A FULL-COLOR SINGLE-CHIP-DLP PROJECTOR WITH AN EMBEDDED 2400-FPS HOMOGRAPHY WARPING ENGINE

Shingo Kagami, Koichi Hashimoto

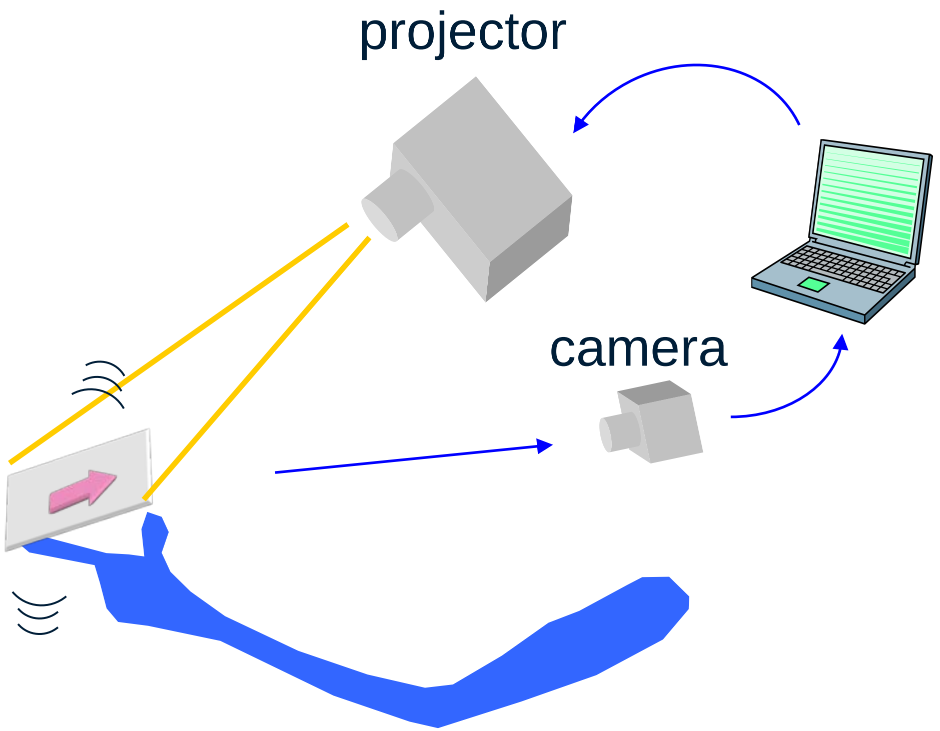
Tohoku University

Photography & Recording Encouraged

MOTIVATION

Make every surface around you a display

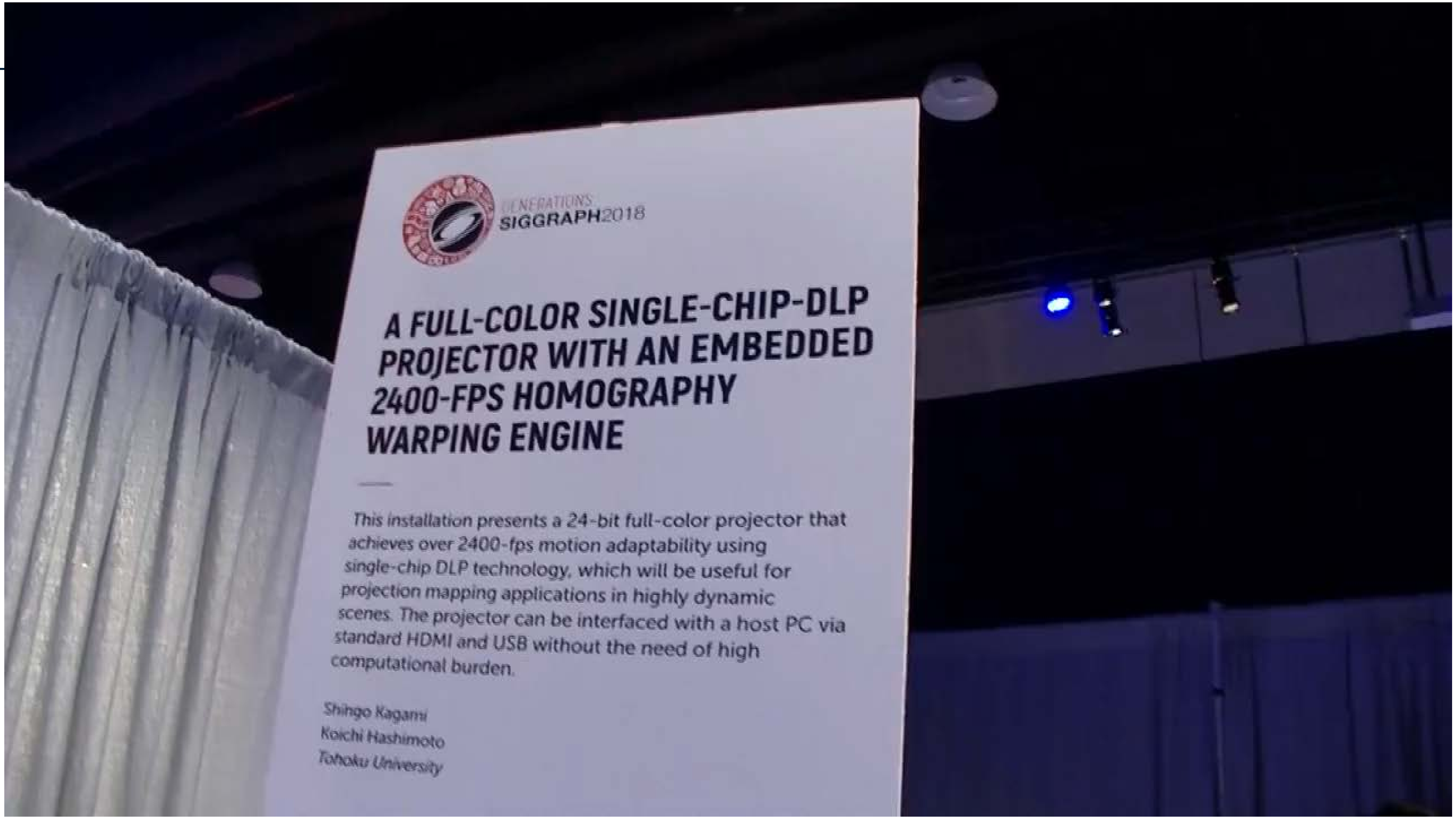
- augmented-reality user interfaces
- media art installations
- stabilized projection by handheld projectors



Key Challenge:

