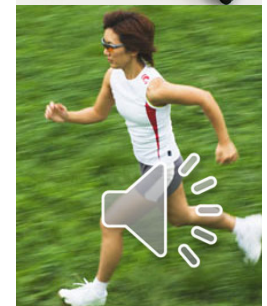# Interactive System インタラクティブシステム特論 (3)

Hiroyuki Kajimoto
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Twitter kajimoto

Outline of the lecture

1. 人間計測手法／Measuring Human
2. 視覚／Human Vision System
3. 視覚センシング／Visual Sensing
4. 視覚ディスプレイ／Visual Display
5. 聴覚、聴覚インタフェース／Auditory Interface
6. 触覚、触覚インタフェース／Tactile Interface
7. 力覚、力覚インタフェース／Haptic Interface
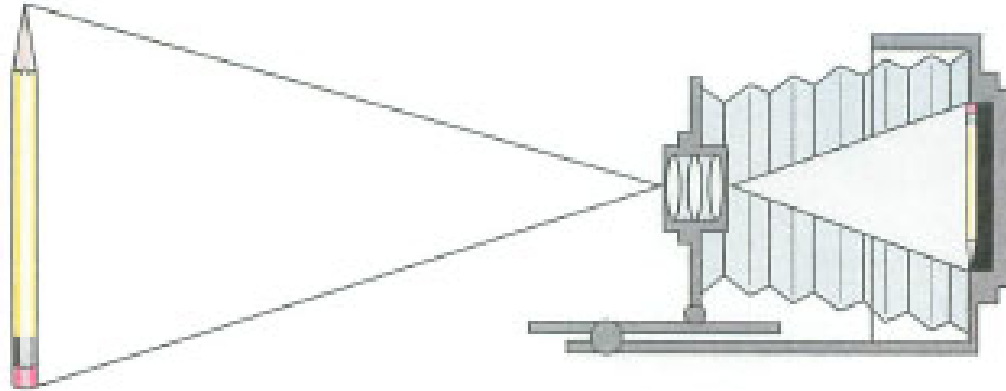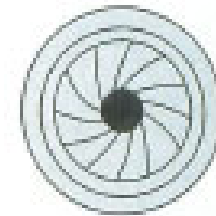8. 移動感覚インタフェース／Locomotion Interface

TODAY's TOPIC

- 光学素子／Optical Elements
- 光学の基礎／Basics of Optics
- 3次元イメージング／ 3D Image Sensing

Structure of a Camera

カンデル神経科学(Principles of Neural Science)
https://www.medsi.co.jp/kandel/syousai/index.html

- Lens
- Iris
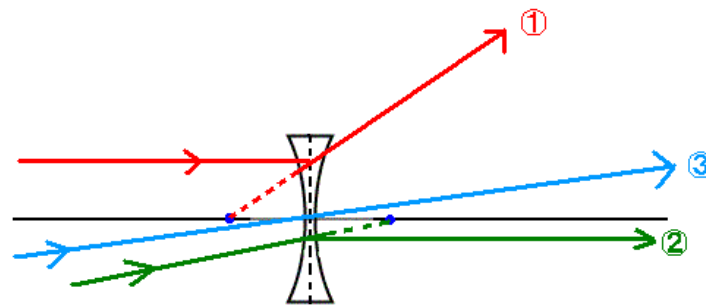- Shutter
- Film

レンズ／Lens

- ## Convex Lens
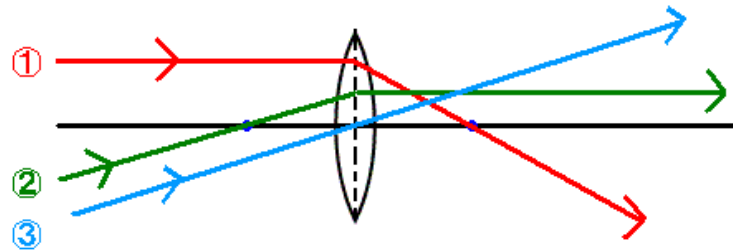
- ## Concave Lens

レンズ，ミラー以外でインタラクティブシステムでよく用いられる光学素子（の一部）
Other optical elements for interactive system

- フレネルレンズ／Fresnel Lens
- レンチキュラレンズ／Lenticular Lens
- ハーフミラー／Half Mirror
- 偏光板／Polarization Plate
- プライバシーフィルタ
- 波長フィルタ／Low-pass/High-pass/Band-pass Filter
- 光ファイバ／Optical Fiber
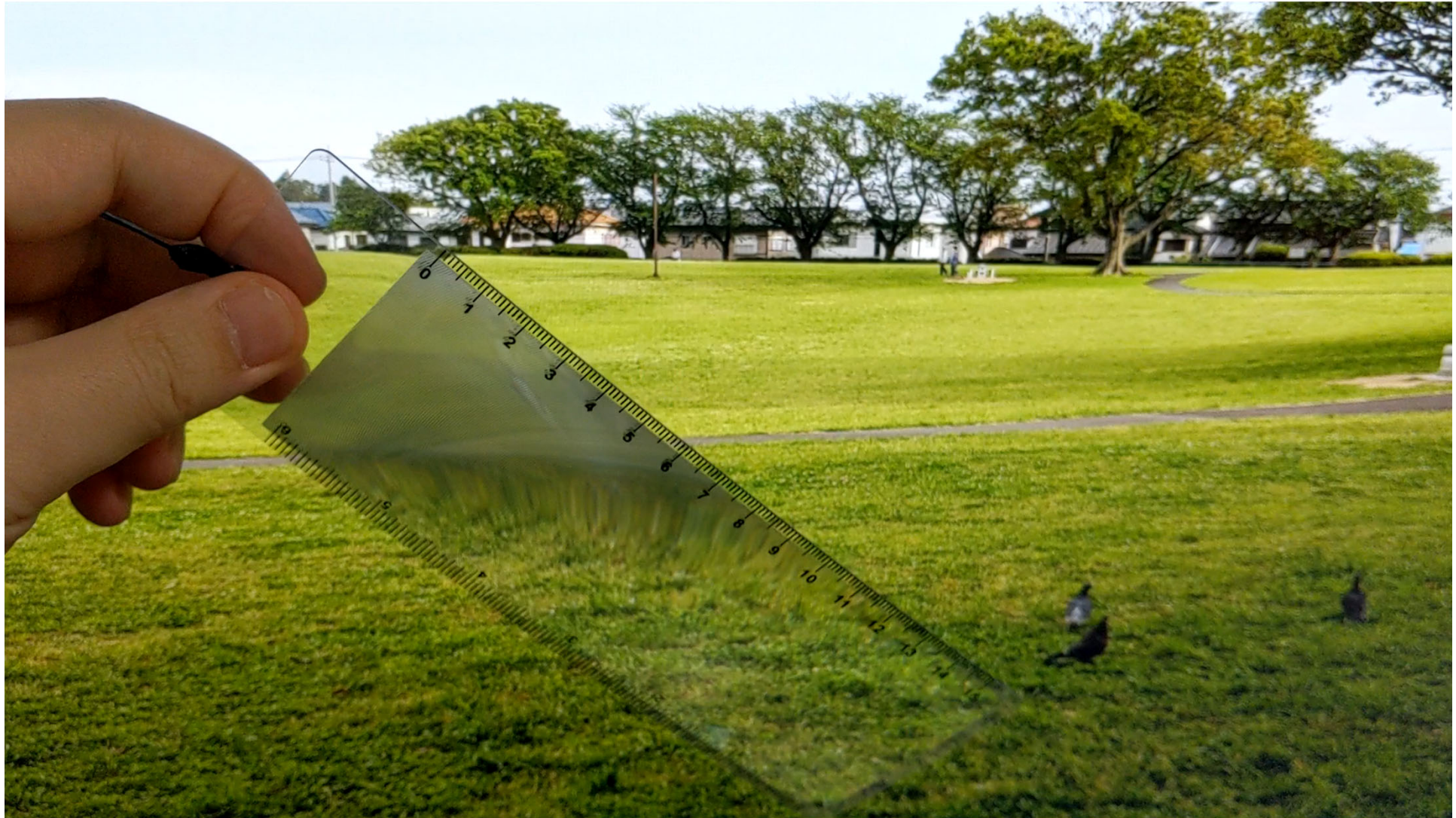- 再帰性反射材 / Retroreflector
- 再帰透過光学素子 / Micro Mirror Array Plates

フレネルレンズ／Fresnel Lens
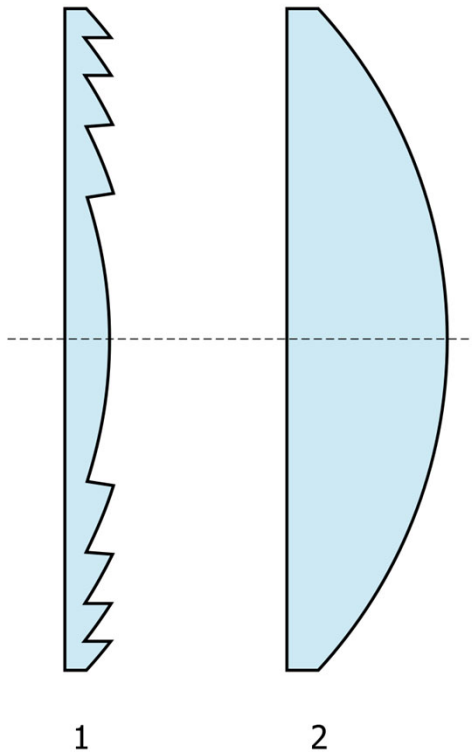
- 薄い平板状のため，大面積のレンズが安価，軽量に作成可能
  Thin plate which surface has lens structure. Becomes cheap and light weight.
- 照明光学系に多く使用（カメラのストロボ，灯台等）
  Occasionally used for lighting (flash, lighthouse, etc)
- フレネルミラーもある（表面に蒸着）
  Fresnel mirror can be made with surface metal coating.
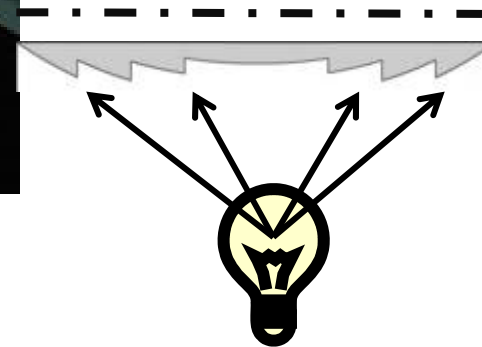
フレネルレンズ／Fresnel Lens

オーバーヘッドプロジェクタ
Overhead Projector
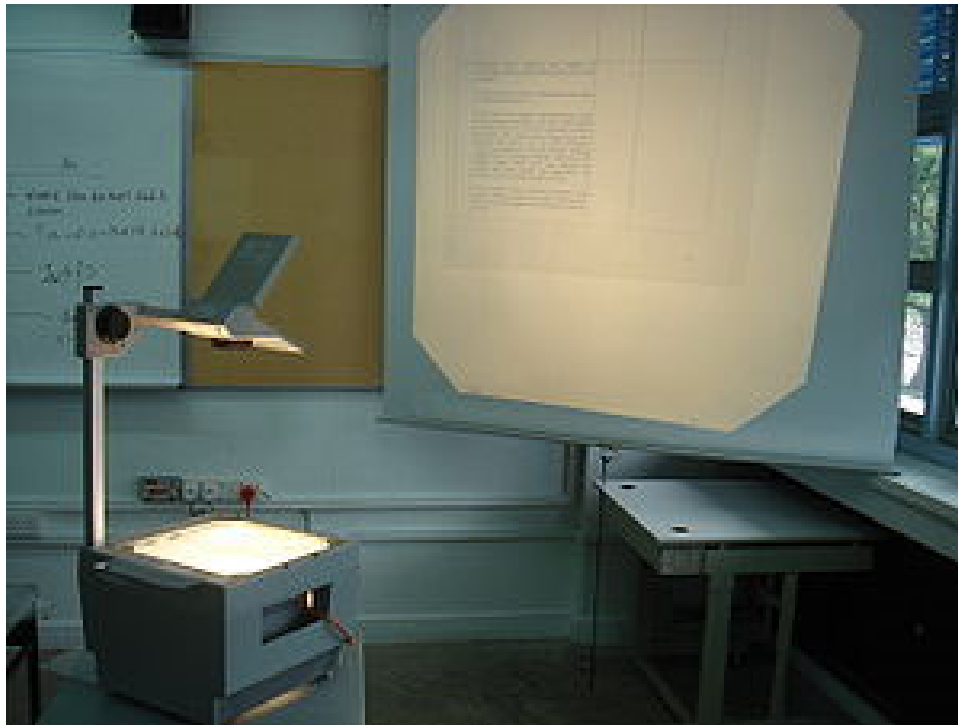
Overhead Projector (Wikipedia)
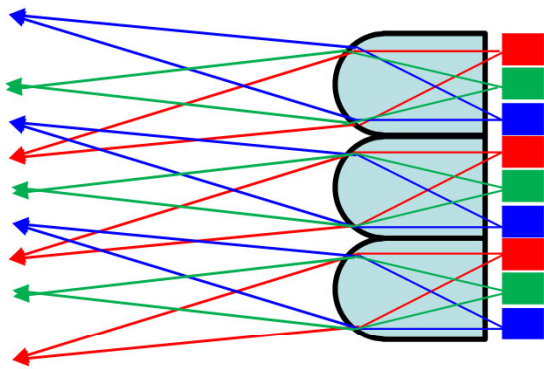https://en.wikipedia.org/wiki/Overhead_projector

