A SXGA 3D Display Processor with Reduced Rendering Data and Enhanced Precision

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  - 3D Graphics + 3D Display
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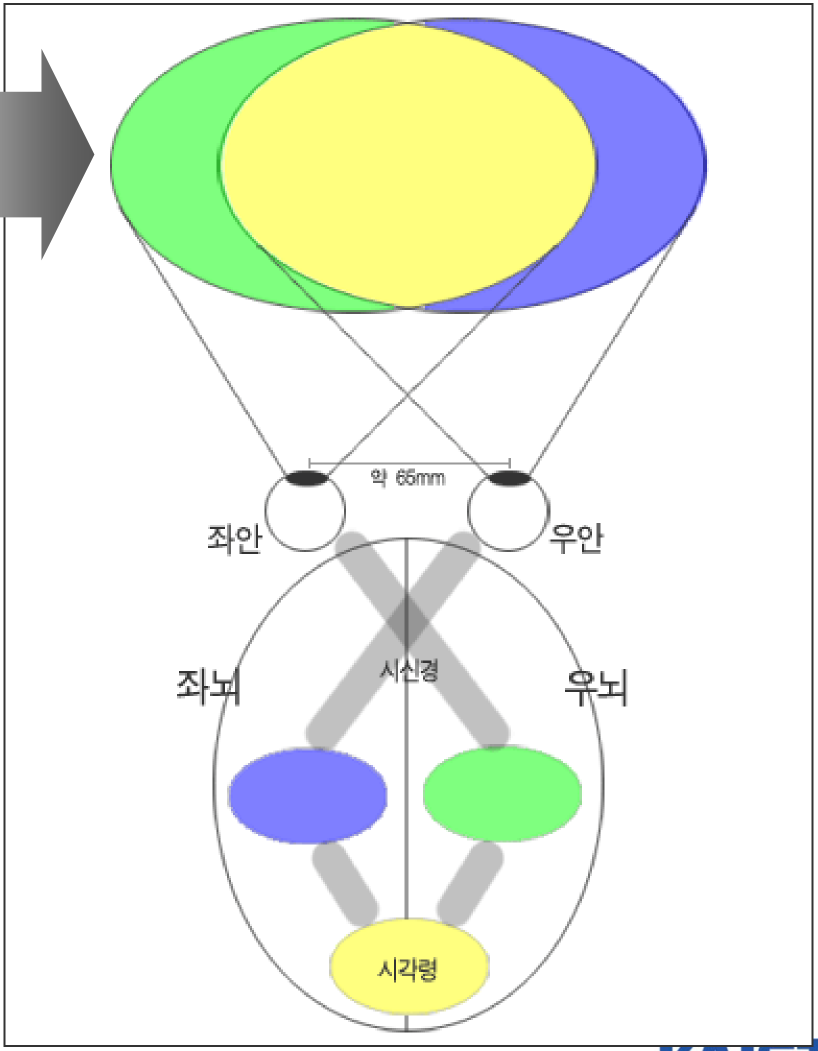
Background
: Principle of 3D Display



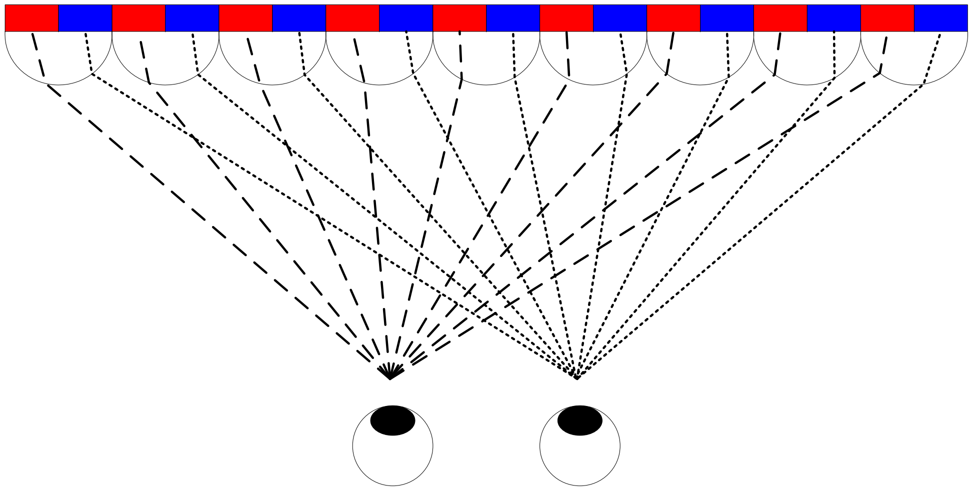
A separate image to each eye

Perception of depth

Stereoscopy

Background
: Target 3D Display

- **Lenticular display**
  - Convey different image to each eye
  - Feel depth-perception
  - Widely used



- **Slanted lenticular display**
  - Improve resolution characteristic

- **Multiview lenticular display**
  - Wide view range
  - Multiplexing

9-view Slanted Lenticular Display

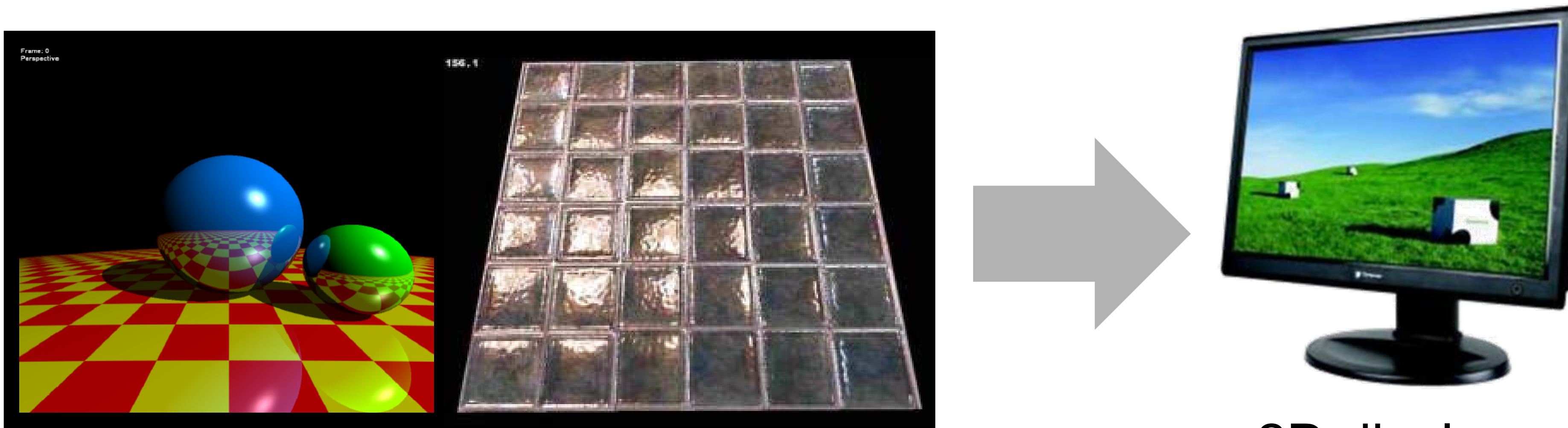
Motivation
: 3D Graphics

Vertex Texture Mapping

Shadow

Ray Tracing

Motivation
: 3D Graphics



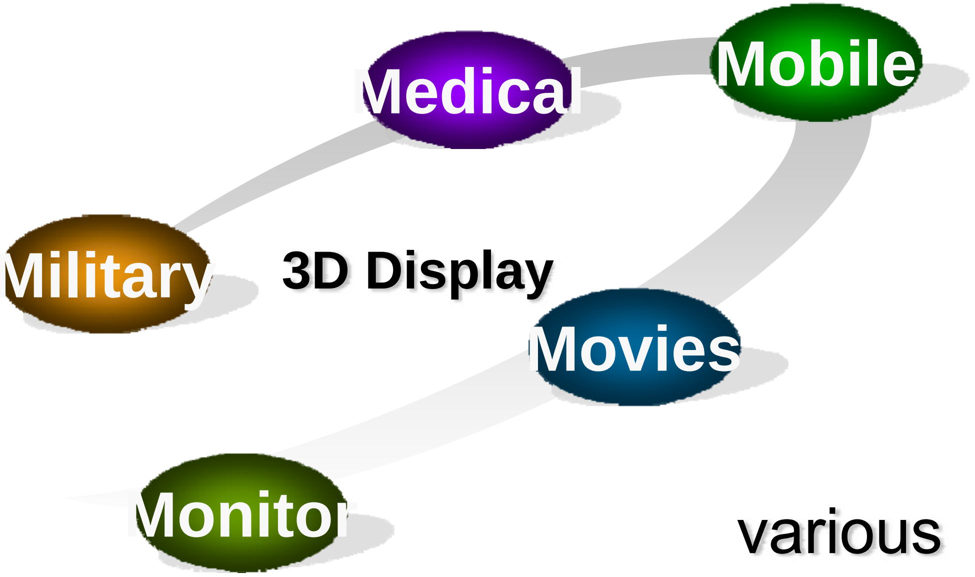
2D display

- **3D graphics hardware**
  - Photorealistic rendering effects
- **2D display**
  - Lack of depth-perception
  - Not provide 3D effects