- How to achieve low latency

SEE OUR E-TECH BOOTH

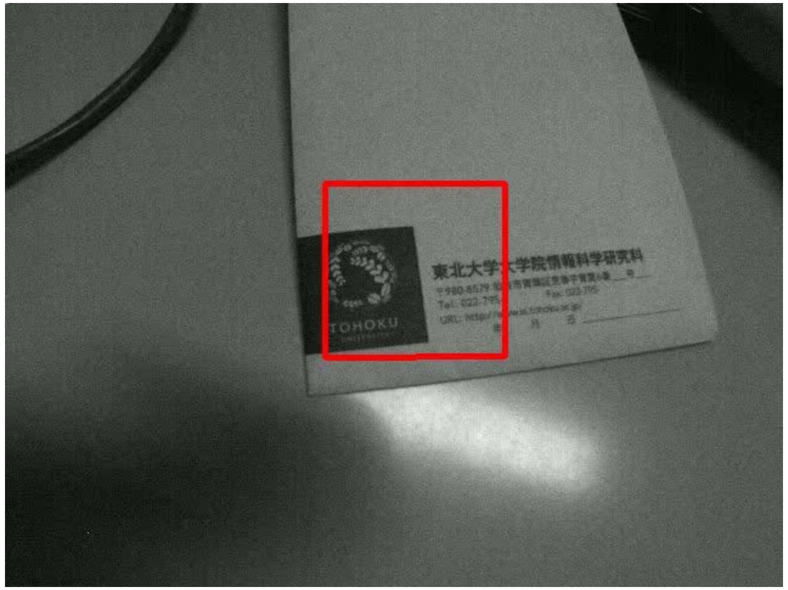


OUTLINE

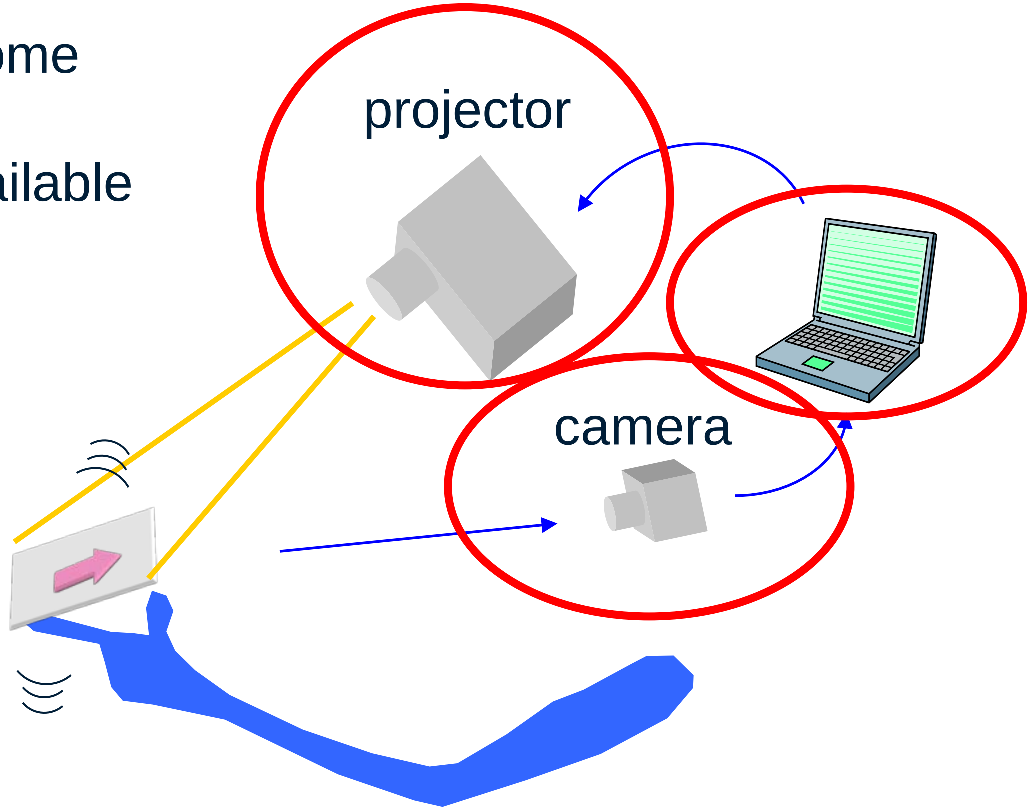
- Motivation
- Low-Latency Vision and Projection
- Our Approach for Low-Latency Projection
- Hardware Implementation
- Color Representation
- Results

LOW-LATENCY VISION AND PROJECTION

- High-speed real-time-streaming cameras have already become commodity
- Lightweight fast visual processing algorithms are readily available



[Kagami+, SII2016]

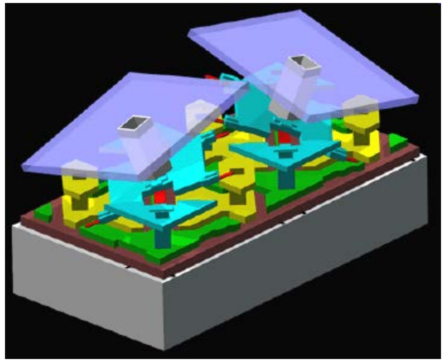


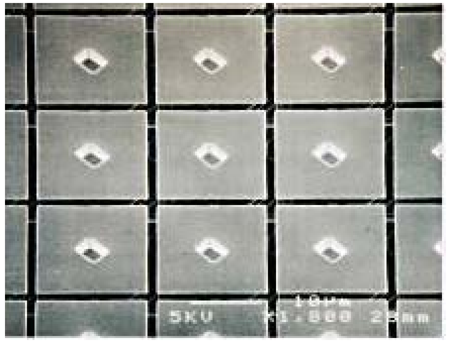
- Then, what about projection?

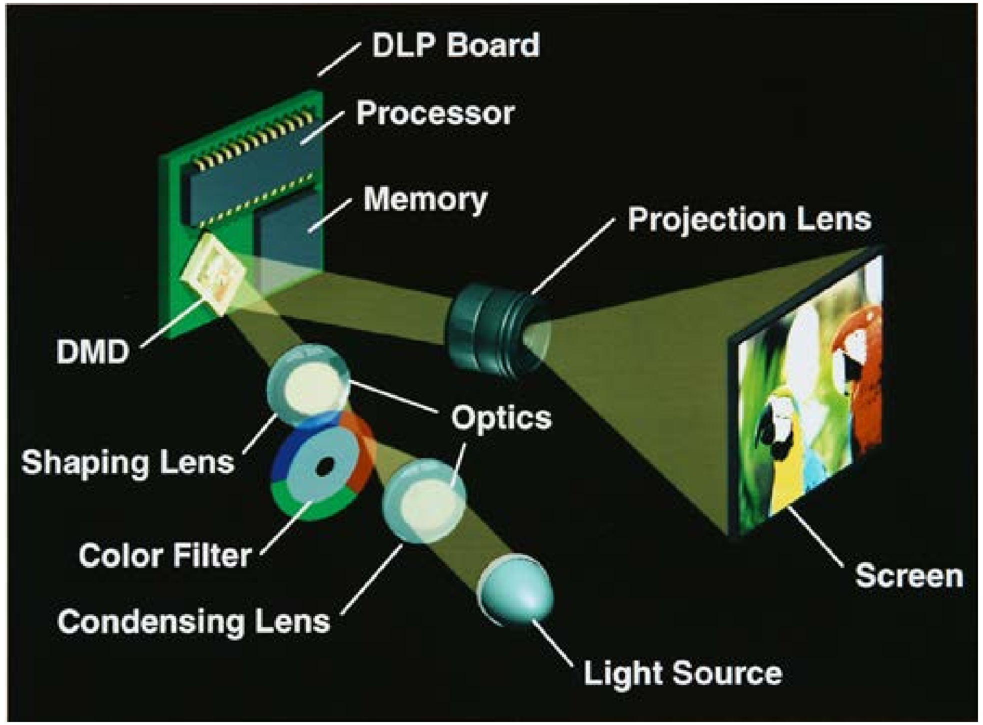
DLP PROJECTORS

Digital Micromirror Devices (DMD)

