Raytrix Lightfield Camera

*www.**raytrix**.de*

One Camera – One Lens – One Shot

Content

- **Introduction**
- Application Examples
- Technology
- Conclusion

The Company

Raytrix

- Founded 2009 in Kiel, Germany
- Development of lightfield cameras and lightfield image processing software
- Lightfield cameras for industrial applications and research

Products

- Lightfield cameras available since 2010 with 4, 5, 11 and 29 megarays and framerates from 6 to 30fps
- Available interfaces: USB2, USB3, GigE and CameraLink
- CUDA based fast lightfield processing software

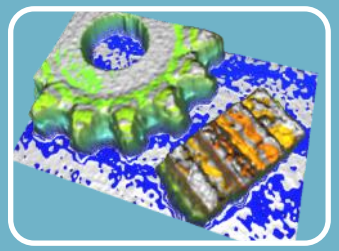
Innovations

- High effective resolution of up to ¼ of the sensor resolution
- Extended depth of field through patented microlens array design
- Fast 3D algorithms based on CUDA processing

Lightfield Advantages

Robust

- One camera, one lens.
- No need to synchronize multiple cameras.
- No decalibration of camera setup.



Easy 3D calibration

- No calibration needed for non-metric 3D data
- Single image calibration for metric measurements

Advanced Post-Production

- For stereo output can vary baseline length and orientation
- Multi-View output for autostereoscopic displays
- Refocus over extended depth of field

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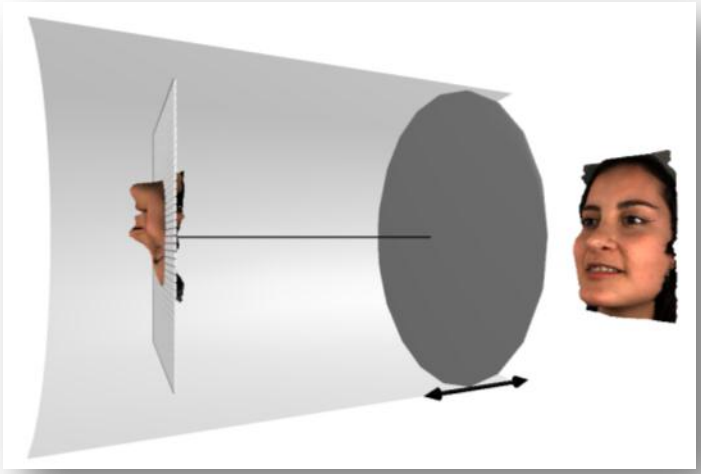
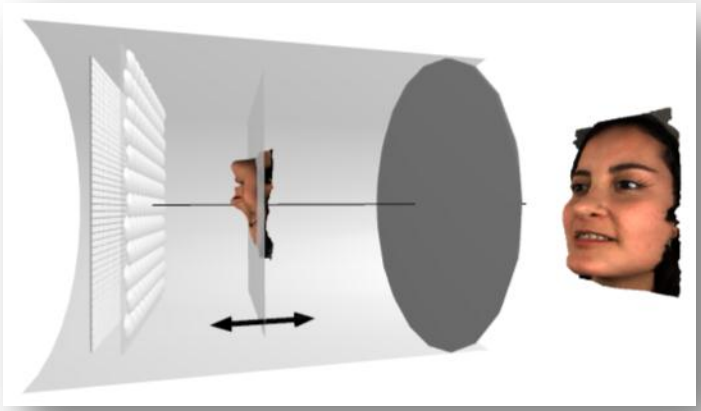
Basic Image Generation

Standard Camera
Main lens focuses directly onto image plane.



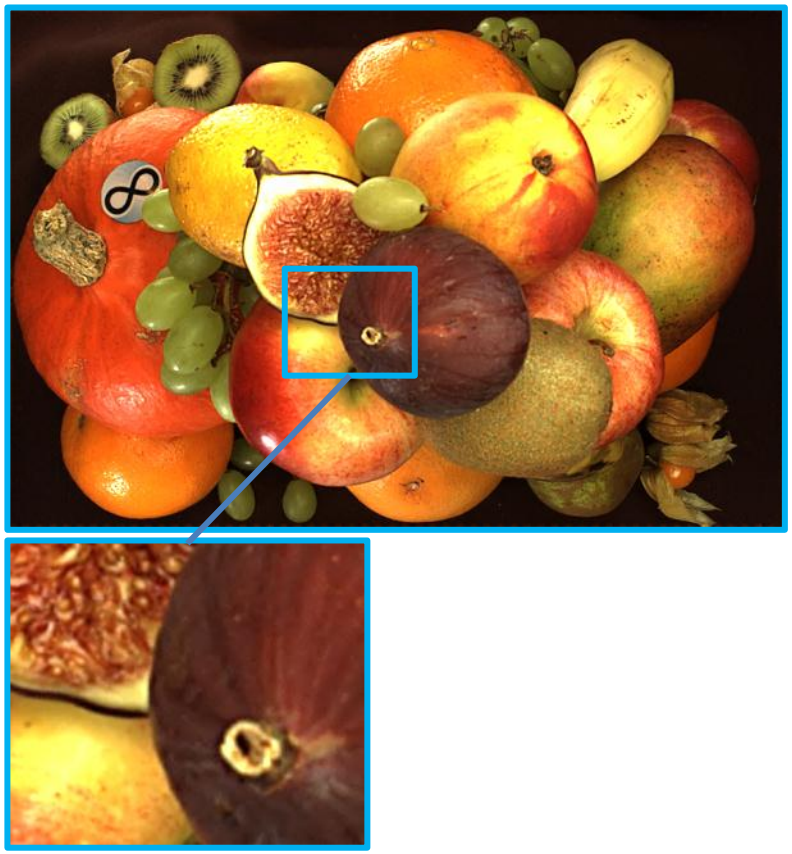
Lightfield Camera
Main lens generates intermediate image. Microlens array acts as camera array that focuses intermediate image onto image plane.



Extended Depth of Field Comparison

Standard Camera

Raytrix Lightfield Camera



Both images were taken with same 11 megapixel sensor, same lens and same aperture.

Some Plenoptics History

1903 Ives (barrier camera)
1908 Lippman (microlens camera)
1911 Sokolov
1935 Coffey
1948 Ivanov
1968 Chutjian (first digital lightfield device)
1970 Dudnikov
1991 Adelson (plenoptic camera)
1996 Levoy & Hanrahan (lightfield)
2000 Isaksen (refocusing)
2005 Ng (handheld plenoptic camera)
2006 Levoy (microscopy)
2006 Georgiev & Lumsdaine (plenoptics 2.0)
2008 Fife (plenoptic CCD sensor)
2010 Raytrix (first commercial lightfield camera)

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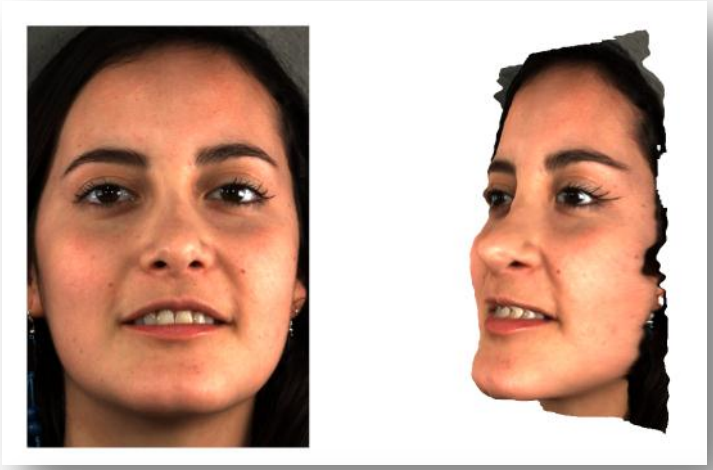
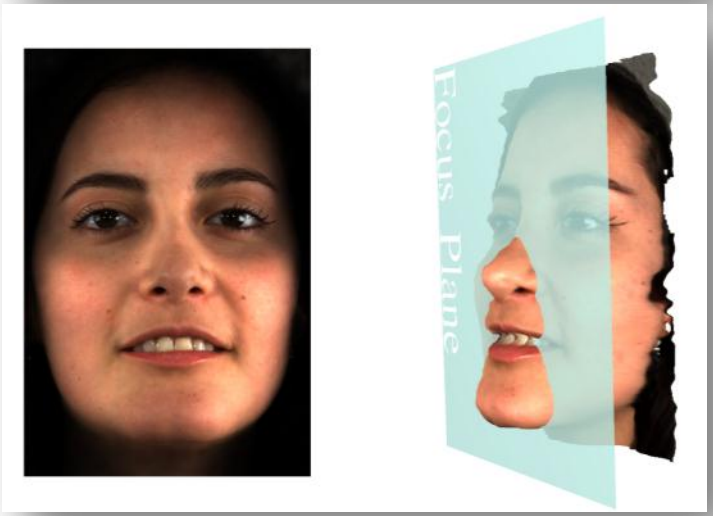
3D-Face Capture

3D Reconstruction
3D reconstruction of face from single shot with Raytrix camera.



Re-Lighting of Image
3D information can be used to re-light image depending on depth.

