase with distance of virtual view from available original view

Does not support wide range multi-view 3D displays

Very limited free viewpoint navigation

Problem of depth estimation

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MPEG-C Part 3

Video + depth as data representation for 3DTV

Enables 3DV with limited FVV

Very simple but efficient

Results from ATTEST: depth can be compressed very efficiently using video coders such as AVC (5-10% bitrate compared to color signal)

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MPEG-C Part 3

Initiative driven by Philips, FhG-HHI and other partners:

Define a simple container format that includes video + depth + auxiliary data (stereo config)

Fast solution: no long standardization process

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MPEG-C Part 3

Full specification has been proposed, evaluated and accepted by MPEG

January 2007 FDIS

ISO/IEC 23002-3 Representation of Auxiliary Video and Supplemental Information

ISO/IEC 13818-1:2003 Carriage of Auxiliary Data

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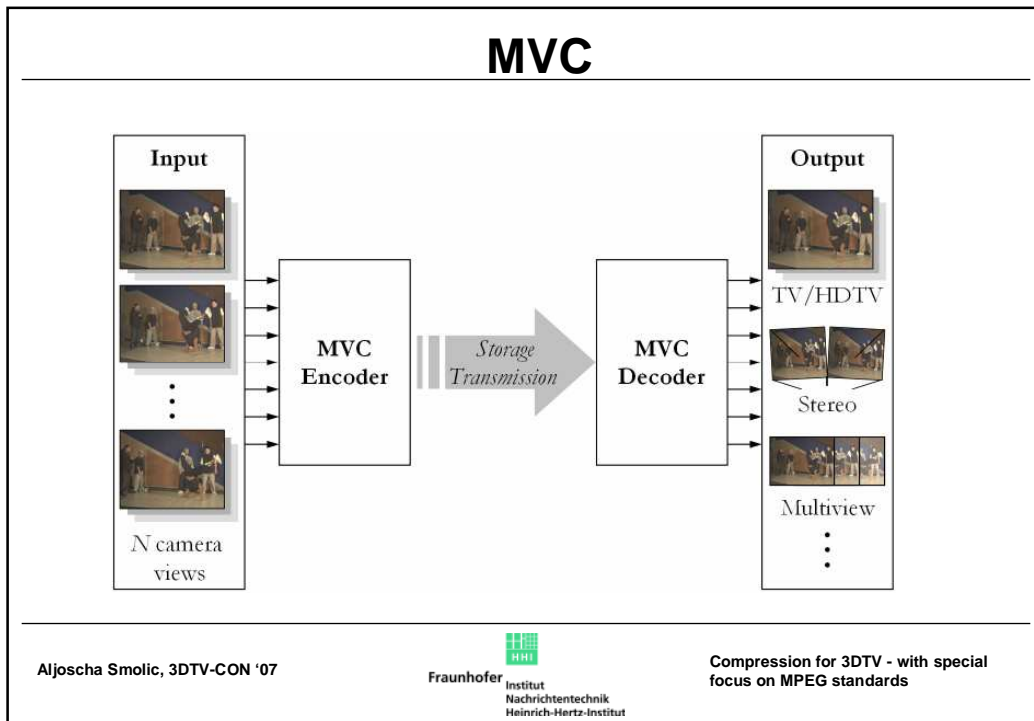
Multi-view Video Coding (MVC)


- FVV and 3DV representations require transmission of **multiple synchronized video signals** that show the same scenery from different viewpoints
- **Huge amount of data** that need to be compressed efficiently
- Contains a large amount of **inter-view statistical dependencies**



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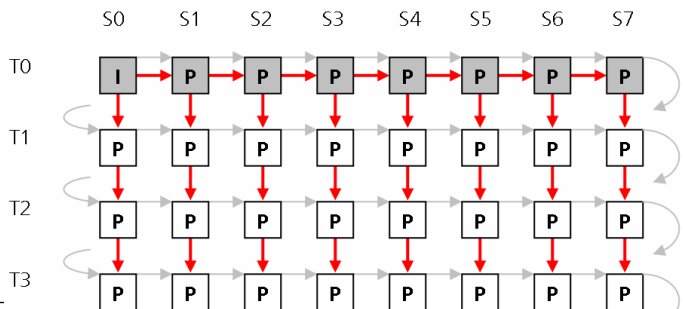
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- ## MVC Applications
- Multi-view displays, e.g. MERL, Philips
 - Autostereoscopic for multiple users
 - Support head motion parallax viewing
 - Integral imaging
 - FVV based on ray-space, light-field
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Multi-view Video Coding (MVC)

- Evaluations have shown that specific MVC exploiting inter-view statistical dependencies provides significant coding gain
- Only for dense camera settings, not for dome-type arrangements

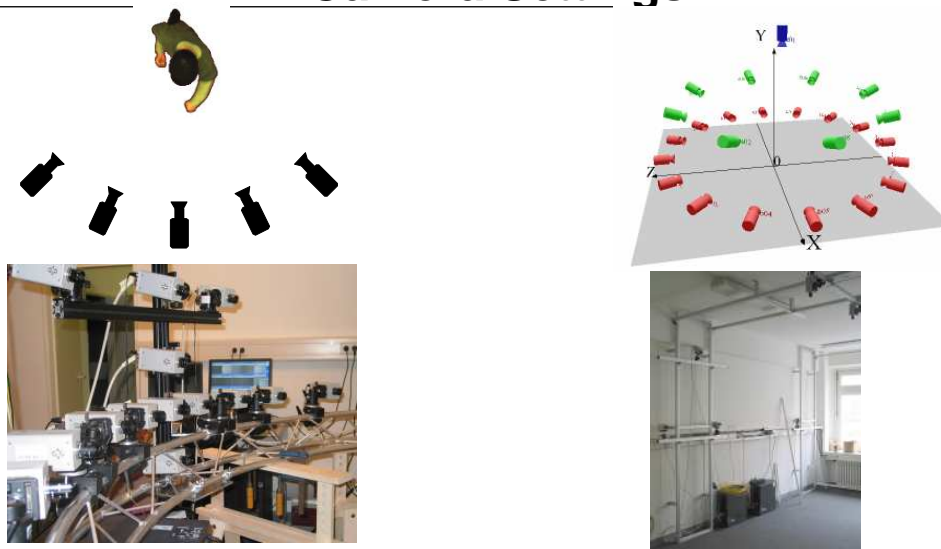


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Camera Settings



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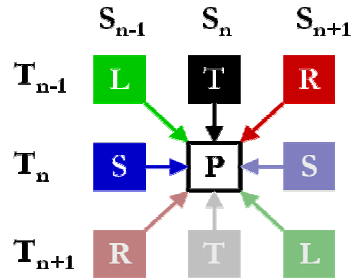
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Multi-view Prediction

1st order neighbors

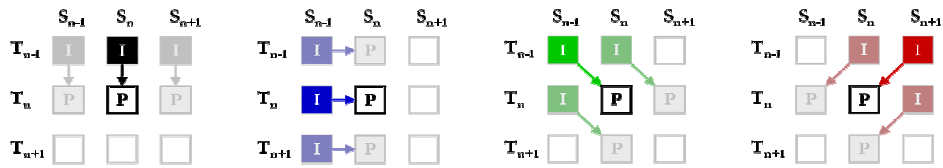
- **T** (temporal)
- **S** (inter-view)
- **L/R** (combined)



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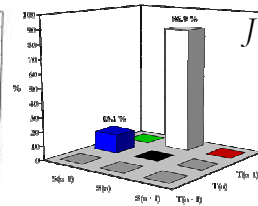
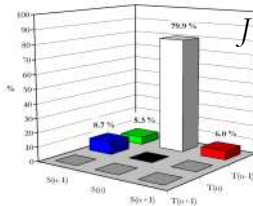
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T better than S better than R/L

Influencing factors

Frame rate, camera distance, complexity of
Content (motion, spatial detail)



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MVC Standard

- MPEG decided to launch a new standard based on H.264/MPEG4-AVC
- MPEG-4 Part 10, Amd. 4

<input type="checkbox"/> Evaluation of Call for Proposals	January 2006
<input type="checkbox"/> WD	July 2006
<input type="checkbox"/> PDAM	January 2007
<input type="checkbox"/> FPDAM	July 2007
<input checked="" type="checkbox"/> FDIS	January 2008

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Test Data & Conditions

- 8 MV data sets with 5-16 sequences each
- Different frame rates, image resolutions, camera distances, camera setups
- Representative test set for MV applications
- 3 bitrates, low, medium, high quality
- Over 200 sequences to be generated

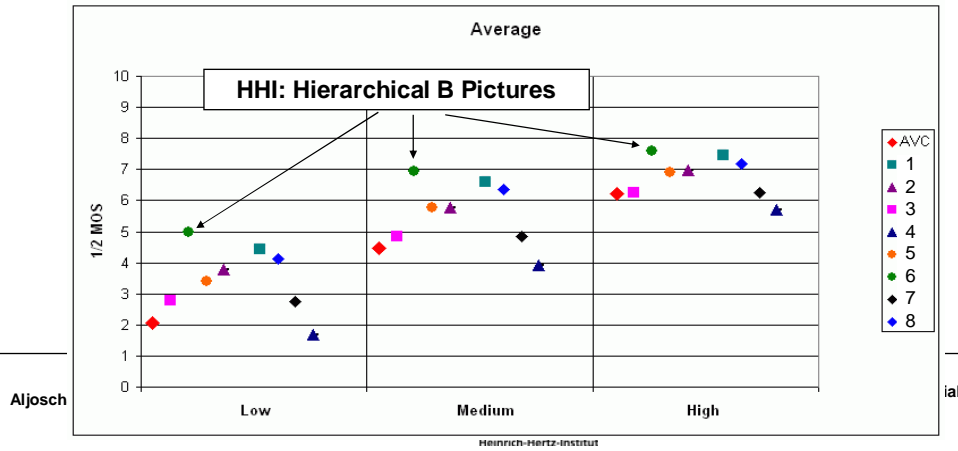
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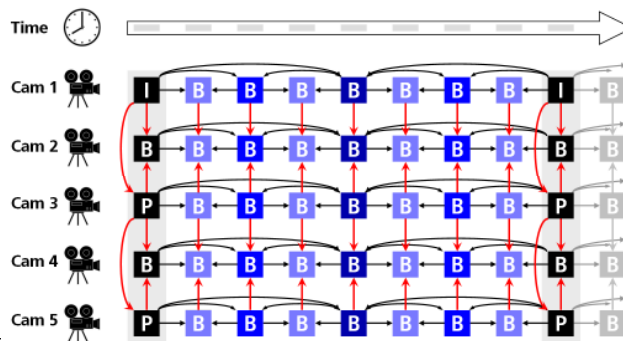
MVC Call for Proposals

- Current reference model is based on a proposal made by FhG-HHI
- Proved best performance out of 8 proposals in response to a CfP in formal subjective tests



MVC Reference Model

- Fully compatible to H.264/MPEG4-AVC
- Reorganization of input images into a single stream prior to encoding
- Uses hierarchical B-pictures combined in temporal and inter-view dimension