- switches at up to tens of thousands of fps
- binary pattern is displayed at a time instant

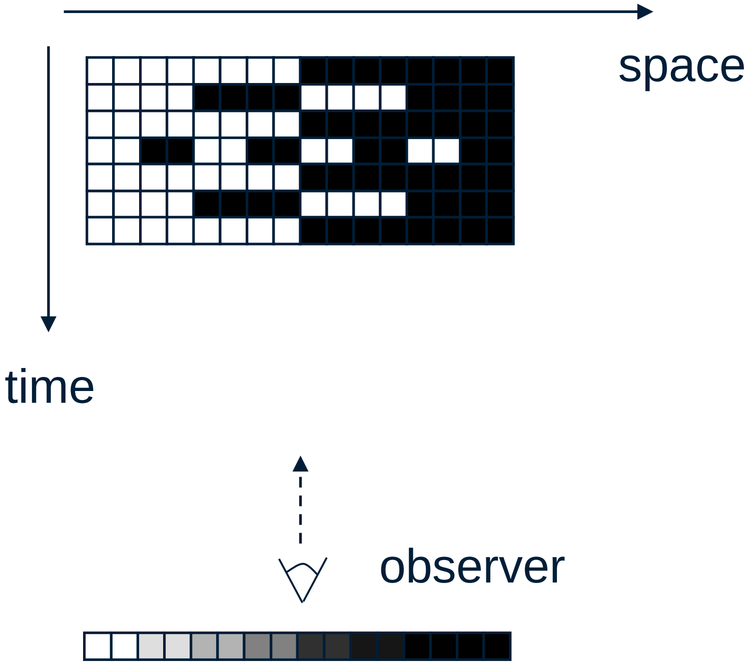


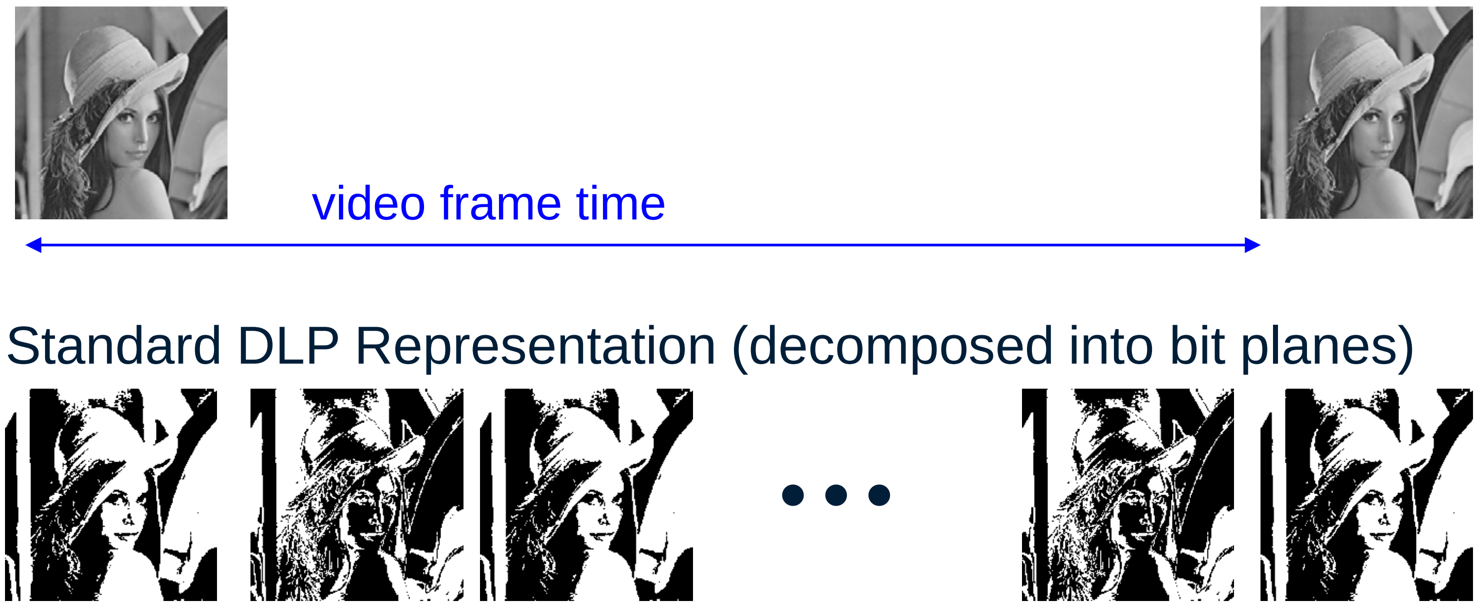




http://www.dlp.com/jp/technology/how-dlp-works/

GRAY-LEVEL IMAGES COMPOSED OF BINARY PATTERNS

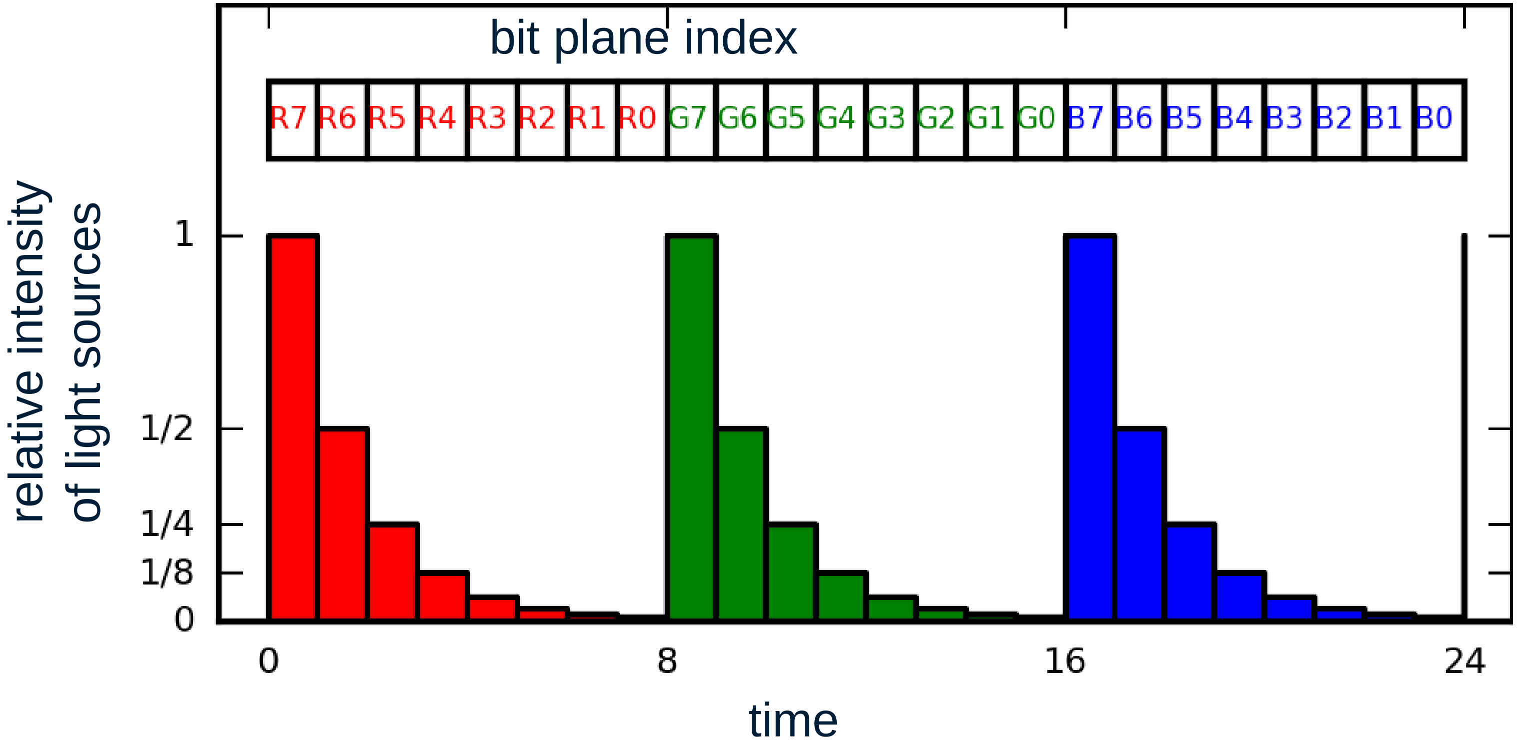




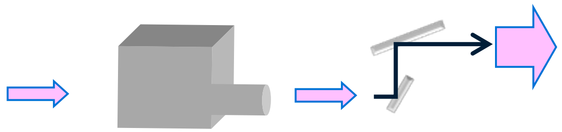
A number of binary patterns are time-integrated by human vision

HOW TO ACHIEVE HIGH FRAME RATE

- Combine with intensity modulation of light sources
- 8-bit monochrome image represented by (at least) 8 binary frames
- 3 times more for RGB color images



POSSIBLE APPROACHES FOR LOW-LATENCY MOTION-ADAPTIVE PROJECTION



video-rate input

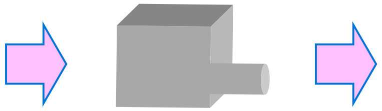
fast pan/tilt mirrors

output image

✓ “normal” projectors can be used

X limited motion DoF

[Okumura+, ICME 2012]



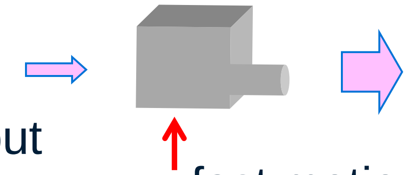
high-frame-rate input

output image

✓ high versatility

X high data generation/transfer cost

[Watanabe+, IDW 2015]