- ミラー
  光路屈曲＋反転
- レンズ
  実像の生成（反転）

- OHPシート
- フレネルレンズ
  平行光ないし集約光
  の生成（コリメータ）

- 光源

レンチキュラレンズ／Lenticular Lens

- かまぼこ型レンズの群れ
  array of magnifying lenses.
- マイクロレンズアレイの1次元版

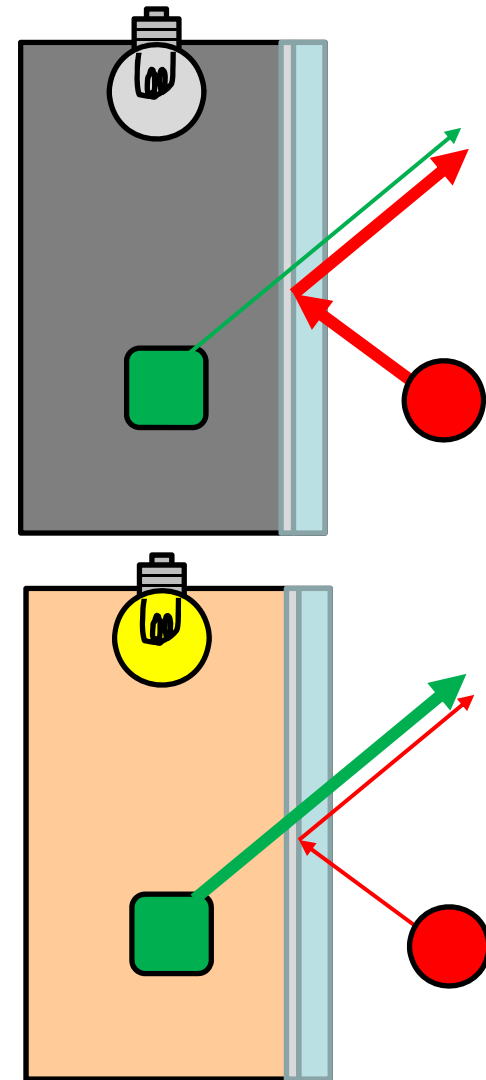# （参考）レンチキュラレンズを用いた歩行誘導／Walk Navibation by Lenticular Lens

http://www.youtube.com/watch?v=VSBRG1_5s2E

Hiromi Yoshikawa, Taku Hachisu, Shogo Fukushima, Masahiro Furukawa, Hiroyuki Kajimoto: ""Vection Field" for Pedestrian Traffic Control", Emerging Technologies Session, ACM SIGGRAPH, 2011
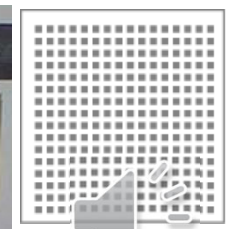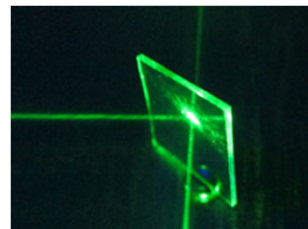
ハーフミラー（ビームスプリッタ・マジックミラー）／Half Mirror, Beam Splitter

全反射＋透過の両方の性質を持つ
Half reflected and half transmitted.

- 平面蒸着タイプ、プリズムタイプ、特殊タイプ
  half-silvered mirror, prism, etc.

Beam splitter (Wikipedia)
https://en.wikipedia.org/wiki/Beam_splitter

ハーフミラーで表情？を作る ／Half Mirror for face modification

ハーフミラーを用いたインタラクティブAR
Interactive AR using Half Mirror

Monitor

Half-Mirror

Virtual Image

Haptic
Display

Typical setup
for tangible AR

A-me: Augmented Memories (SIGGRAPH
ASIA2013)
J. Puig, A. Perkis, A. S. Hoel, A. Cassinelli
https://www.researchgate.net/publication/26238
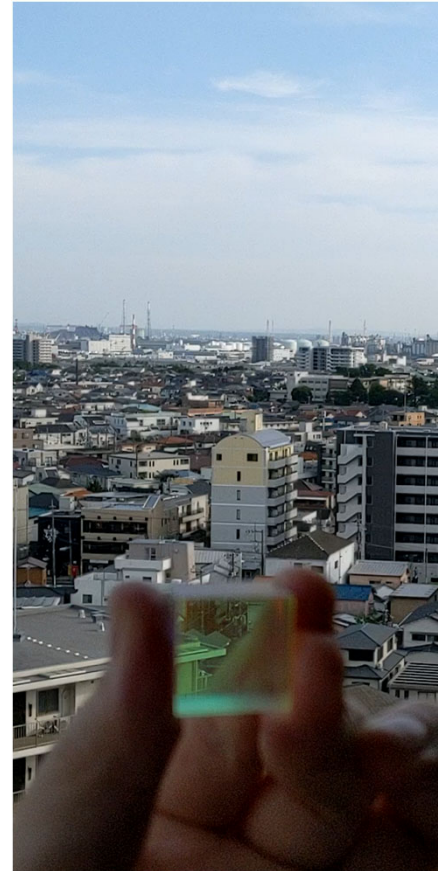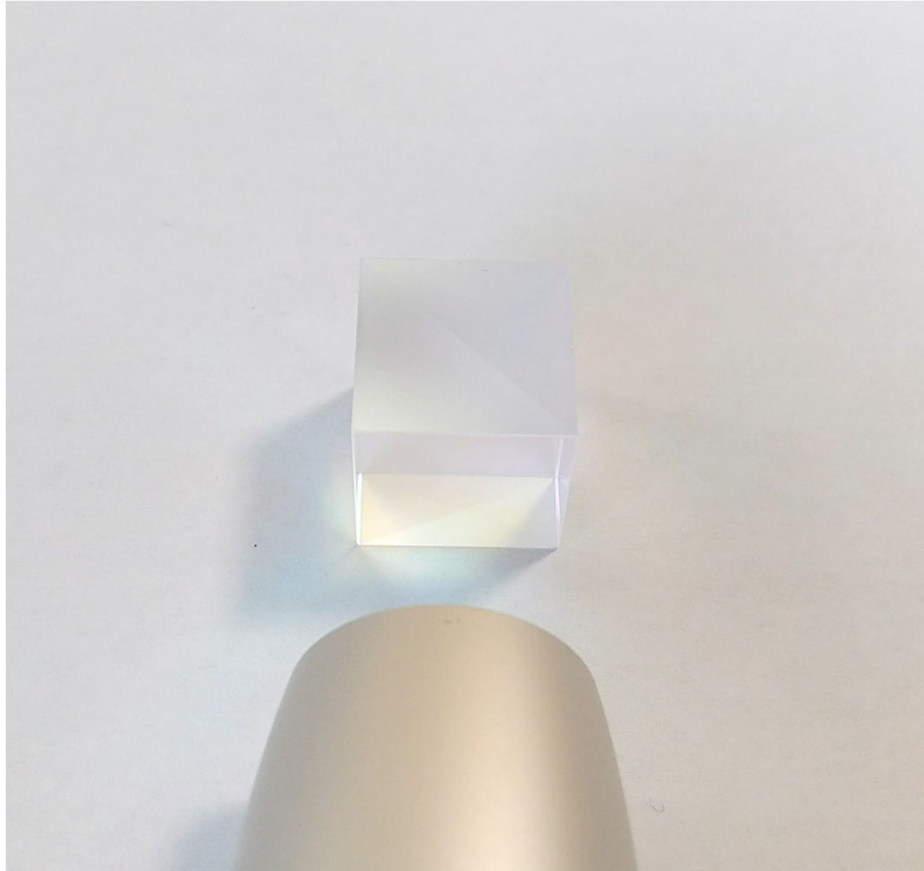9666_A-me_Augmented_memories
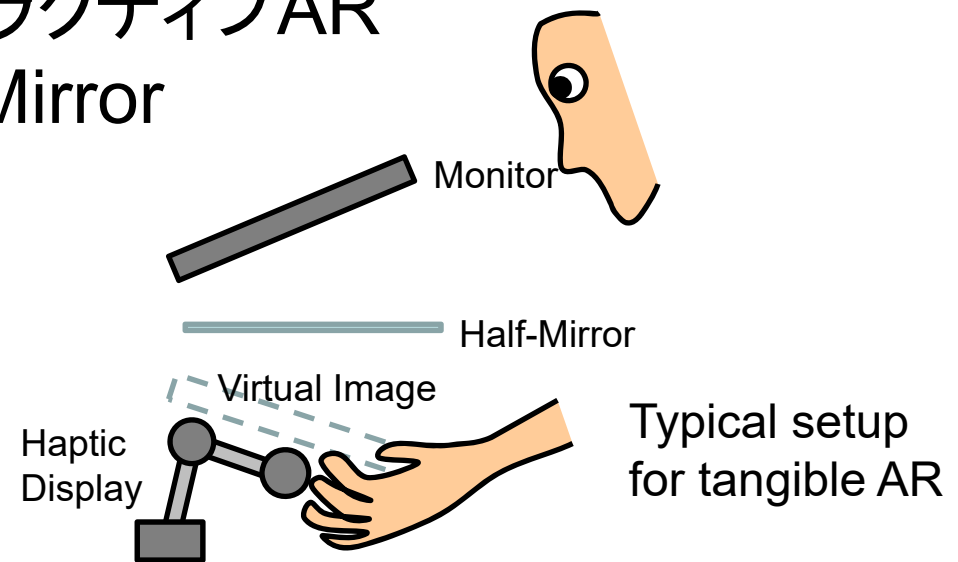
https://www.youtube.com/watch?v=I-gXGT-guPQ
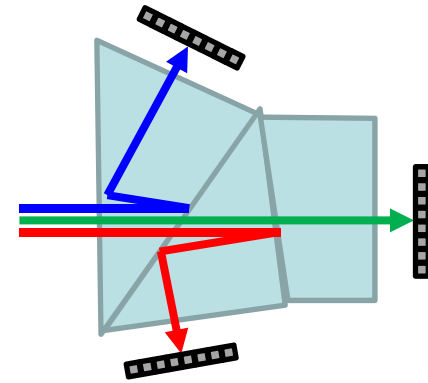T. Yoshinaga, Tabletop Holographic AR with Half-mirror and Marker Tracking

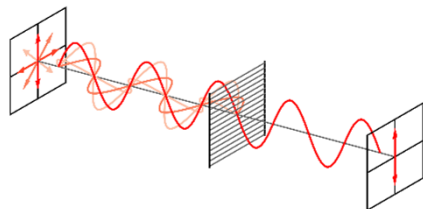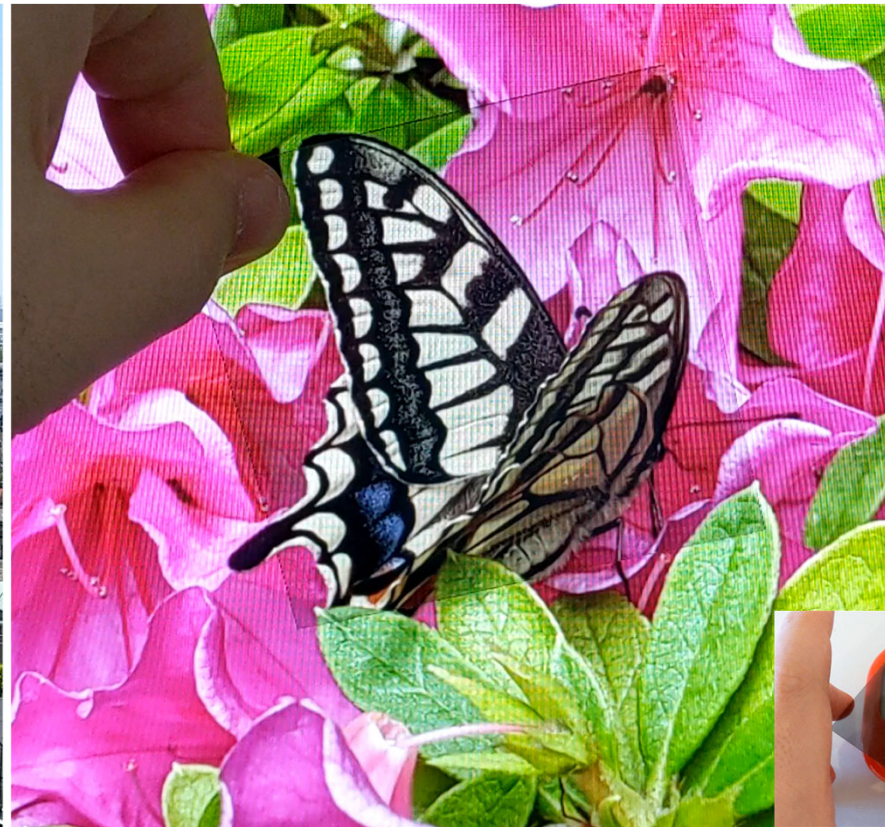# ダイクロイックミラー：特定波長のみ反射
Dichroic Mirror: reflect specific wavelength

- 3板式CCDカメラ等で色分解に使用
- コールドミラー：可視光を反射，赤外を透過
- ホットミラー：コールドミラーの逆

# 偏光板／Polarization Plate

Polarizer (Wikipedia)
https://en.wikipedia.org/wiki/Polarizer

液晶分子の性質を利用した液晶パネルの仕組み

偏光フィルタ　　　配向膜　　　偏光フィルタ

光

液晶分子

- Optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations.
- Two polarization plates can modulate the amount of light.
- Used in LCD displays.

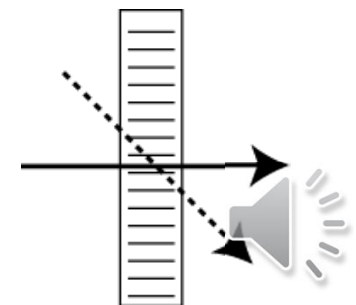http://www.tdk.co.jp/techmag/knowledge/200702/index.htm
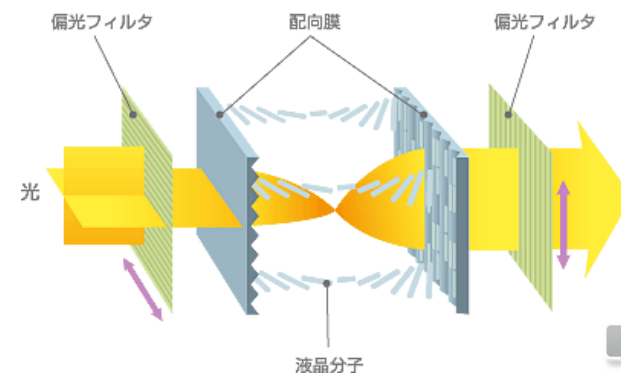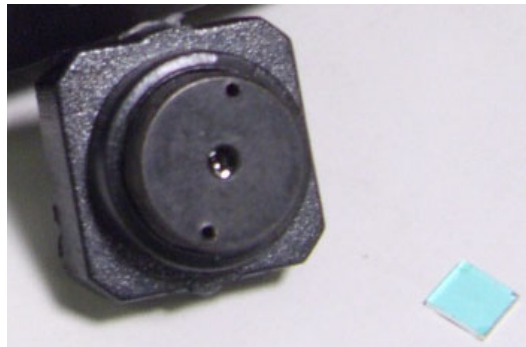
プライバシーフィルタ / Privacy Filter

- 深さ方向の微小な柵により覗き見防止
  Fine shutters blocks oblique incident light.
- 撮影時の照明光入射防止など

波長フィルタ
／Low-pass/High-pass/Band-pass Filter

- 照明光による反射光のみ撮影したい
- 太陽光の影響を避けたい

- ハイパスフィルタ（赤外防止フィルタ）
  - カメラレンズに必ず付属.
    赤外光でホワイトバランスが崩れるのを防ぐ.