No True Realism

Motivation
: 3D Display

- **Depth-perception of 3D display → True Realism**



various applications

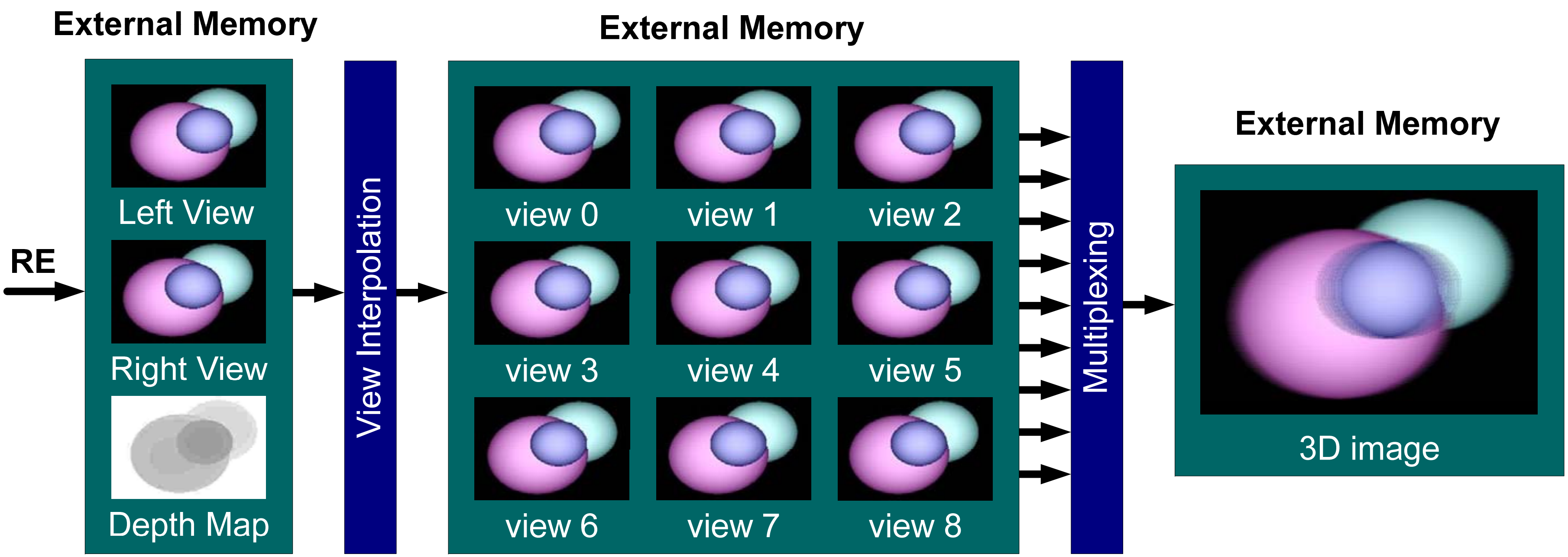
- **3D image processing is too complicate.**
  - Display static or pre-processed data
  - Difficult for supporting interactive applications

Motivation
: 3D Graphics + 3D Display

+

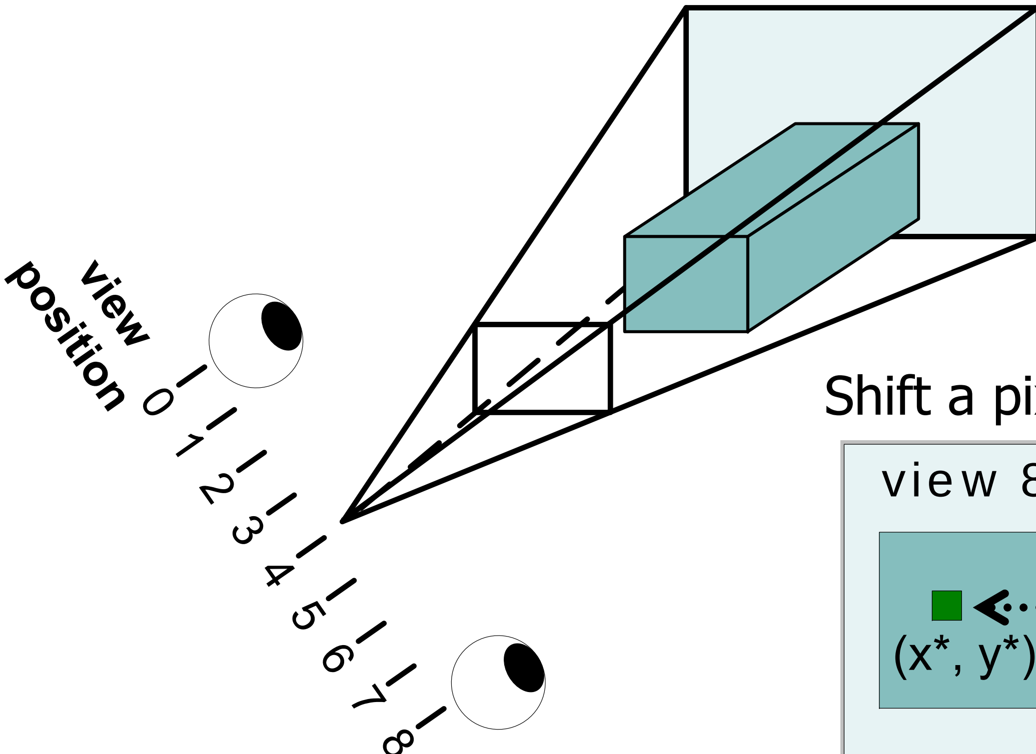
3D graphics + 3D display supports
interactive applications & true realism

Previous Works
: Conventional Method



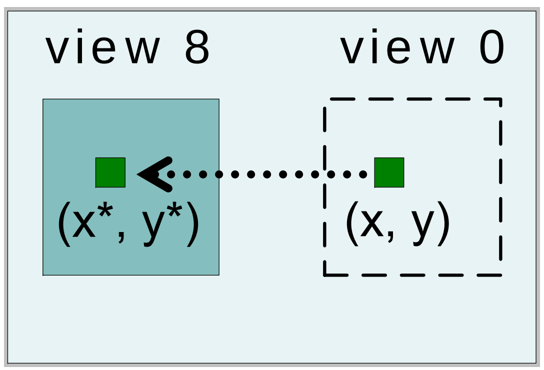
- **View interpolation**
  - Interpolate 7 view images between left and right view image
- **Multiplexing**
  - Allocate sub-pixels of 9 view images to lenticular LCD
  - View image (427x342), 3D image (1280x1024)