video-rate input

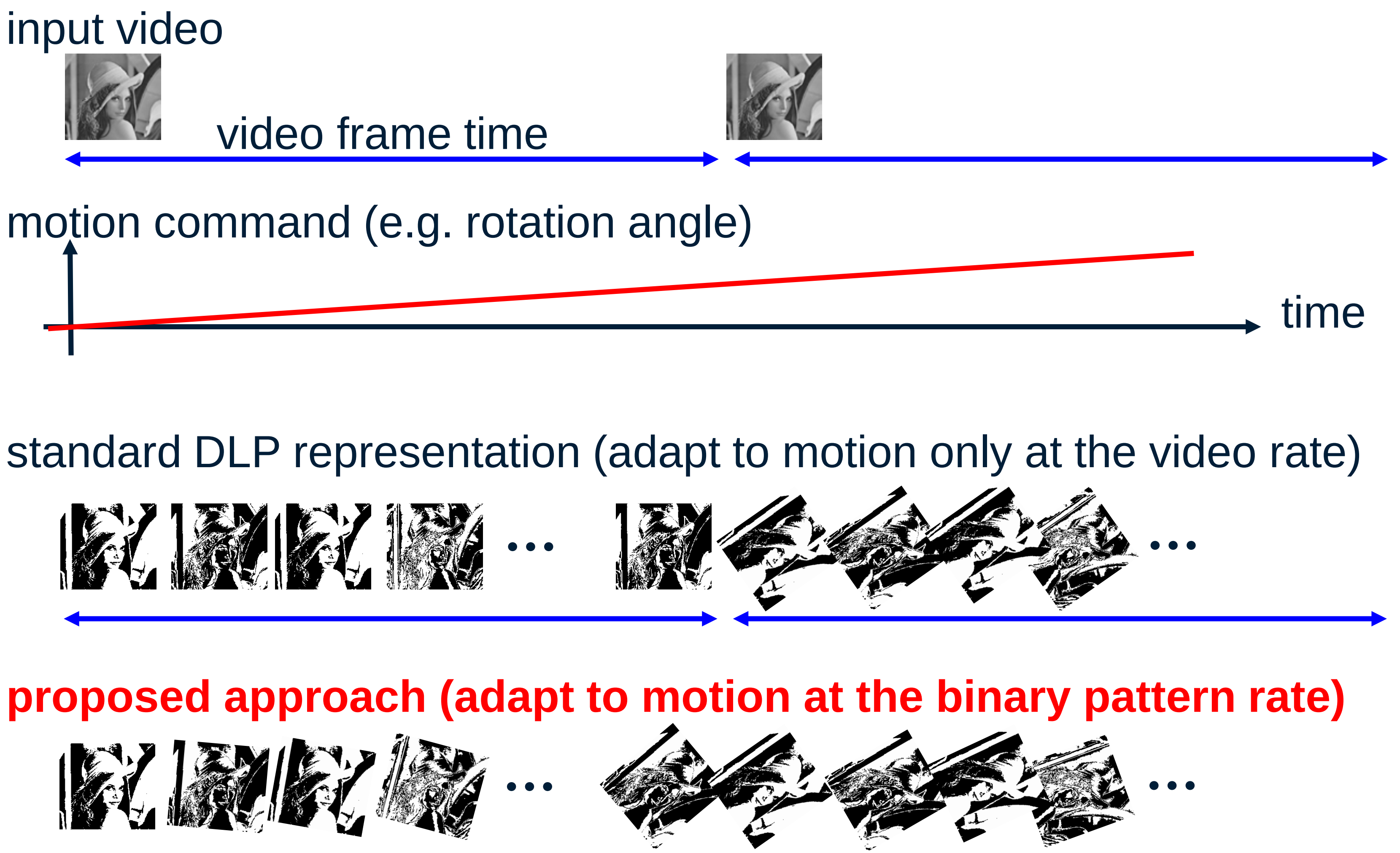
fast motion command

output image

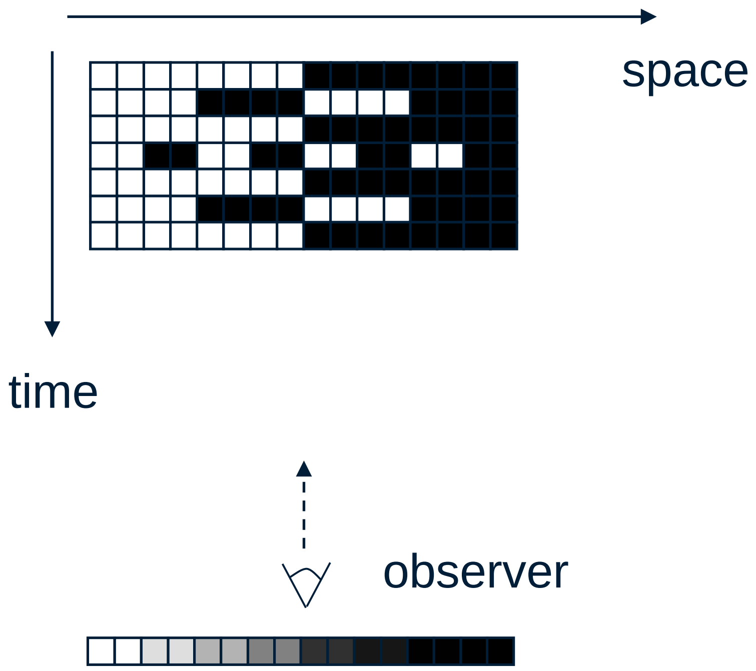
Our Approach

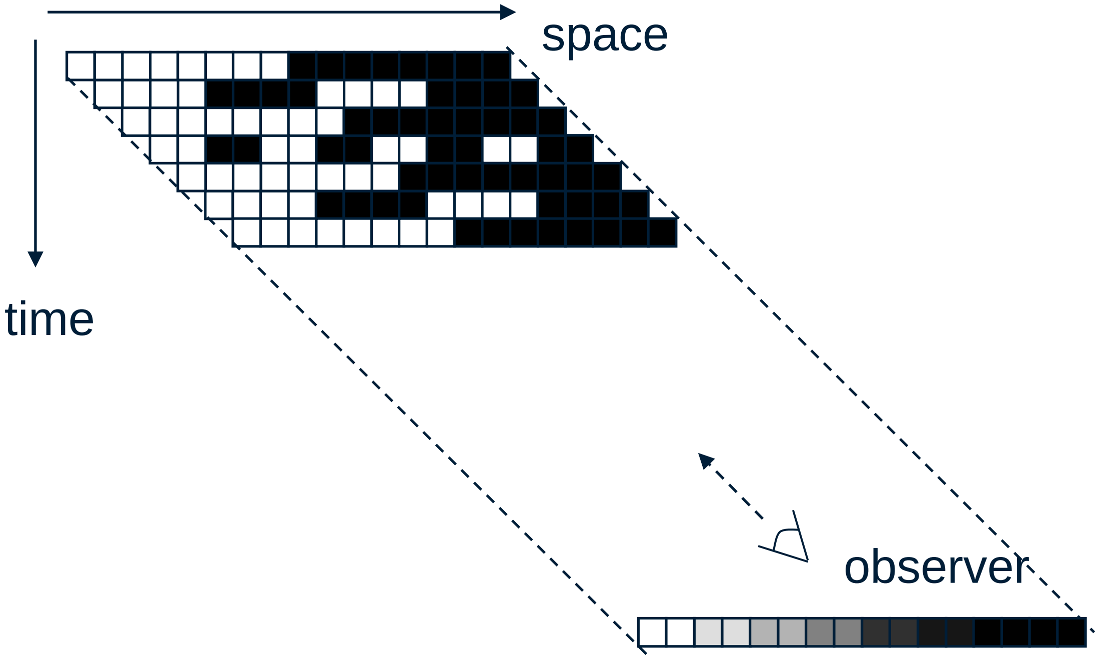
[Kagami+, SIGGRAPH Asia 2015 E-tech]

OUR APPROACH



WHAT HAPPENS IN THE OBSERVER'S EYES?





Direction of integration in time-space becomes changed

RELATED WORK (FOUND IN HMD LITERATURE)

Low-latency DMD-based HMD:

- Maintain “ideal” target gray-level image at high rate