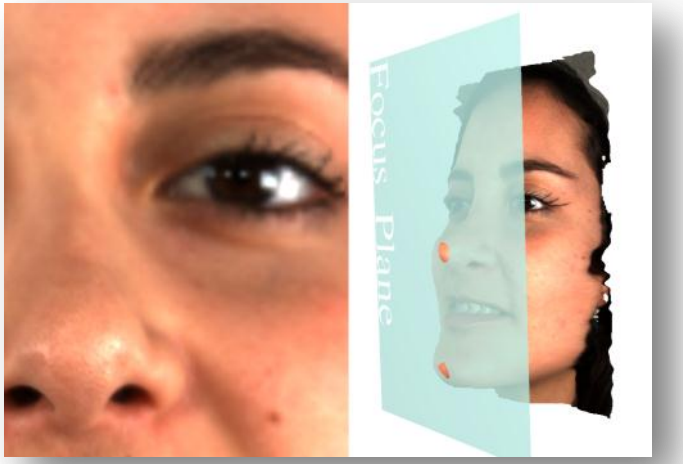


Picture taken with Raytrix R11C camera

3D-Face Capture

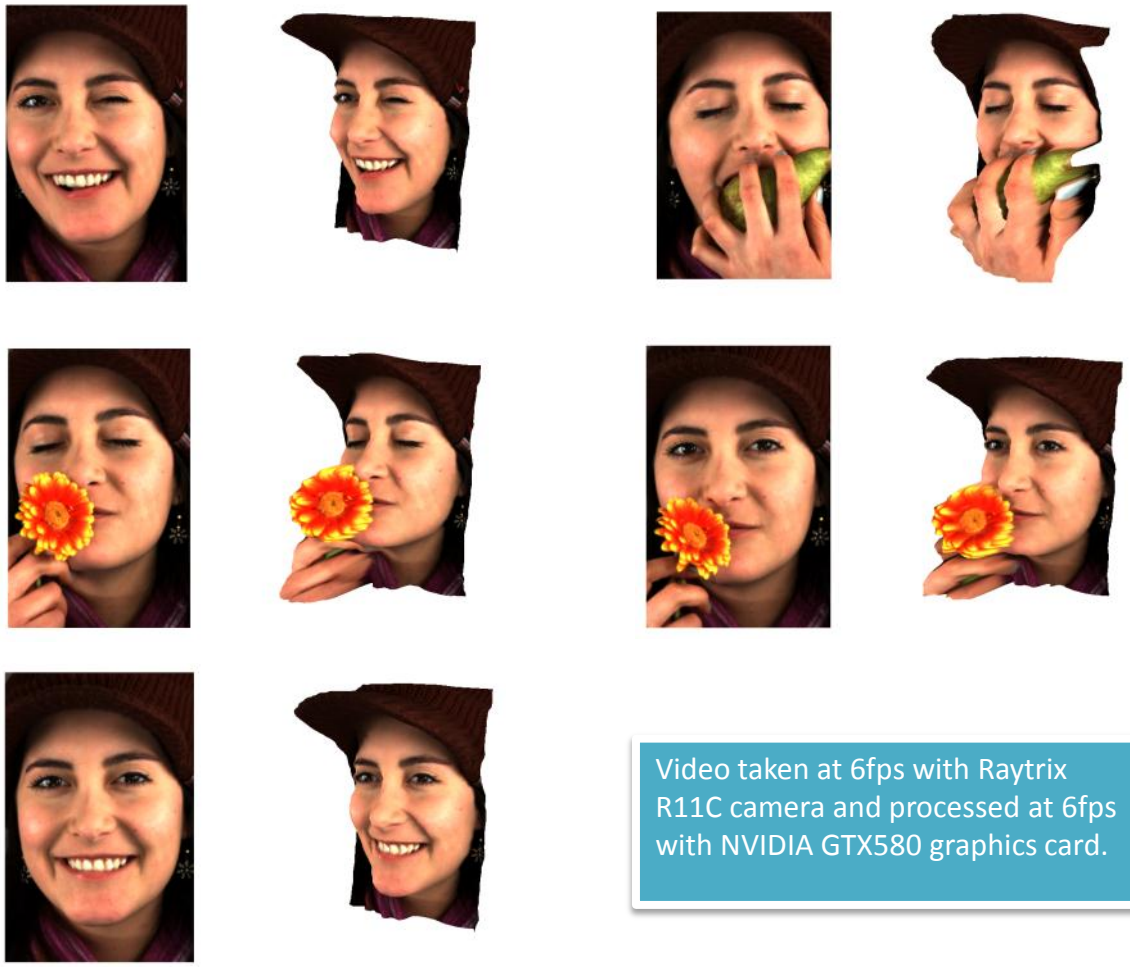
Re-Focus on Eye
Use 3D image information to blur image parts outside the focus plane.

Re-Focus on Nose
Use 3D image information to blur image parts outside the focus plane.



Picture taken with Raytrix R11C camera

3D-Face Video



Video taken at 6fps with Raytrix R11C camera and processed at 6fps with NVIDIA GTX580 graphics card.

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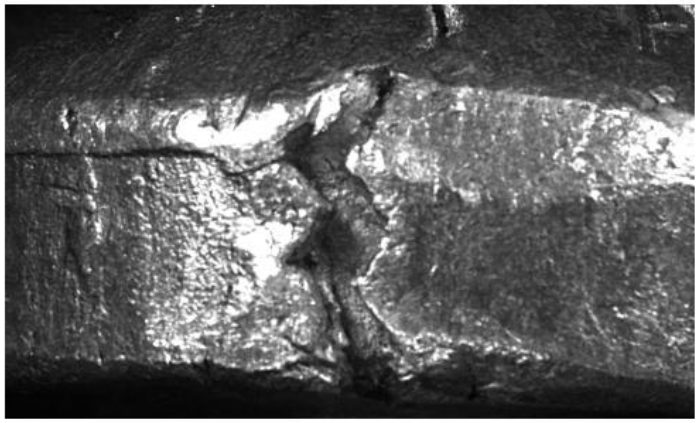
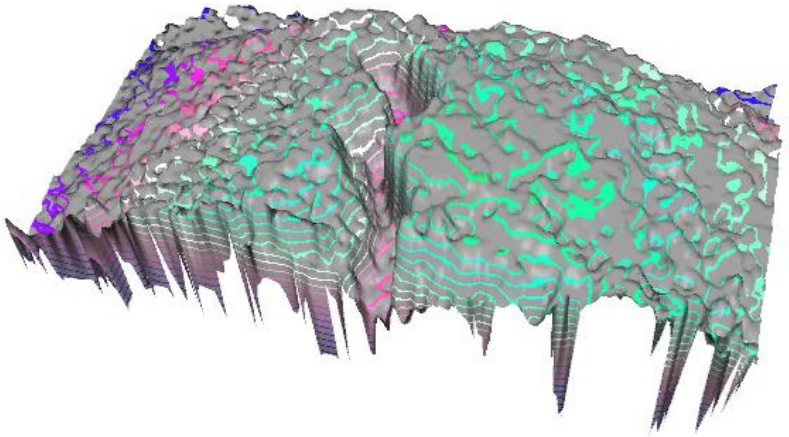
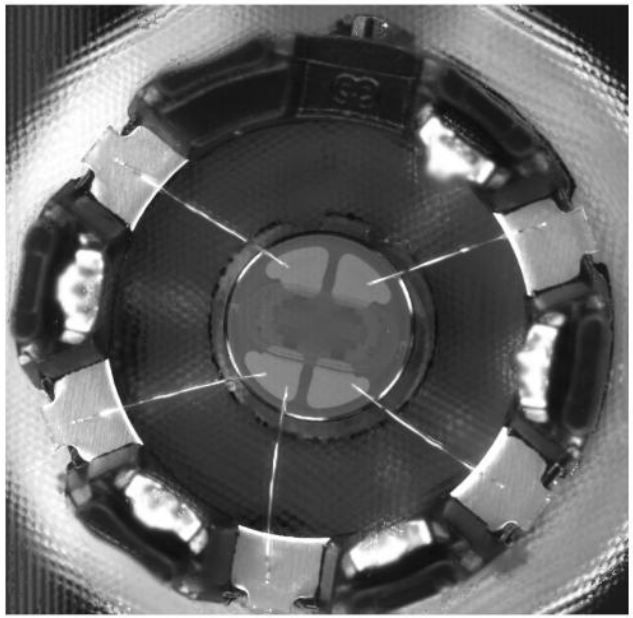
Quality Inspection – Bolt Head