- ローパス（ロングパス）フィルタ（赤外透過フィルタ、IRフィルタ）
  - 赤外照明による撮影
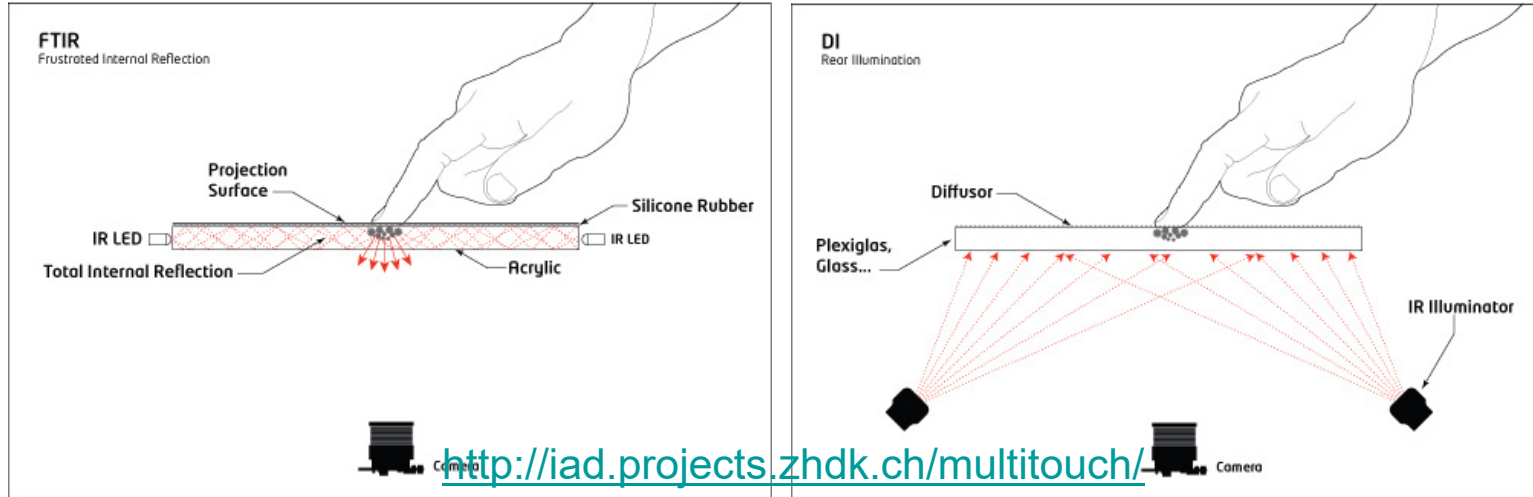 - 水蒸気等による拡散が少なくなり、風景がクリアになる

- バンドパスフィルタ

（参考）IRフィルタの利用

- 水蒸気等による拡散が少なくなり、風景がクリアに
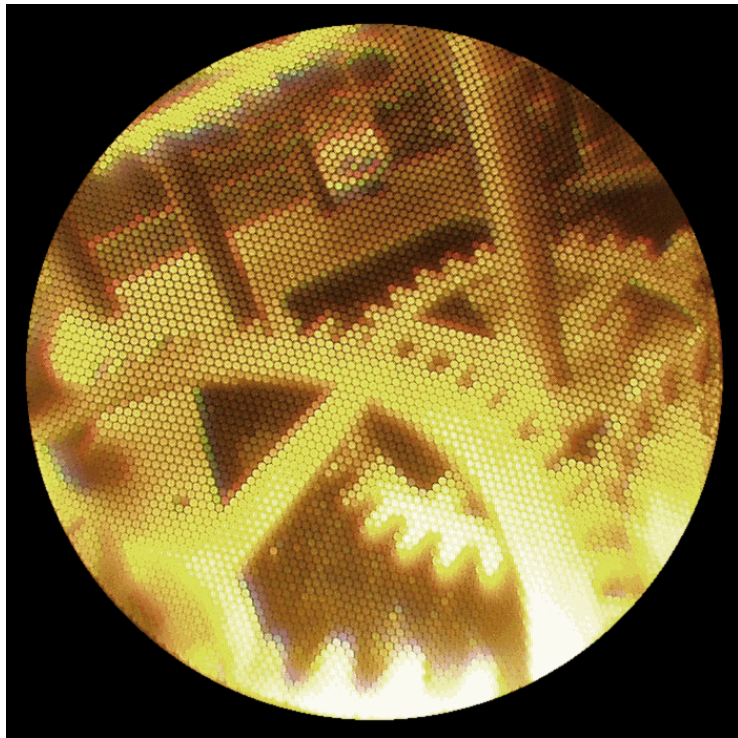- 血管をクリアに観察

http://www.youtube.com/watch?v=S2eexdjIHSU

http://www.youtube.com/watch?v=I7qq6XPDVO8&NR=1

赤外線を用いた接触検出 / Touch detection by IR

http://iad.projects.zhdk.ch/multitouch/

FTIR方式。
白色光＋通常の
カメラでの撮影例
White lighting +
RGB cam
example.

光ファイバ／Optical Fiber

Fiber scope (Wikipedia)
https://en.wikipedia.org/wiki/Fiberscope

https://www.olympus-ims.com/ja/fiberscope/

- ファイバスコープ／Fiber Scope
  - 撮像素子が入れない微細な場所で使用。現在はほぼイメージセンサに置換。
    Used to observe thin places. Most is now replaced by image sensor.
- テレビ石／Ulexite
  - 光ファイバ束。自然の鉱石。人工的にも作成。テーパをつけた拡大鏡としても。
    Bundle of Optical Fiber. Natural
  - テーパー型で画素拡大／縮小機能をもつものも。
    Tapered-type is used to change size of the image.

https://ja.gz-honsun.com/china/cdicc dcmos-fiber-optic-taper

テレビ石の再発見 / Rediscovery of Ulexite

https://www.youtube.com/watch?v=82r4l9Ks5Zc
(ITS2011) K. Fukuchi, R. Nakabayashi, T. Sato, Y. Takada: Ficon: a tangible display device for tabletop system using optical fiber

https://www.youtube.com/watch?v=eTeXTbXA6-Y
(UIST2012) K.D. D. Willis, E, Brockmeyer, I. Poupyrev: Printed Optics: 3D Printing of Embedded Optical Elements for Interactive Devices

https://fukuchilab.org/projects-j/ficon-j

https://la.disneyresearch.com/publication/printed-optics-3d-printing-of-embedded-optical-elements-for-interactive-devices/
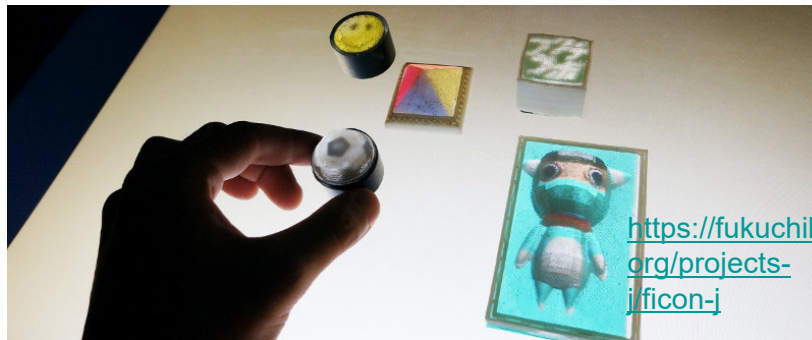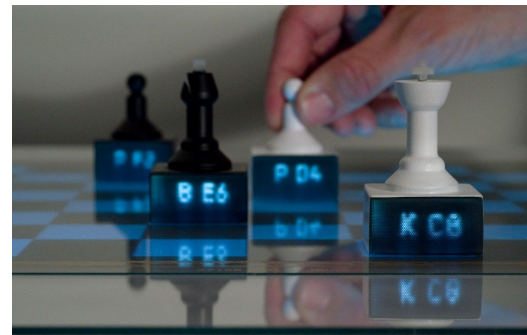
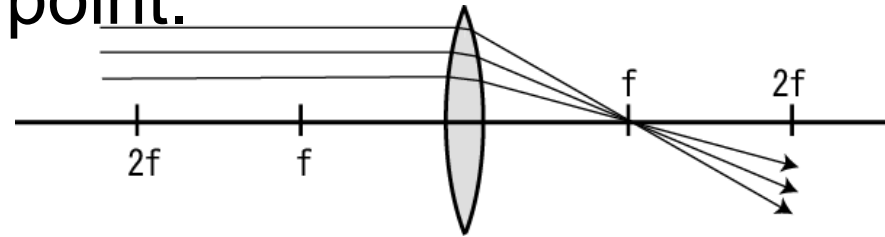3Dプリンタが光ファイバ構造を造形できるようになり、テレビ石がインタラクション要素として再発明された。

TODAY's TOPIC

- 光学素子／Optical Elements
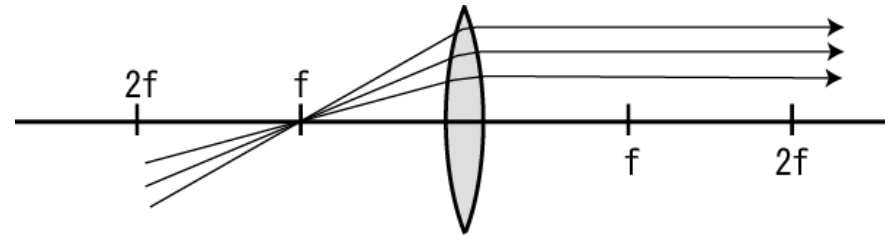- 光学の基礎／Basics of Optics
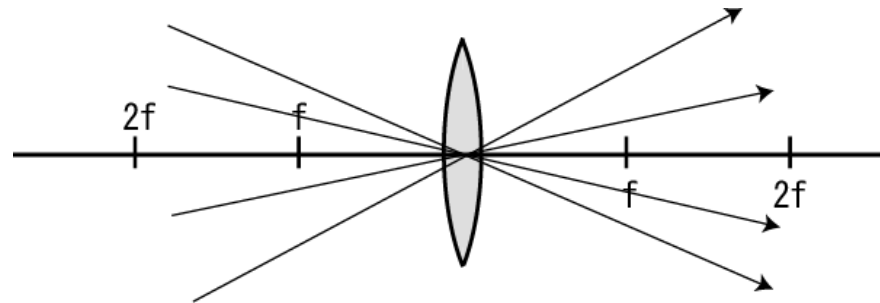- 3次元イメージング／ 3D Image Sensing

凸レンズの原理／Convex Lens Principles

- Rule1：Ray that runs parallel to the lens axis passes through focal point.