- Residual error image toward the “ideal” one is binarized and presented [Zheng+, ISMAR2014]
- Or, “ideal” image is binarized with random threshold [Lincoln+, TVCG 2016]

Microsoft Hololens:

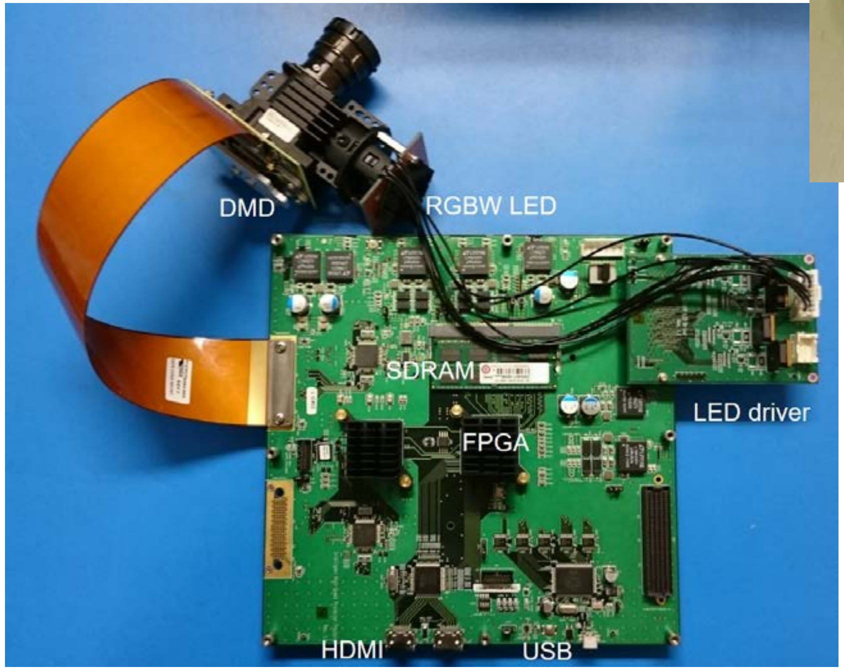
- RGB color fields are sequentially post-warped by newest motion sensor readings [Klein, ISMAR2017 plenary]
- Decomposition into binary patterns does not take place (since LCoS is used)

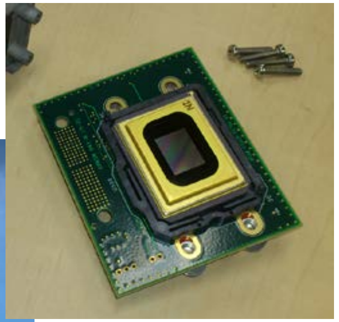
HARDWARE IMPLEMENTATION

Our previous prototype [Kagami+, 2015]