Previous Works
: Conventional Method – View Interpolation

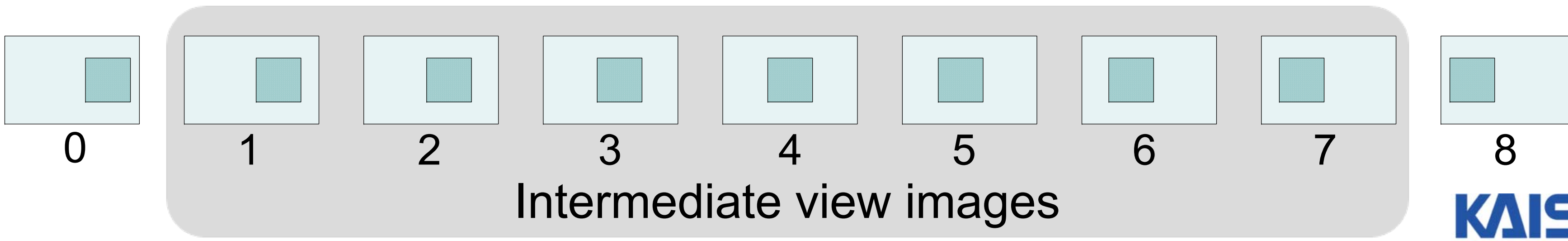


$$\text{disparity} = \text{const.} \times \text{view} \times \text{depth}$$

Shift a pixel of left image to left by disparity



$x^* = x - \text{disparity}$
$y^* = y$



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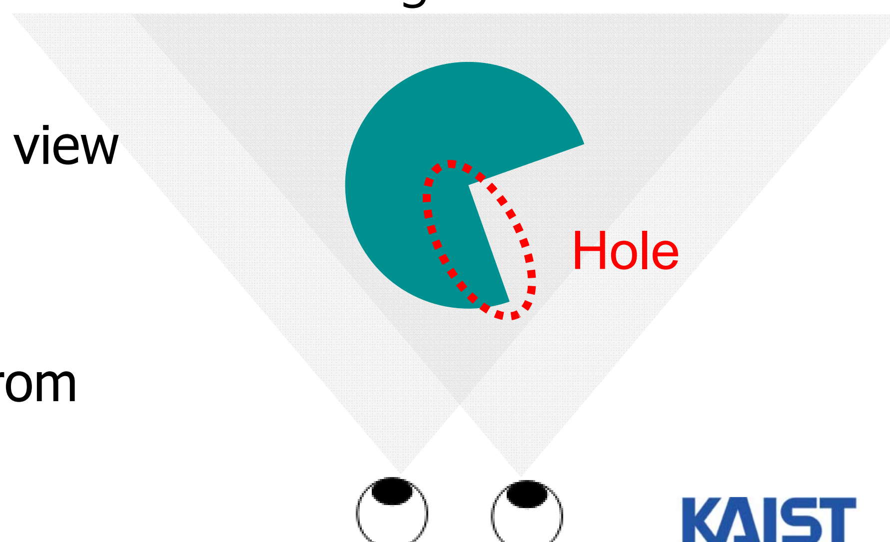
Previous Works
: Conventional Method – View Interpolation

left image

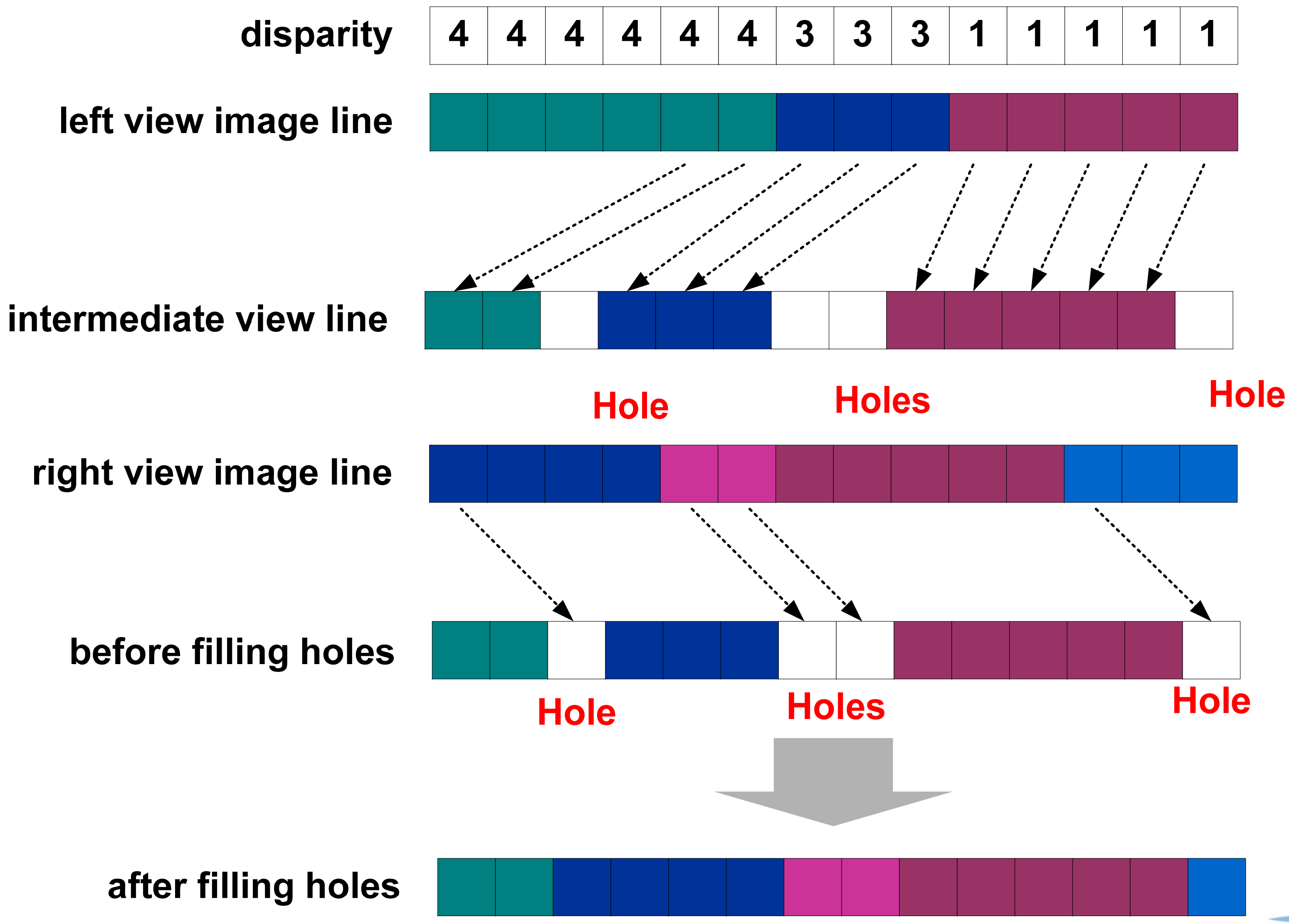
interpolation

intermediate
view image

- **Hole**
  - Not filled pixels in intermediate view images
  - Visible from only one view
  - Remove holes bringing pixels from **right image**



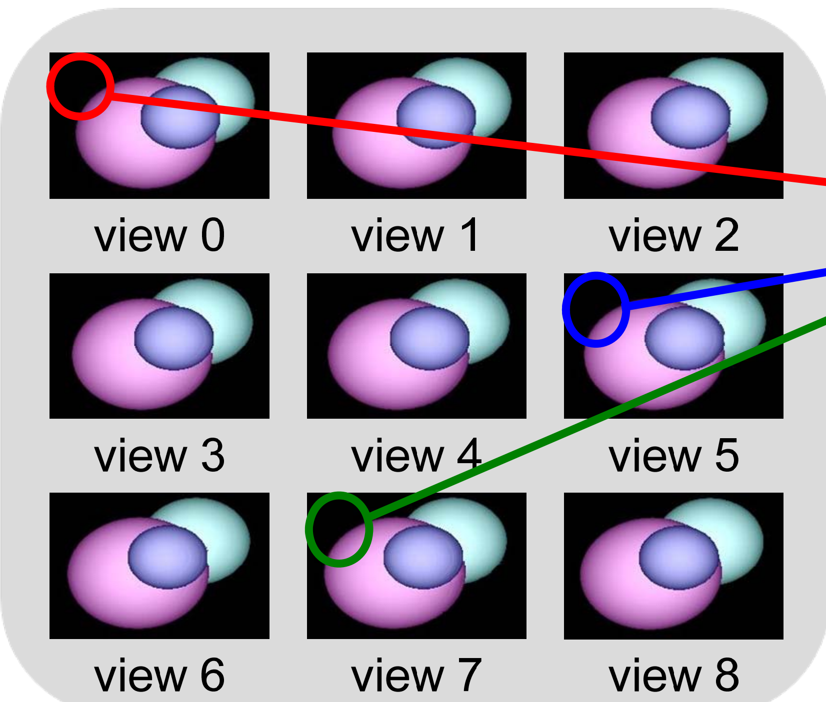
Previous Works
: Conventional Method – View Interpolation