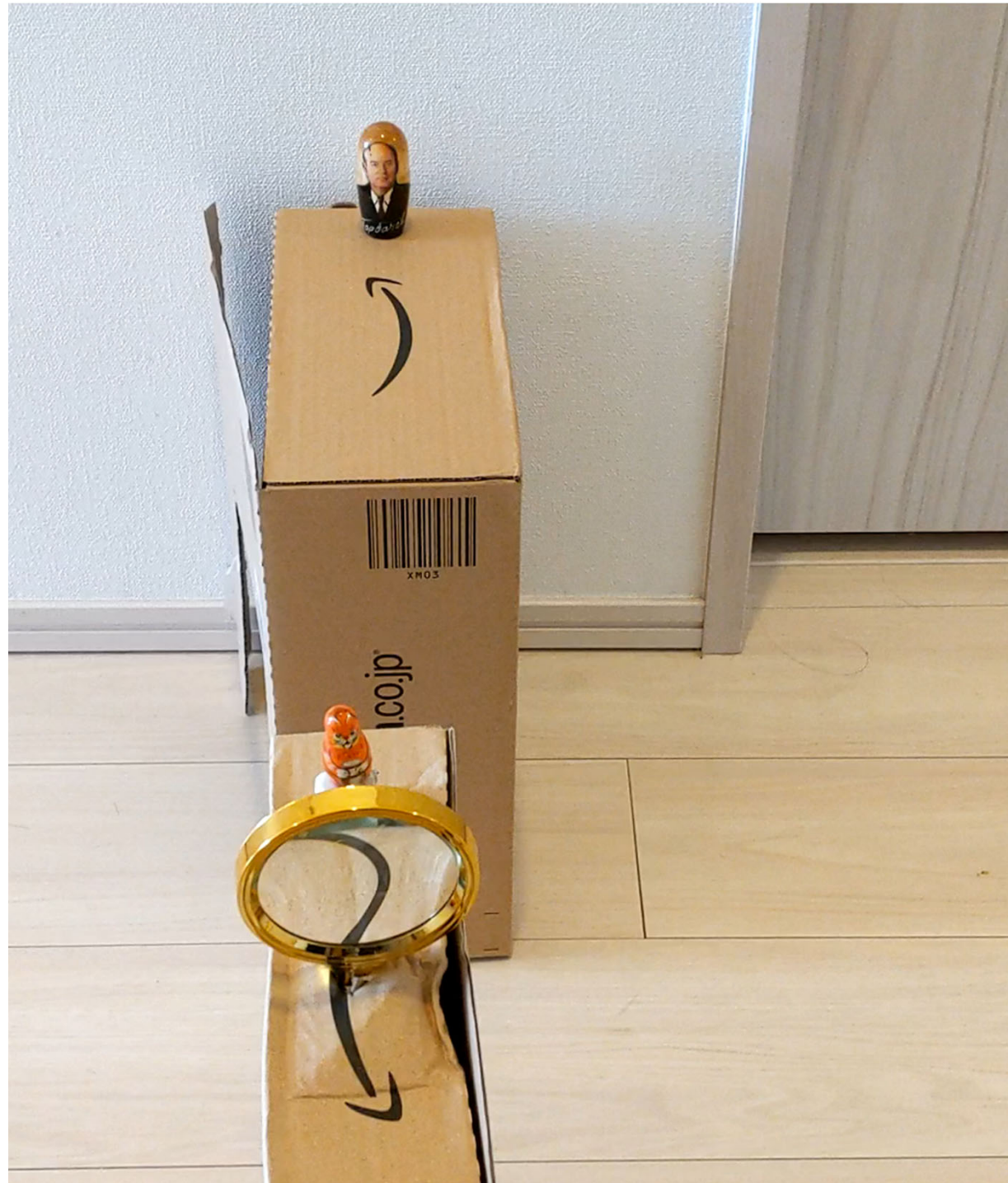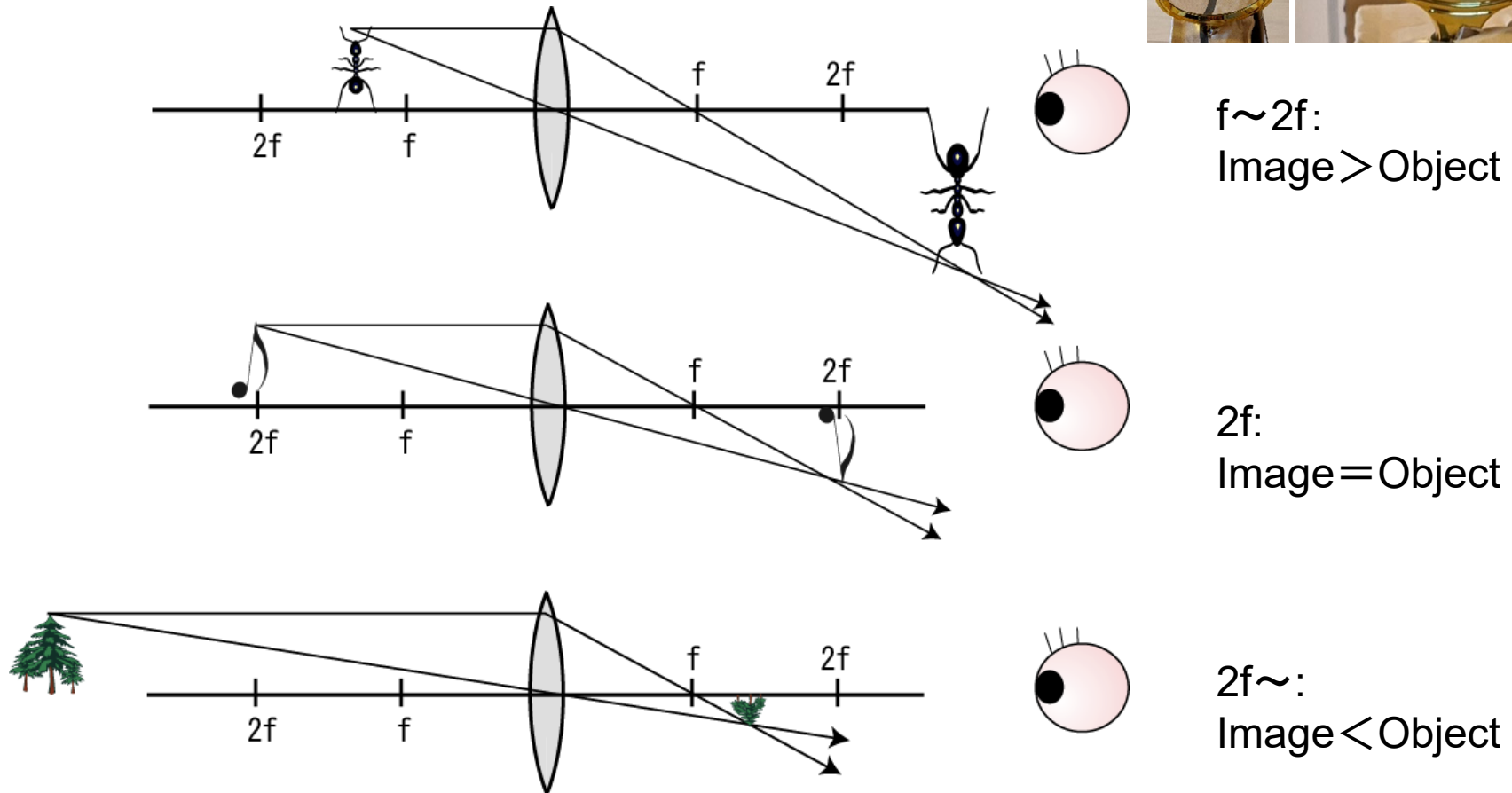 - Lemma : Ray that passes focal point becomes parallel to the lens axis.

- Rule2：Ray that passes lens center does not change its direction.
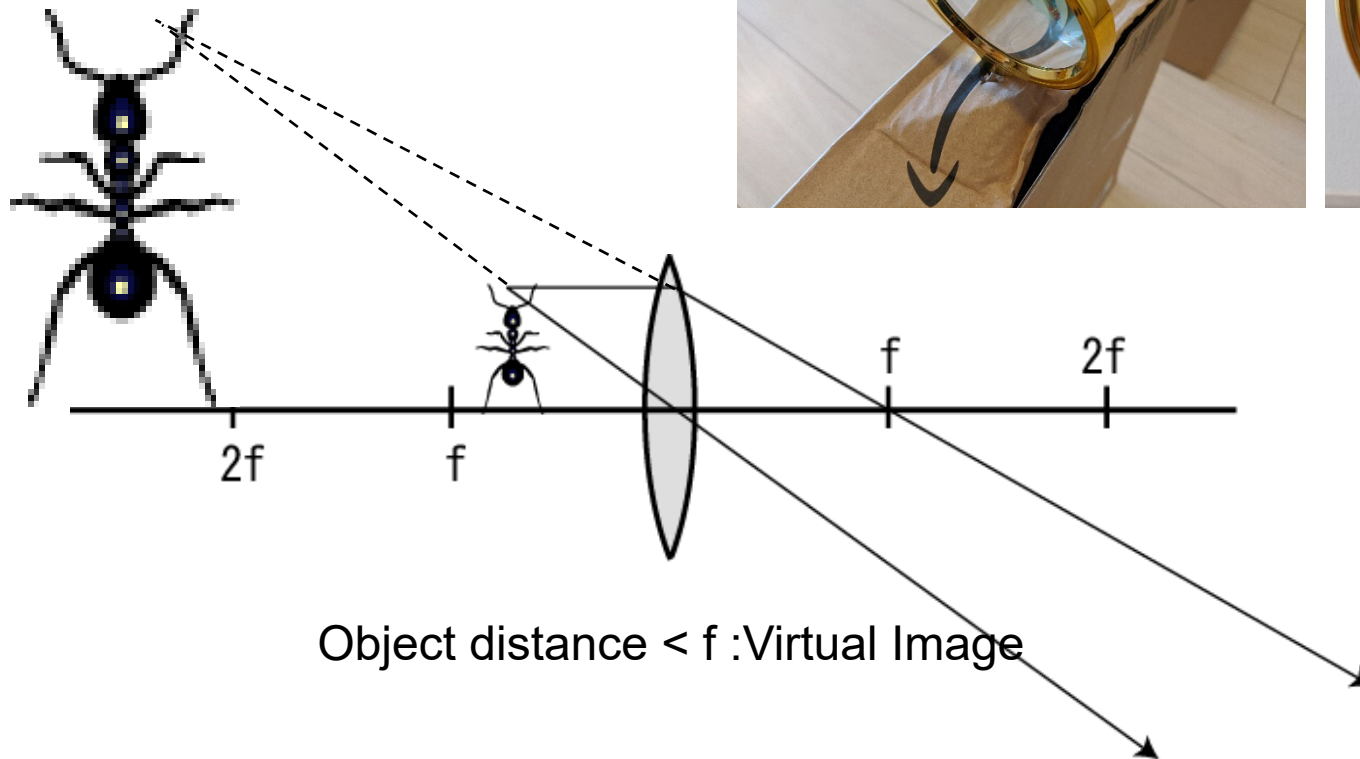
虚像と実像

実像／Real Image

f〜2f:
Image＞Object

2f:
Image＝Object

2f〜:
Image＜Object

The rays really comes out from the image.
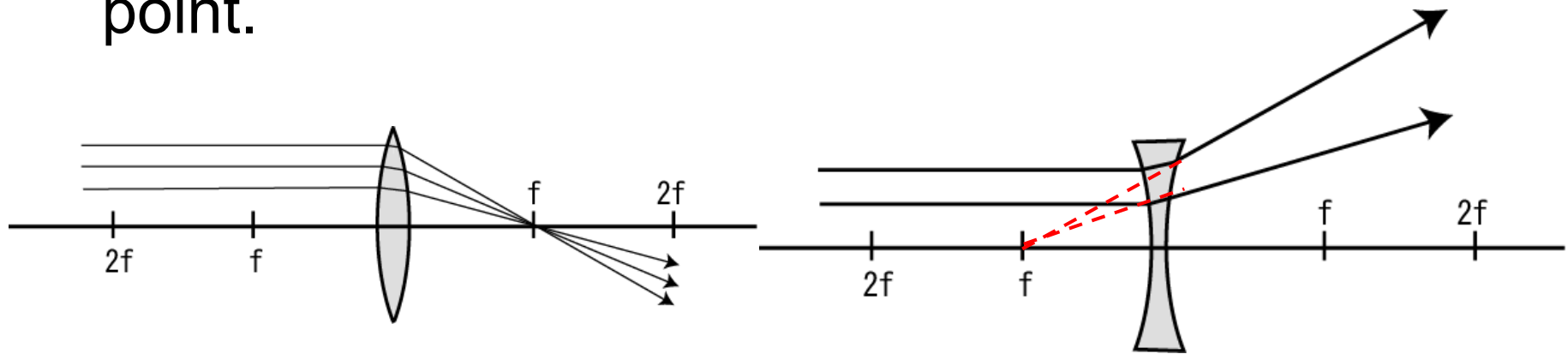
虚像／Virtual Image

Object distance < f :Virtual Image

The ray does not really come out from the image, but virtually (=has the same effect as if) comes out from the image.
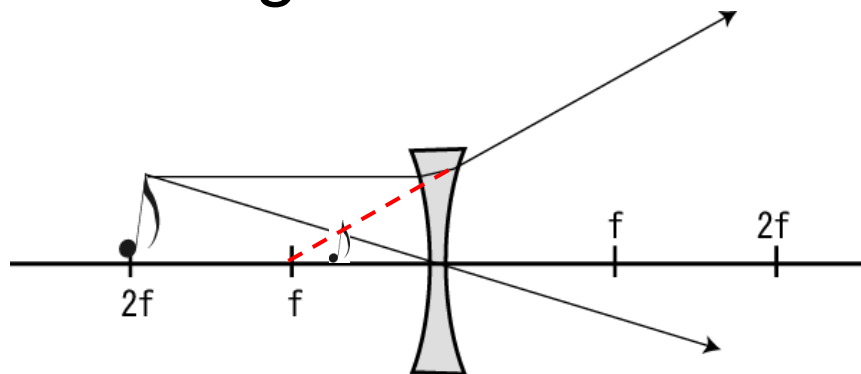
凹レンズの原理／Concave Lens Principles

- Fixed Rule 1：Ray that runs parallel to the axis refracts, and runs as if it comes from back focal point.

- Only virtual image can be formed.
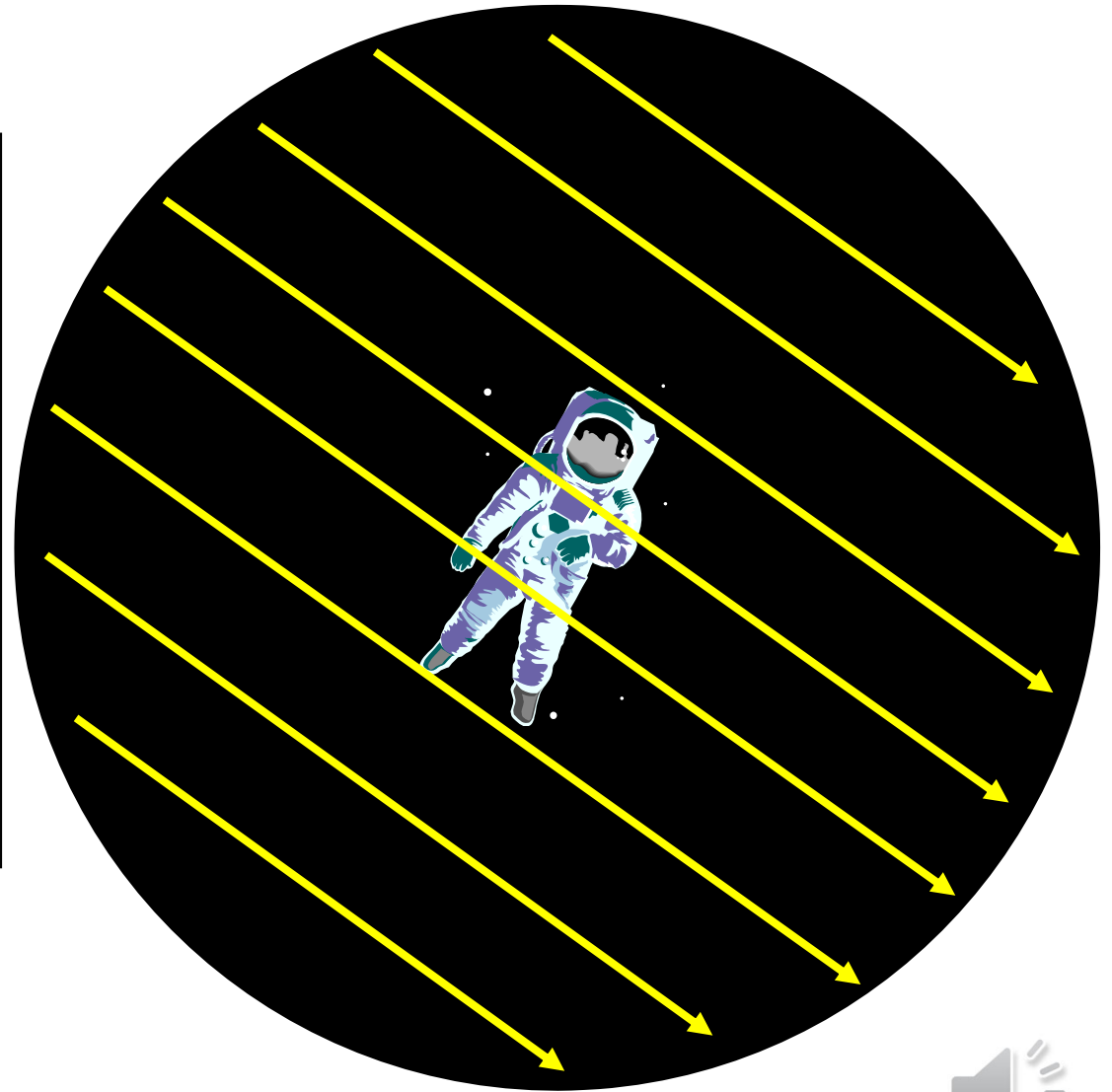
像とは何か
What is Image?