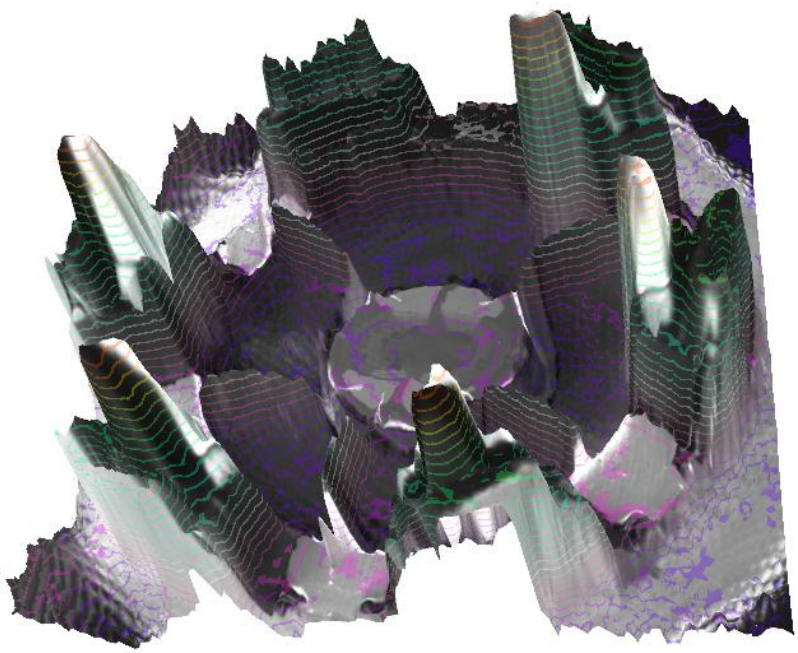




Picture taken with Raytrix R1M camera

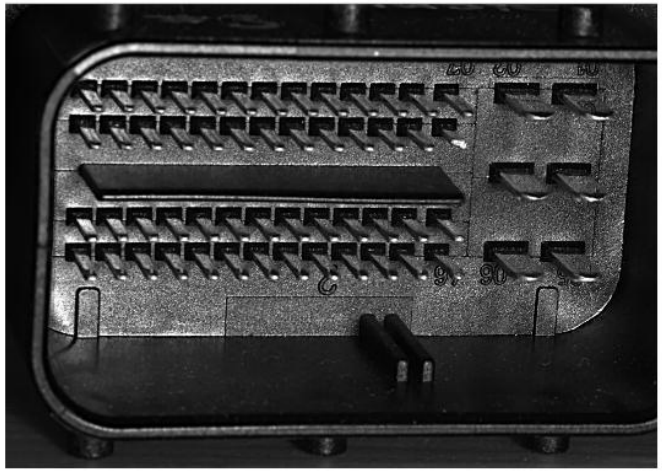
Quality Inspection - Bonding Wires

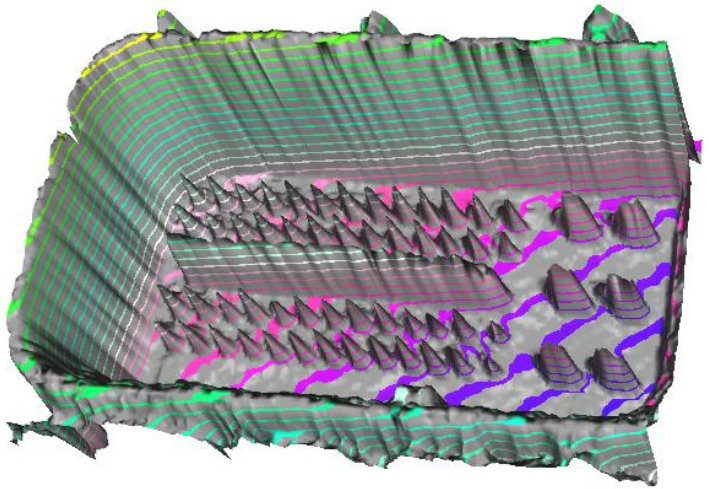




Picture taken with Raytrix R11M camera

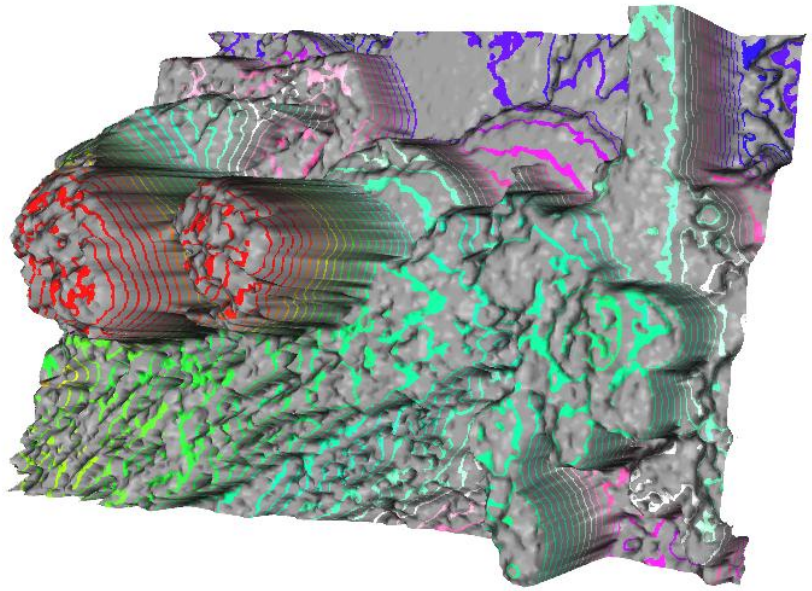
Quality Inspection - Pinout





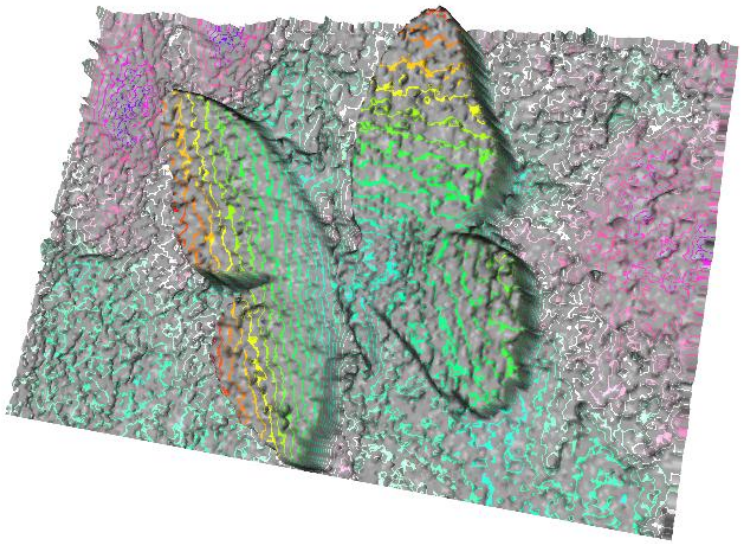
Picture taken with Raytrix R11M camera

Natural Images



Picture taken with Raytrix R11C camera

Natural Images

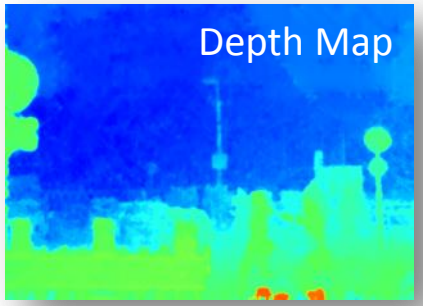


Picture taken with Raytrix R11C camera

Natural Images - *500mm Telephoto Lens*

Photo shoot location

All-in-focus image



Full-HD
Resolution

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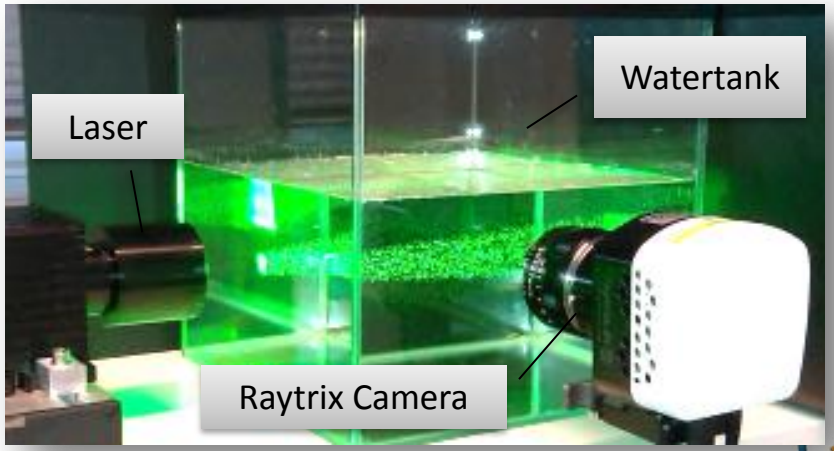
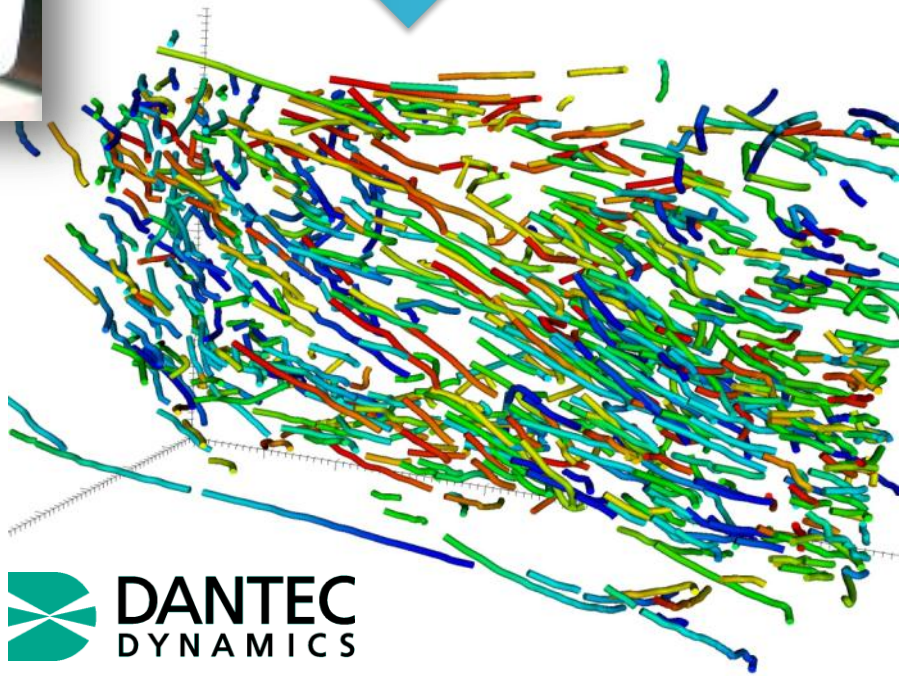
Lightfield Volumetric Velocimetry



Calculate 3D flow vectors and particle time-histories from lightfield data



- Measure 3D flow of particles in water.
- Need only **one** lightfield camera.
- Simple calibration with single image.
- No need to synchronize cameras.
- Robust setup.