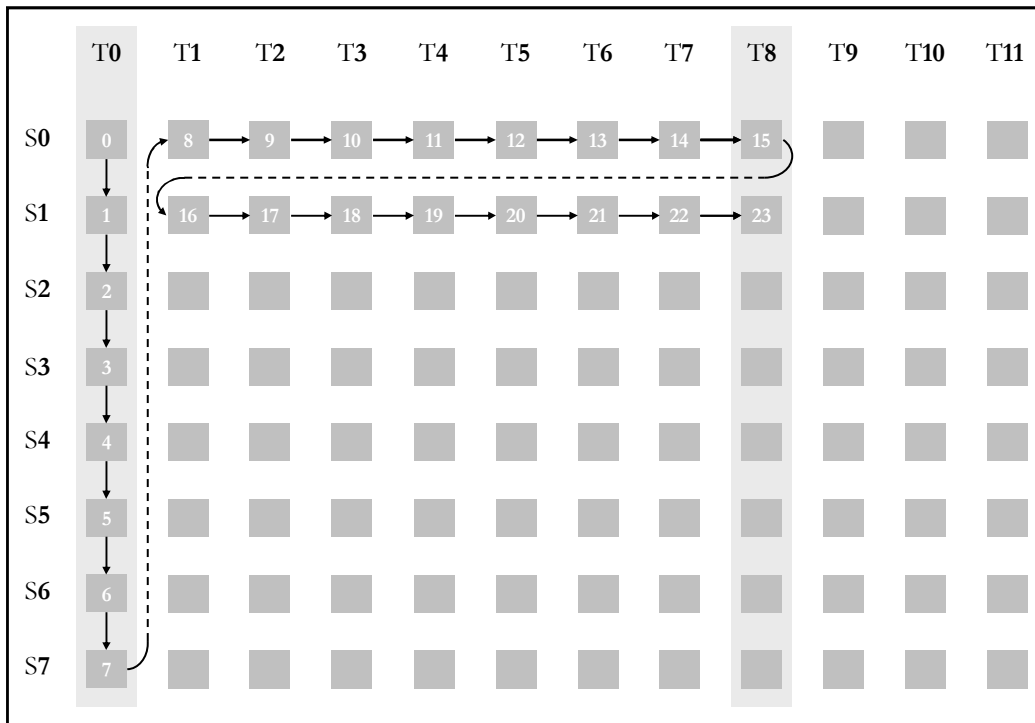
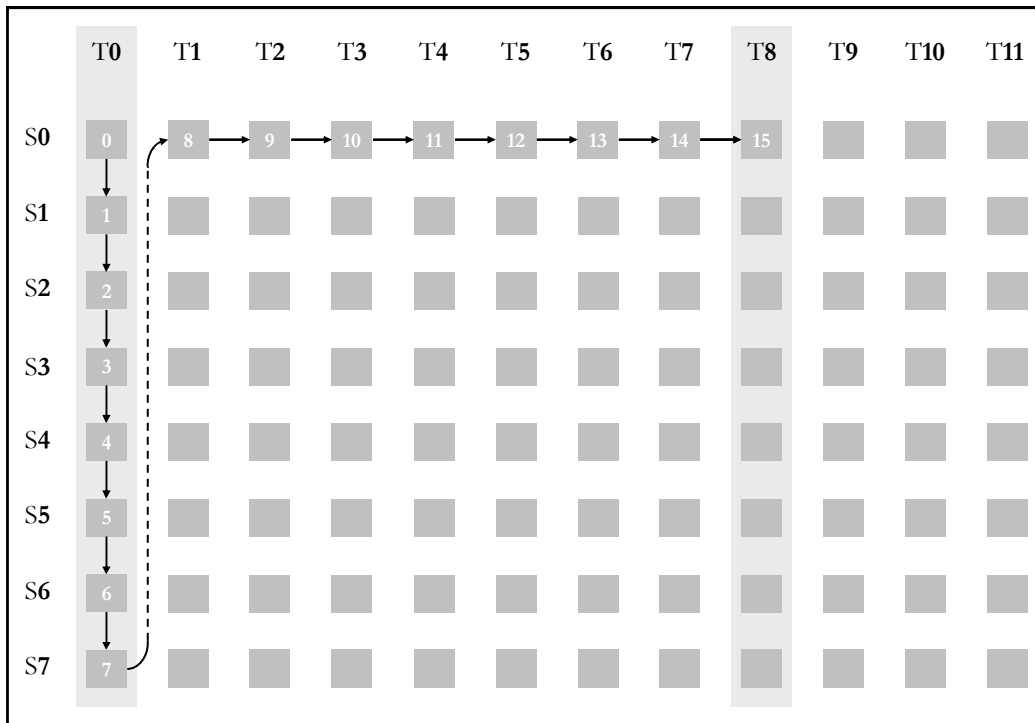
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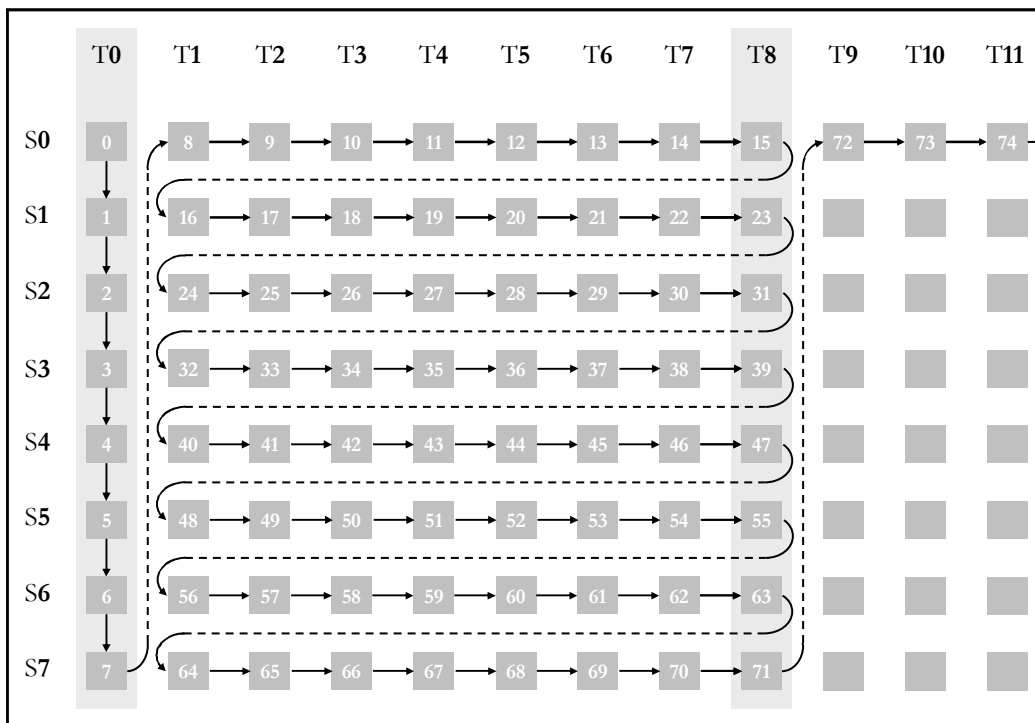
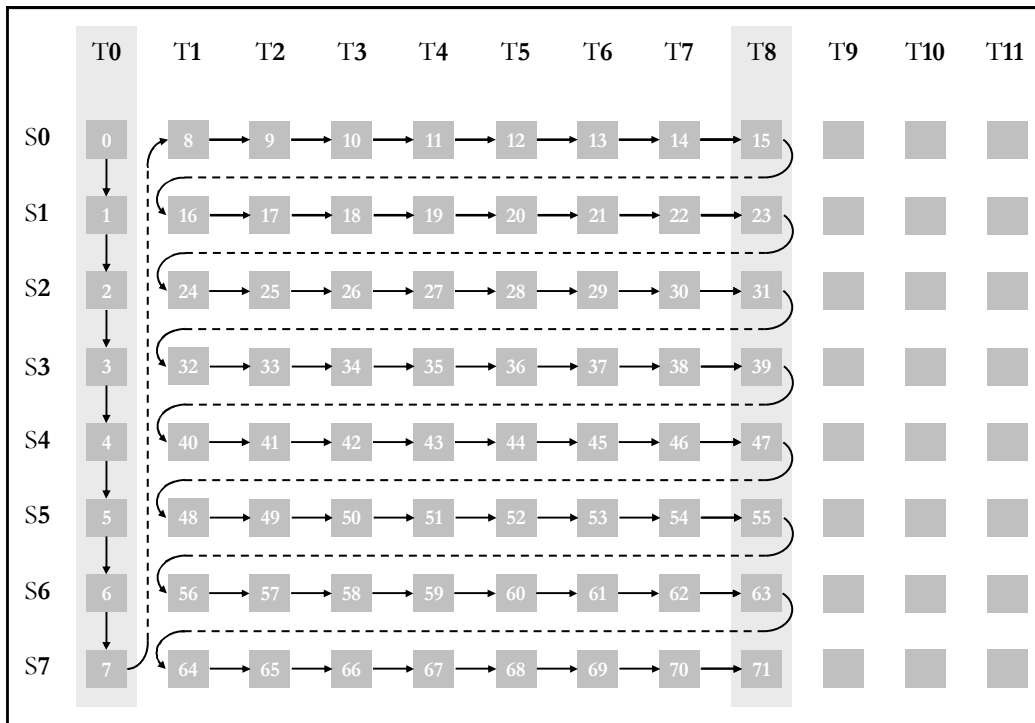
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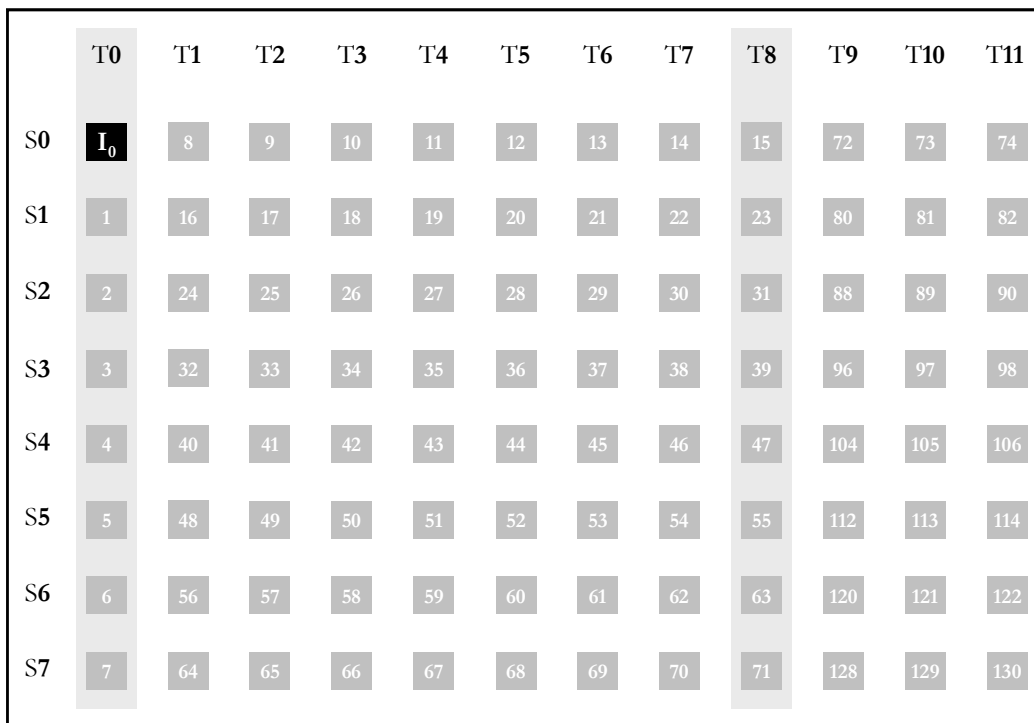
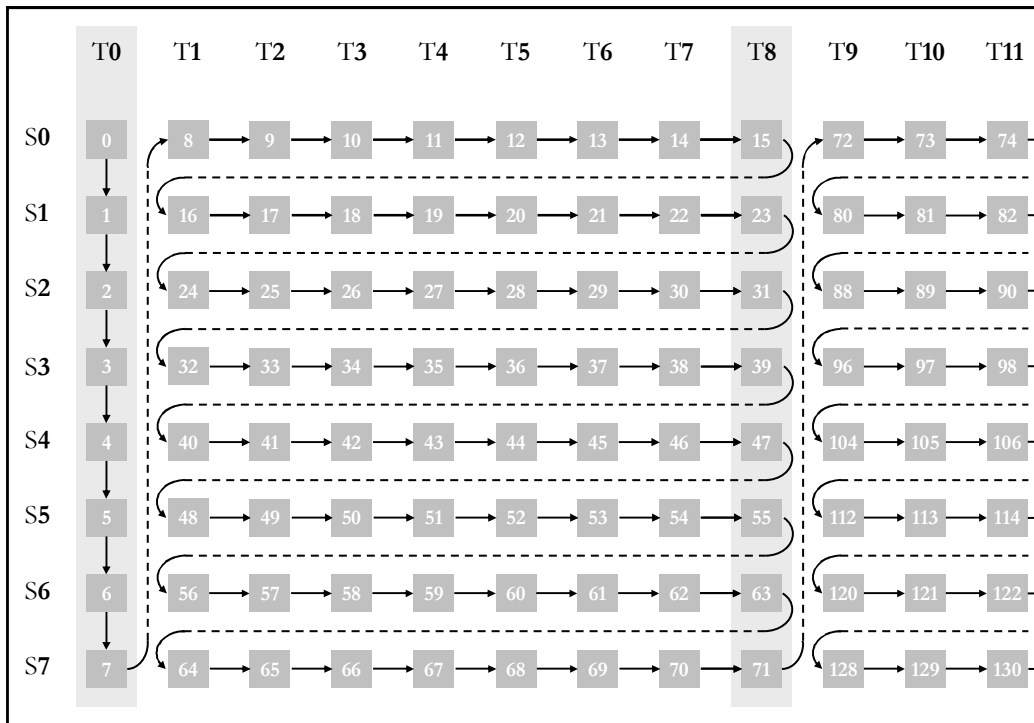
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	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
S0	■	■	■	■	■	■	■	■	■	■	■	■
S1	■	■	■	■	■	■	■	■	■	■	■	■
S2	■	■	■	■	■	■	■	■	■	■	■	■
S3	■	■	■	■	■	■	■	■	■	■	■	■
S4	■	■	■	■	■	■	■	■	■	■	■	■
S5	■	■	■	■	■	■	■	■	■	■	■	■
S6	■	■	■	■	■	■	■	■	■	■	■	■
S7	■	■	■	■	■	■	■	■	■	■	■	■

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
S0	0	■	■	■	■	■	■	■	■	■	■	■
S1	↓	■	■	■	■	■	■	■	■	■	■	■
S2	↓	■	■	■	■	■	■	■	■	■	■	■
S3	↓	■	■	■	■	■	■	■	■	■	■	■
S4	↓	■	■	■	■	■	■	■	■	■	■	■
S5	↓	■	■	■	■	■	■	■	■	■	■	■
S6	↓	■	■	■	■	■	■	■	■	■	■	■
S7	↓	■	■	■	■	■	■	■	■	■	■	■







	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
S0	I₀	8	9	10	11	12	13	14	15	72	73	74
S1	1	16	17	18	19	20	21	22	23	80	81	82
S2	P₀	24	25	26	27	28	29	30	31	88	89	90
S3	3	32	33	34	35	36	37	38	39	96	97	98
S4	4	40	41	42	43	44	45	46	47	104	105	106
S5	5	48	49	50	51	52	53	54	55	112	113	114
S6	6	56	57	58	59	60	61	62	63	120	121	122
S7	7	64	65	66	67	68	69	70	71	128	129	130

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
S0	I₀	8	9	10	11	12	13	14	15	72	73	74
S1	B₁	16	17	18	19	20	21	22	23	80	81	82
S2	P₀	24	25	26	27	28	29	30	31	88	89	90
S3	3	32	33	34	35	36	37	38	39	96	97	98
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S5	5	48	49	50	51	52	53	54	55	112	113	114
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S7	7	64	65	66	67	68	69	70	71	128	129	130