クイズ／Quiz

You are wandering dark space.

Now, One directional, parallel rays fill the whole space.
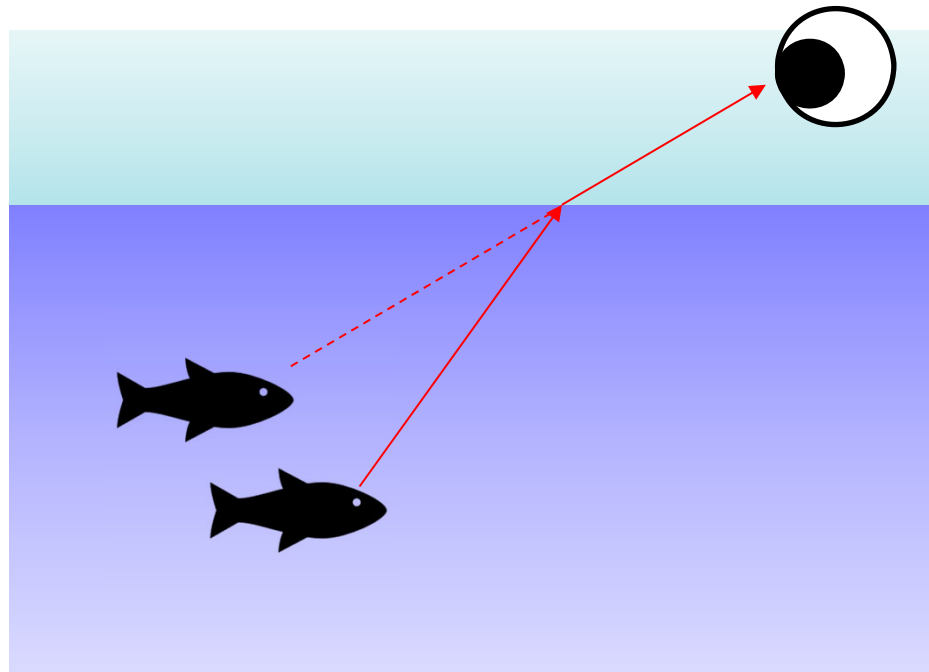
What do you see?

像とは何か？／What is IMAGE?

Image is a virtual/real light source from which rays come out omnidirectionally.

「像」の理解は簡単ではない
Do we really understand refraction IMAGE?

Figures in elementary school textbooks:
Only one line explains "shallow fish".
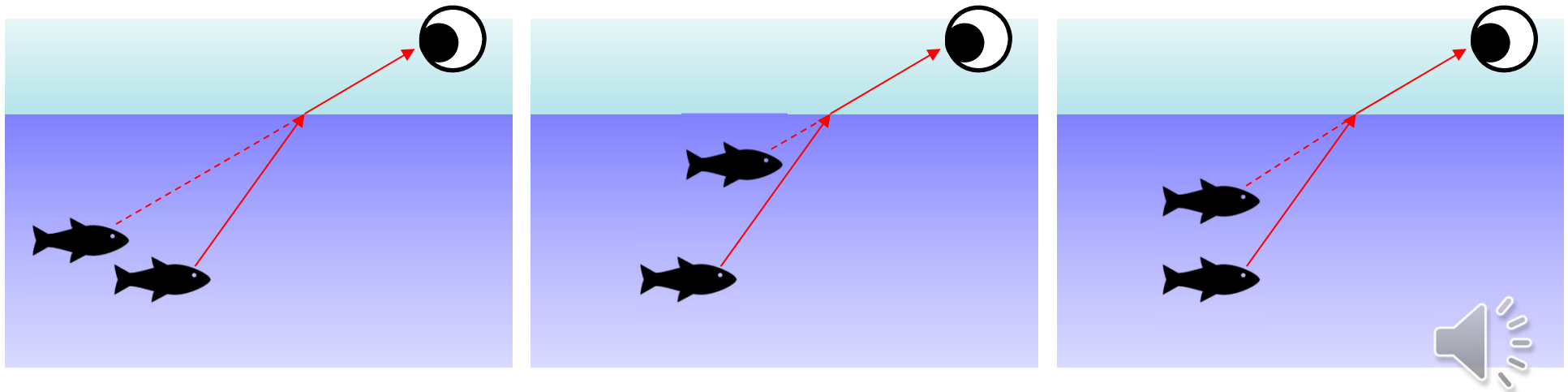●Is one line enough to explain the fish position?
●Is oblique incident angle necessary?

クイズ／Quiz
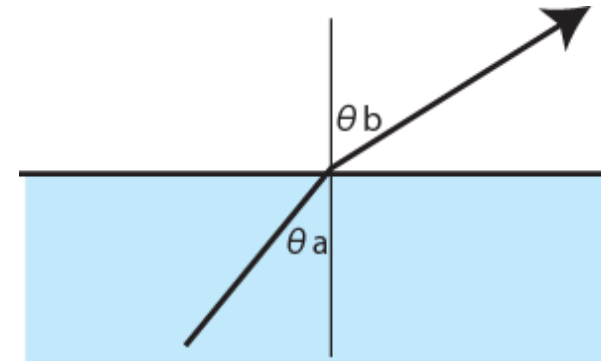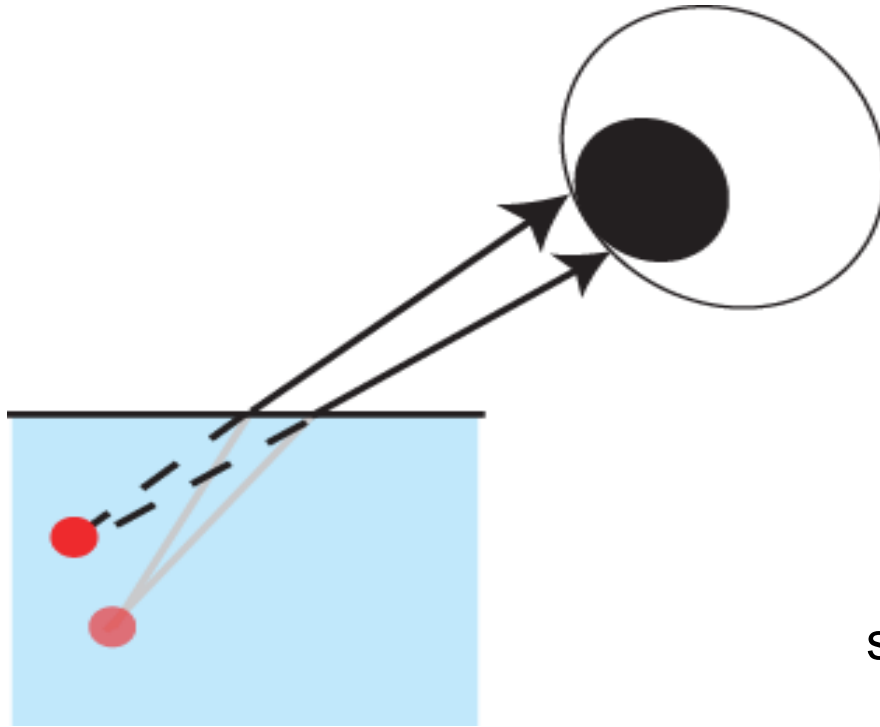
What we know: Due to refraction, objects in water seem shallower.

Question: What about horizontal distance?
(A) A little far
(B) A little near
(C) Does not change

クイズからわかること／What the quiz shows is

Snell's law：
sinθb / sinθa = n (index of refraction）

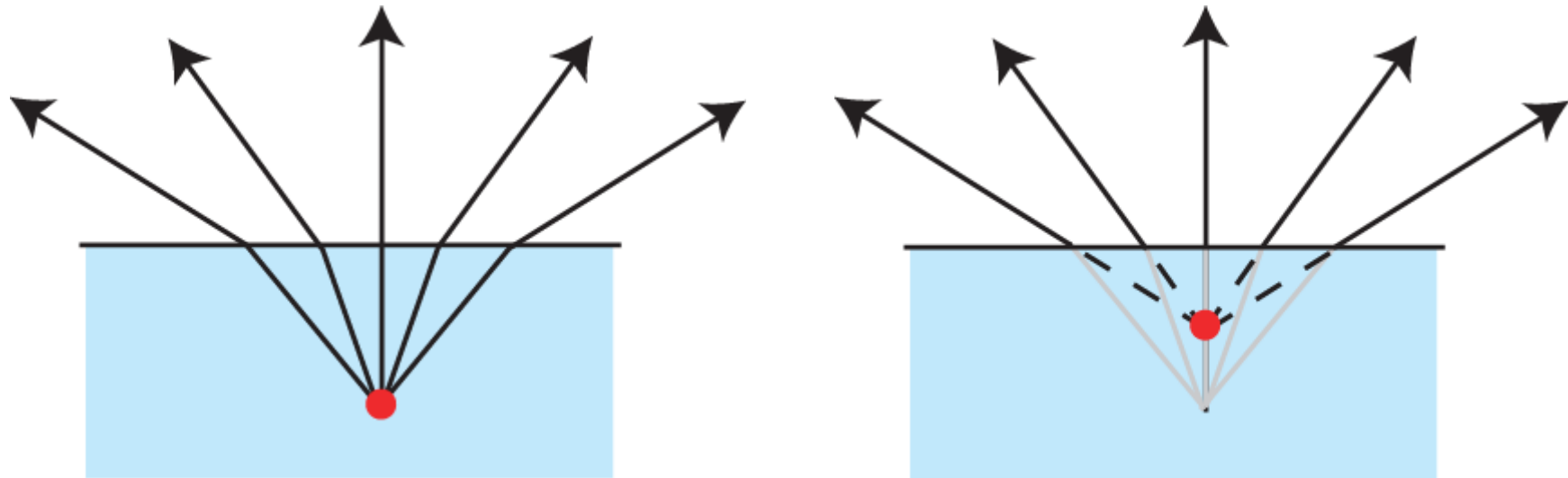"One line" does not explain everything.

Remember the definition of "IMAGE",
and think about omnidirectional rays
by using 2 rays.
It gives the position of "IMAGE"

「浅く見える」ためには「斜めから見る」必要なし
Oblique incident angle is not necessary for "Shallow" perception.
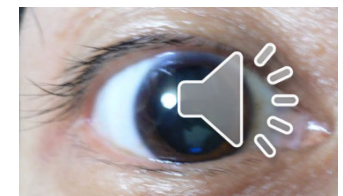

Looking from overhead, it still looks shallower.
IMAGE redefinition:
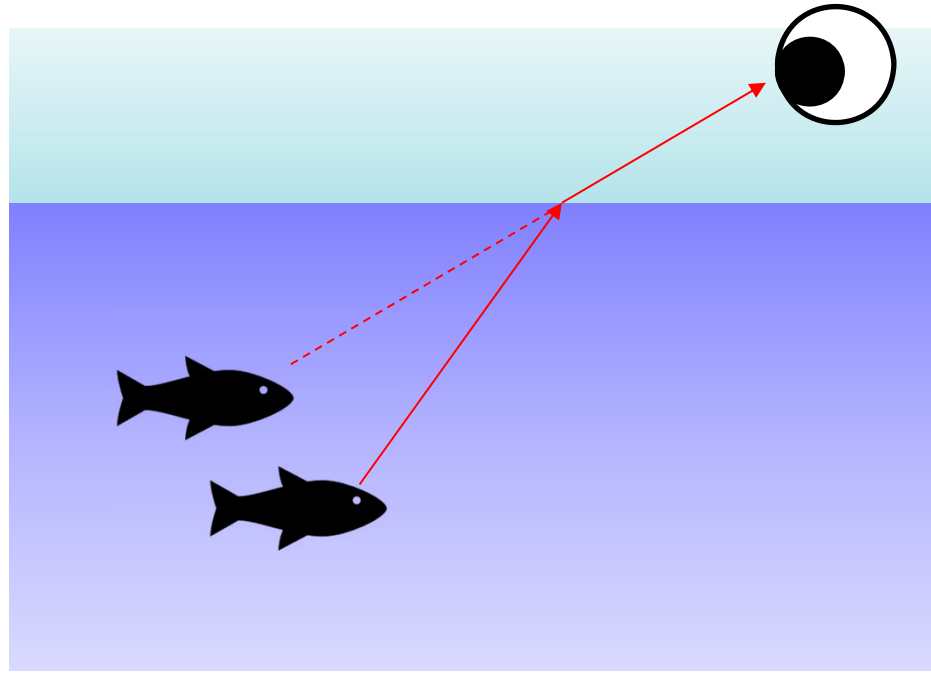●Ideally...   Any rays from a point can be regarded as rays from different point.
●Practically...   Rays from a point to eye's pupil can be regarded as rays from different point.

「屈折像」に関する誤解
Misunderstanding of refraction phenomenon.

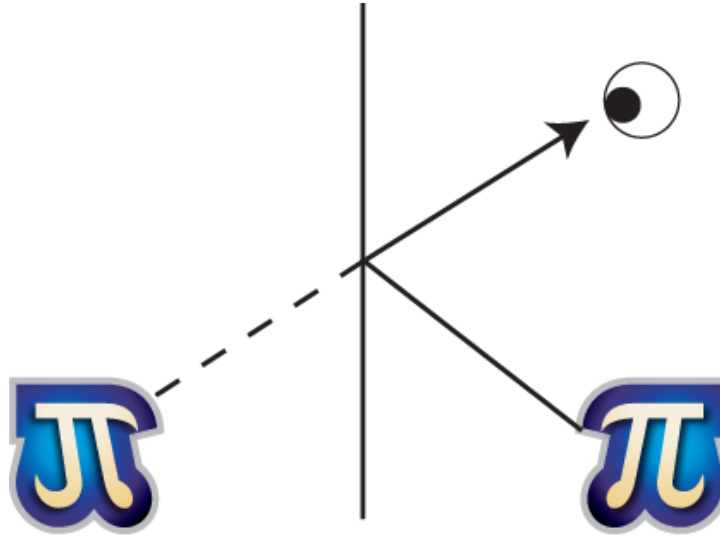"Single line" can explain refraction phenomenon, but not IMAGE.
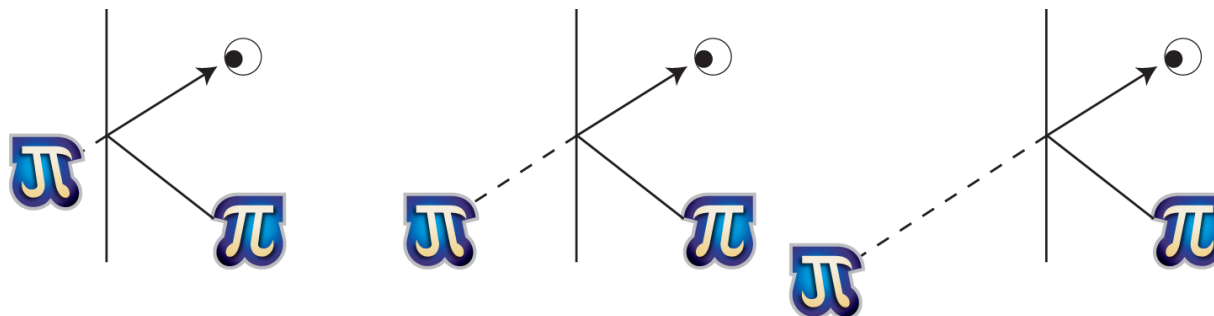
IMAGE should emit rays to any directions, like real object .