DANTEC DYNAMICS

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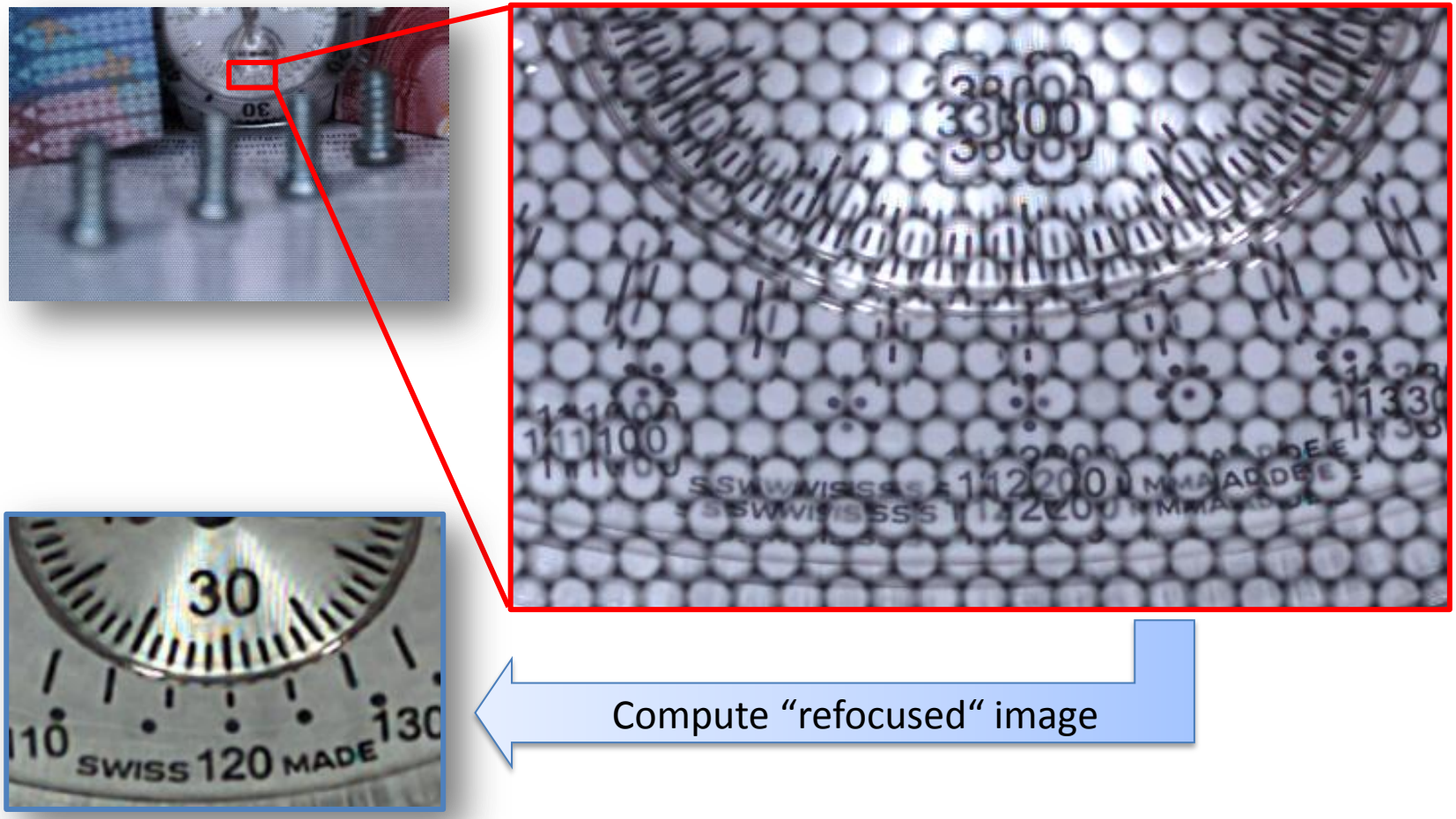
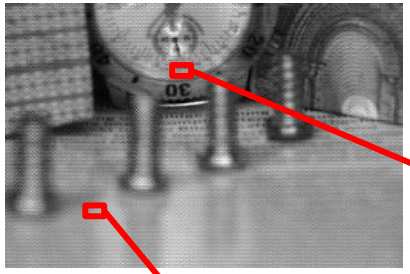
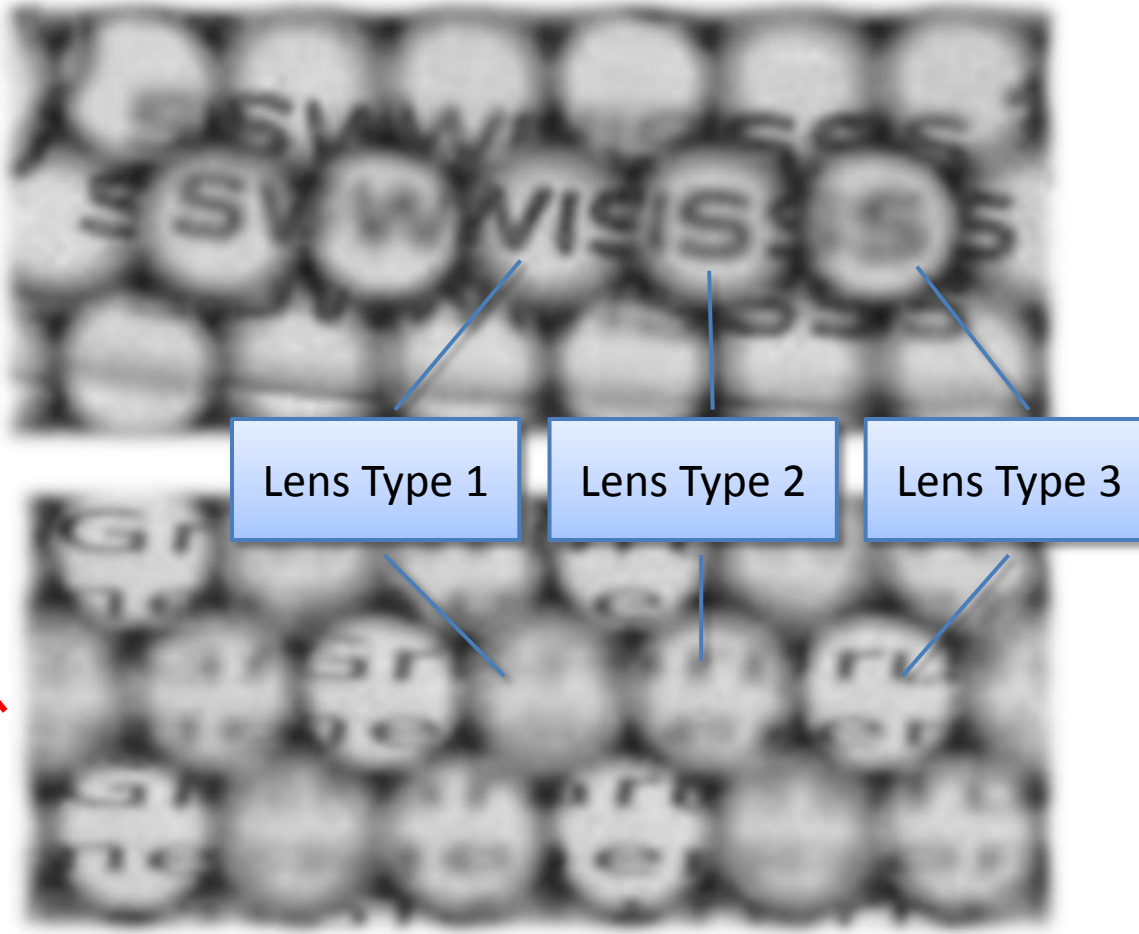
Example: Plenoptic Camera Raw Image



Extended Depth-of-Field





Raytrix cameras use micro lens arrays with different micro lens types which differ in their focal length. This extends the depth-of-field of the camera.

Patent pending

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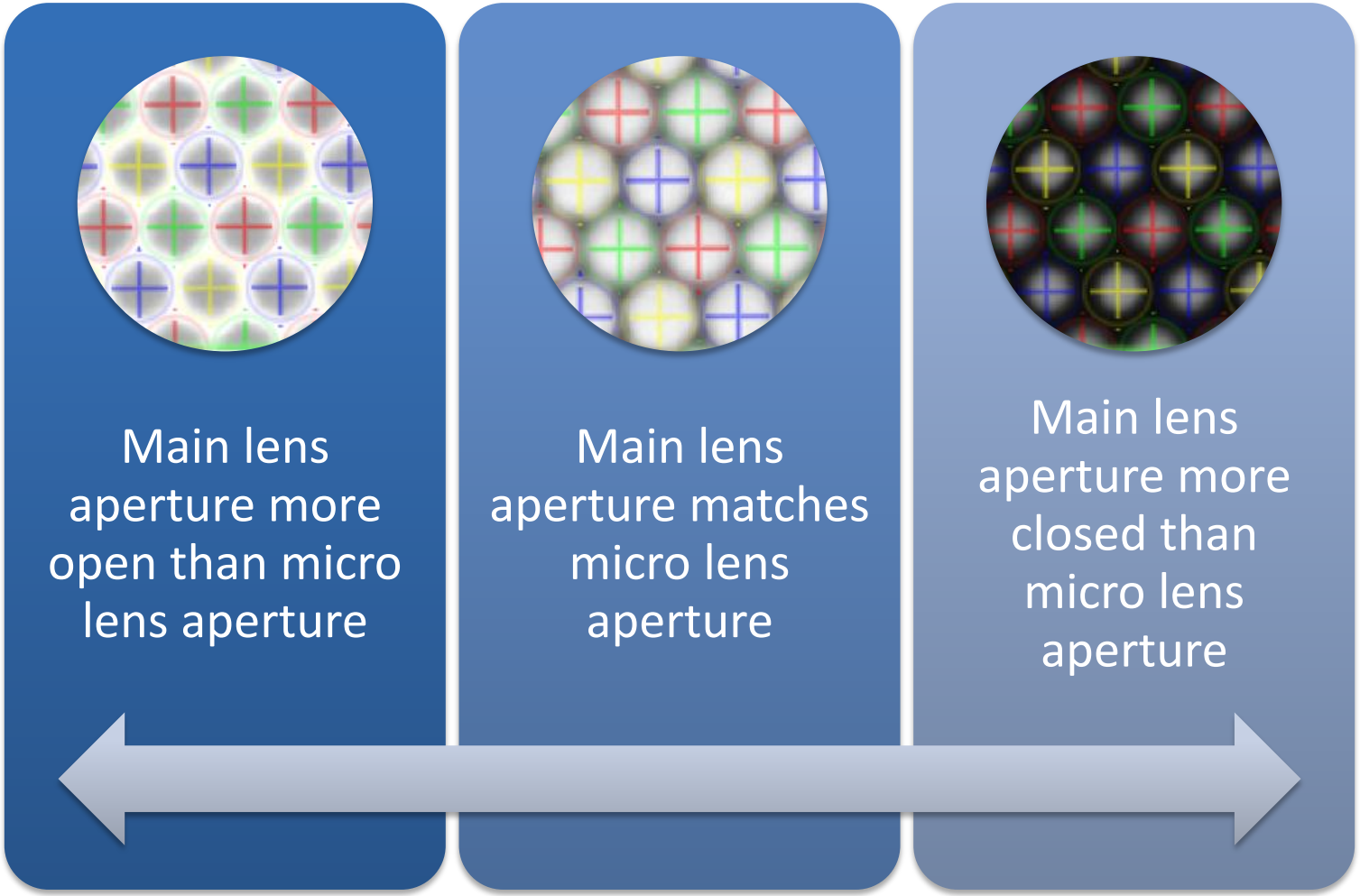
Lightfield Camera F-Matching