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
S0	I₀	8	9	10	11	12	13	14	15	72	73	74
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S5	5	48	49	50	51	52	53	54	55	112	113	114
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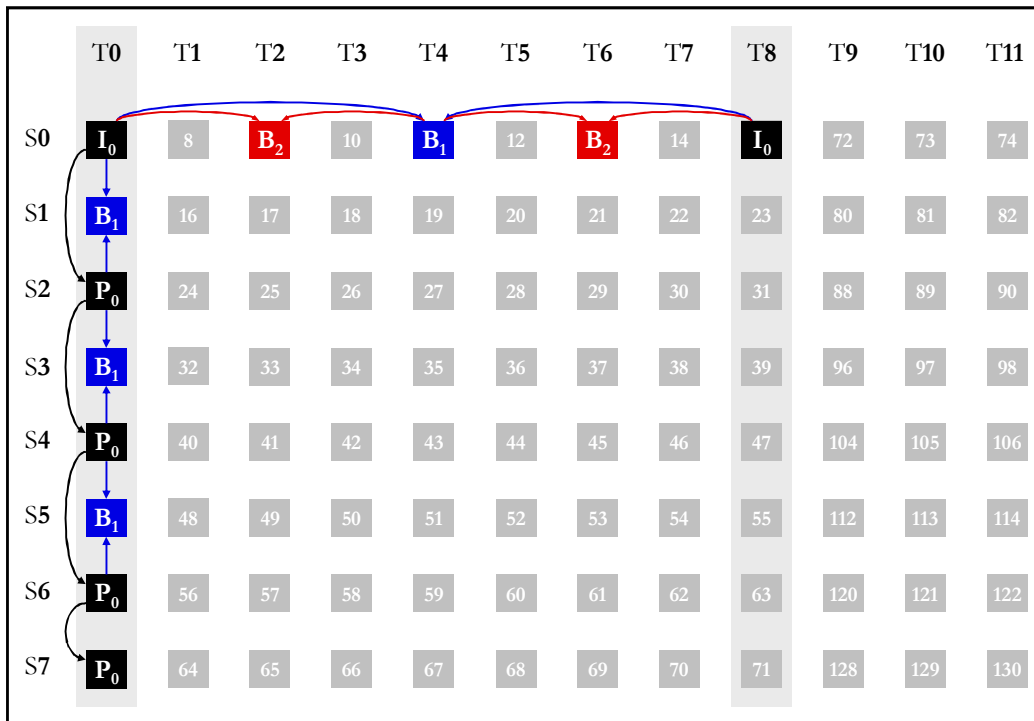
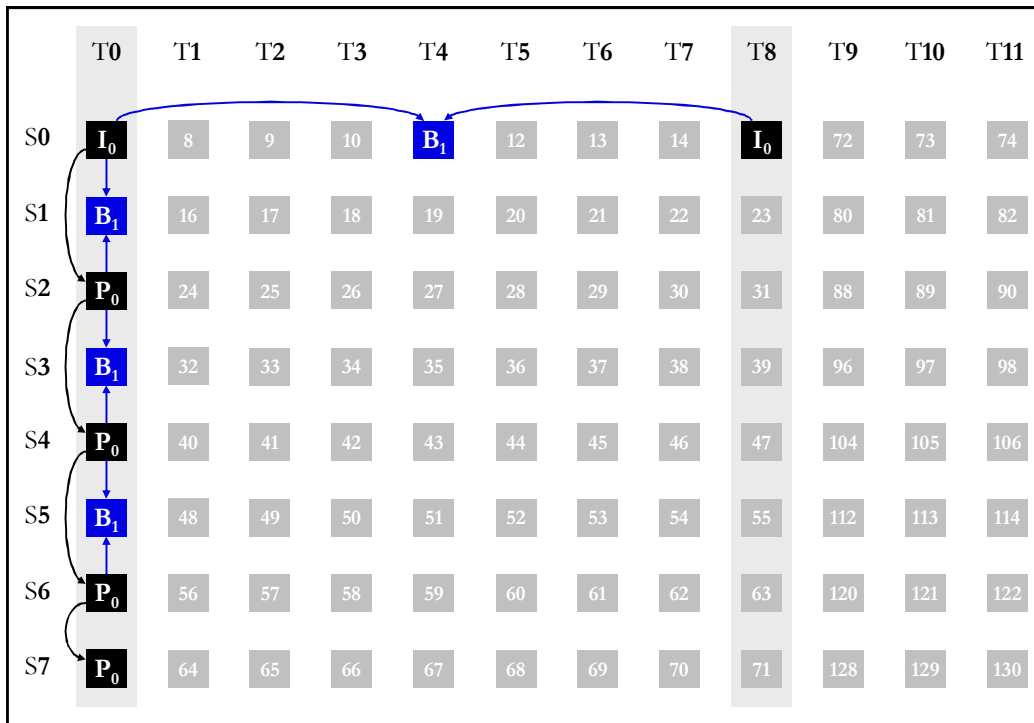
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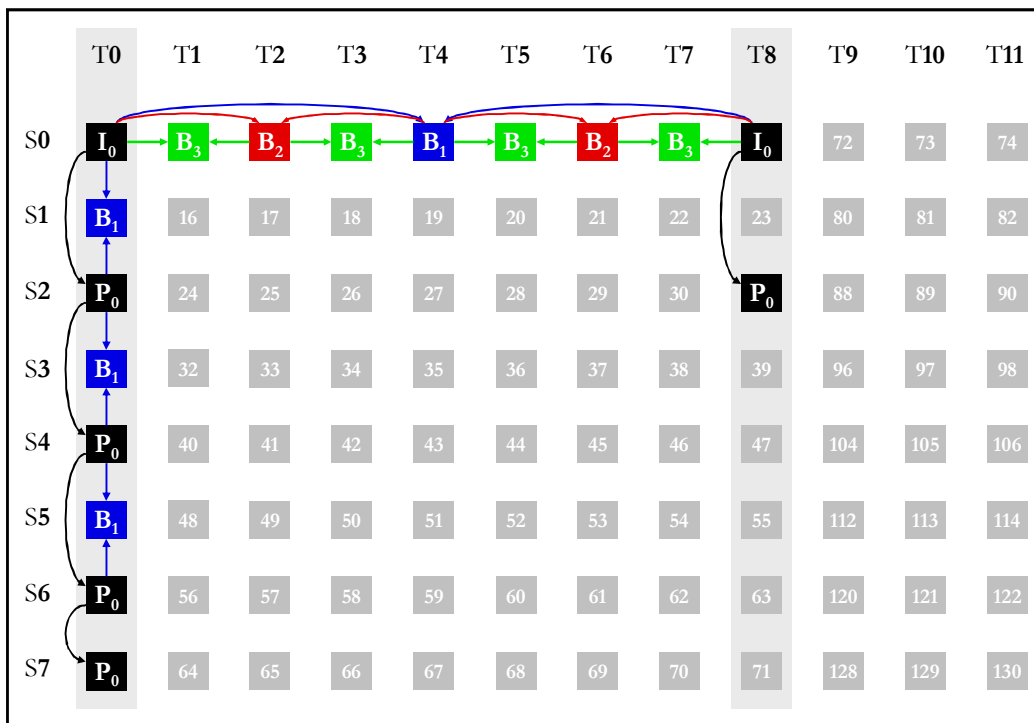
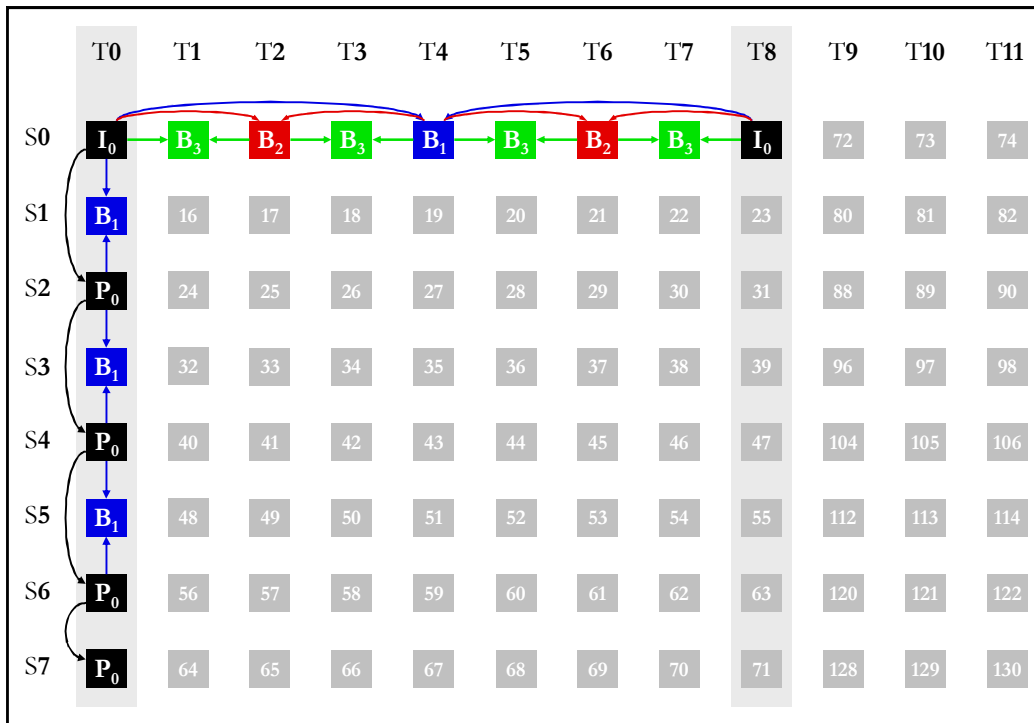
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S5	5	48	49	50	51	52	53	54	55	112	113	114
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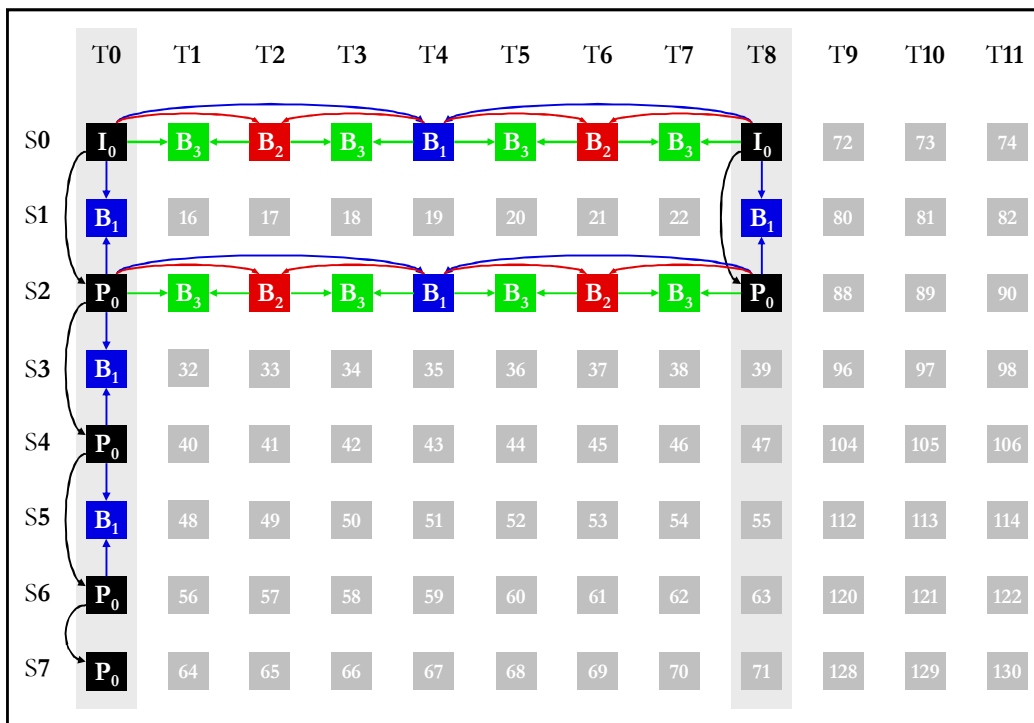
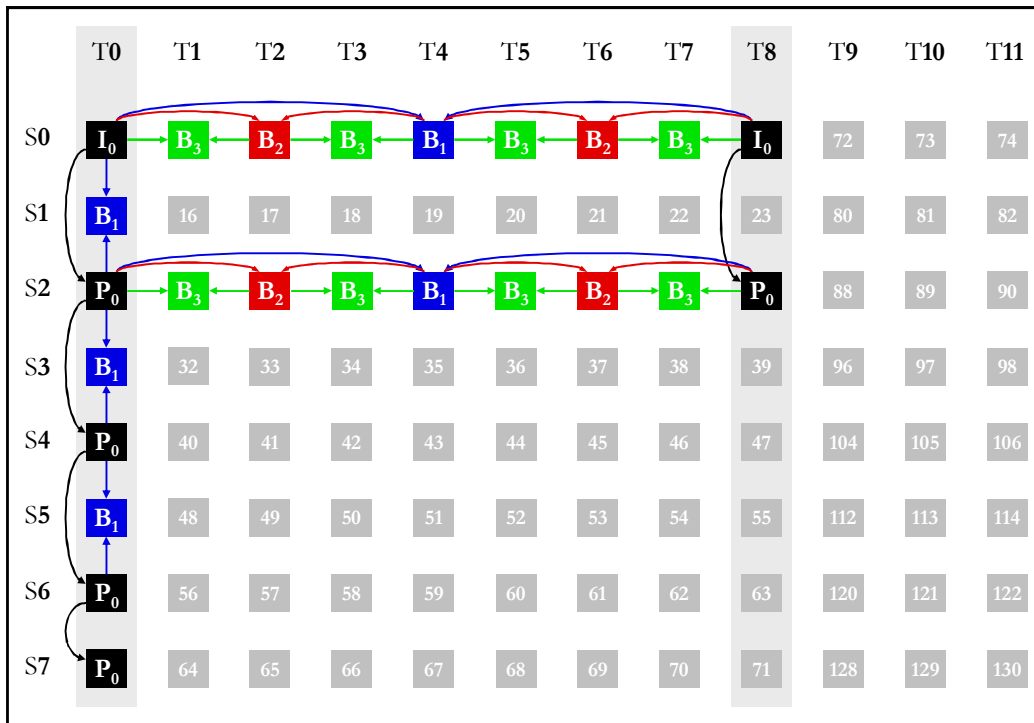
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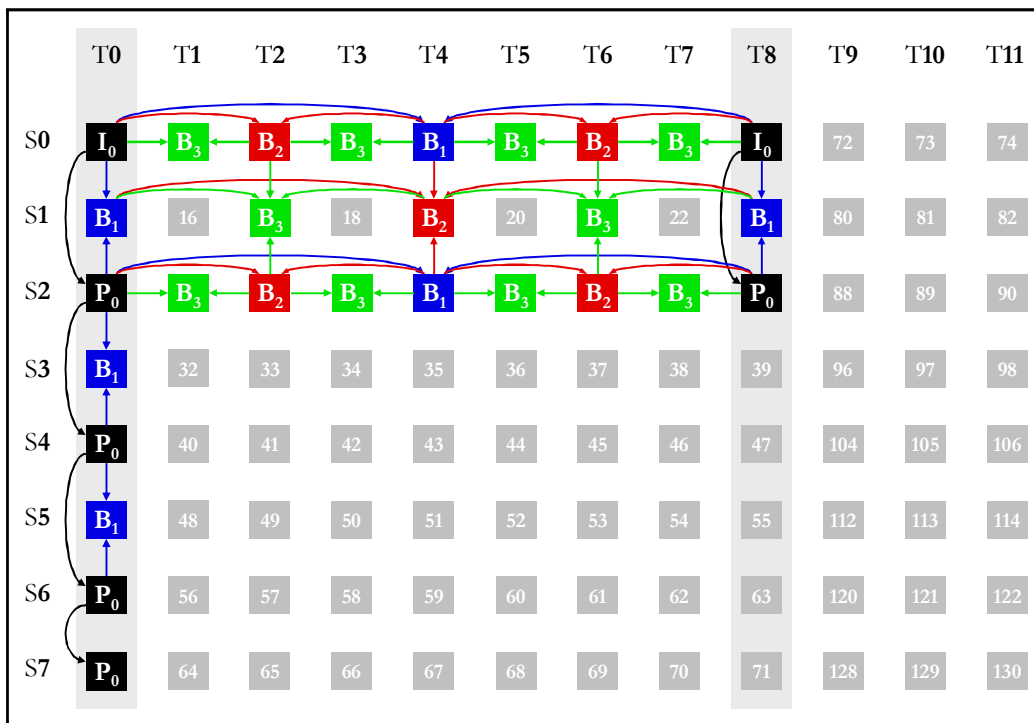
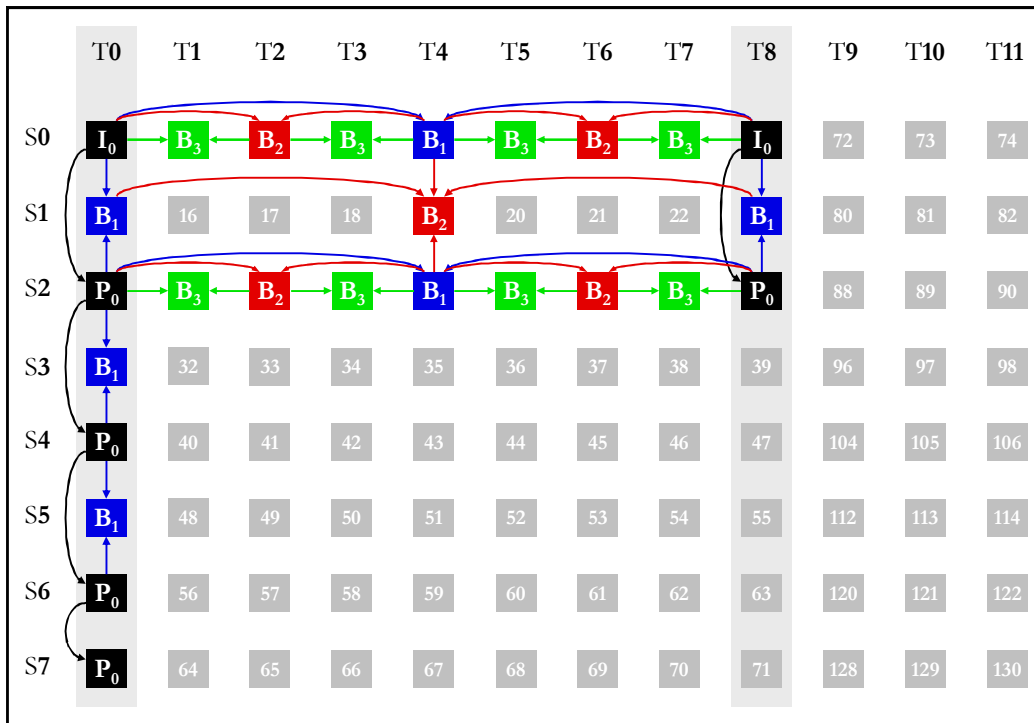
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S5	B₁	48	49	50	51	52	53	54	55	112	113	114
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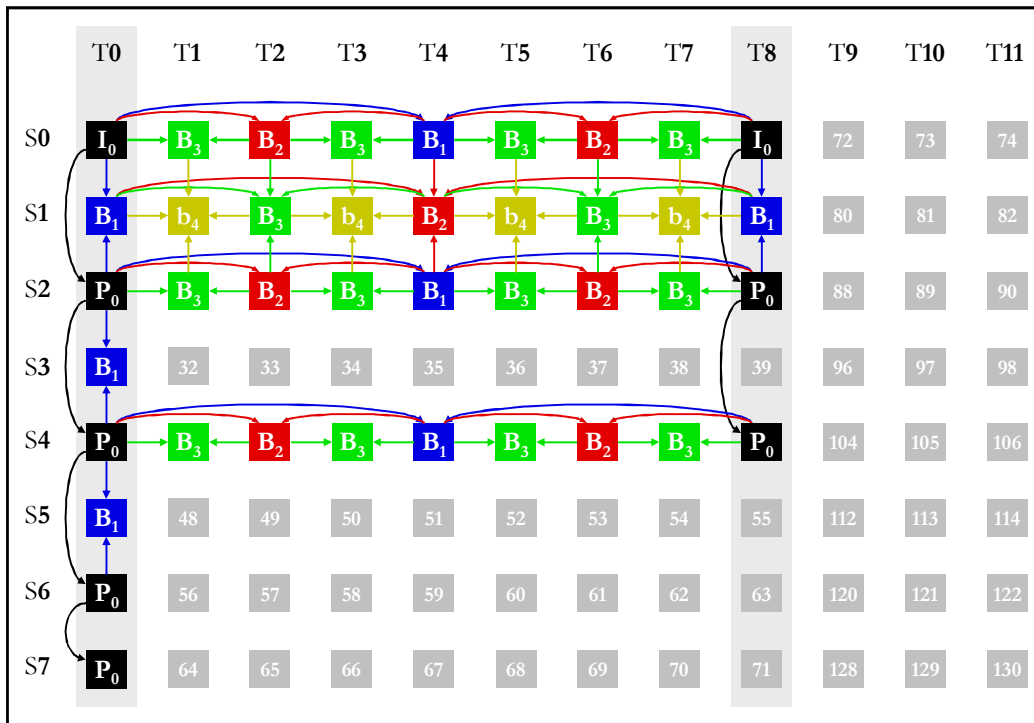
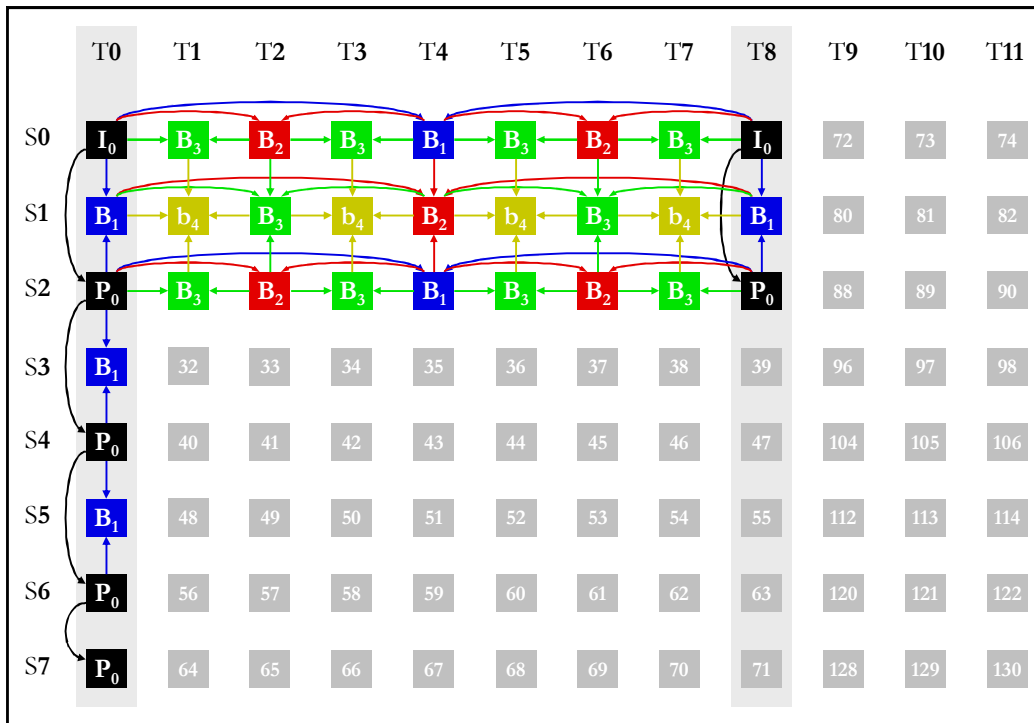
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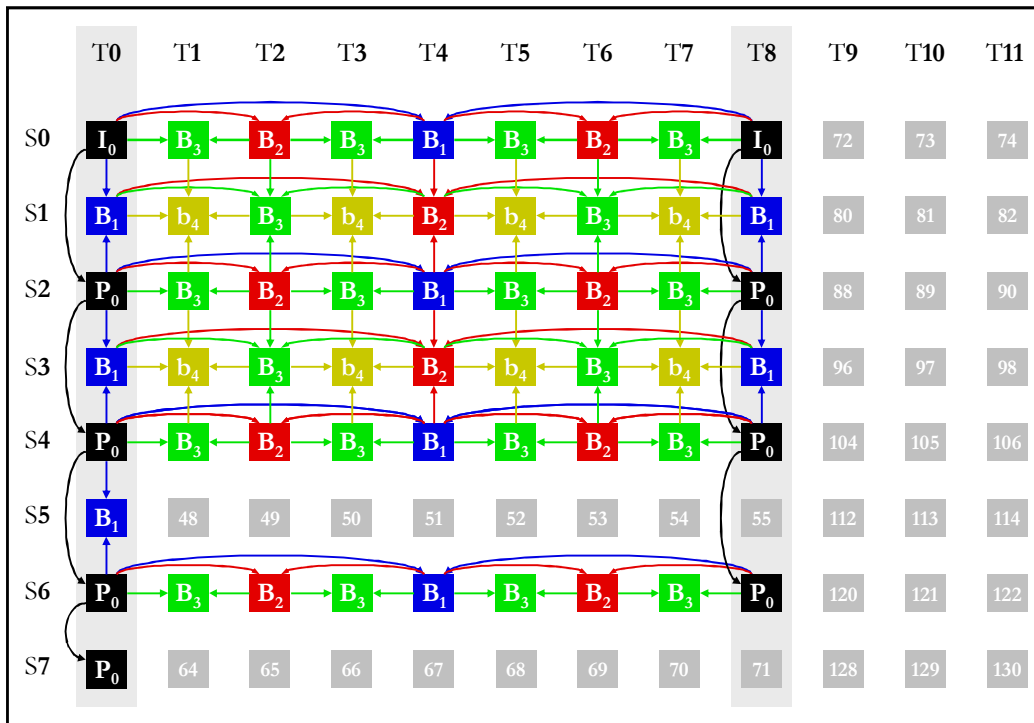
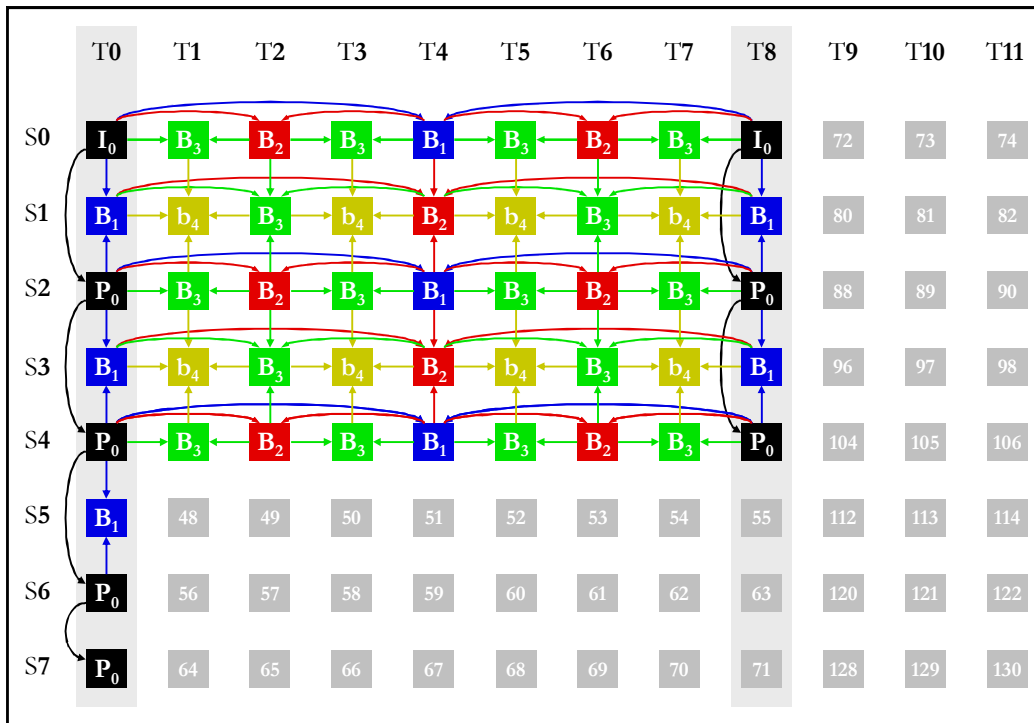