そもそも「反射像」を理解しているか？
Do we really understand reflection IMAGE?
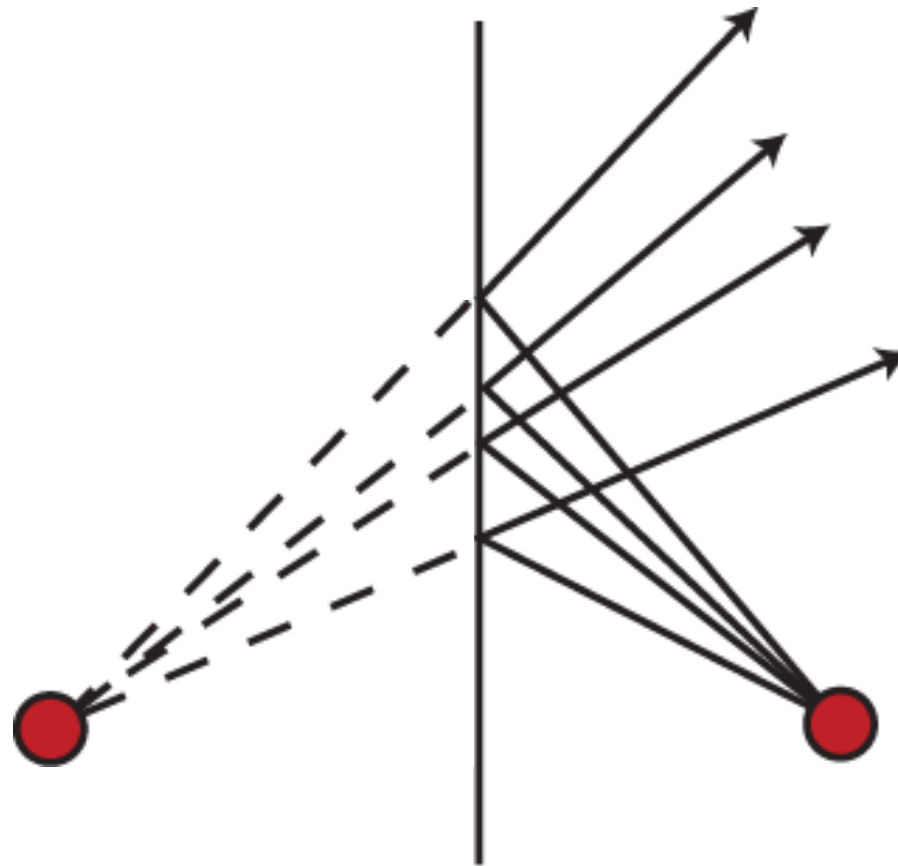
Single ray line can explain reflection phenomenon,
but can not explain reflection IMAGE.

Which one is correct? →can not be judged by single line.
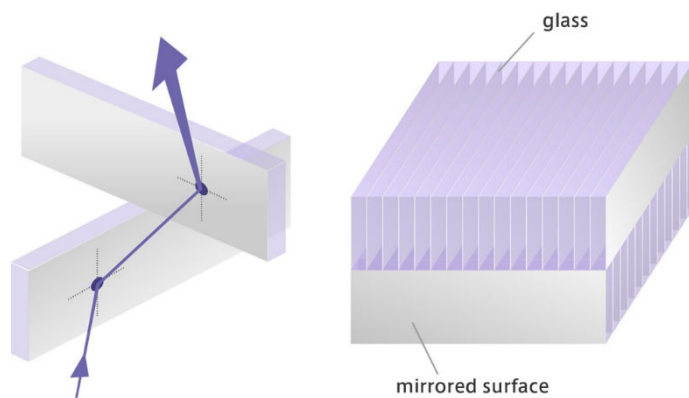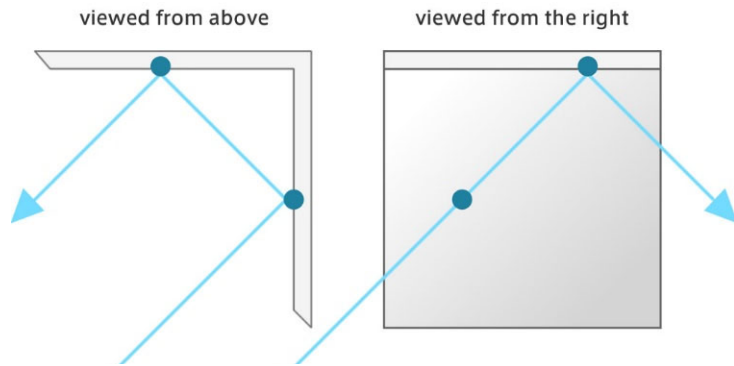
ミラーはミラクル／Mirror is Miracle

By flat mirror, (almost) ANY rays from a point
can be regarded as rays from a different point,
which obeys the pure definition of IMAGE.
In this case, the image is "Virtual Image"

再帰透過光学素子 / Micro Mirror Array Plates (MMAPs)

viewed from above   viewed from the right

glass

mirrored surface

image formation

ASKA3D plate

actual image

https://aska3d.com/en/technology.php
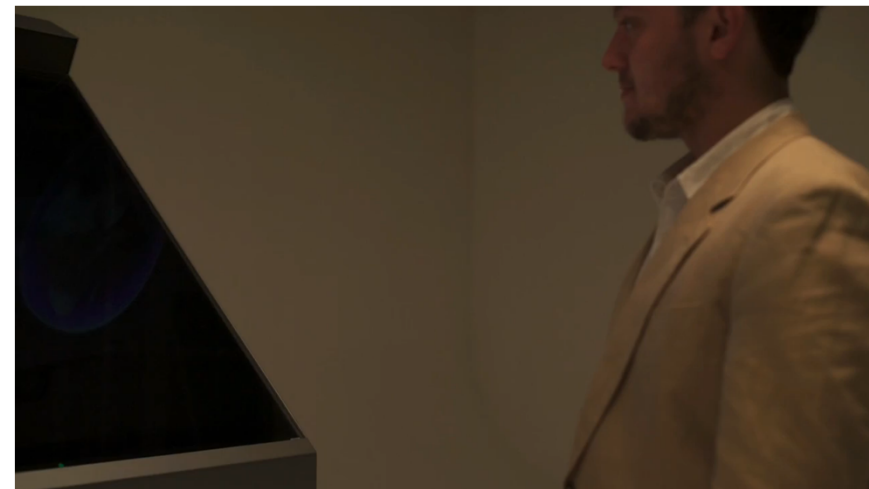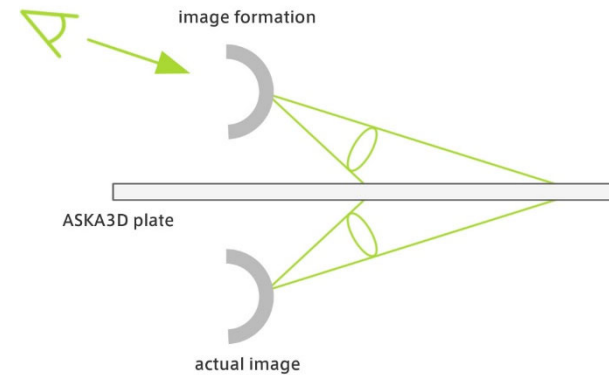
https://www.youtube.com/watch?v=KgAvRtpPY-4
DS976 - ASKA3D

- 直交する短冊状ミラーの集合体を貼り合わせたもの。
- コーナーキューブと同様に再帰反射する軸と透過する軸。
- 歪みのない空中像（実像）を簡便なセットアップで実現可能。
- 2D corner cubes made by orthogonal plates, to achieve retroreflection and transparency.

平面ミラーの奇跡：他の可能性は？
Is Flat Mirror Really Miracle?
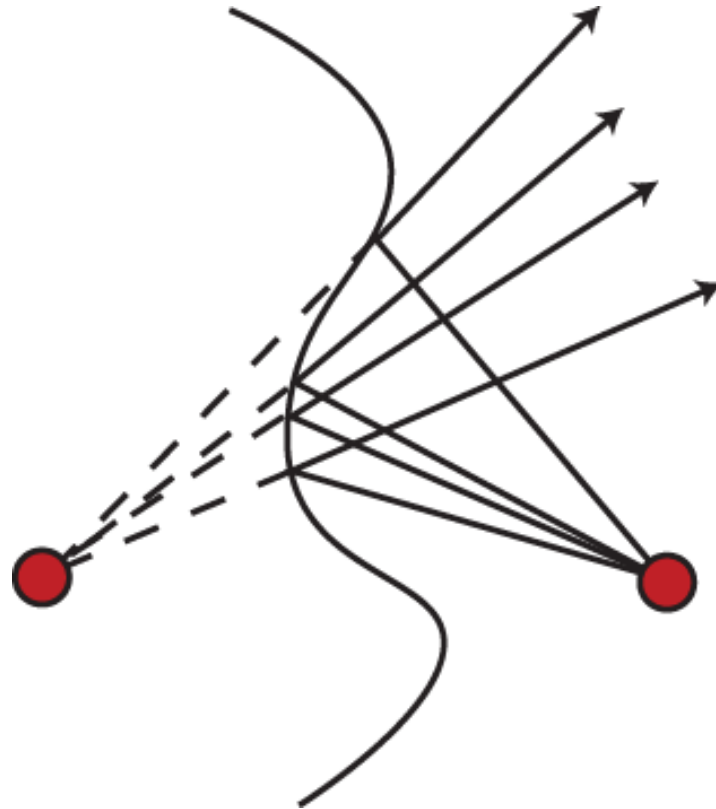
Is there any other surface shape,
that can convert "rays from a point" into
the "rays from a different point".

楕円鏡／Elliptic Mirror
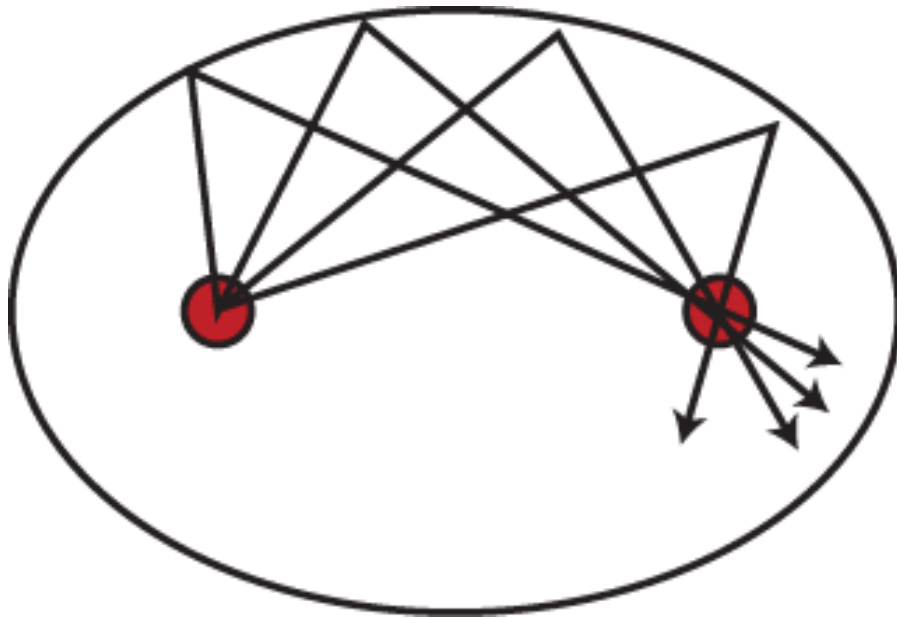
Quantum Design IR Image Furnace
https://www.qdusa.com/products/ir_image_furnace.html