Based on Texas Instruments DLP Discovery 4100
Non-modulated white LED

New prototype

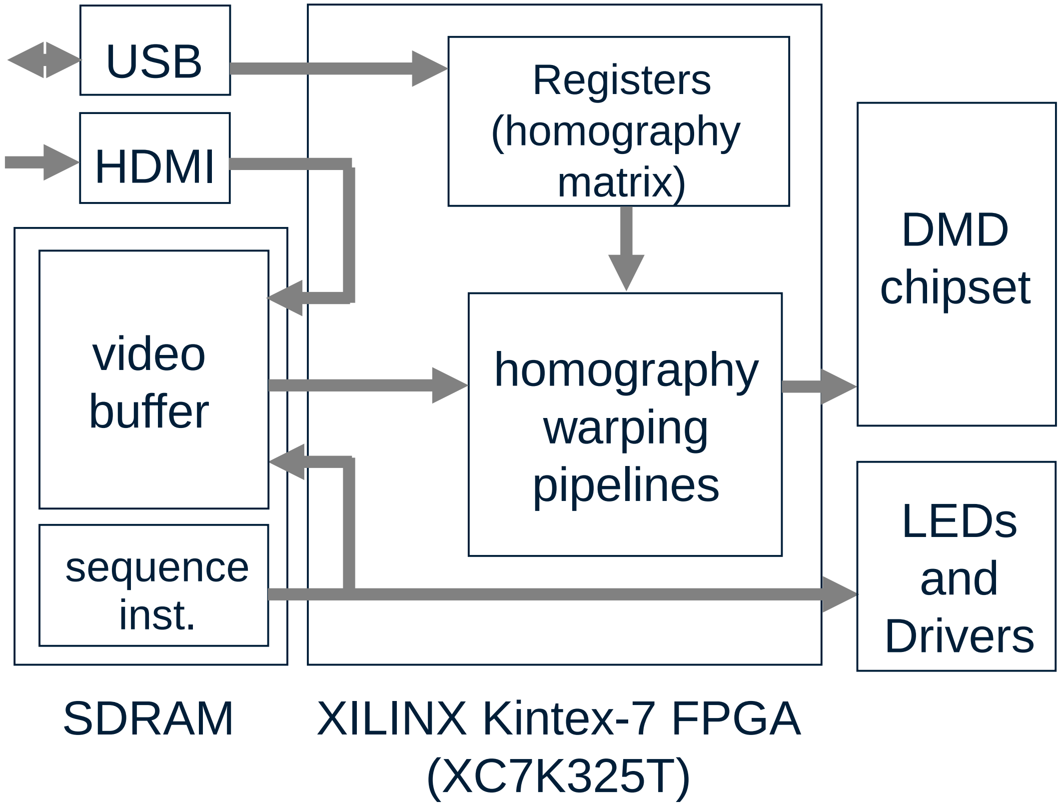




DLP7000

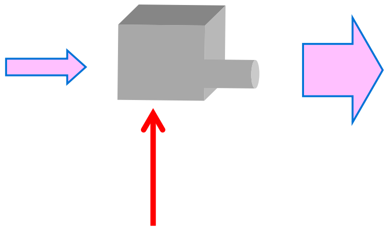
Custom controller board
Intensity-modulated RGB LED

HARDWARE IMPLEMENTATION



video-rate input
stored in SDRAM storage
or
streamed via HDMI

output image

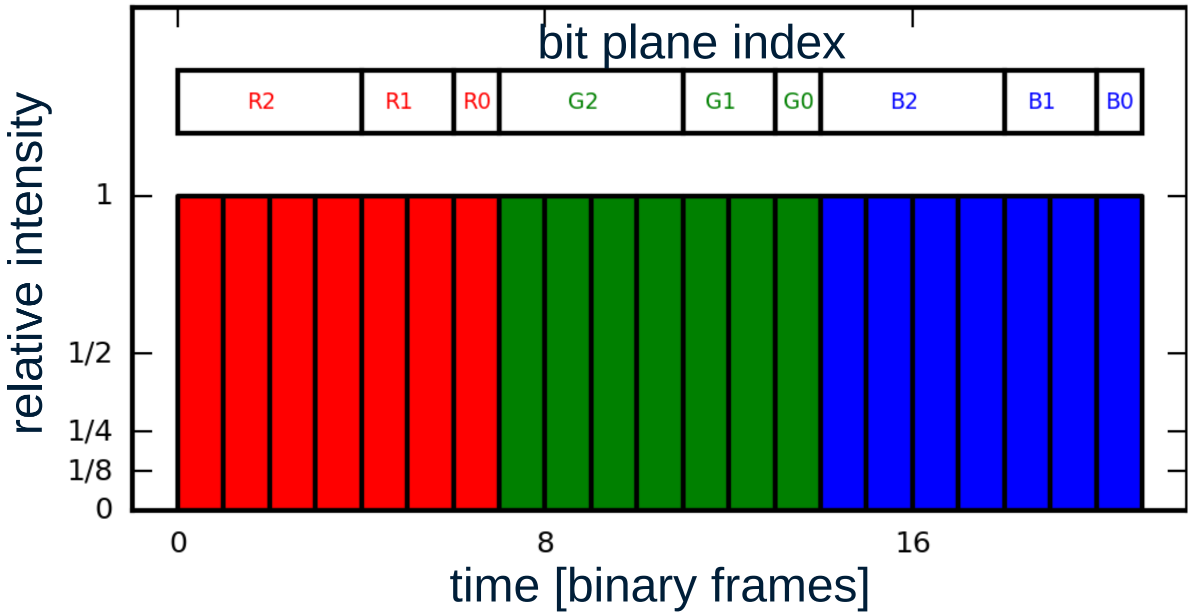


Homography warping parameters
(any perspective mapping from plane to plane)

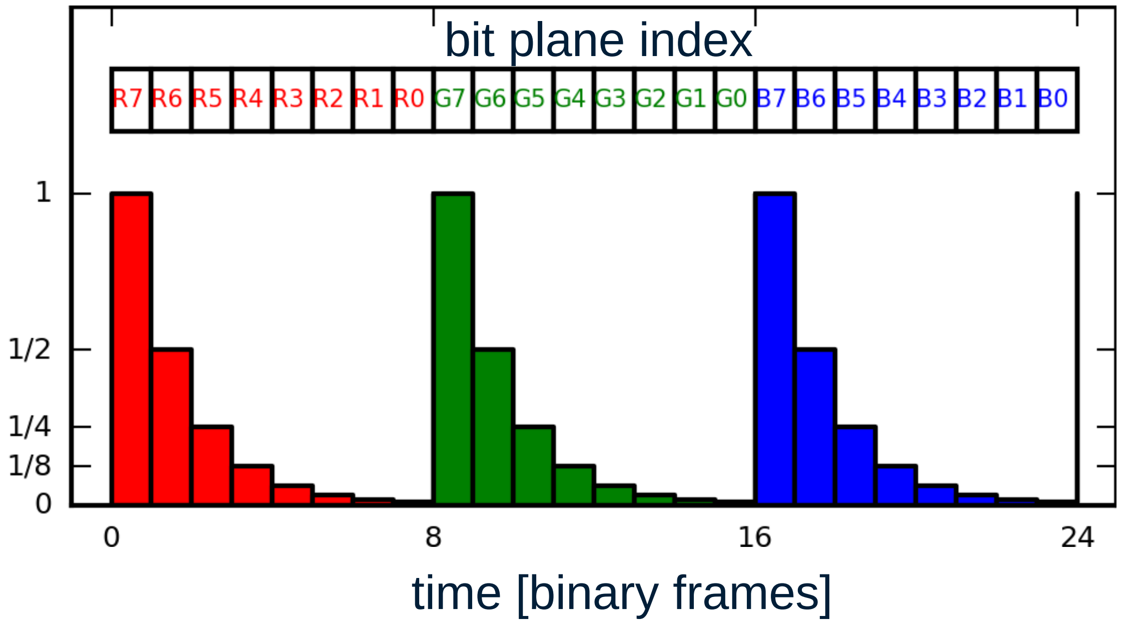
2740 transforms/s for 1024x768 binary image