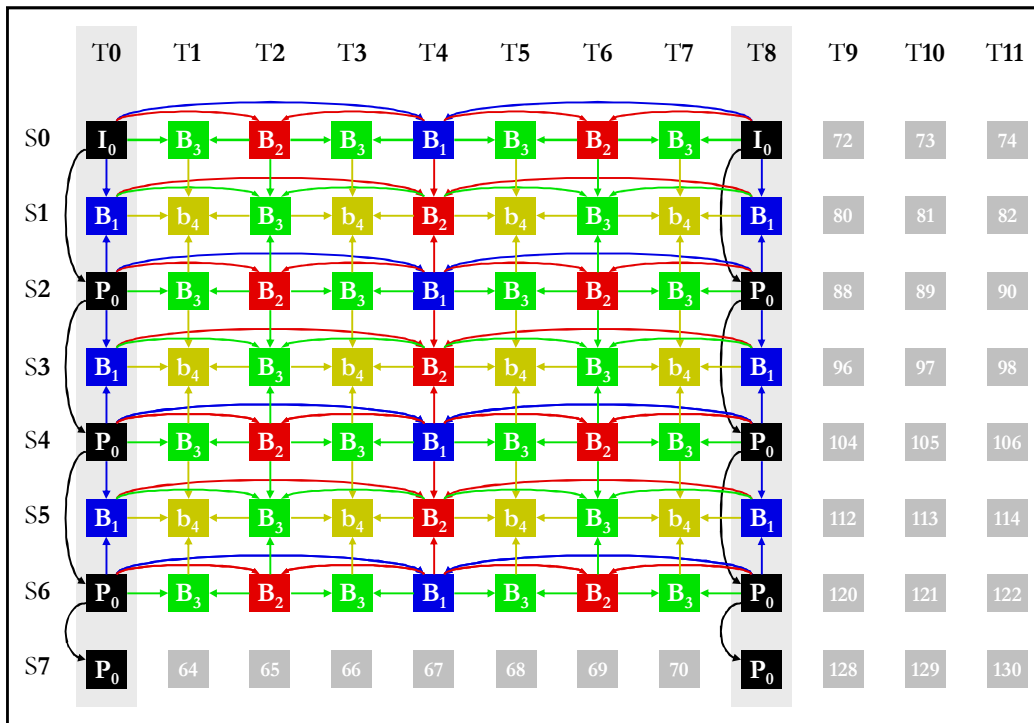
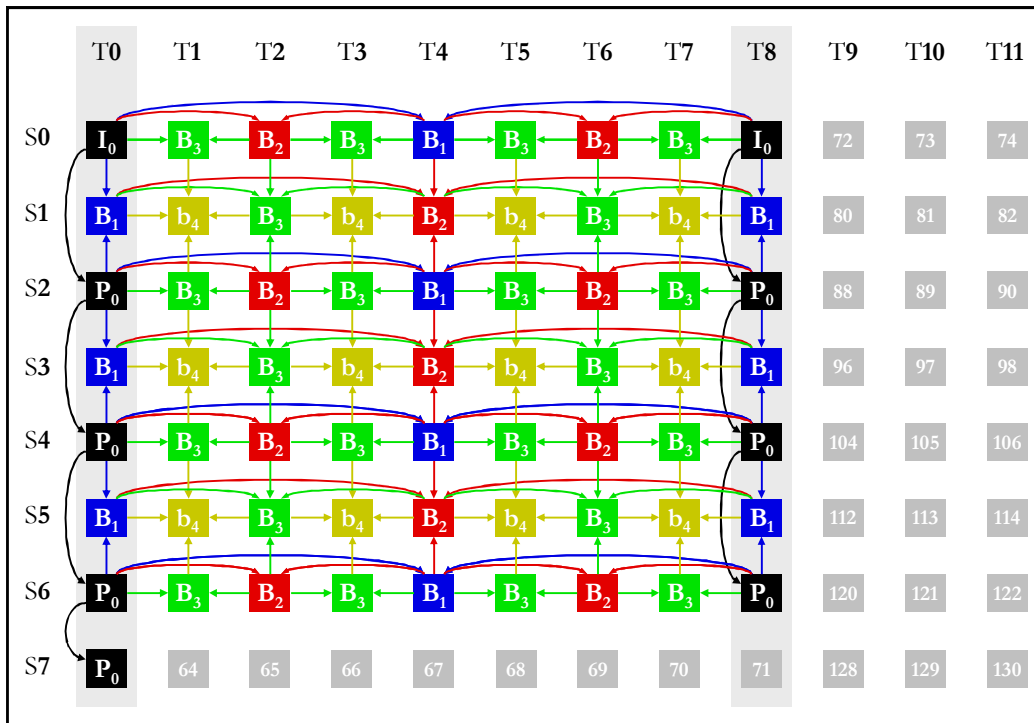


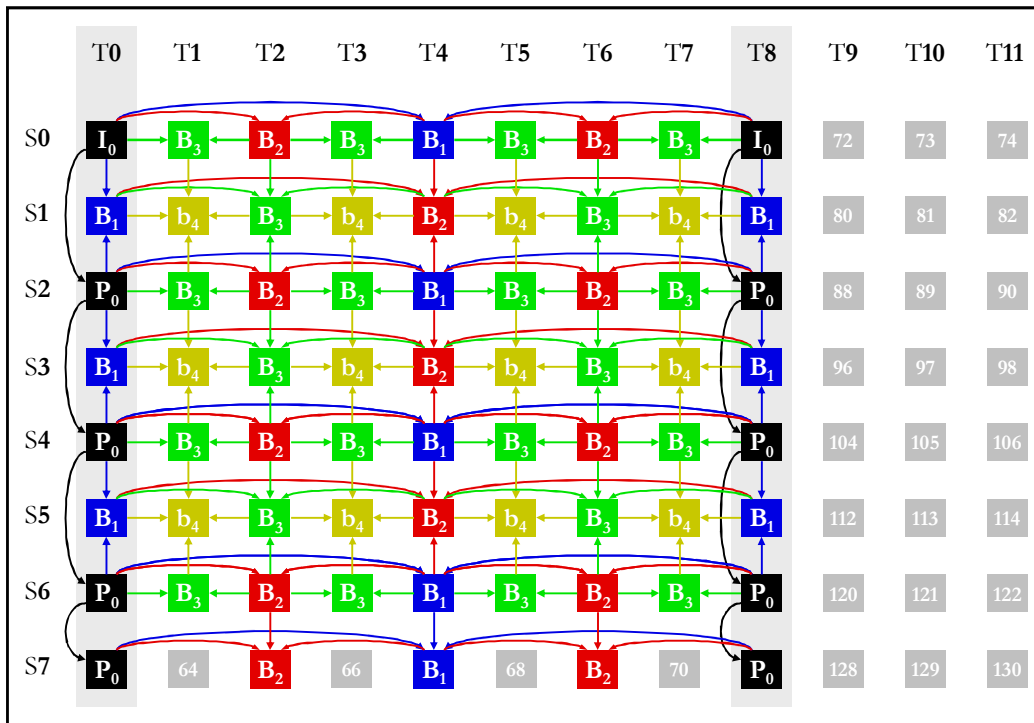
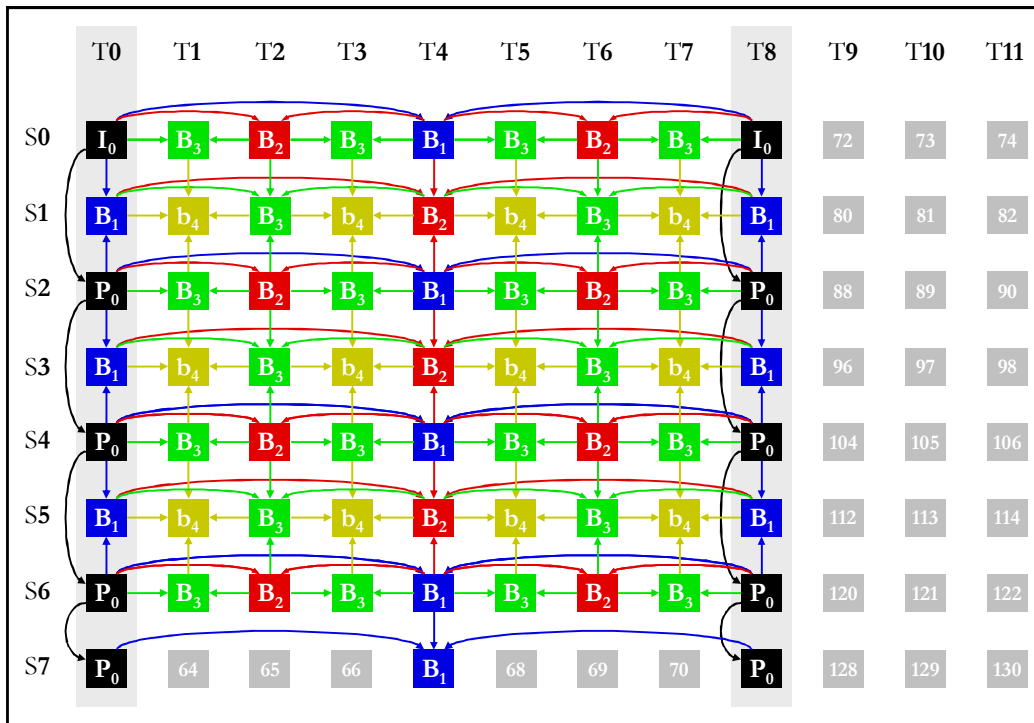