Previous Works
: Conventional Method – Multiplexing

- **Allocate sub-pixels to appropriate positions in LCD**
- **View numbers are calculated at sub-pixel level**

After view interpolation



R: $view_{LCD} = (\alpha*(x_{LCD}*3+0)+\beta*y_{LCD}+\Gamma)\%9$

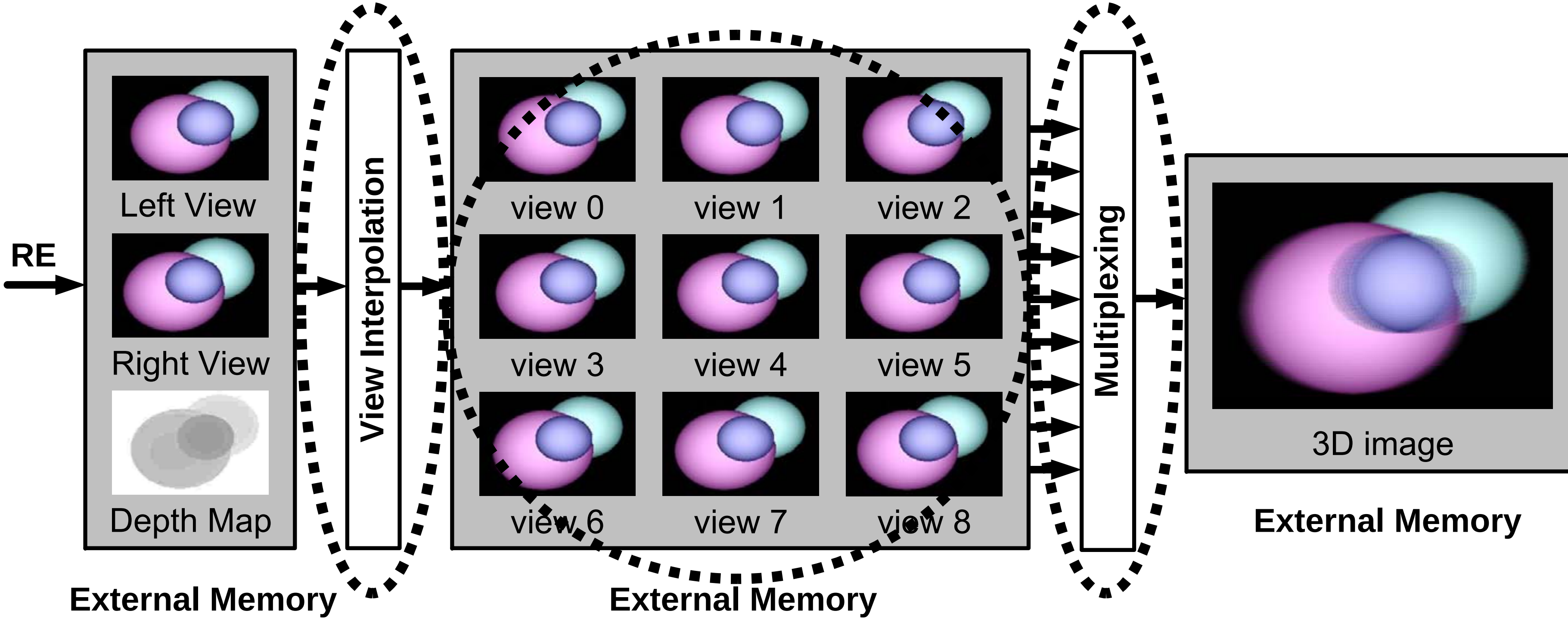
G: $view_{LCD} = (\alpha*(x_{LCD}*3+1)+\beta*y_{LCD}+\Gamma)\%9$

B: $view_{LCD} = (\alpha*(x_{LCD}*3+2)+\beta*y_{LCD}+\Gamma)\%9$

0	7	5	3	1	8	6	4	2	0
1	8	6	4	2	0	7	5	3	1
2	0	7	5	3	1	8	6	4	2
3	1	8	6	4	2	0	7	5	3
4	2	0	7	5	3	1	8	6	4
5	3	1	8	6	4	2	0	7	5

Some Part of 3D Display

Previous Works
: Conventional Method – Problems

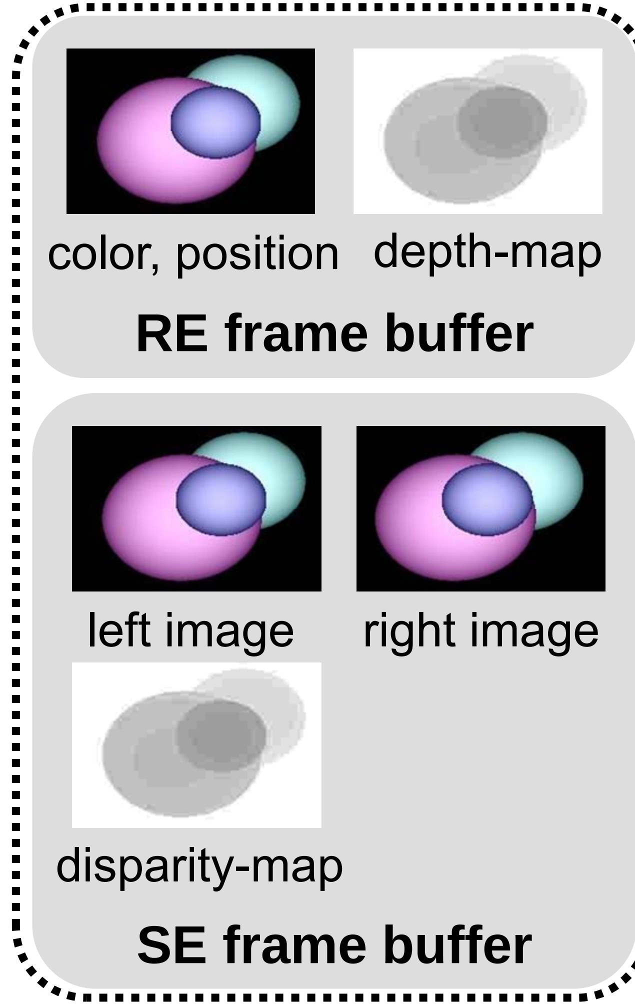


- **Frequent external memory accesses**
  - Difficult to support interactive applications
- **Large memory** for storing intermediate images

Previous Works
: ISSCC2007 – Merged Architecture(1)

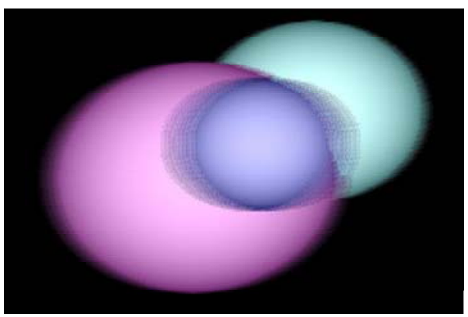
3D Graphic Pipeline

Geometry Engine(GE) → Rasterization Engine(RE)



3D Image Synthesis Pipeline

3D Image Synthesis Engine (SE)



- Both frame buffers store the same data (color, position, and depth)

→ **Merged Architecture**

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Previous Works
: ISSCC 2007 – Merged Architecture(2)