DISCUSSION ON COLOR REPRESENTATION

3-bit RGB with 21 binary patterns



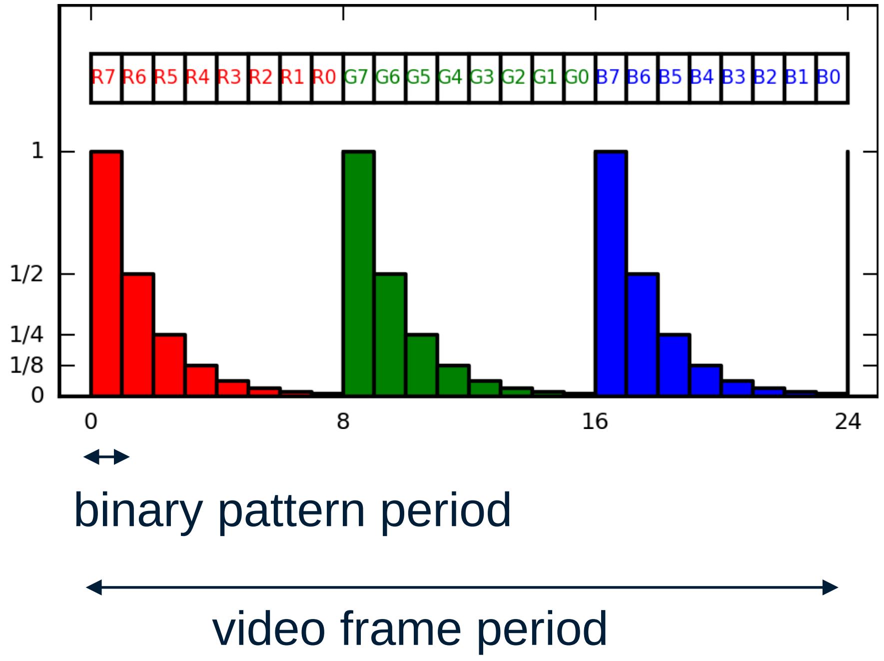
8-bit RGB with 24 binary patterns



- longer sequence needed for more bit depths
- lower utilization of light

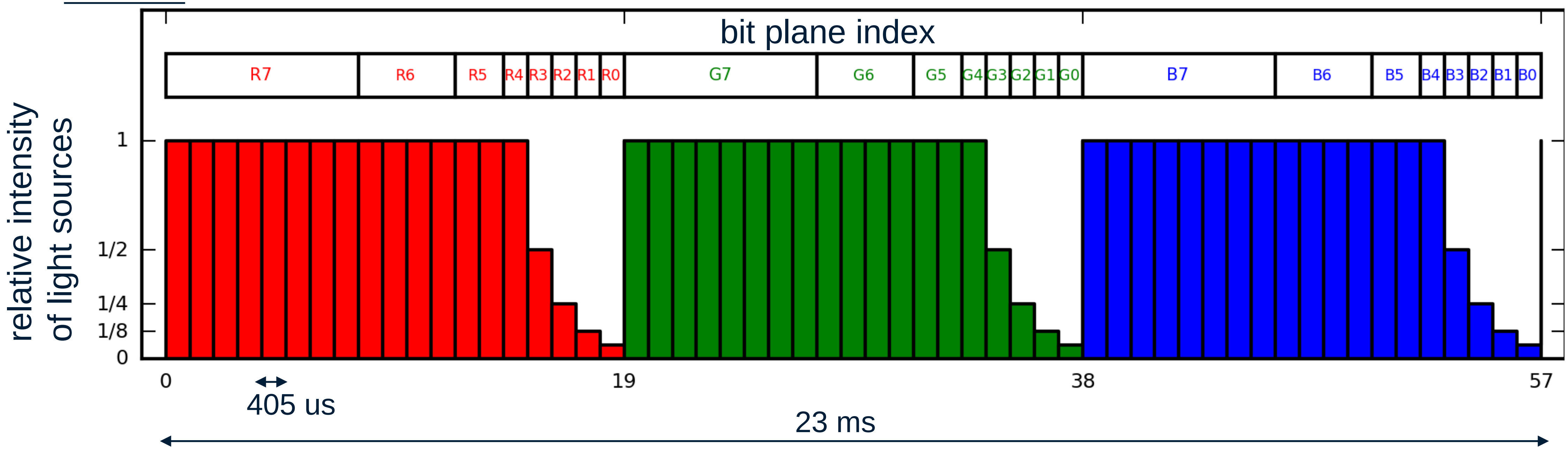
DESIGN TRADEOFFS

- **binary pattern period**:
  - should be short for more color depths with better light utilization
  - should be long for cheaper DMD employed or for small data bandwidth
- **video frame period**:
  - should be long for more color depths with better light utilization
  - should be short for quick motion adaptability, **if video frame period equals to the unit time for motion adaptation**



OUR REPRESENTATION FOR 8-BIT RGB

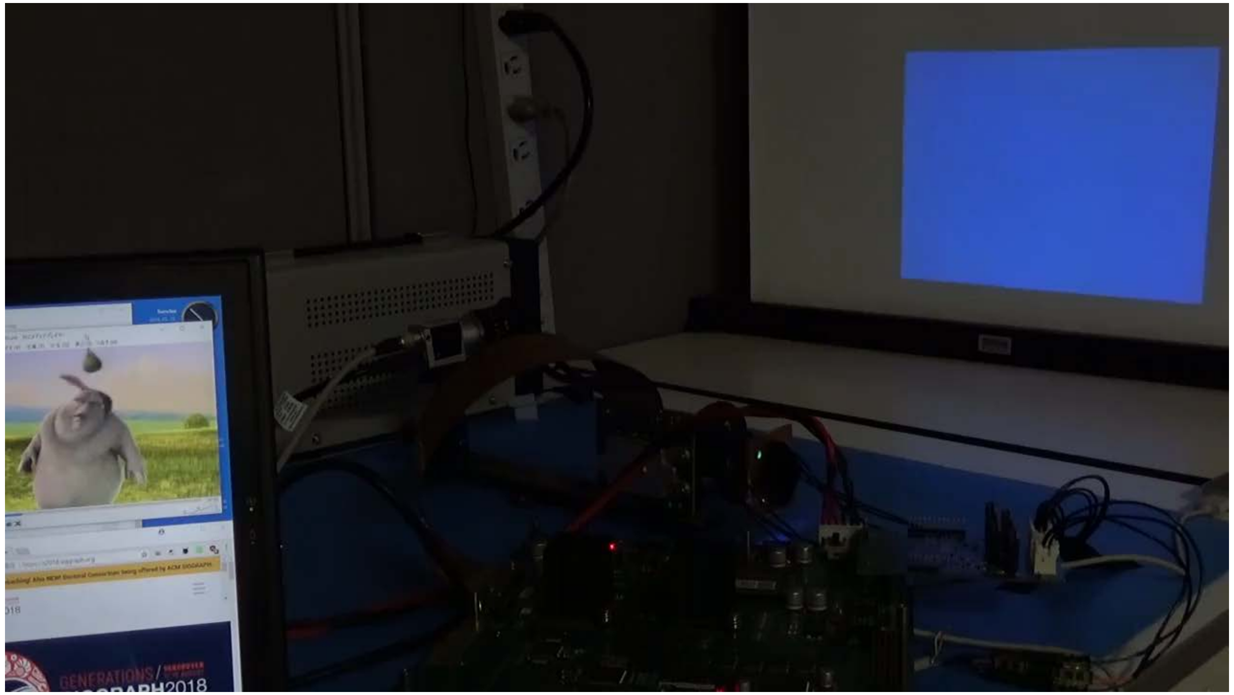
* This diagram ignores bit splitting and color interleaving