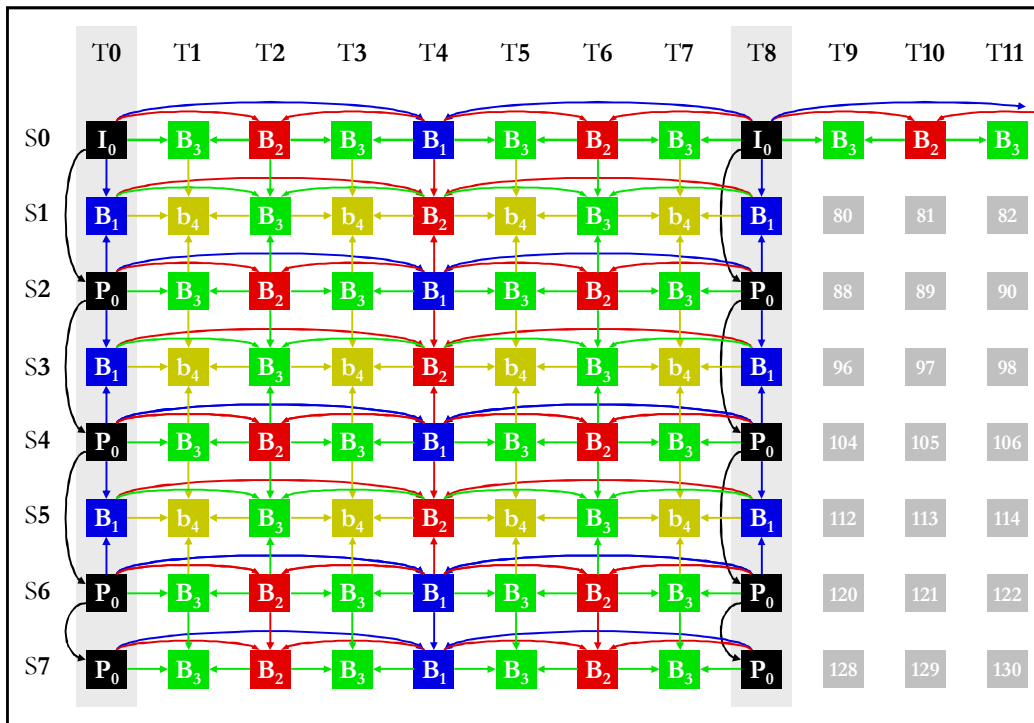
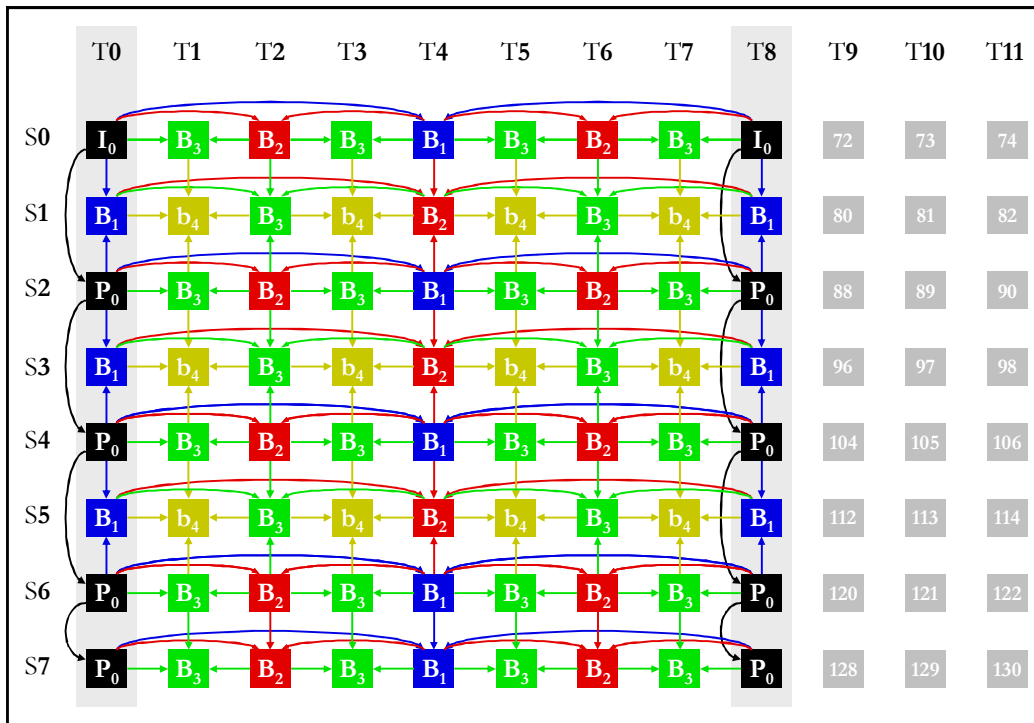


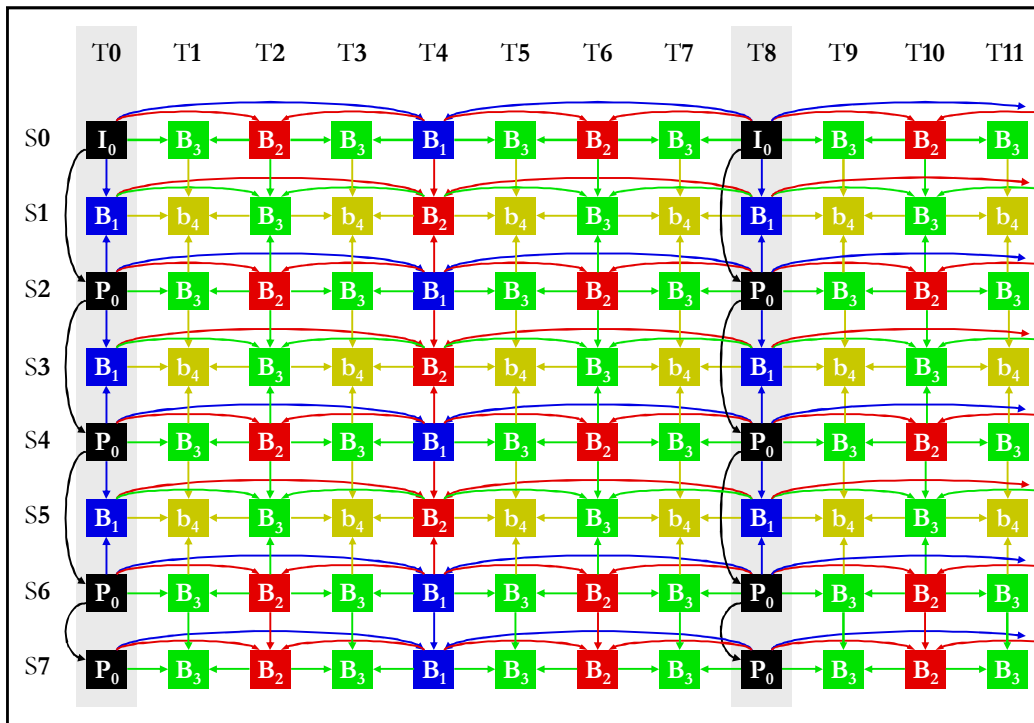
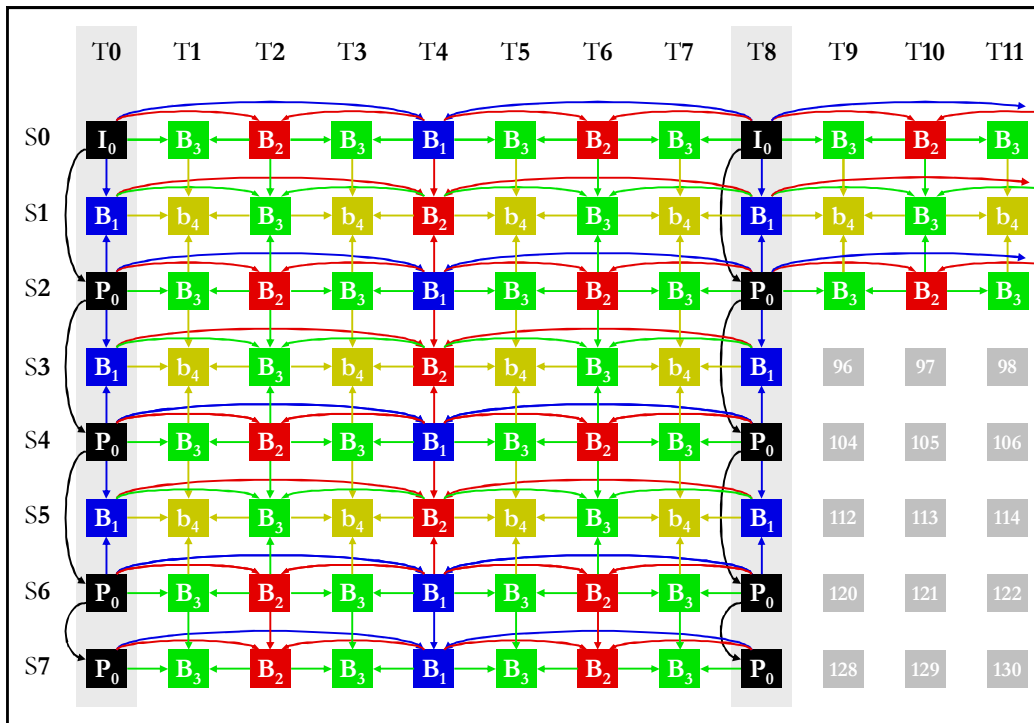