- **Disparity is calculated using a linear equation**

$$d_{eye} = \frac{f}{z_{eye}} \cdot b \cdot \frac{view}{8}$$

$$d_{eye} : h_{eye} = d_{screen} : h_{screen} \qquad z_{screen} = \frac{F}{F-N} \cdot (1 - \frac{N}{z_{eye}})$$

$$d_{eye} = \frac{h_{eye}}{h_{screen}} \cdot d_{screen} \qquad \frac{N}{z_{eye}} = \frac{f}{z_{eye}} = 1 - (\frac{F-N}{F}) \cdot z_{screen}$$

$$d_{eye} = \frac{f}{z_{eye}} \cdot b \cdot \frac{view}{8}$$

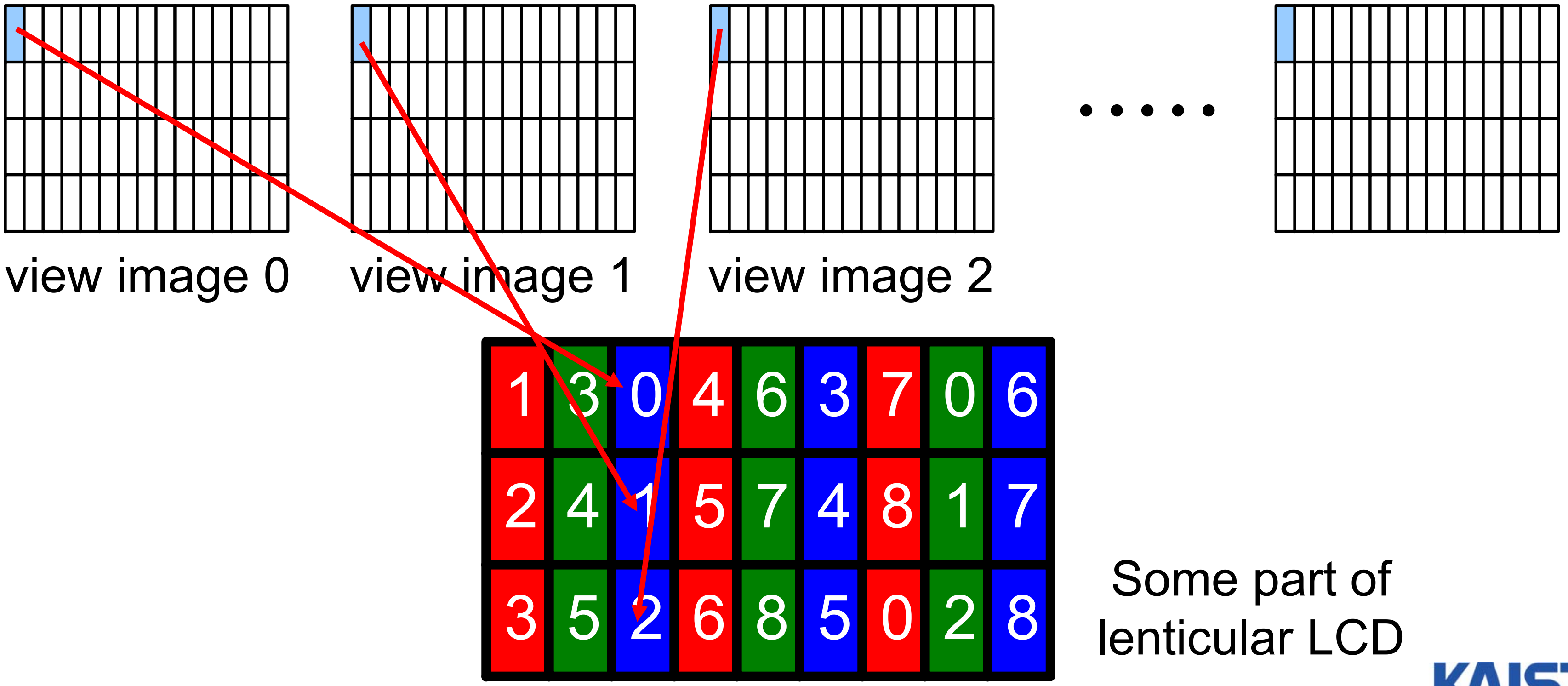
$$\frac{h_{eye}}{h_{screen}} \cdot d_{screen} = \{1 - (\frac{F-N}{F}) \cdot z_{screen}\} \cdot b \cdot \frac{view}{8}$$

$$d_{screen} = \{1 - (\frac{F-N}{F}) \cdot z_{screen}\} \cdot b \cdot \frac{view}{8} \cdot \frac{h_{eye}}{h_{screen}}$$

$$d_{screen} = (\alpha - \beta \cdot z_{screen}) \cdot view$$

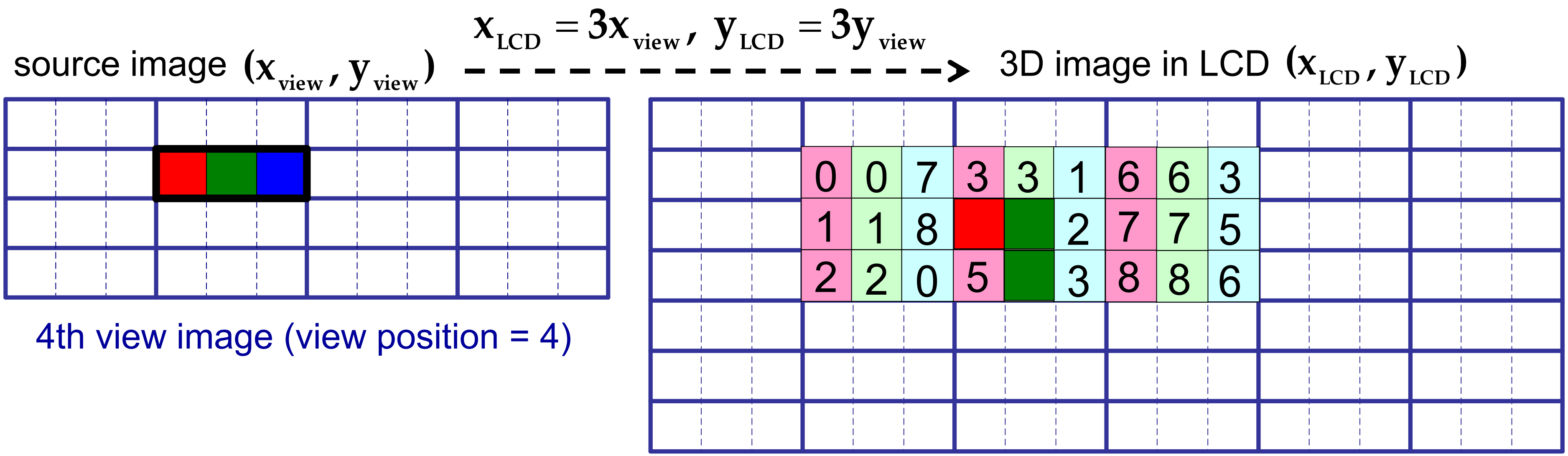
Previous Works
: ISSCC 2007 – Real-time Synthesis(1)

- Simultaneous view interpolation and multiplexing
  - No intermediate memory
  - Reduced memory size & external memory accesses



Some part of
lenticular LCD

Previous Works
: ISSCC 2007 – Real-time Synthesis(2)