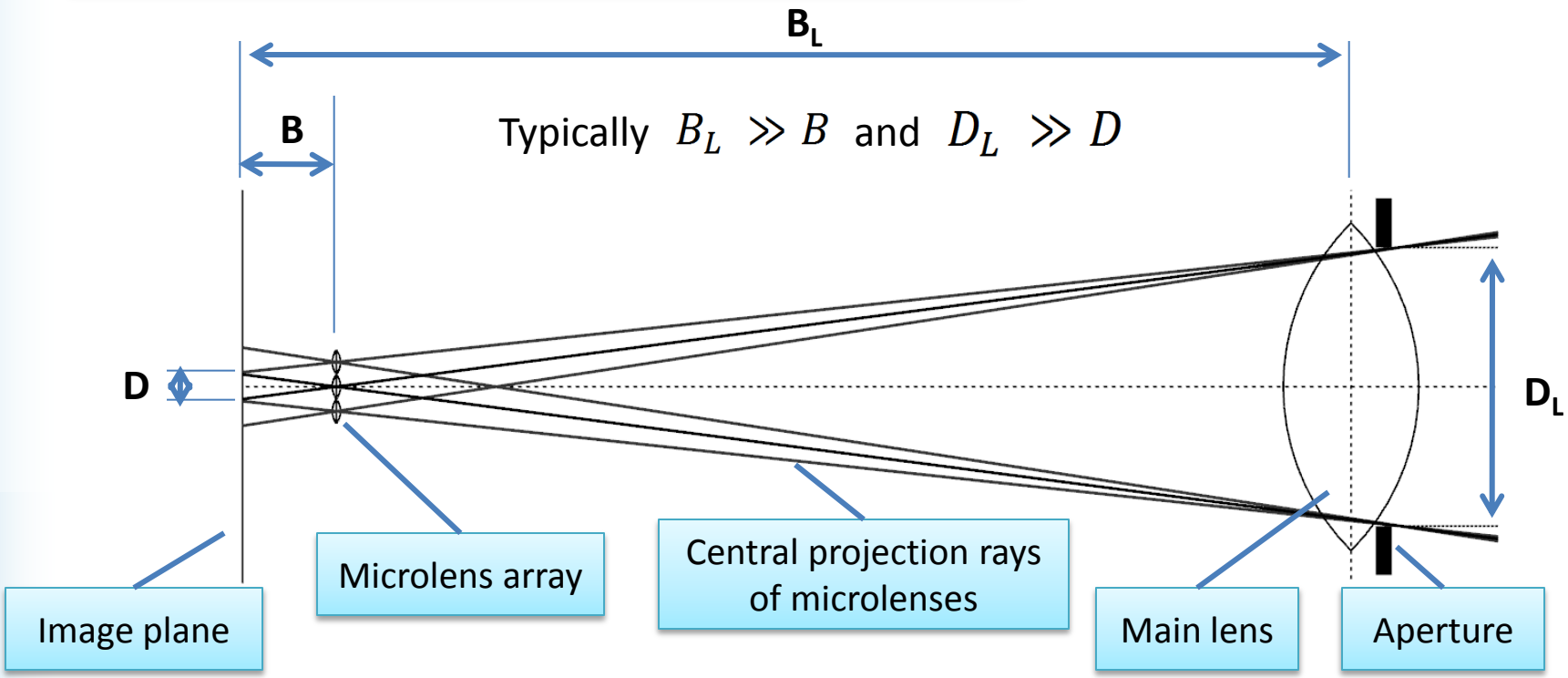


Light Field Camera F-Matching

The F-numbers of the main aperture has to equal the F-numbers of the microlenses. Otherwise, either the micro images overlap or there are gaps between neighbouring micro images.

Microlens $F = \frac{B}{D}$

Main lens $F_L = \frac{B_L}{D_L}$



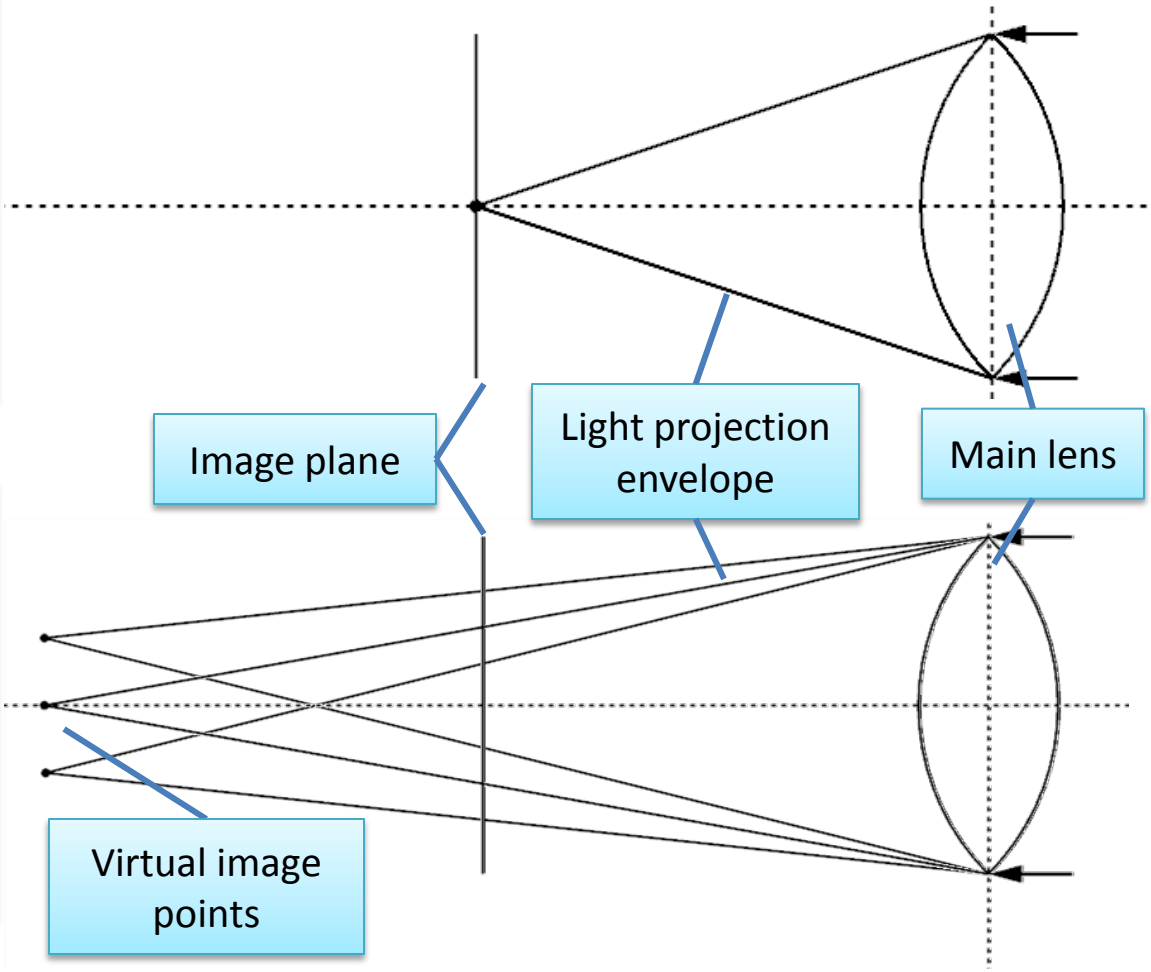
Standard Camera Image Formation

Light rays focused onto point on image plane by main lens.

All light rays inside the light projection envelope are integrated at the image point.

Sets of light rays focused to points behind the image plane.

Pixel on image plane sample light rays from different directions but also from different points.