● Generates Real Image
● Used in IR image furnace

双曲面鏡／Hyperbolic Mirror

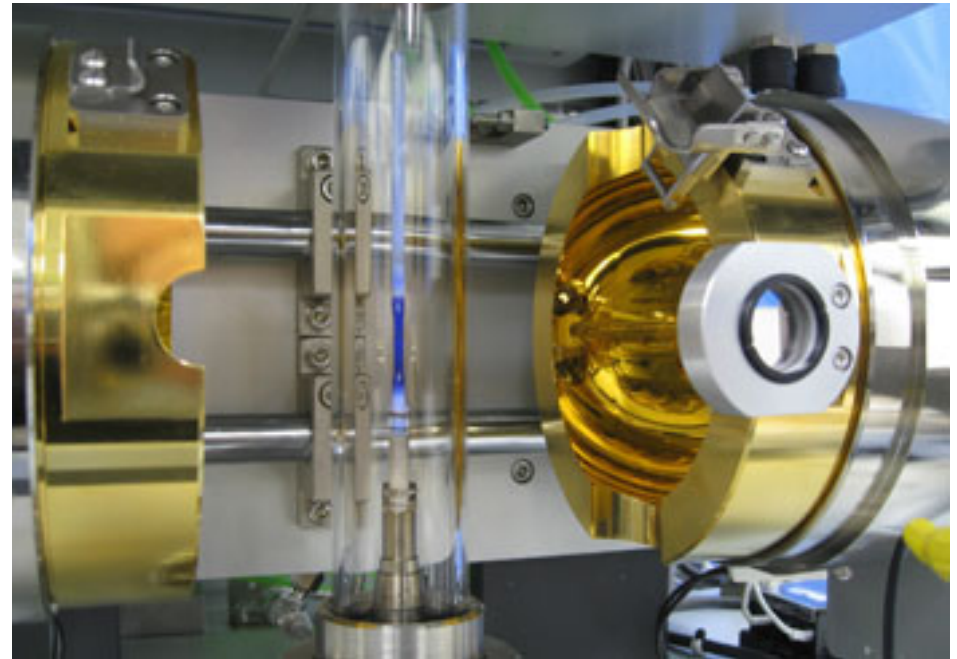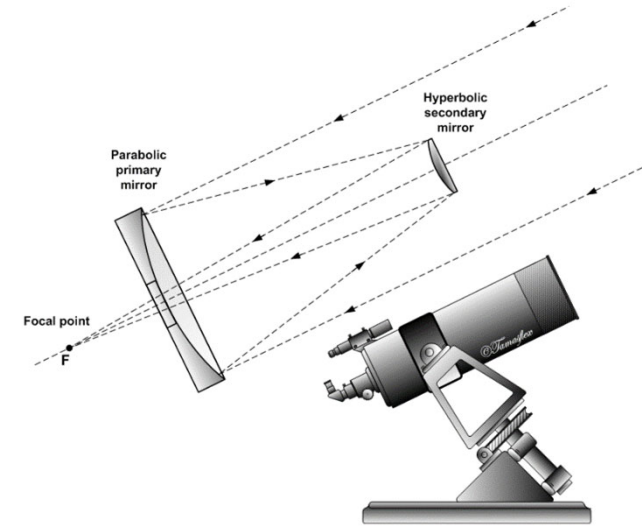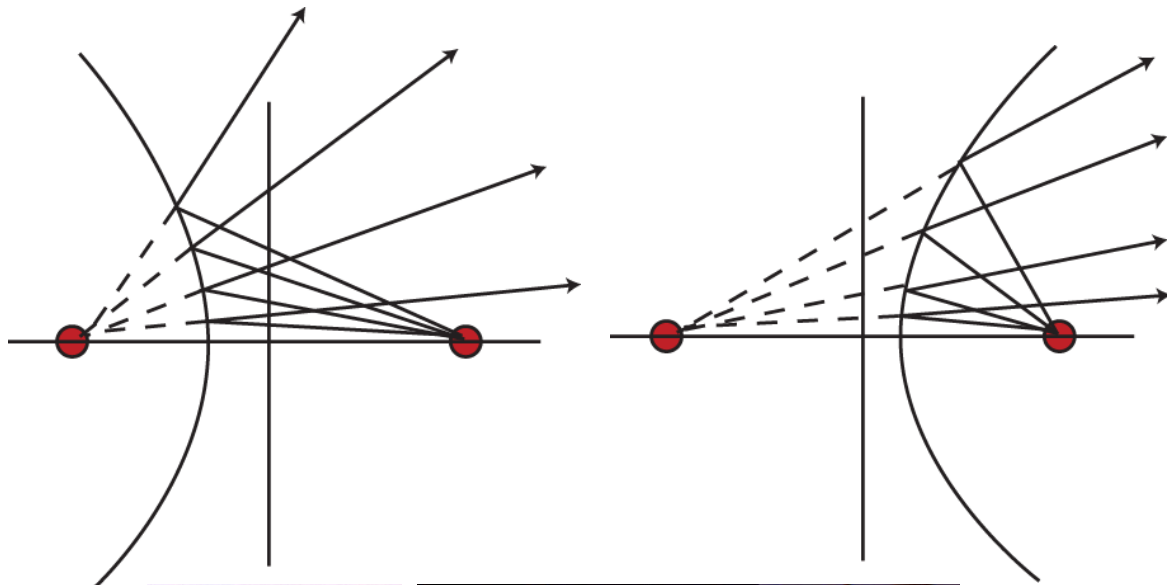Cassegrain reflector (Wikipedia)
https://en.wikipedia.org/wiki/Cassegrain_reflector

Omnidirectional Vision
http://cmp.felk.cvut.cz/~svoboda/Demos/Omnivis/

- Generates Virtual Image.
- Used for secondary mirror for telescope.
- Used for surveillance camera.

放物面鏡／Parabolic Mirror
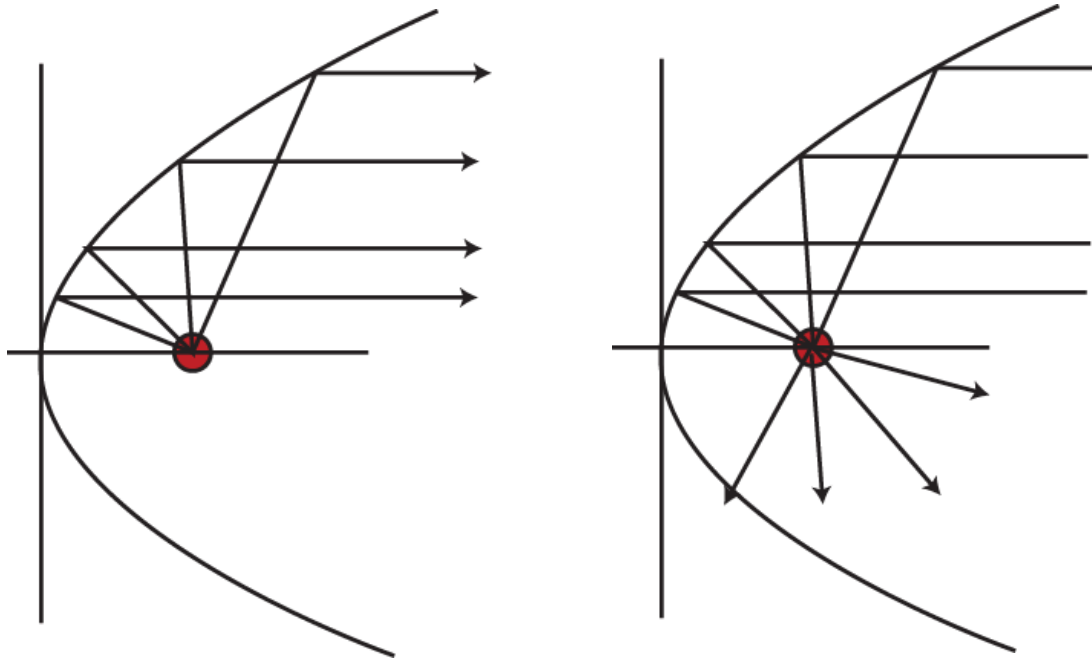
- Converge parallel rays to a focus.
- Change rays from focus to parallel beam and vice versa.

Parabolic reflector (Wikipedia)
https://en.wikipedia.org/wiki/Parabolic_reflector

ミラースコープ、マジックスコープ
Mirascope, magic scope
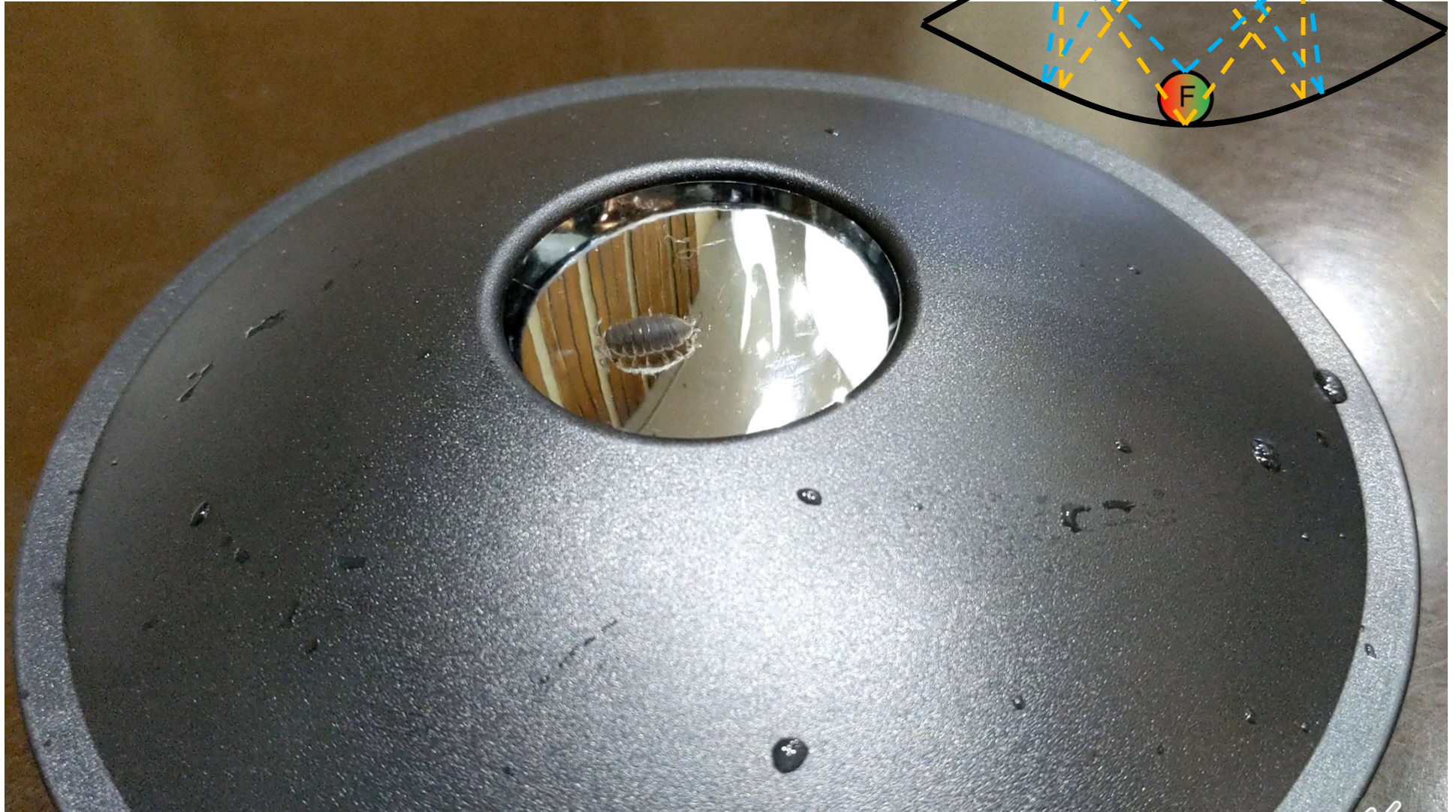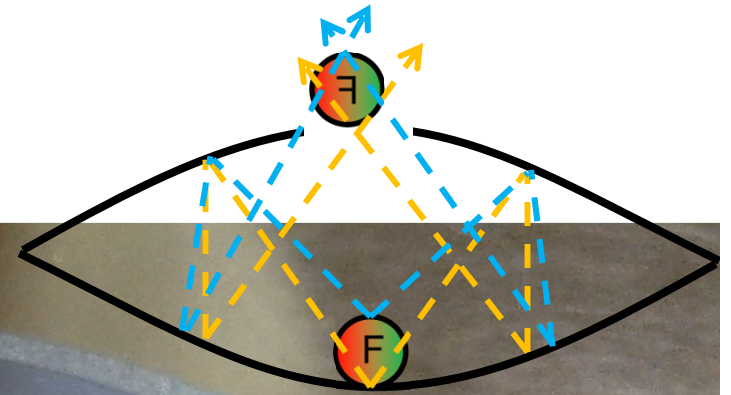
•Two near-parabolic mirrors gives floating real image.

レンズの「像」に戻って／Go back to the lens image

We draw two representative rays,
But actually, there are infinite number of rays,
and seems as if the rays come out from the image.

Real Image

Virtual Image
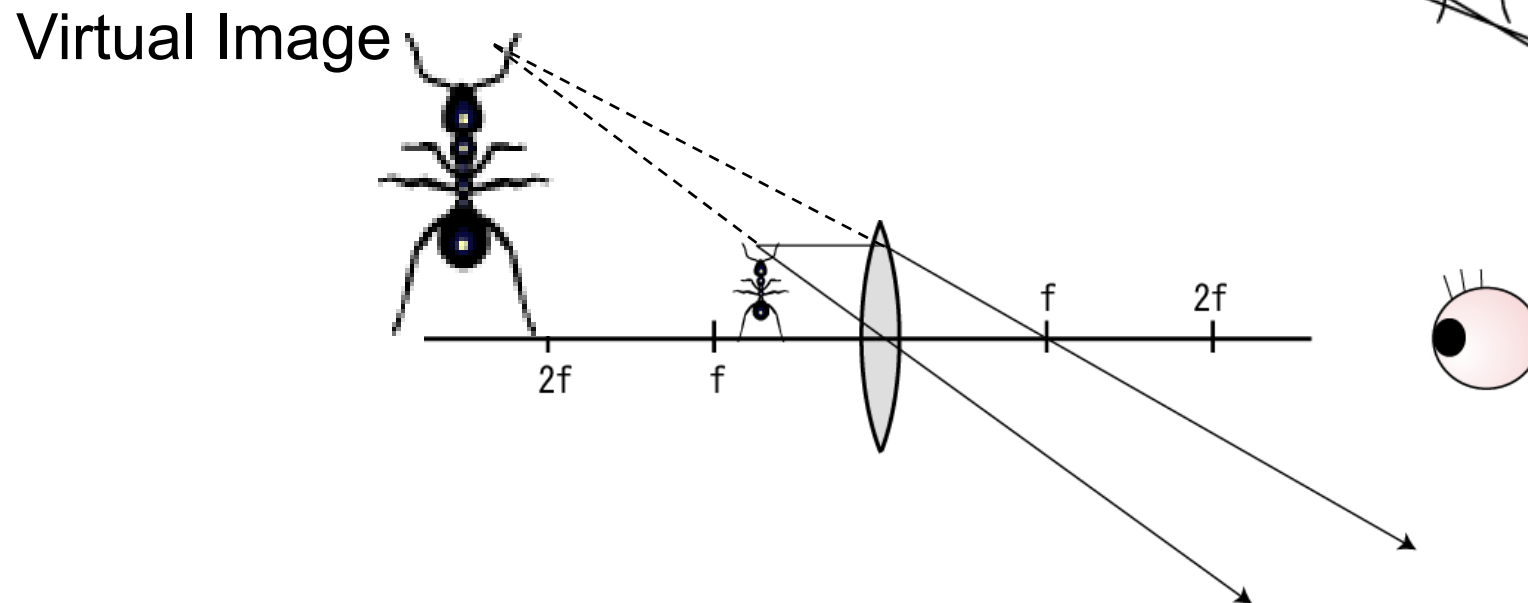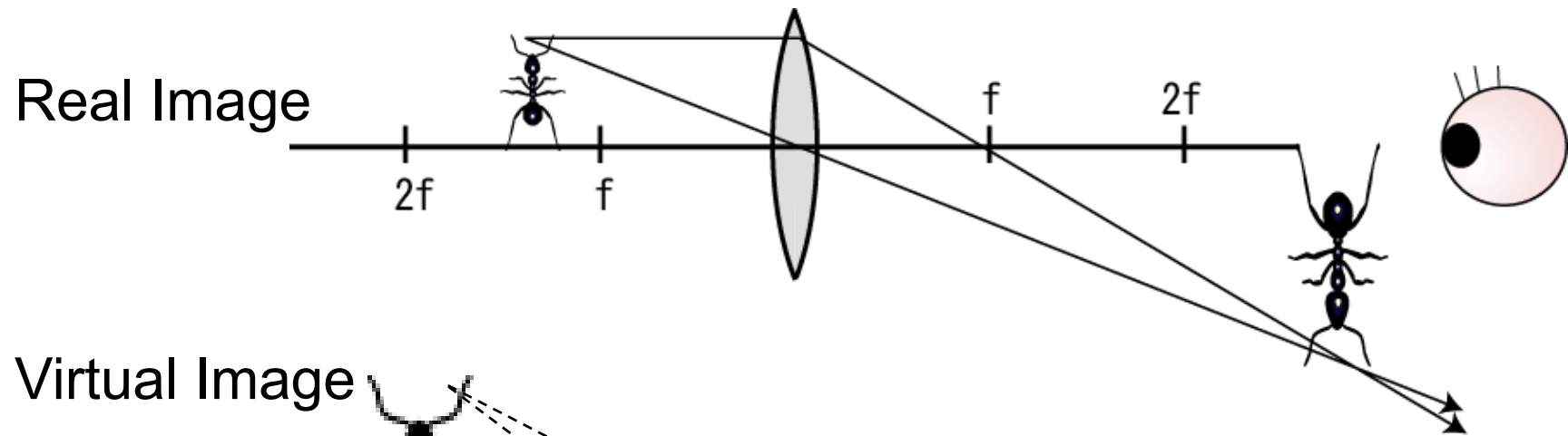
HMDは虫眼鏡／HMD and Magnifying glass