- With our approach, **video frame period and unit time for motion adaptation are independent**
- But the frame period should be short enough to avoid flicker perception

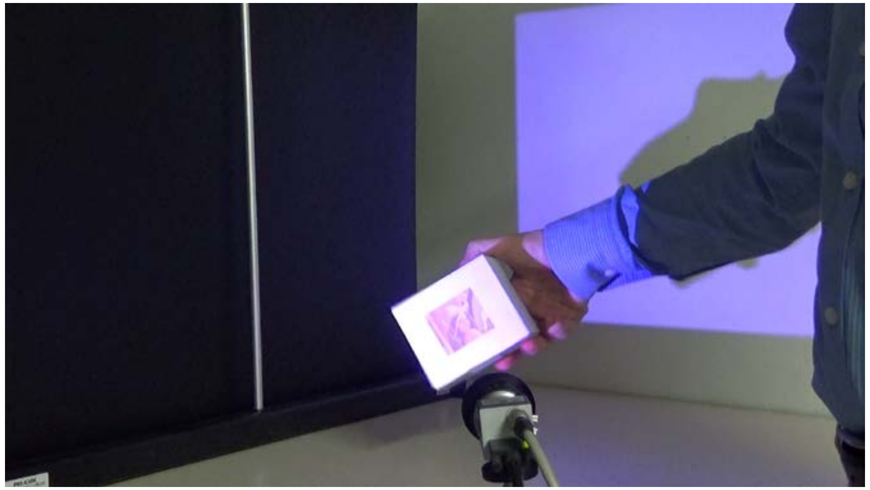
PROJECTION RESULTS

How 24-bpp color image is represented



recognized as an external monitor by Windows PC

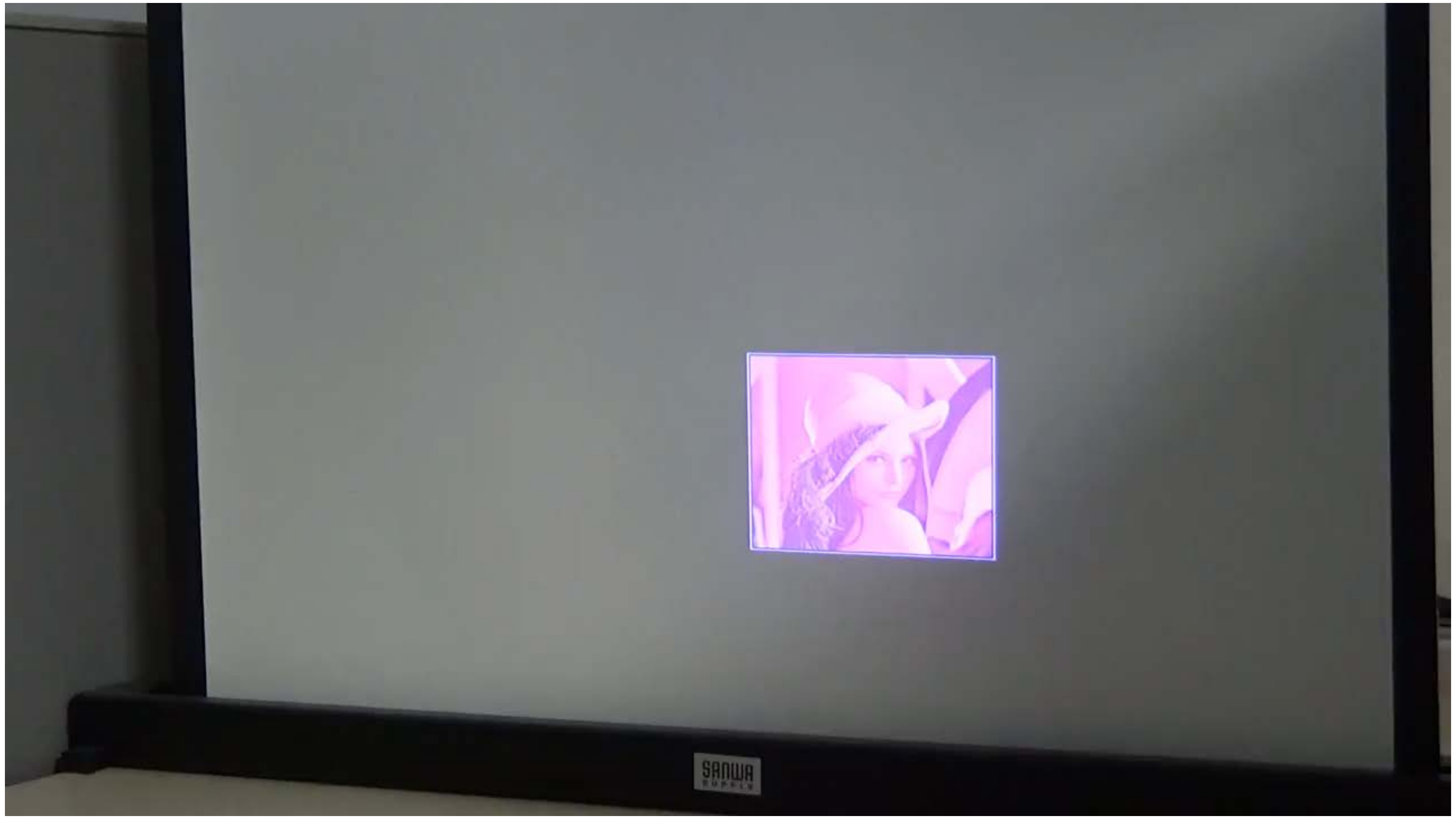
PROOF-OF-CONCEPT DEMO: TRACKING PROJECTION ONTO A MOVING SURFACE



Basler acA640-750 USB-3 camera
(run at around 400 fps)

See [Kagami+, SIGGRAPH Asia 2015]
for the detailed algorithm

PROOF-OF-CONCEPT DEMO: WARPED PROJECTION BY HAND GESTURE



Leap Motion sensor (run at around 200 fps)

SUMMARY

A full-color projector with low-latency motion adaptability

- per-bitplane warping approach
- color representation in single-chip-DLP configuration

Limitations

- Warping functions are hard-wired
- Brighter LEDs should be used for real applications

Future work

- Extending warping functions (e.g. for multiple polygons)
- User tests for image quality and latency perception

Tell us how we did!

Complete the Survey by

- Navigating to this session in the app,
- Scrolling to the bottom of the screen, and
- Answering less than 5 questions