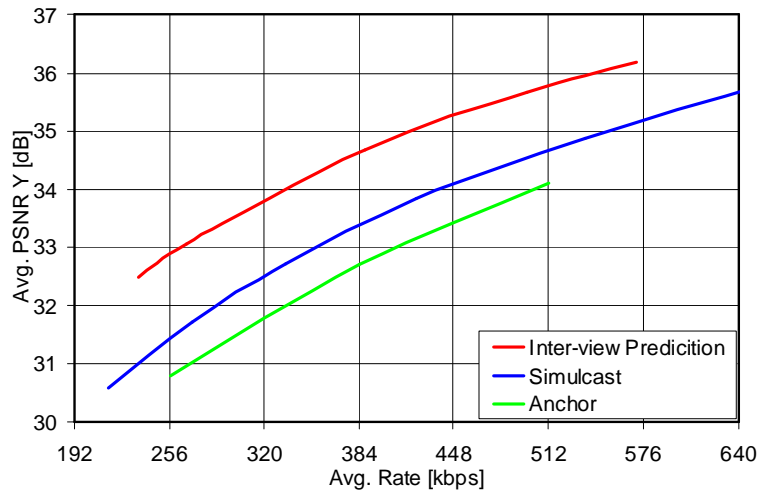








Objective Results Ballroom

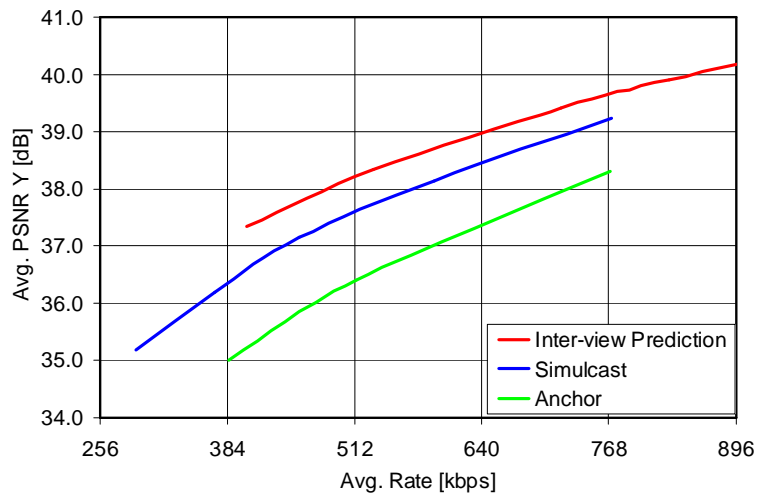


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Objective Results Race1

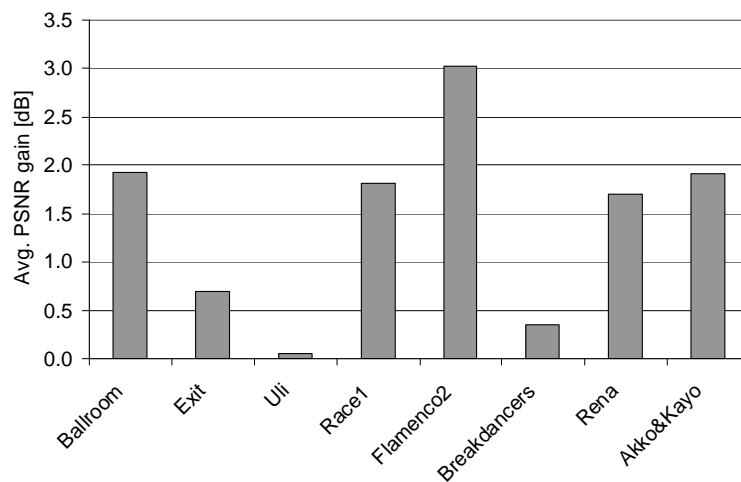


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Summary Objective Results

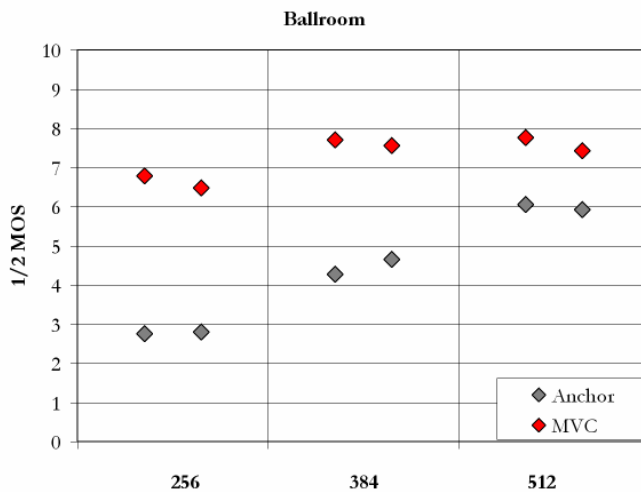


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Subjective Results

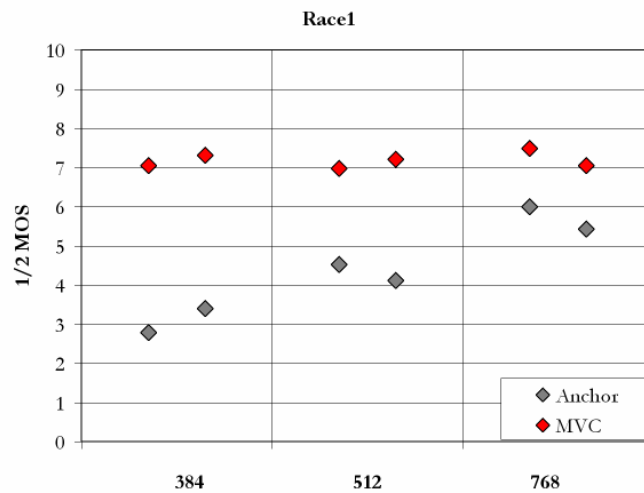


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Subjective Results

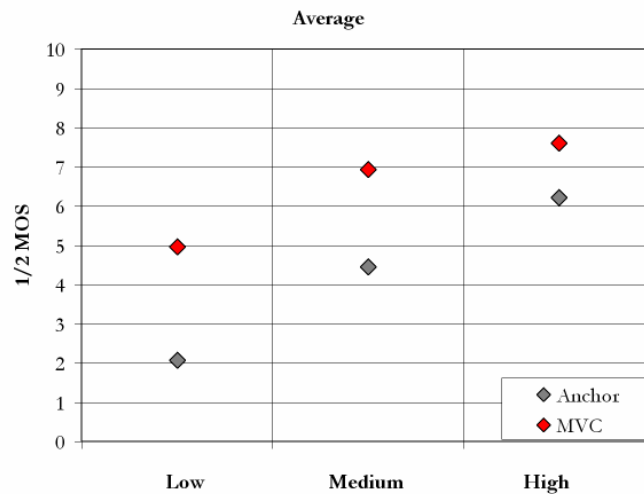


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Subjective Results



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Results

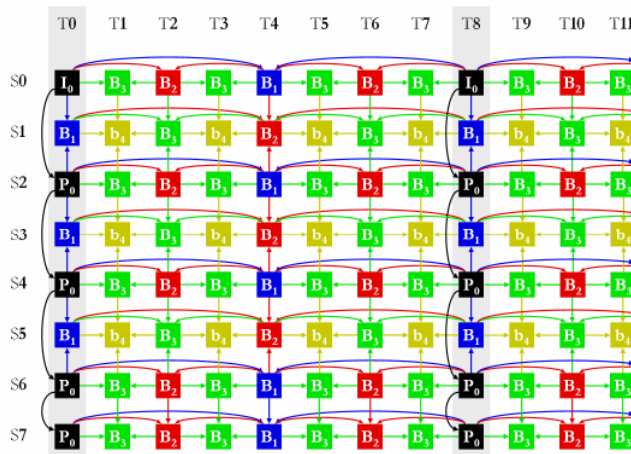
- Fully H.264/MPEG4-AVC compatible bitstream
- Decoder needs to de-interleave the decoded pictures into MV video streams
- Sophisticated temporal+inter-view prediction structures can be implemented based on hierarchical B-picture syntax

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Full MVC Structure

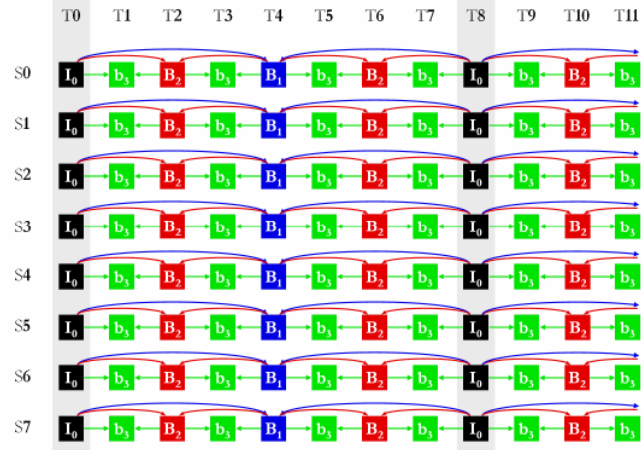


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Simulcast

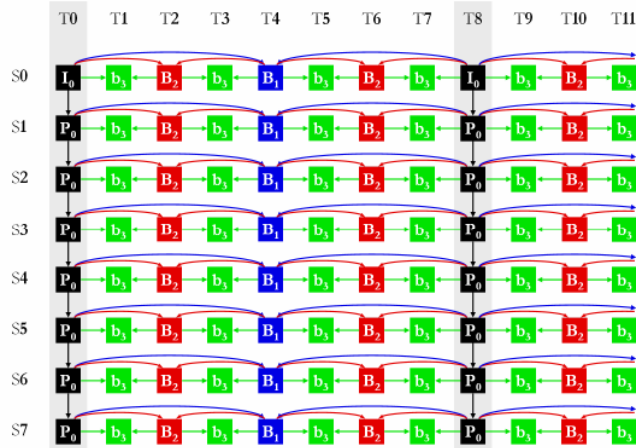


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KS_IPP

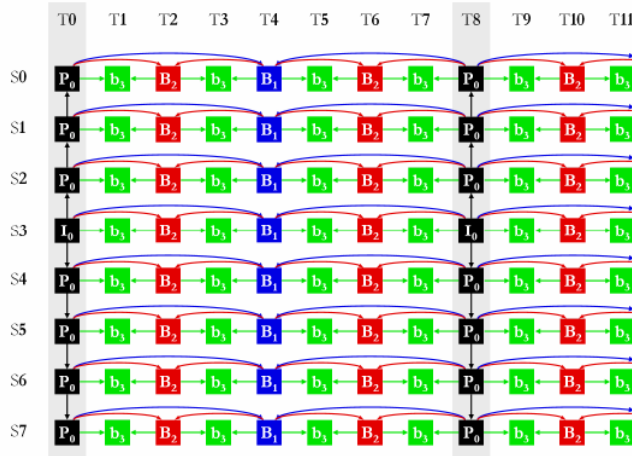


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KS_PIP

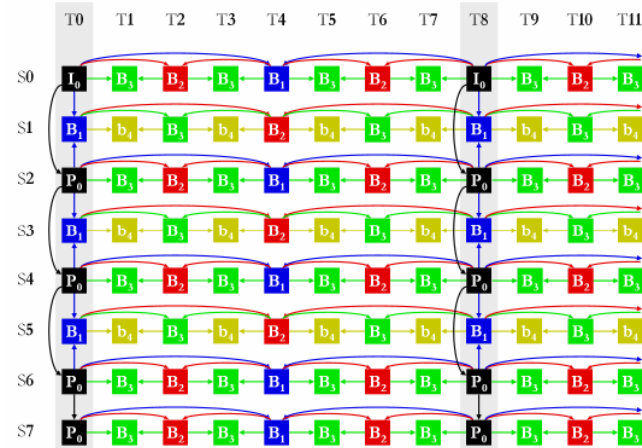


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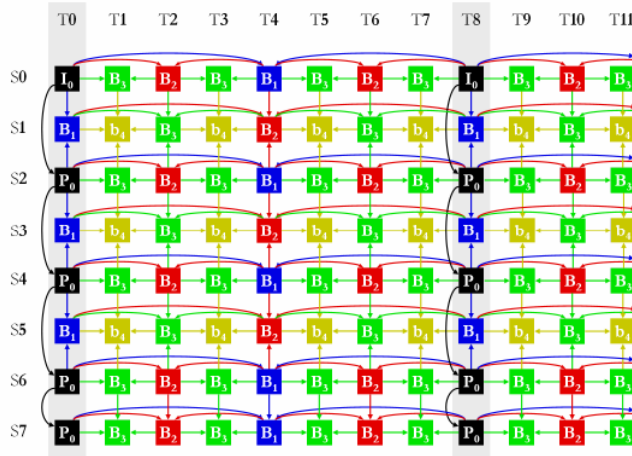


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Full MVC Structure

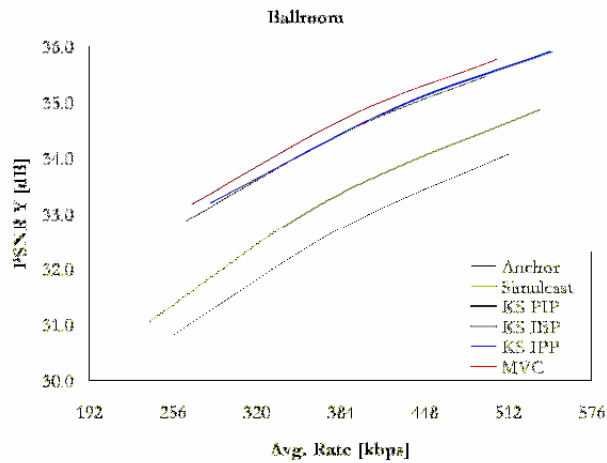


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Compression for 3DTV - with special focus on MPEG standards

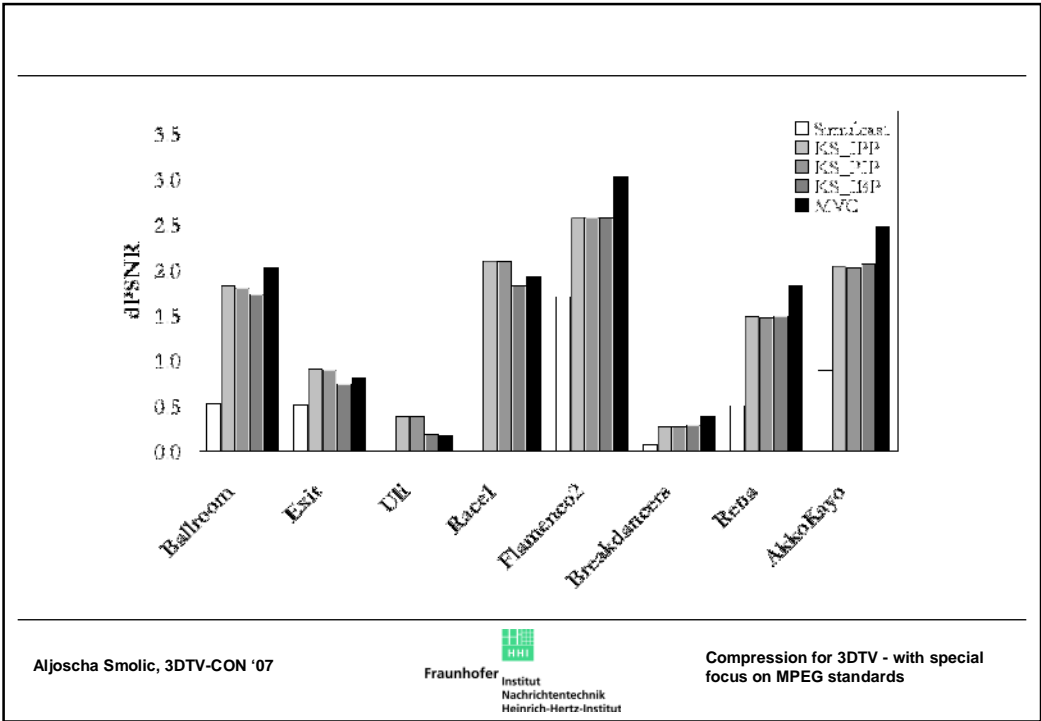
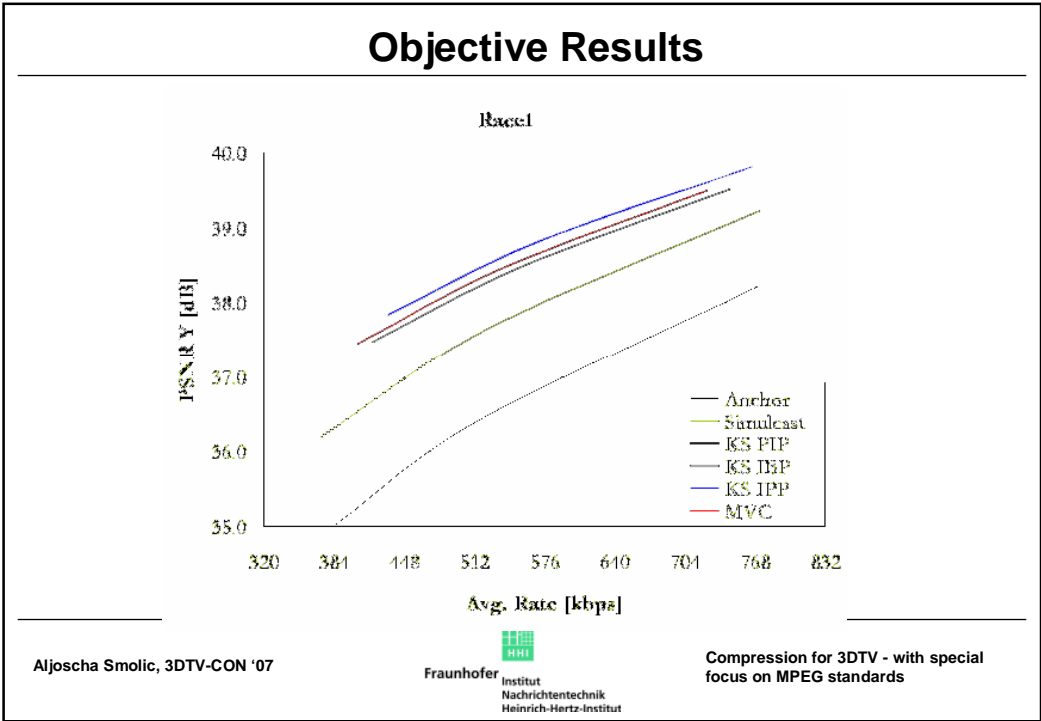
Objective Results



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MVC High-level Syntax

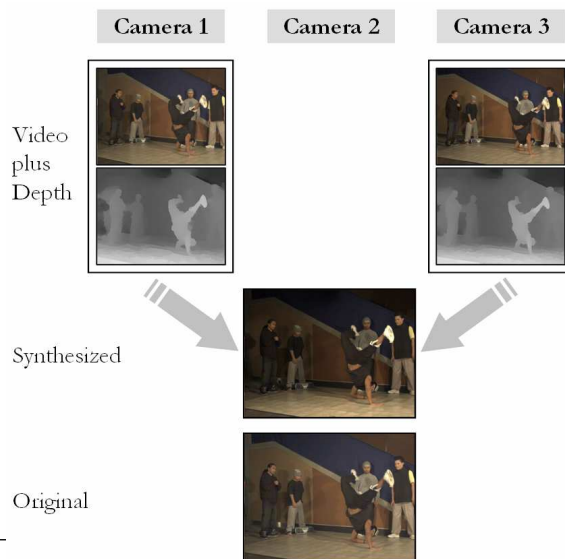
- Improved random access
- Low delay
- Memory optimization

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View Interpolation Prediction



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Illumination Compensation



Adopted for JMVM, technology under consideration

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MVC Core Experiments

Specific tools under investigation in Core Experiments:

- **Disparity vector prediction**
- **Disparity estimation/compensation**
- **Inter-view direct mode**
- **Motion skip mode**
- **Deblocking filter**

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MVC Standard

MPEG-4 Part 10, Amd. 4

- High-level syntax will be included, part of WD
- IC is part of JMVM, under consideration
- Specific tools under investigation in Core Experiments
- Inclusion of signal processing tools requires major redesign of H.264/AVC implementations
- Will only be done if “sum of improvements” exceeds a reasonable threshold (e.g. 30% bitrate saving)

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Overview

- Introduction, terms, market and standards
- 3D scene representation
- Conventional stereo video coding
- Video plus depth coding
- Multi-view video coding (MVC)
- **Multi-view video plus depth (MVD) coding**
- 3D mesh compression
- Summary & Conclusions

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Holografika Wide Range 3D Display

- Up to 45 views are displayed at the same time
- Others: Philips, MERL



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FVV Examples



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FVV Examples



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Requirement

- These systems and applications require an input format that allows
- **rendering a wide range (quasi) continuum of output views**
- at the decoder