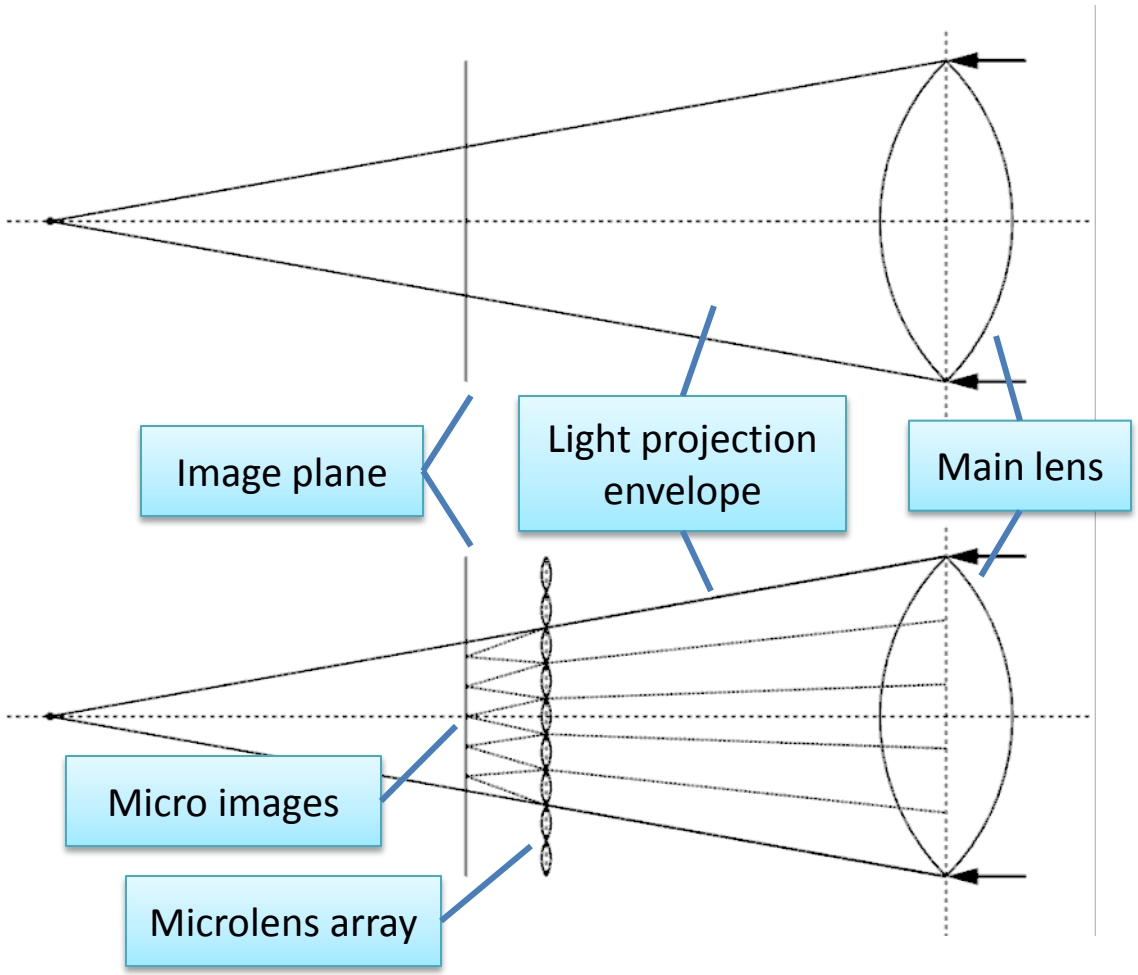


Light Field Camera Image Formation

Light rays focused to point behind image plane by main lens.

Light rays focused to a point behind the image plane by main lens.

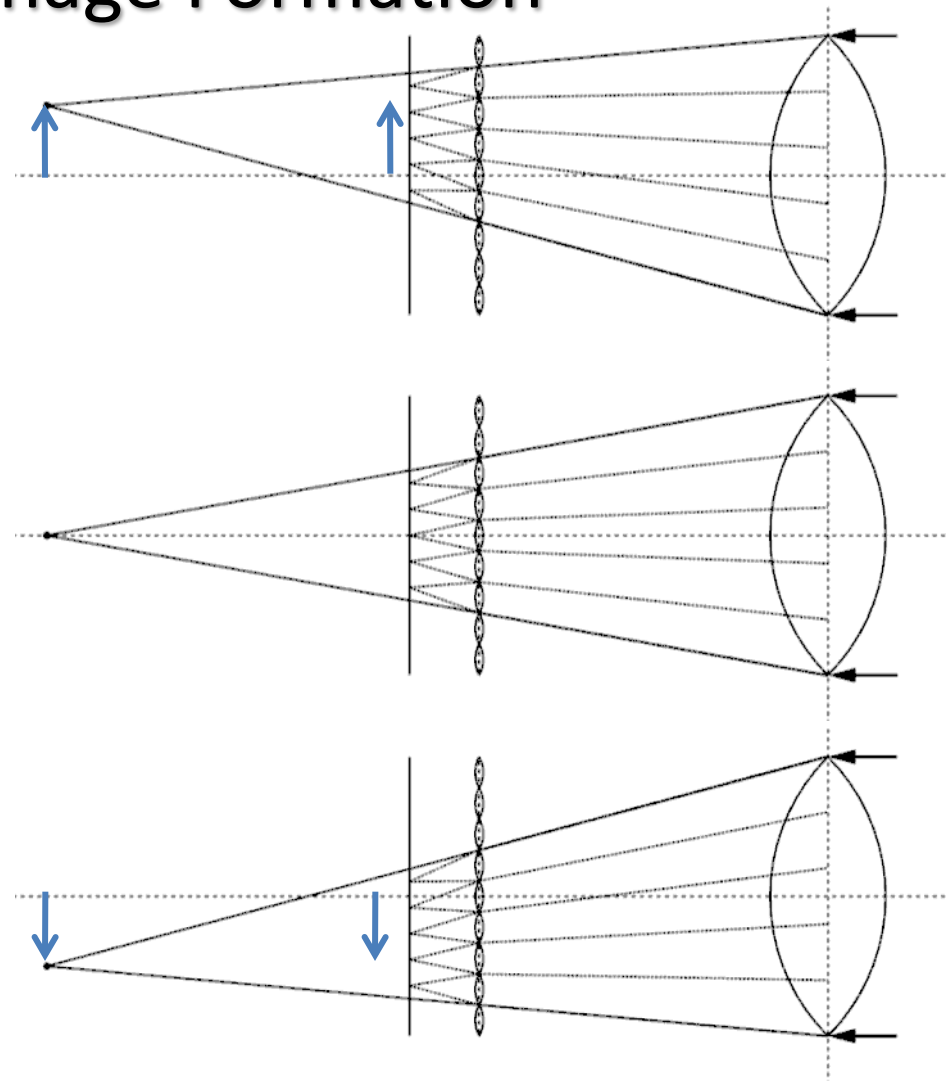
Microlenses sample sub-sets of light rays and focus them to a set of points.



Light Field Camera Image Formation

The light projection envelopes for virtual image points at ***different positions*** create non-overlapping sets of micro images.

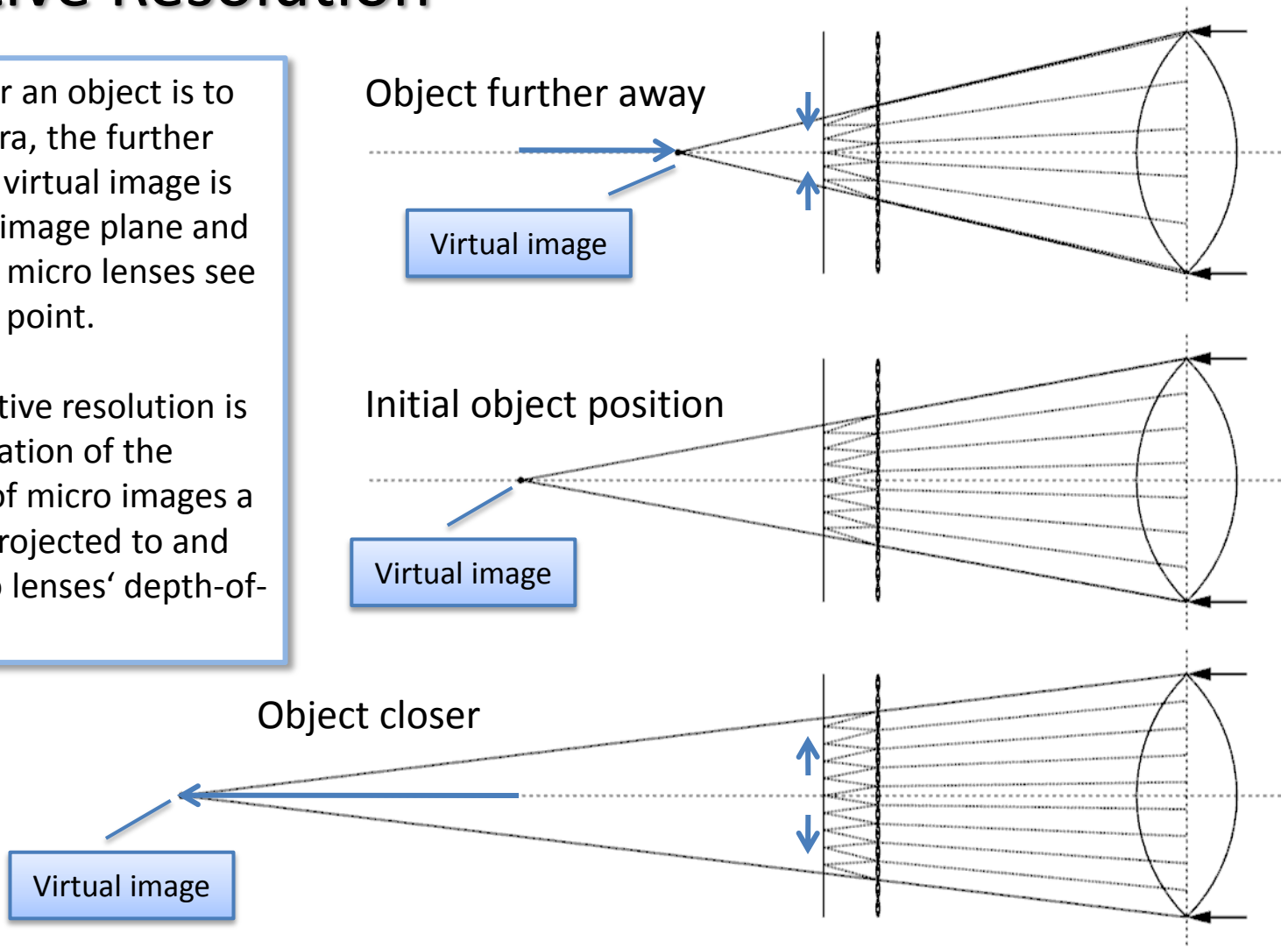
The original light projection envelope can be reconstructed.