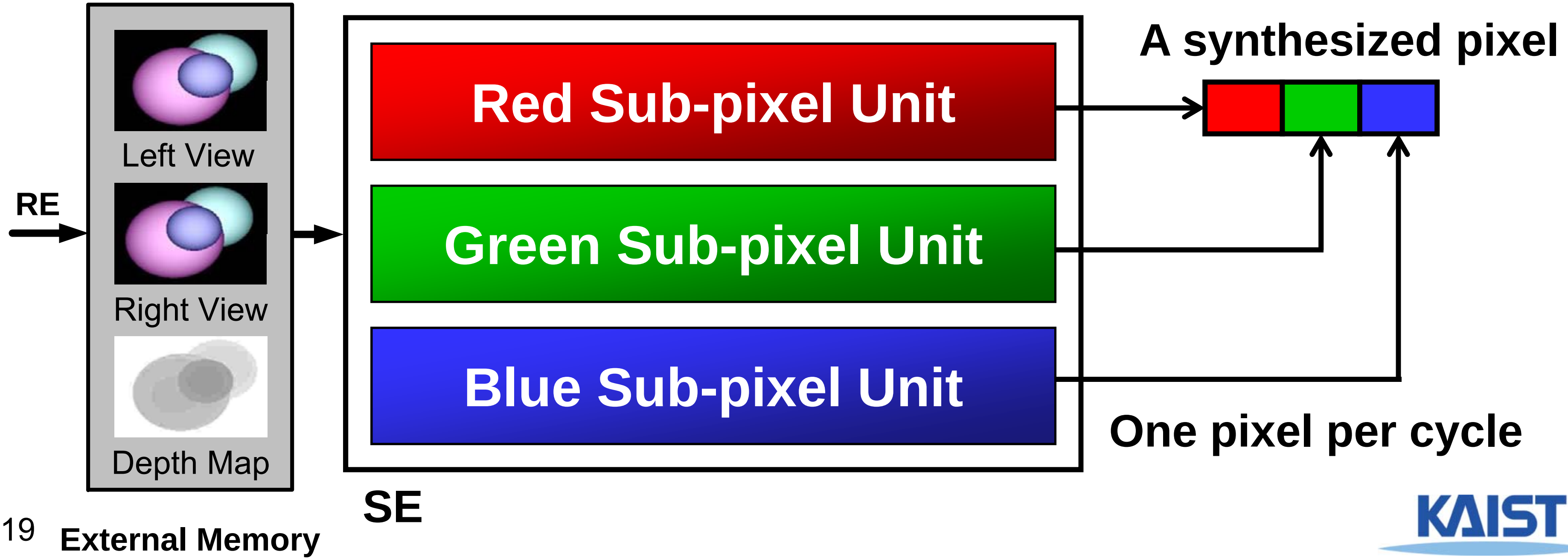
4th view image (view position = 4)

Synthesized image

$$R: view_{LCD} = (\alpha*(x_{LCD}*3+0)+\beta*y_{LCD}+\Gamma)\%9$$
$$G: view_{LCD} = (\alpha*(x_{LCD}*3+1)+\beta*y_{LCD}+\Gamma)\%9$$
$$B: view_{LCD} = (\alpha*(x_{LCD}*3+2)+\beta*y_{LCD}+\Gamma)\%9$$

Previous Works
: ISSCC 2007 – Architecture

- Real-time frame rate : more than 30fps
  - Generate one pixel per cycle @ 50MHz
  - 5×10^7 /1280/1024 ≈38fps
- SE consists of three sub-pixel units.
  - A sub-pixel unit generates a sub-pixel per cycle



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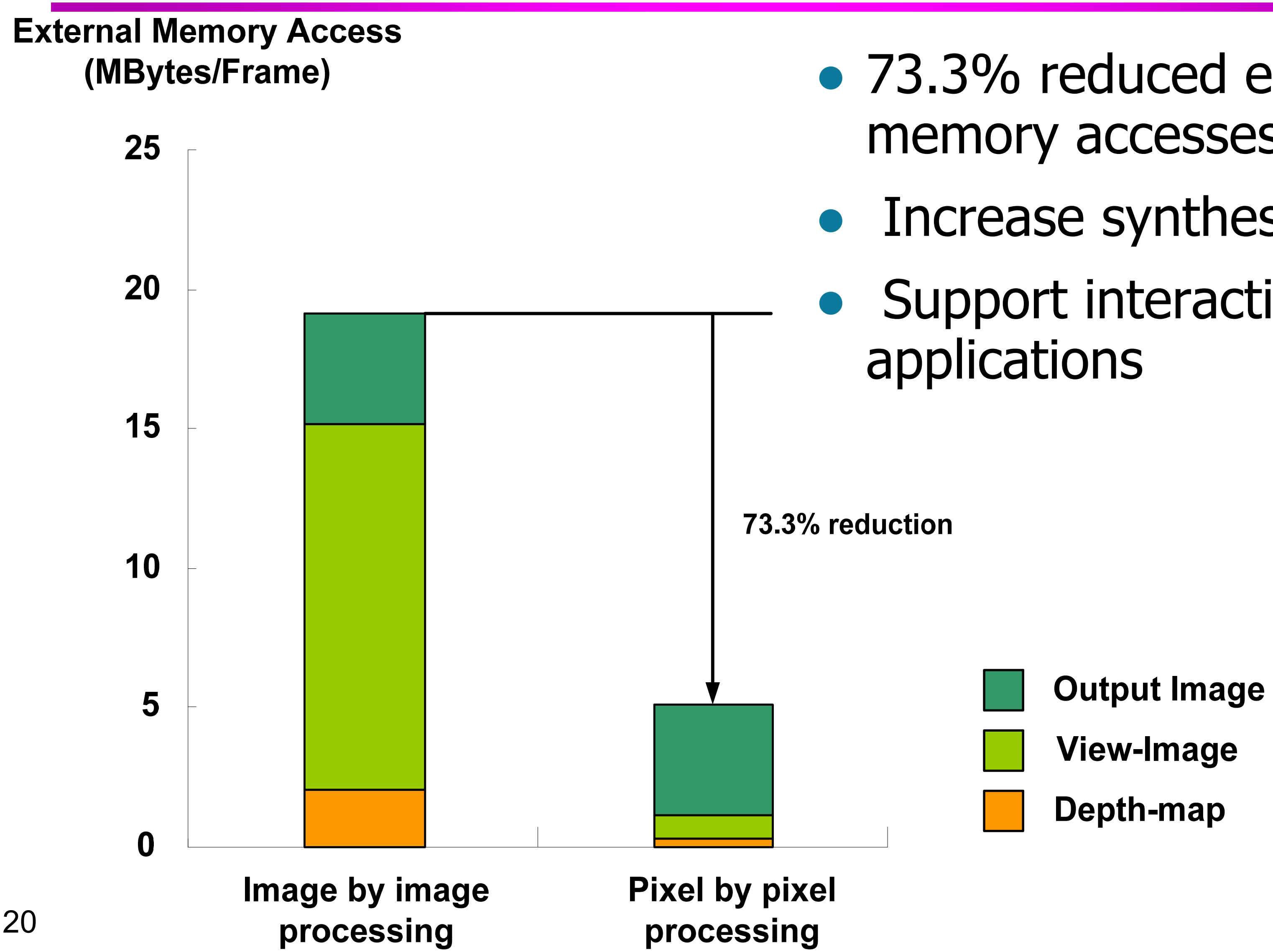
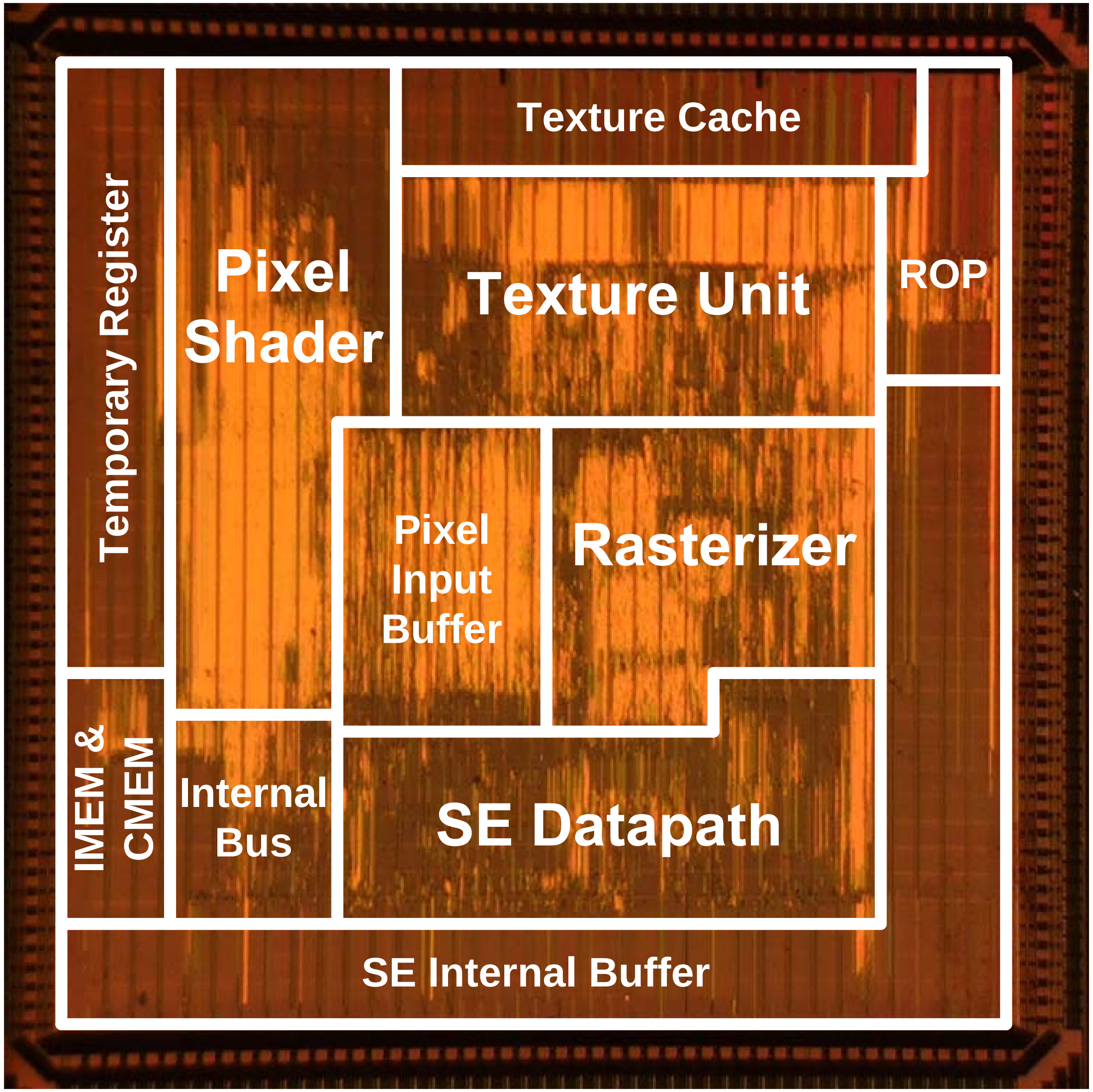
Previous Works
:ISSCC2007 – performance