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Extension to MVD

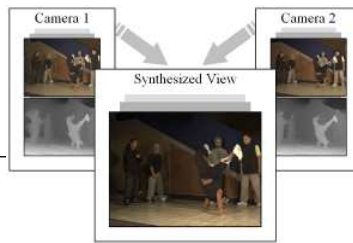
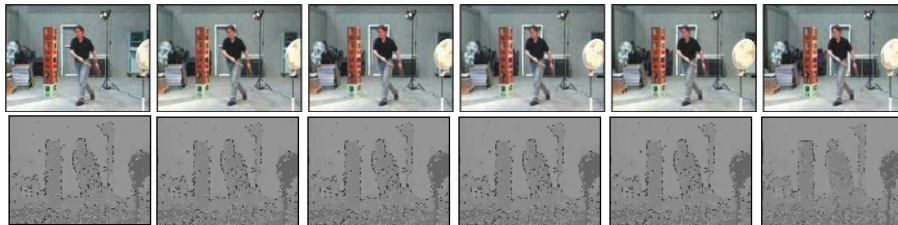
- **MVC**
 - Usage of N views
 - No continuum
 - For large N very inefficient
- **MPEG-C Part 3**
 - Disocclusion artifacts increase with distance of virtual view from available original view
 - Does not support wide range multi-view 3D displays
 - Very limited free viewpoint navigation

We would like to thank the Image Based Realities Group of Microsoft Research for providing the Breakdancers and Ballroom data sets.

ision for 3DTV - with special
MPEG standards

Multi-view Video plus Depth (MVD)

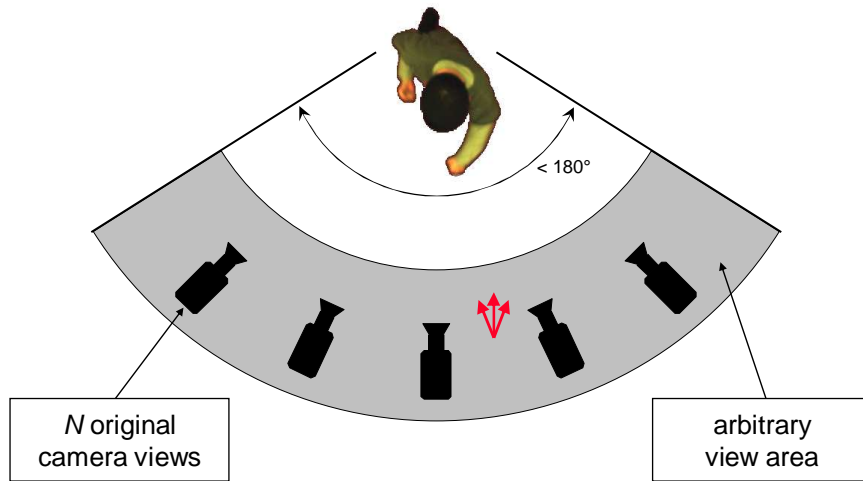
- Usage of N videos with depth information
- Interpolation of virtual intermediate views along all cameras (pair-wise switching)



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Multi-view Video plus Depth (MVD)

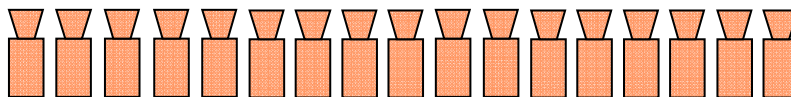


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Example – Synthesis of Motion Parallax



45 Virtual Intermediate Views

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Virtual View Interpolation



Camera 1



Camera 7

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Virtual View Interpolation



Camera 1



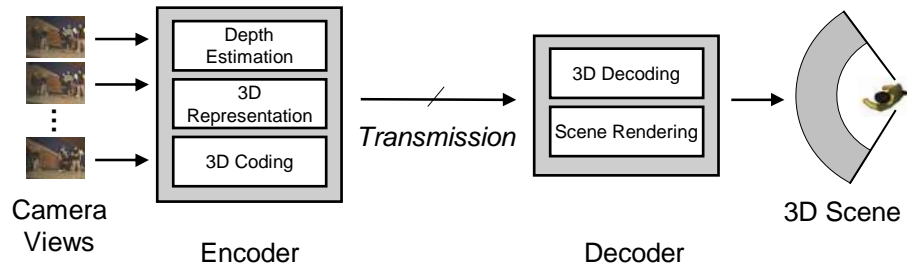
Camera 6

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MVD System Overview

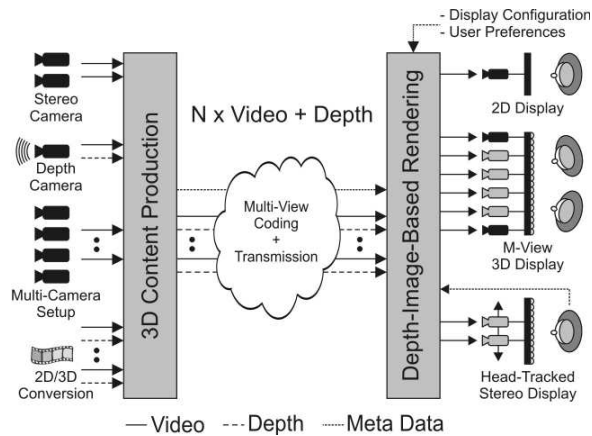


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MVD System Overview

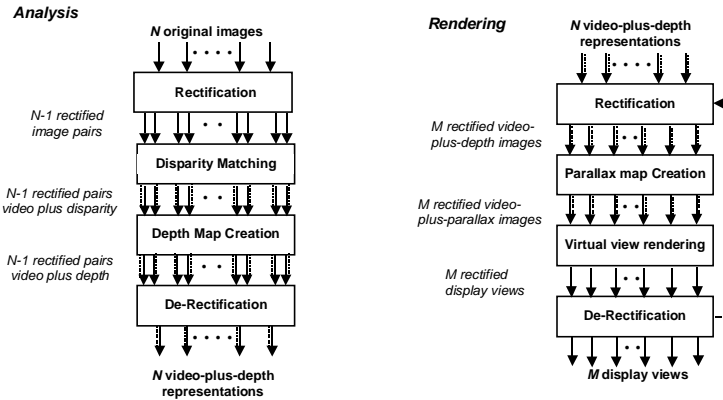


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MVD Signal Processing



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Alternative: LDV

- Layered Depth Video (LDV)
 - One video
 - One associated depth map
 - One background video layer (those parts that are occluded by original pixels)
 - One background depth layer
- May be more efficient (less data)
- May be more difficult to generate (occlusion layers)

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Initiative in JVT

- There are advanced 3D video applications and systems, which are not efficiently supported by standards
- These require a format that allows rendering a wide range (quasi) continuum of output views at the decoder
- MVD is a format that would support this, LDV as alternative
- Can be regarded as extension of MVC, MPEG-C Part 3
- **Proposal: start a study to investigate how MVD can be efficiently supported by standards**

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Work Plan

- **Specification of requirements,**
- **Evaluation of available ISO and ITU standards regarding efficient support of MVD,**
- **Collection and generation of MVD test data,**
- **Specification of test conditions,**
- **Coding experiments, including available standards and new algorithms,**
- **Subjective tests including 3D displays and free viewpoint functionality.**

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Overview

- Introduction, terms, market and standards
- 3D scene representation
- Conventional stereo video coding
- Video plus depth coding
- Multi-view video coding (MVC)
- Multi-view video plus depth (MVD) coding
- **3D mesh compression**
- Summary & Conclusions

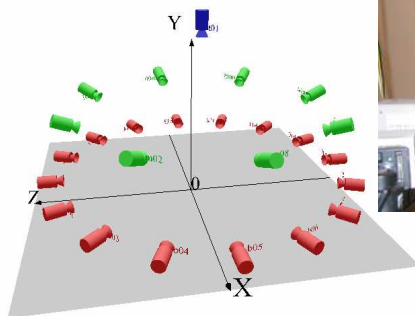
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Free Viewpoint Video

- Capturing a real dynamic scene with **N cameras**
- Transformation into a special **data representation**
- Interpolation of arbitrary **intermediate views**
- Allows **free navigation** within the scene (within practical limits)

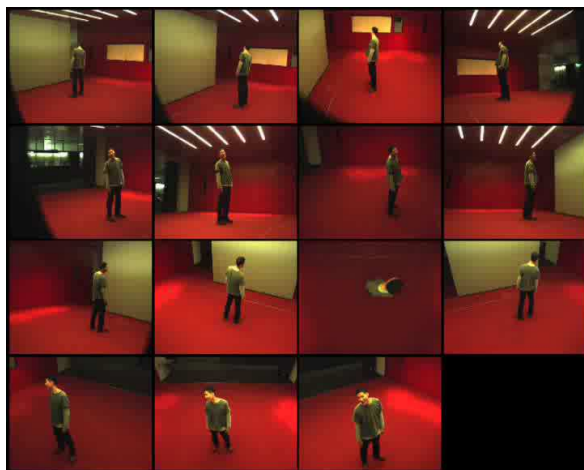


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FVV Acquisition



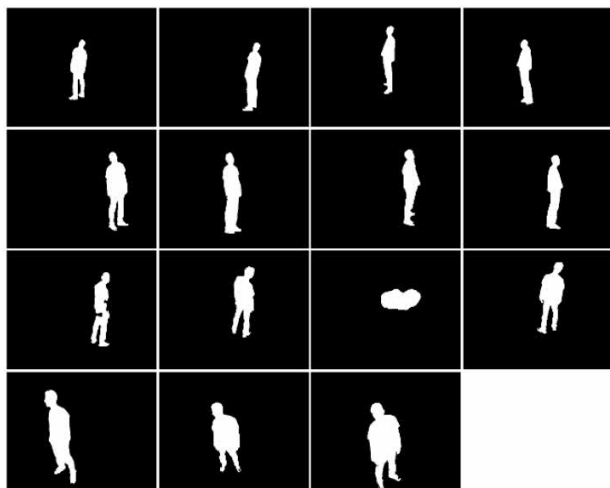
▪ Courtesy of:
Stephan Wuermlin
et al.,
ETH Zuerich,
Switzerland

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FVV Segmentation



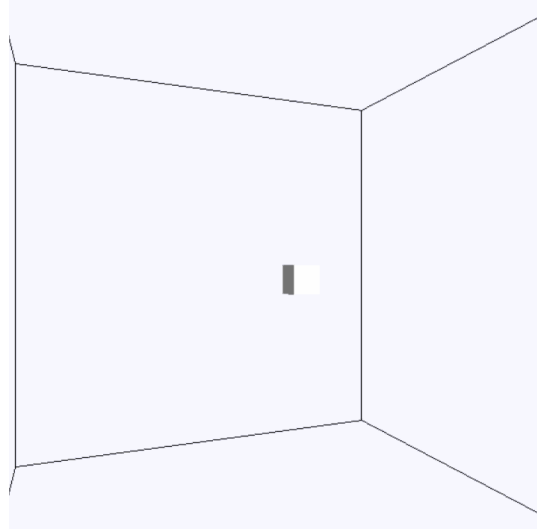
▪ Courtesy of:
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3D Model Reconstruction and Rendering



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Object Reconstruction

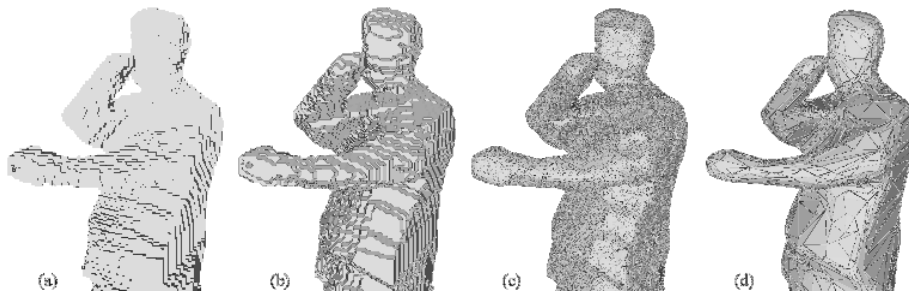
Shape-from-Silhouette-Approach

- a) Hierarchical Voxel Modeling
- b) Marching-Cubes-Approach
- c) Surface Smoothing
- d) Mesh Reduction

T. Lewiner *et al.*: Efficient Implementation of Marching Cubes Cases with Topological Guarantee*, Journal of Graphics Tools, Vol. 8, pp. 1-15, 2003.

G. Taubin: Curve and Surface Smoothing Without Shrinkage, Proc. IEEE International Conference on Computer Vision (ICCV 95), 1995.

H. Hoppe, Efficient Implementation of Progressive Meshes, Computers & Graphics, Vol. 22, No. 2, pp. 27-36, 1998 / Tool in DirectX

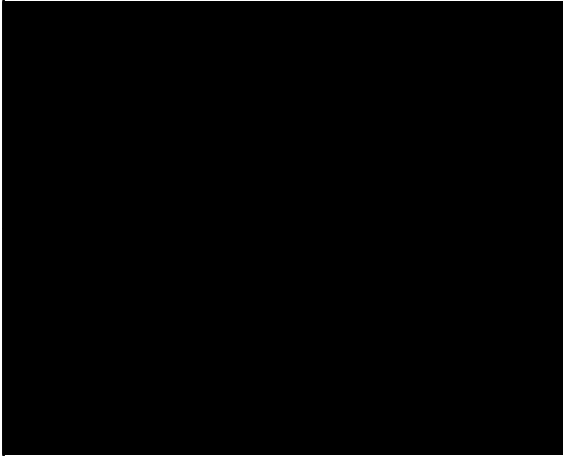


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Free Viewpoint Video



- **Same functionality as CG objects**
 - free navigation, can be viewed from any viewpoint/direction
 - Integration into complete scenes (virtual/augmented/real)
- **But:** depict appearance, motion, deformation of **real world objects**

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Integrated Scene with FVV

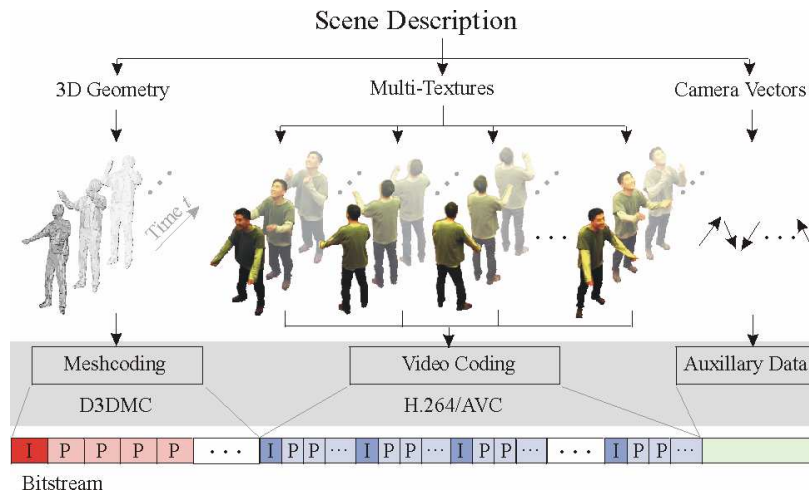


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MPEG-4 Representation



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MPEG-4 Representation

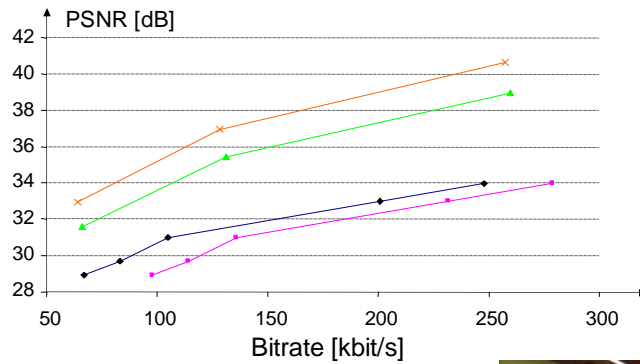
- Geometry: 3D mesh
- Textures (video streams): H.264/AVC
- Rendering: view-dependent texture mapping
- Supported by MPEG-4 due to recent extension of AFX developed by Fraunhofer HHI