Effective Resolution

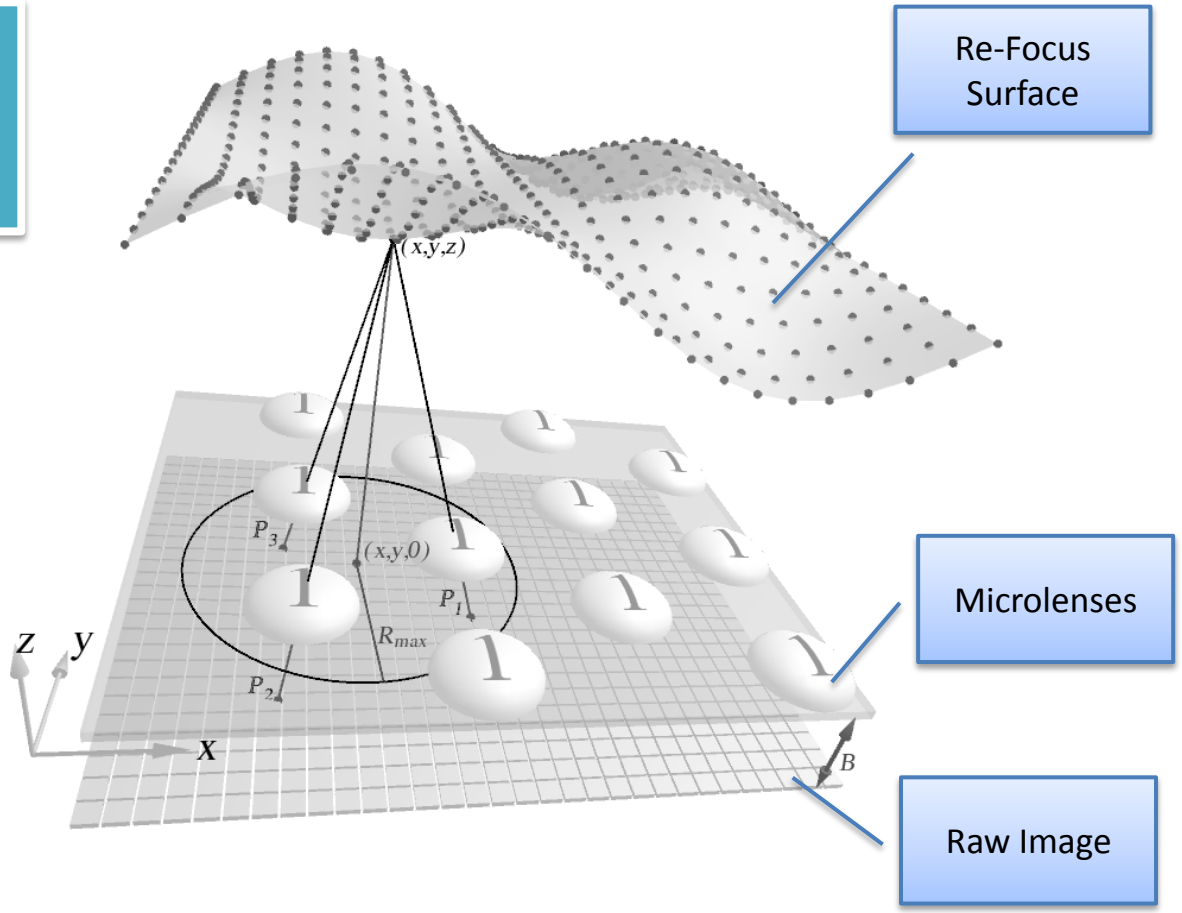
The closer an object is to the camera, the further away the virtual image is from the image plane and the more micro lenses see the same point.

The effective resolution is a combination of the number of micro images a point is projected to and the micro lenses' depth-of-field.



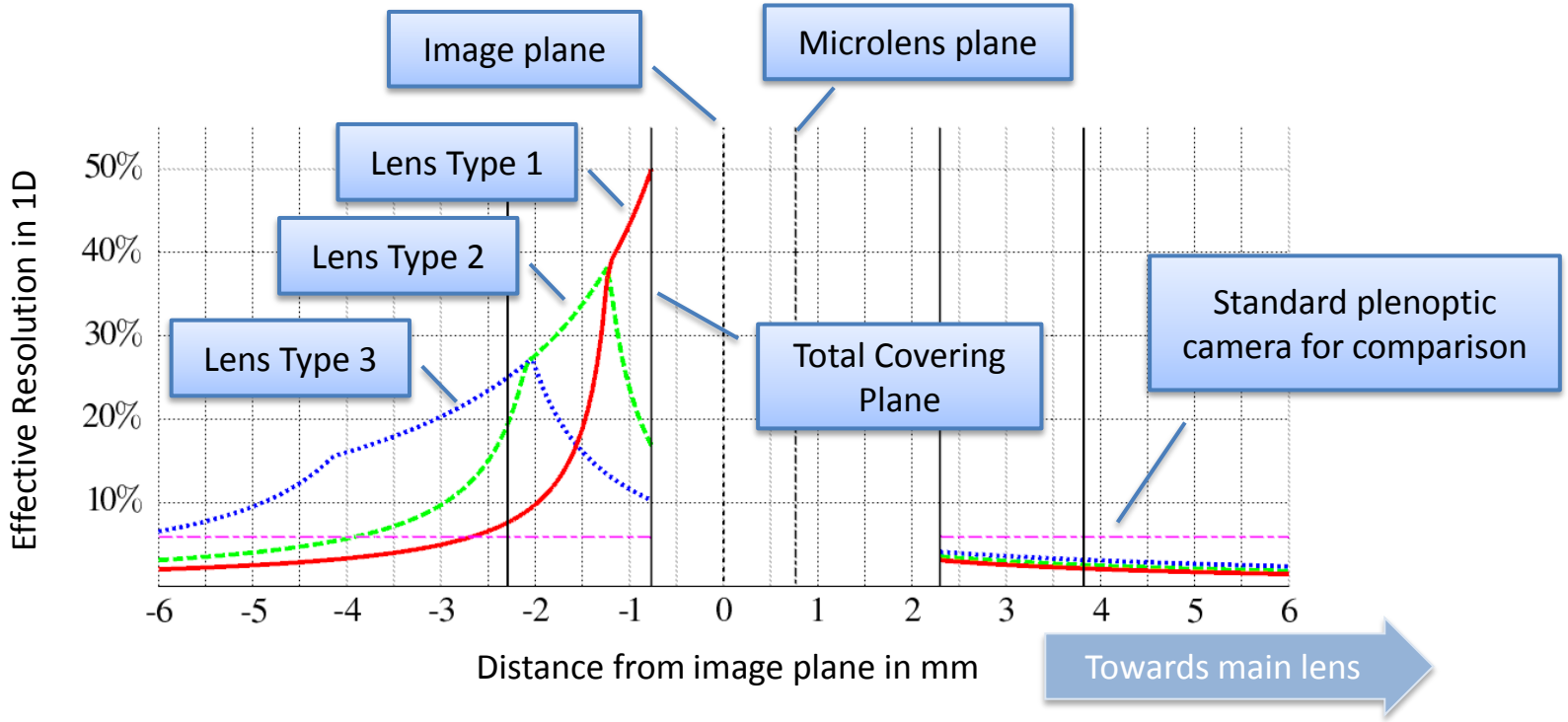
Refocusing

Construction of re-focused image from raw image by calculating projection rays from re-focus surface onto image image.



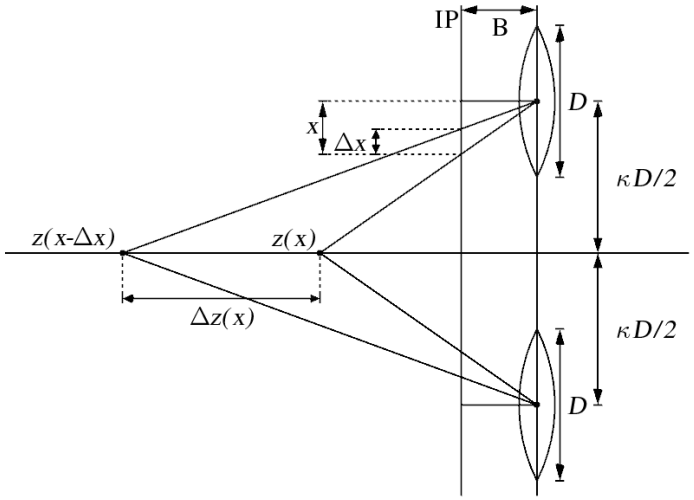
Effective Resolution – Multi Focus

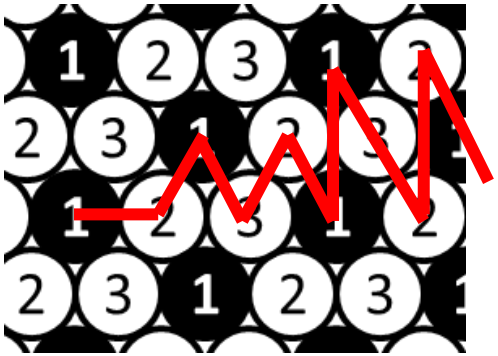
Effective resolution ratio for one image dimension per lens type with respect to virtual image position. Objects projected onto total covering plane are those furthest away that can still be refocused. As objects get closer to camera, the effective resolution is reduced.



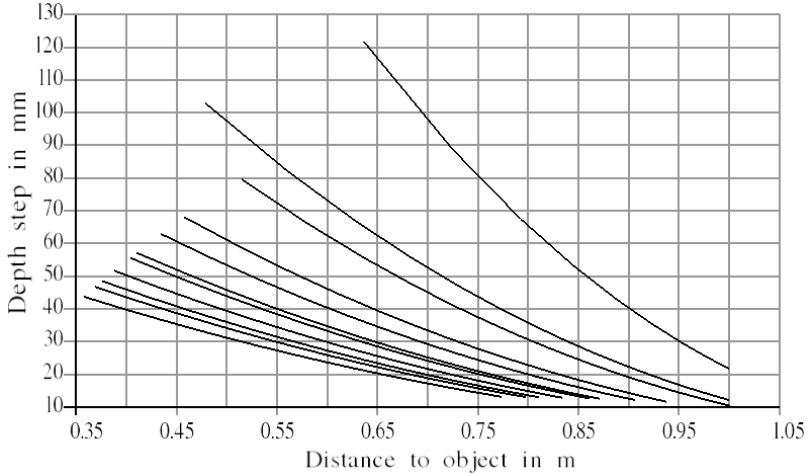
Depth Resolution

Depth is calculated by matching corresponding image patches in neighboring micro lenses. Depending on how close an object is to the camera, micro lenses with a larger distance can be used, which improves the depth resolution.