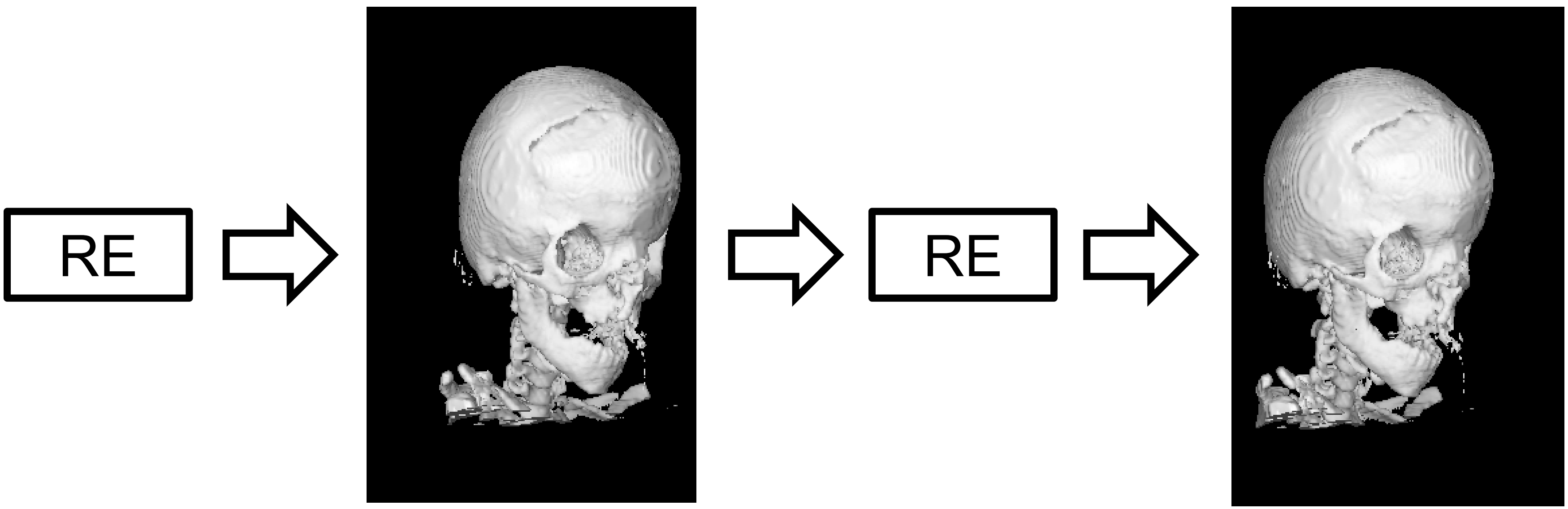
- 73.3% reduced external memory accesses
- Increase synthesis rate
- Support interactive applications

Previous Works
:ISSCC2007 – Chip Micrograph



Problem of RE in Previous Work

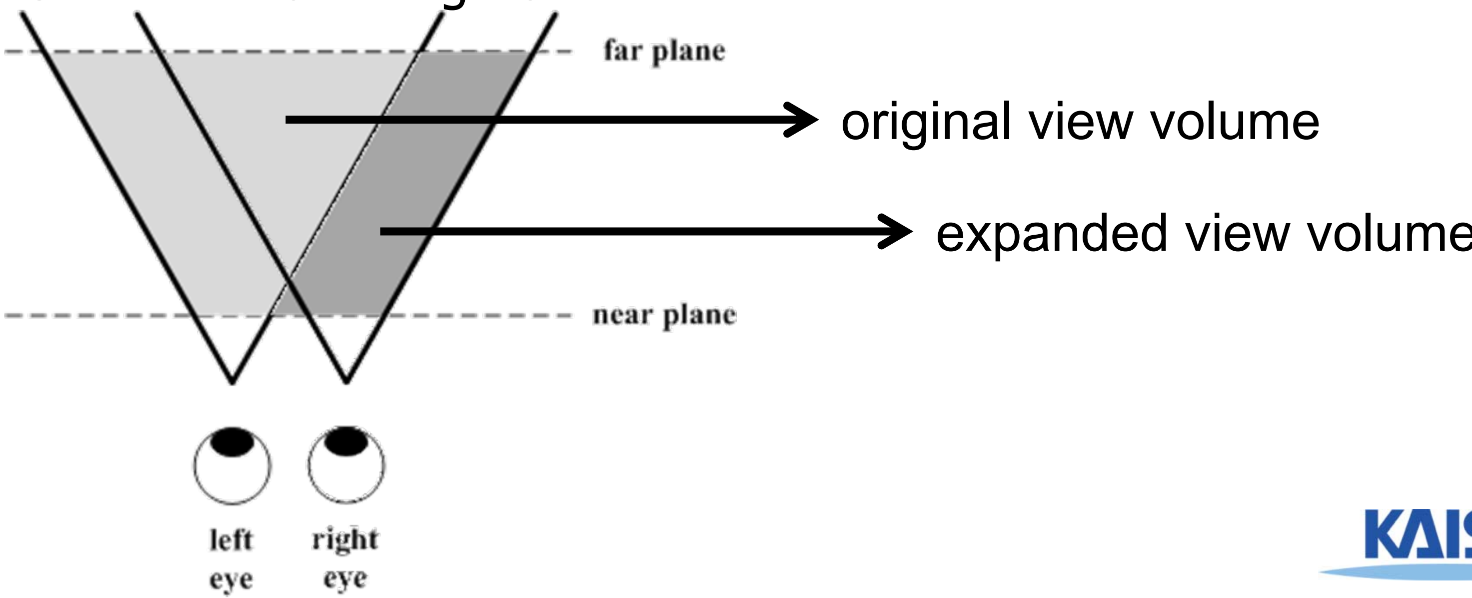
- **Previous work renders the same scene twice for two different view-positions**
  - Waste rendering time to generate duplicate data
  - Require additional memory to store & to load duplicate data
    - Large memory size & increasing external memory accesses