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Coding Results for Textures



- MPEG-4 (Part 2) Core Profile with object shape
- MPEG-4 (Part 2) Core Profile without shape
- H.264/AVC High Profile
- H.264/AVC High Profile with pre-processing

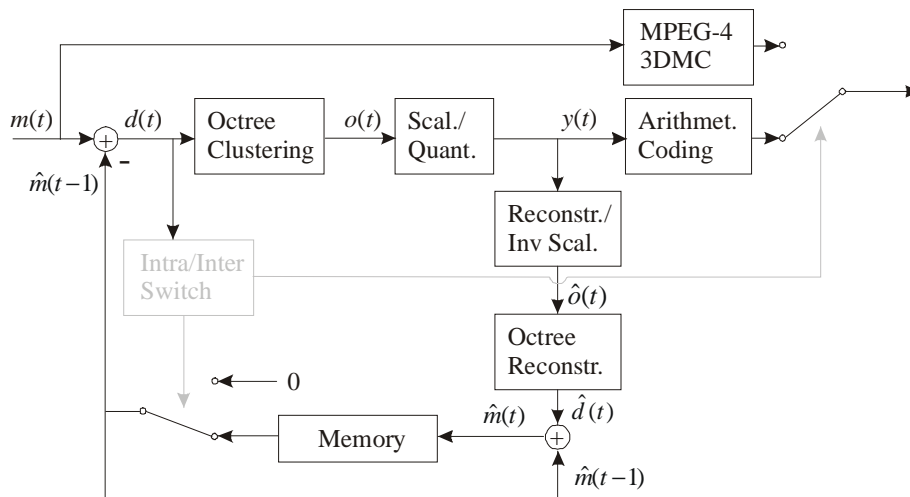


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D3DMC



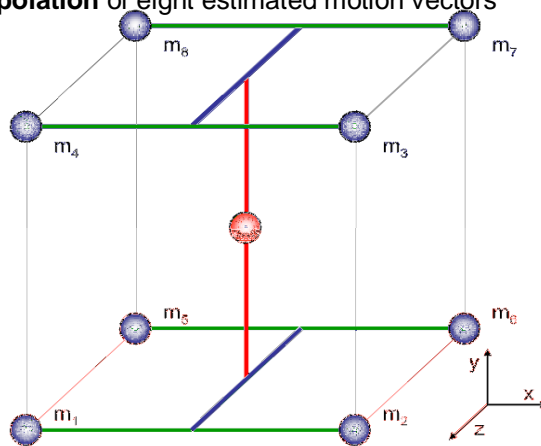
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Differential 3D Mesh Coding (D3DMC)

- Tri-linear interpolation of eight estimated motion vectors



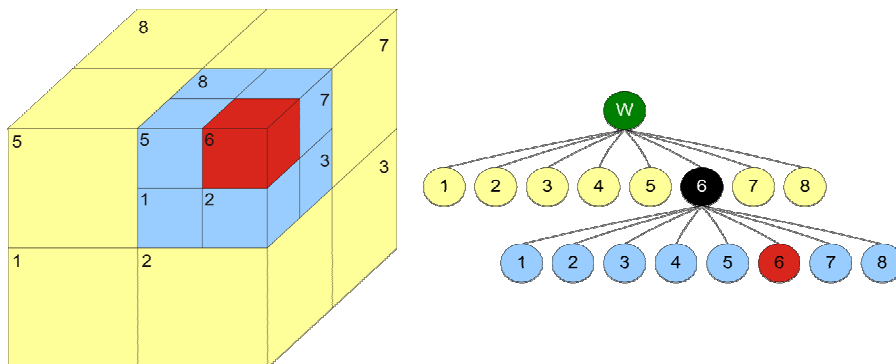
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Differential 3D Mesh Coding (D3DMC)

- Subdivision of space and resulting octree structure



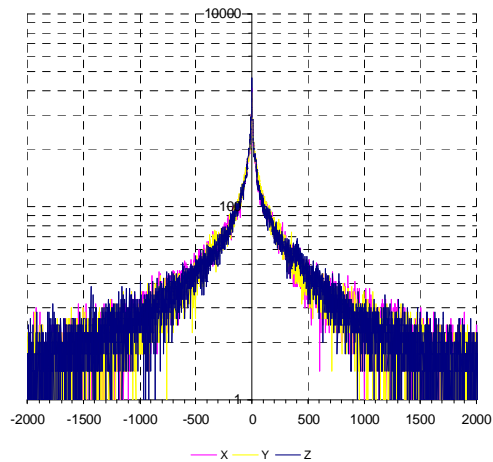
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Arithmetic Coding

- **Linear Quantization** of the estimated motion vectors
- **Entropy coding** of the discrete estimated motion vectors. Usage of the well-known Context-Based Adaptive Binary Arithmetic Coding (CABAC) framework of H.264/AVC



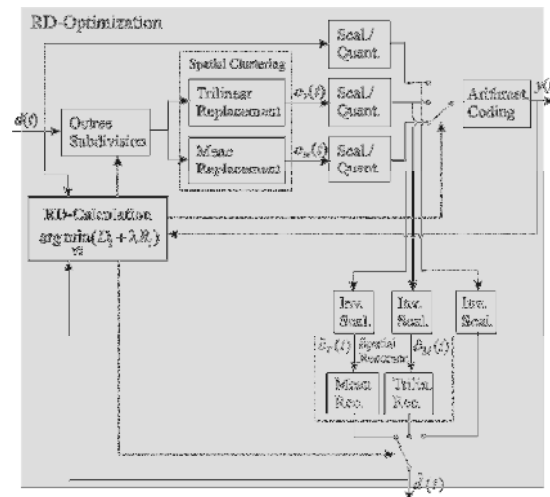
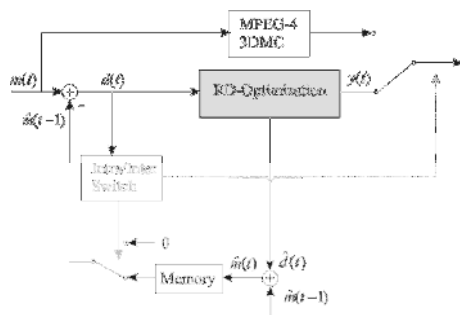
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RD-optimized D3DMC

- **Block diagram of the encoder**



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Evaluation

- **Humanoid sequence** provided by Vrije Universiteit Brussel (VUB) consisting of 117 keyframes in different resolutions



498 vertices



1940 vertices



7646 vertices

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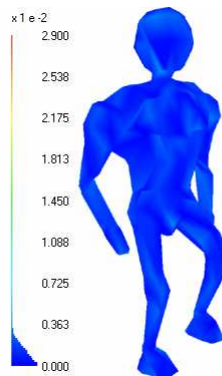


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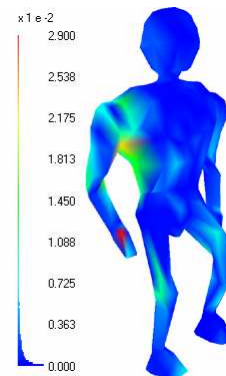
Evaluation – Humanoid, 498 vertices



Original



AFX-IC
22,7 kbit/s



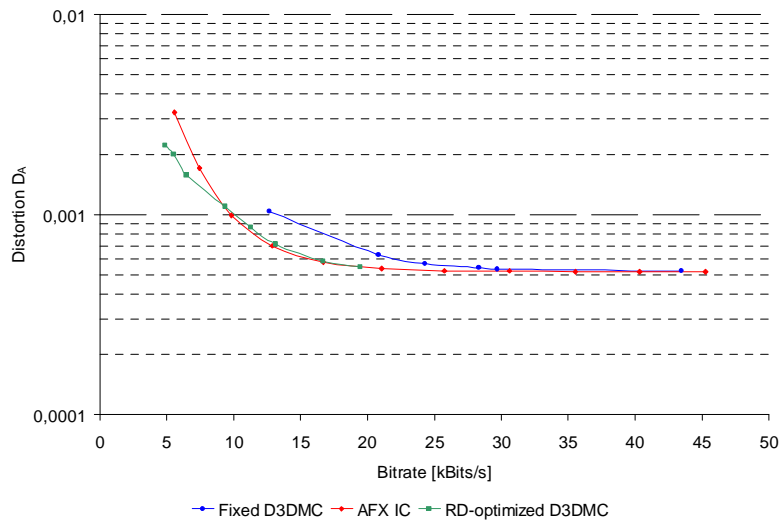
D3DMC
23,0 kBit/s

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Evaluation – Humanoid, 498 vertices

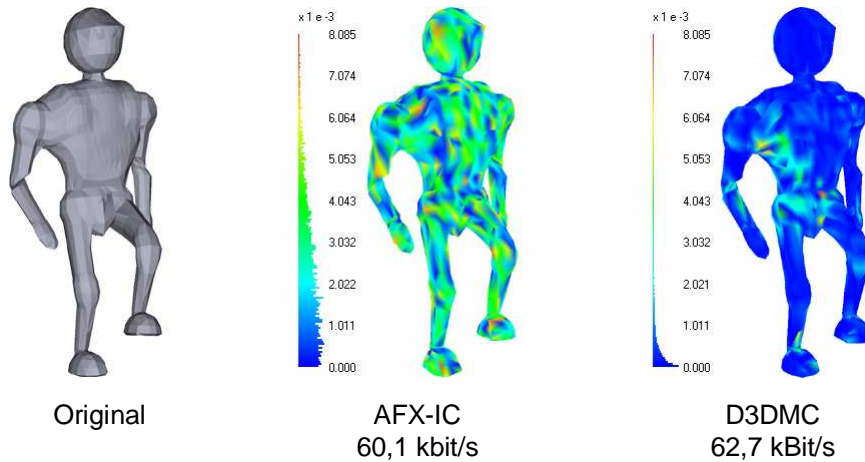


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Evaluation – Humanoid, 1940 vertices

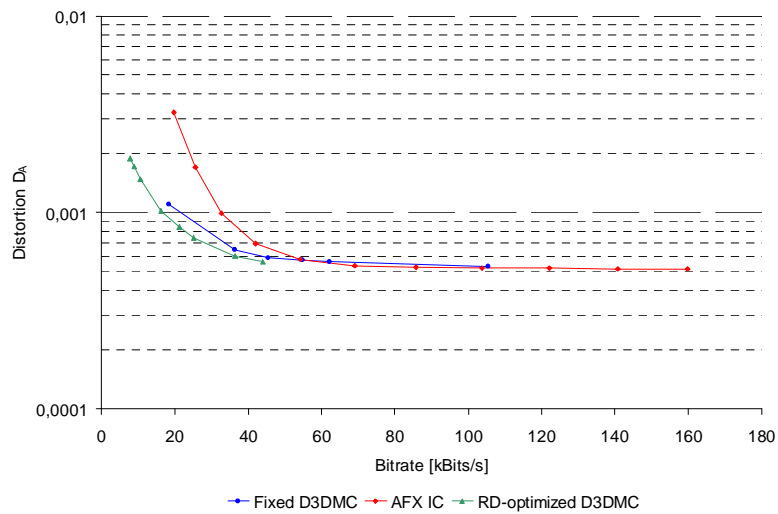


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Evaluation – Humanoid, 1940 vertices

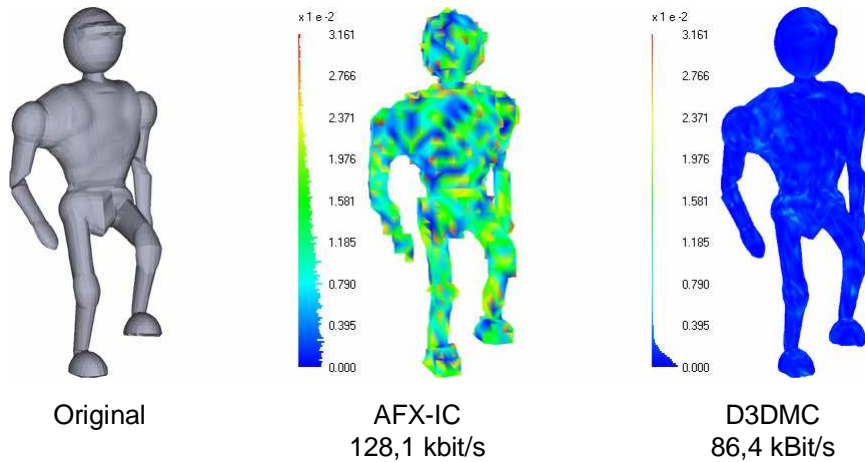


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Evaluation – Humanoid, 7646 vertices

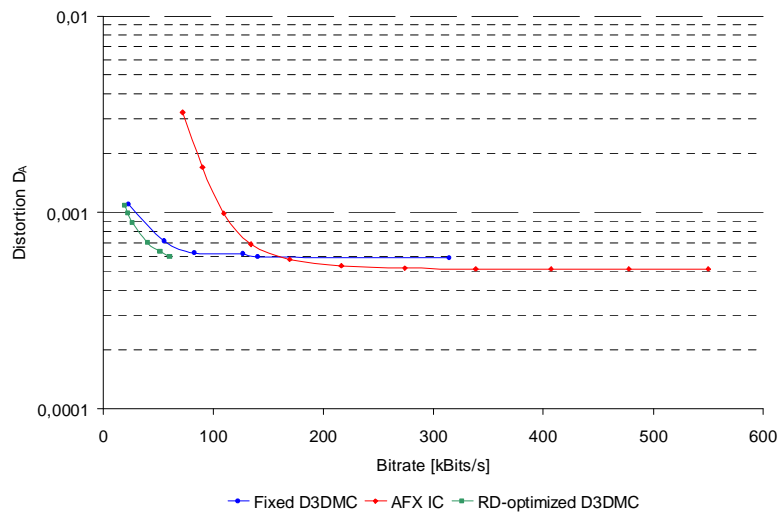


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Evaluation – Humanoid, 7646 vertices



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Evaluation – Chicken, 3030 vertices



AFX-IC at 109 kbit/s

D3DMC at 108 kbit/s

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Improvements

- Skinning: INT, France
- Scalable: University of Hannover, Stefanoski, Ostermann
- New standard for dynamic mesh compression under development in MPEG

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Message

- FVV and 3DV are new functionalities that expand the user's sensation beyond classical 2D video
- Both can be combined
- Technology is available and being optimized
- Standards are available and being developed
- There is the potential for huge new markets
- => **THIS IS READY FOR TAKE OFF**

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What needs to be done?

- Optimization of algorithms and processes (esp. with regard to error prone vision tasks as segmentation, depth estimation, etc.)
- Finalization of standards and addition of missing components (e.g. efficient format for MVD, LDV)
- Development of convincing applications and systems
- **MARKETING**

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Credits

- Besides credits on individual slides this presentation is based on work in the Image Processing and Interactive Media Departments @ Fraunhofer HHI:

Nicole Atzpadin

Peter Eisert

Peter Kauff

Philipp Merkle

Markus Müller

Jürgen Rurainsky

Oliver Schreer

Ralf Tanger

Eddy Cooke

Christoph Fehn

Matthias Kautzner

Karsten Müller

Sabine Lukaschik

Ralf Schäfer

Klaas Schüür

Thomas Wiegand

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Literature

- A. Smolic, P. Merkle, K. Muller, C. Fehn, P. Kauff, and T. Wiegand:
Compression of multi-view video and associated data.
In press in "Three-Dimensional Television: Capture, Transmission, and Display." Editors: Haldun M. Ozaktas and Levent Onural, Springer, Heidelberg, 2007.
- A. Smolic, R. Sondershaus, N. Stefanoski, L. Vasa, K. Mueller, J. Ostermann, and T. Wiegand:
A survey on coding of static and dynamic 3D meshes,
In press in "Three-Dimensional Television: Capture, Transmission, and Display." Editors: Haldun M. Ozaktas and Levent Onural, Springer, Heidelberg, 2007.

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Thank you!

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