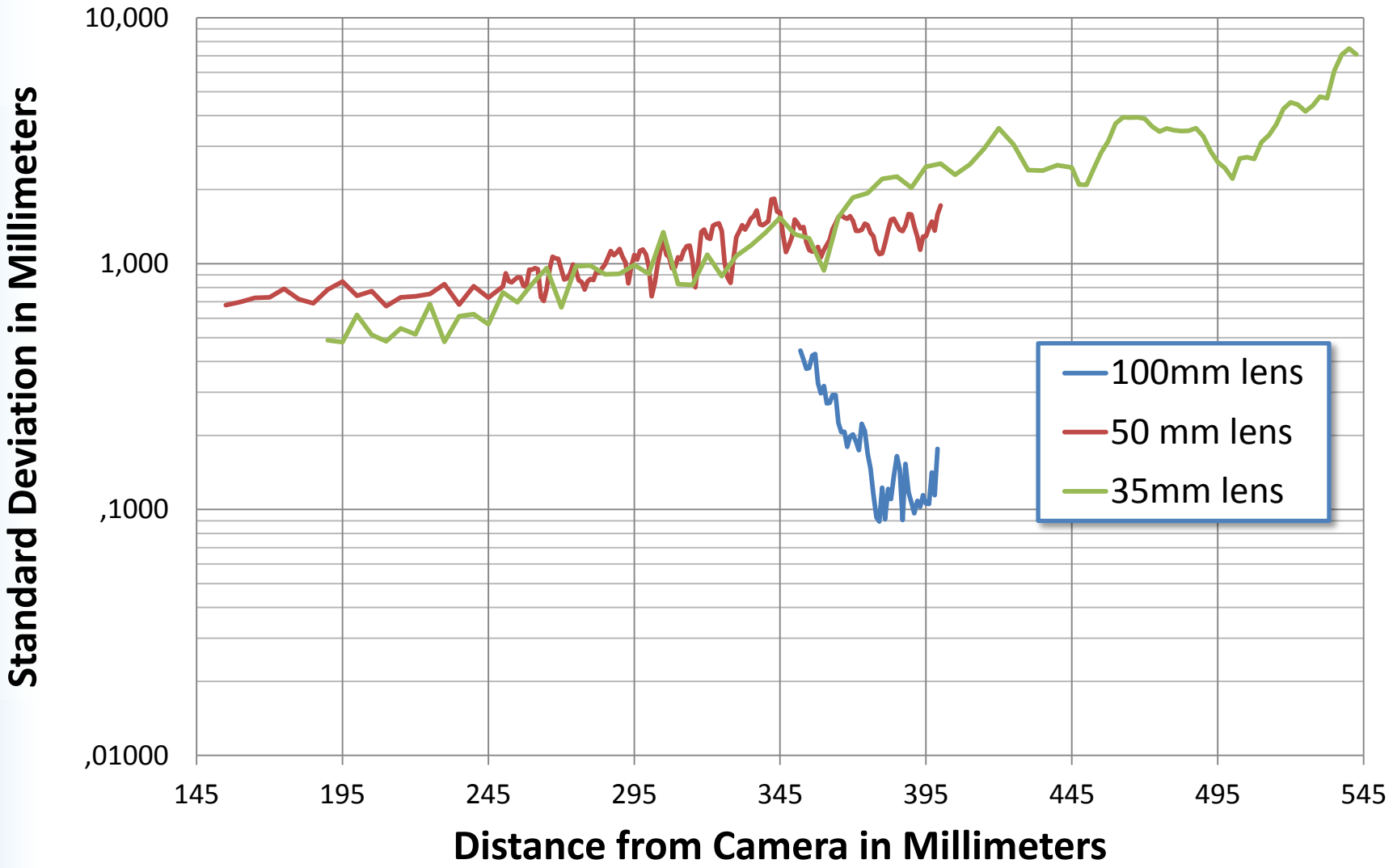


First 10 neighbors with incresing distance

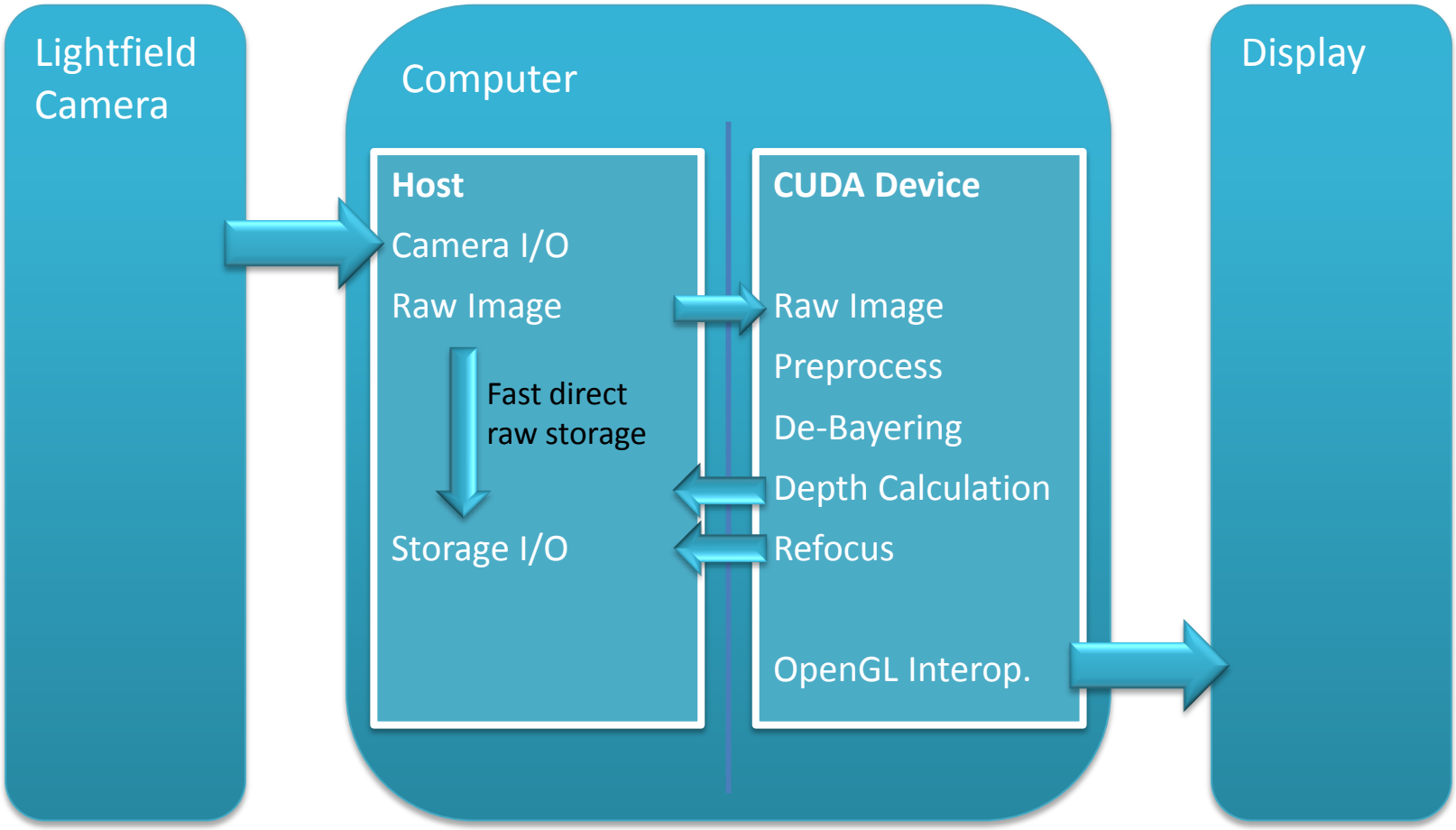


Depth resolution graphs for first 11 neighbors

Depth Resolution - Real Data Results



Software Architecture



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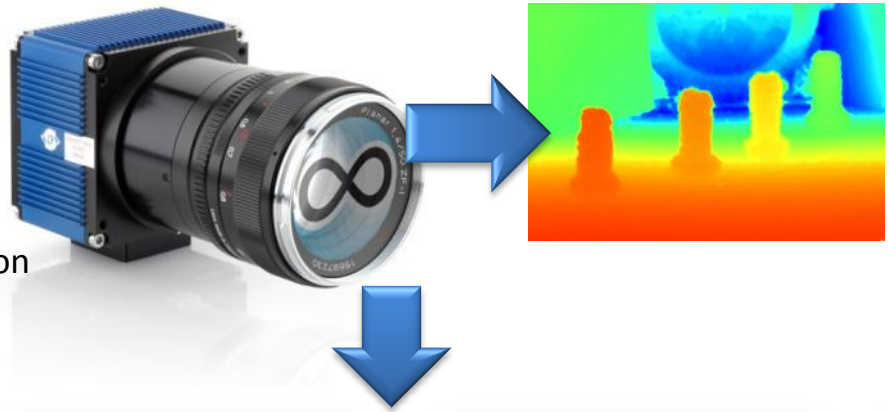
One Shot – Many Outputs

Single shot

- One raw image
- Video possible
- Makro and Tele lenses
- Arbitrary object sizes and distances
- High effective resolution



Depth Map

- No 3D-calibration needed
- Depth can only be calculated at structured areas

3D-Data

3D-View

- Variable base line
- Variable image orientation
- Multi-View for auto-stereoscopic displays

All-In-Focus

Image Processing

- selective per-pixel focus
- Variable view point horizontally and vertically
- Variable 3D-zoom effect

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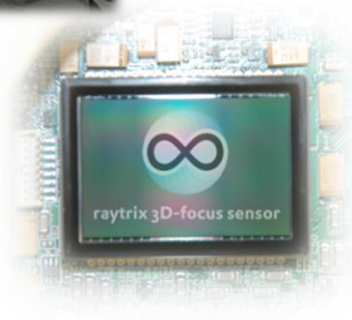
Thank you for your attention!



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