left view-image **right view-image**

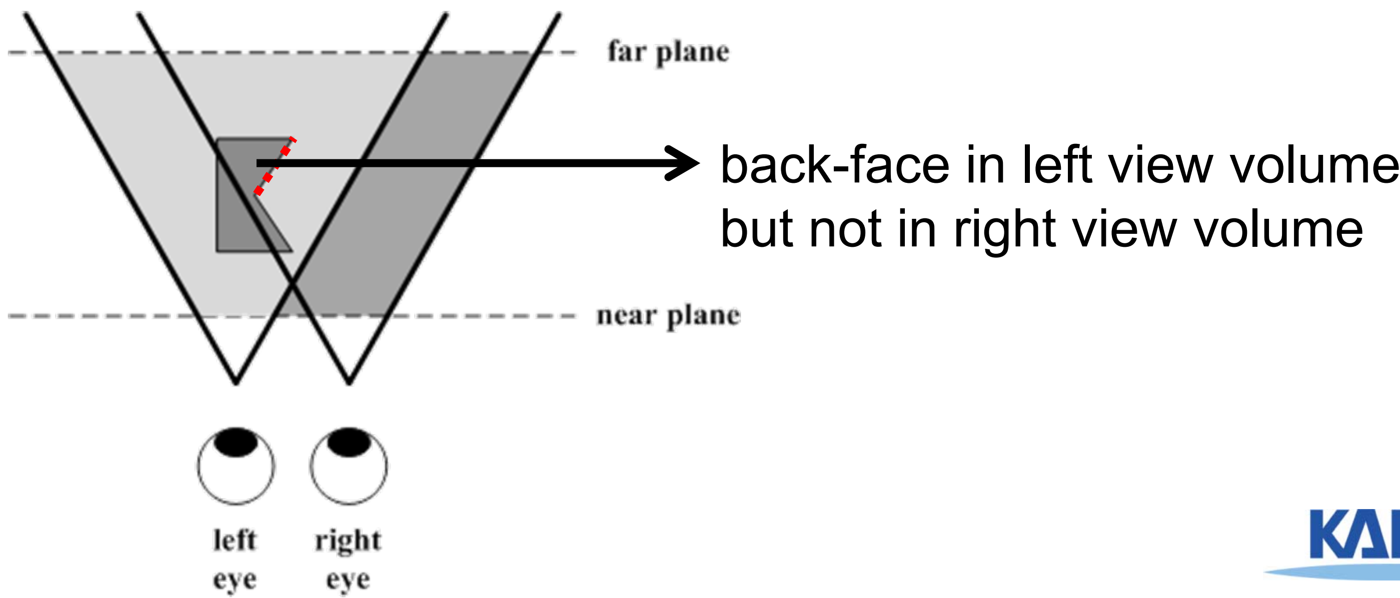
Proposed Idea of RE(1)

- **Renders the same scene only once not twice**
- **Completely removes duplicate data**
- **Modified clipping**
  - Including both left view volume & right view volume
  - Check the pixels in the expanded view volume
    - Use them for filling holes



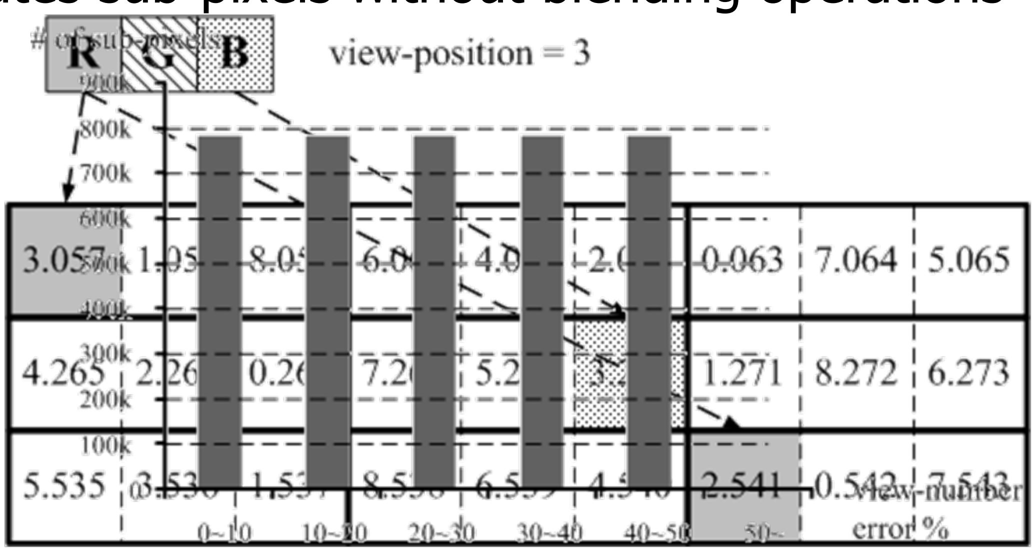
Proposed Idea of RE(2)

- **Modified back-face culling**
  - Back-face culling operations are executed both left view-position and right view-position
  - Check the pixels culled from left view-position but not culled from right view-position
    - Use them for filling holes



Problem of SE in Previous Work

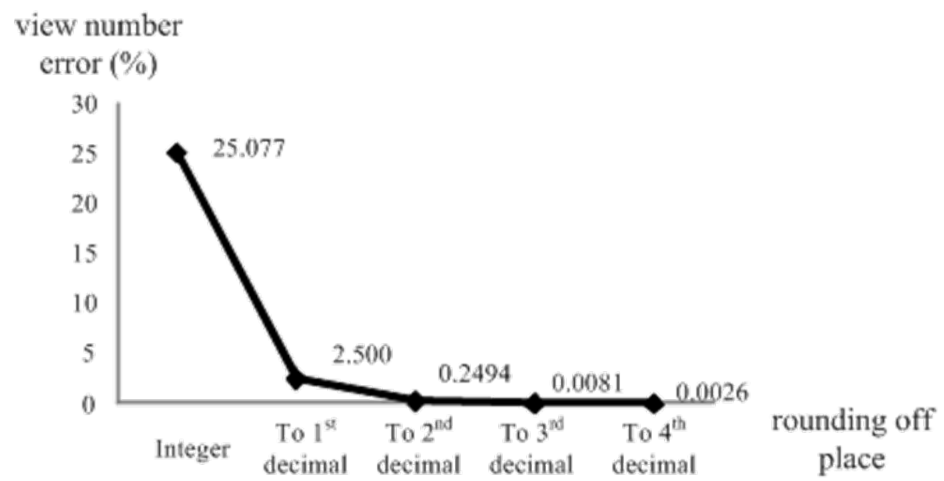
- **View-number error**
  - View-number evaluation equation
    - $view_{LCD} = (A*(x_{LCD}*3+0,1,2)+B*y_{LCD}+C)\%9$
    - A, B, C are floating number constants
  - For blending, reverse multiplexing has been used
  - Previous work rounds off the view-number to the nearest integer
  - Allocates sub-pixels without blending operations



Proposed Idea of SE(1)

- **Precision-enhanced multiplexing**
  - Based on the previous work [ISSCC2007]
  - Conserve the interactive synthesis rate
  - Rounds off the view-number to 2nd decimal place to reduce view-number error to less than 1%

    → improve synthesis image quality



Proposed Idea of SE(2)

- Evaluated view-number = integer part + fragment part
- Integer part is used for finding matching positions
- Fragment part is used for blending
- Additional H/W
  - 5bits more for the view-number evaluator
  - 2 flag bits per a sub-pixel for avoiding overlapping cases → only 5 bytes memory

Conclusion

- **Combine 3D graphics and 3D display**
  - Support both true-realism & interactive applications
- **Expanded clipping & back-face culling**
  - Completely remove duplicate data
  - Reduce required memory size & memory accesses
    → lower H/W cost & improved performance
- **Precision-enhanced Multiplexing**
  - Based on the previous work, conserve interactive synthesis rate
  - Reduce view-number error to less than 1%
  - Require a few of additional H/W