f   2f

2f   f
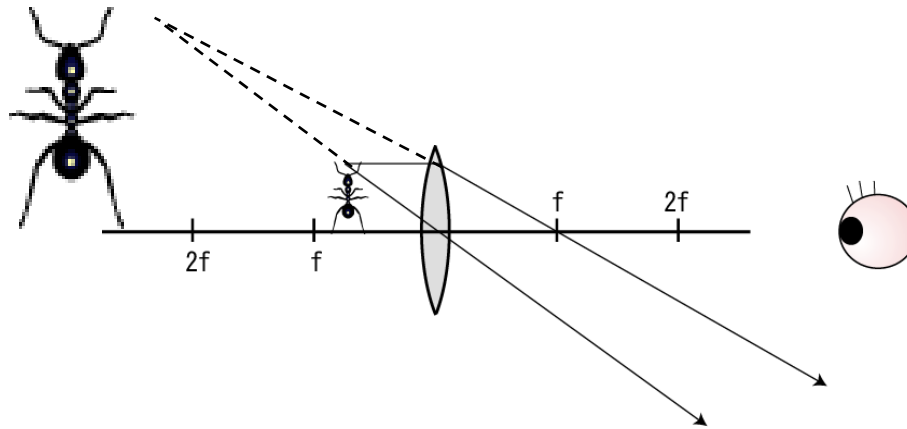
- Head Mounted Display

f   2f

2f   f
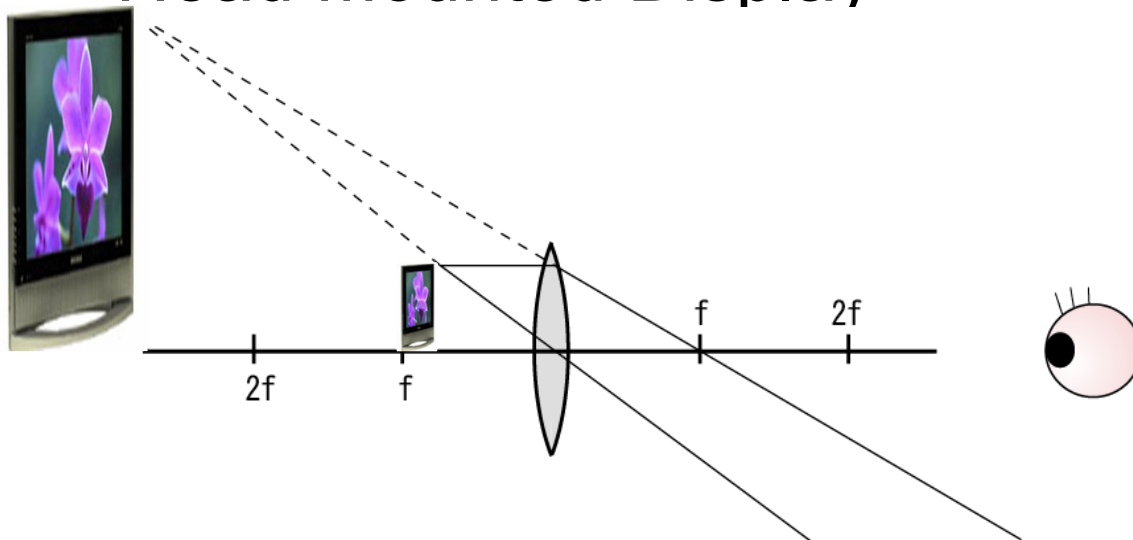
Purpose: change the distance from eye to the image

(復習／review)輻輳・調節矛盾 Vergence-accomodation conflicts

- Accommodation & vergence are slightly coupled.

- Stereo display problem:
  - Accomodation=constant
  - Vergence = variable
  ⇒Severe Fatigue
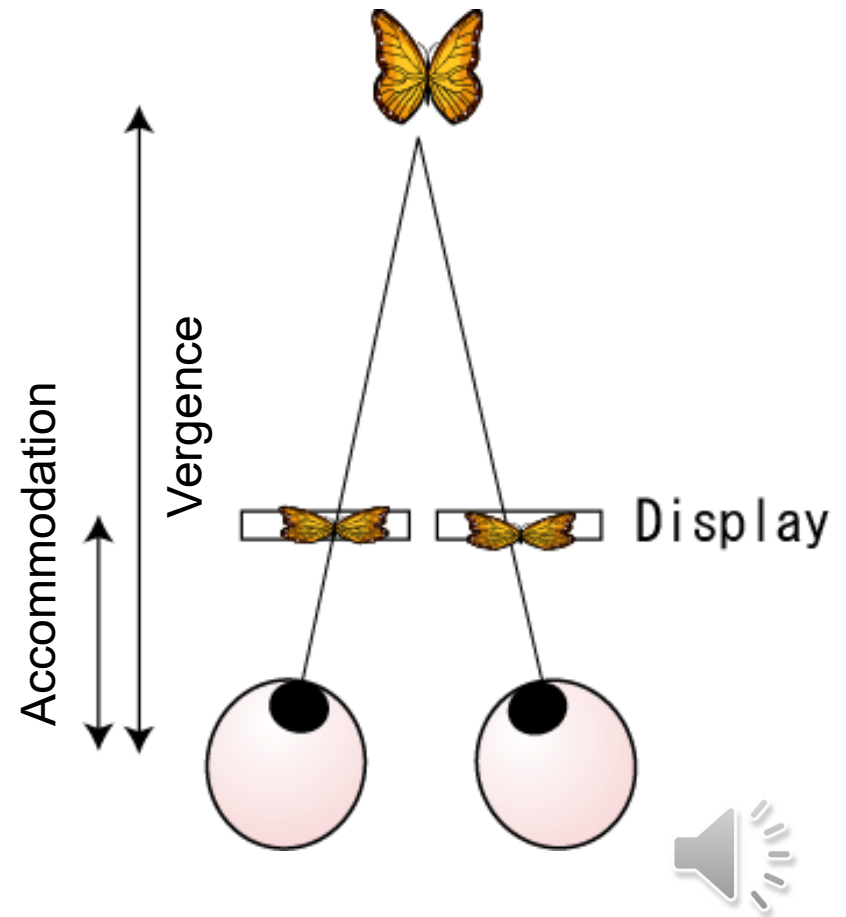
望遠鏡／telescope
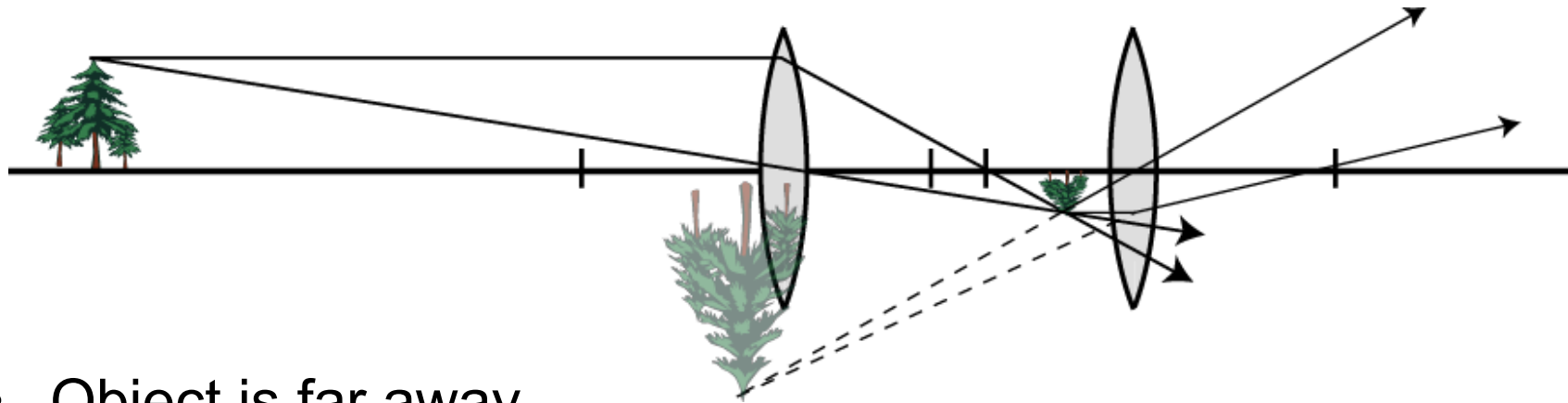
- Object is far away

- Real-image by objective lens (対物レンズ)

- Converted to Virtual-image by occular lens (接眼レンズ）

- 双眼鏡／binocular glasses

Binoculars (Wikipedia)
https://en.wikipedia.org/wiki/Binoculars
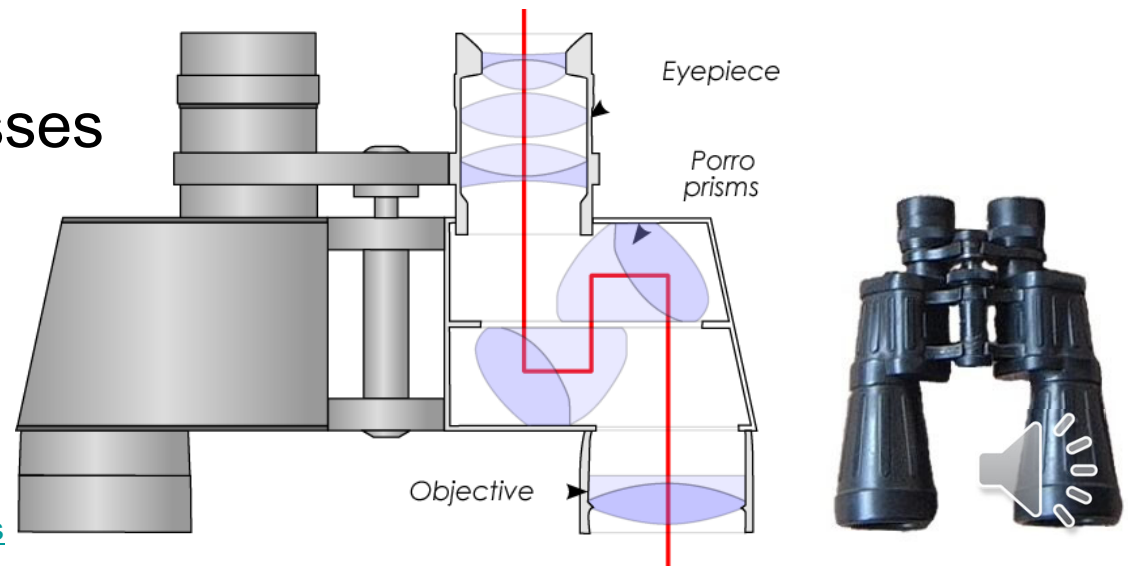
測距儀 / Stadimeter
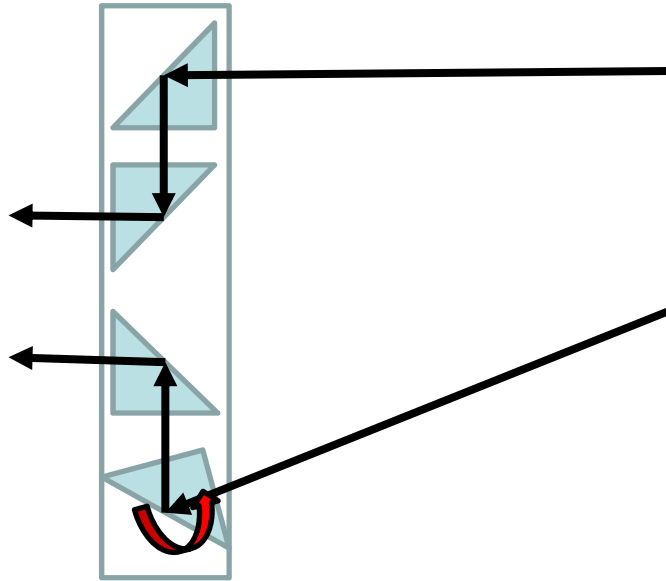
- 片側のミラーを回転、両目映像を重ねる。ミラー回転角度から距離計算。

- 遠い距離だと誤差が大きい（回転角度が非常に小さい）。

- レンズ（望遠鏡光学系）によって距離を等価的に近づける。

- Rotate one mirror to match right and left images. The rotation angle corresponds to distance.

- Lens are used to make optical distance closer.

Rangefinder (Wikipedia)
https://en.wikipedia.org/wiki/Rangefinder

顕微鏡／Microscope
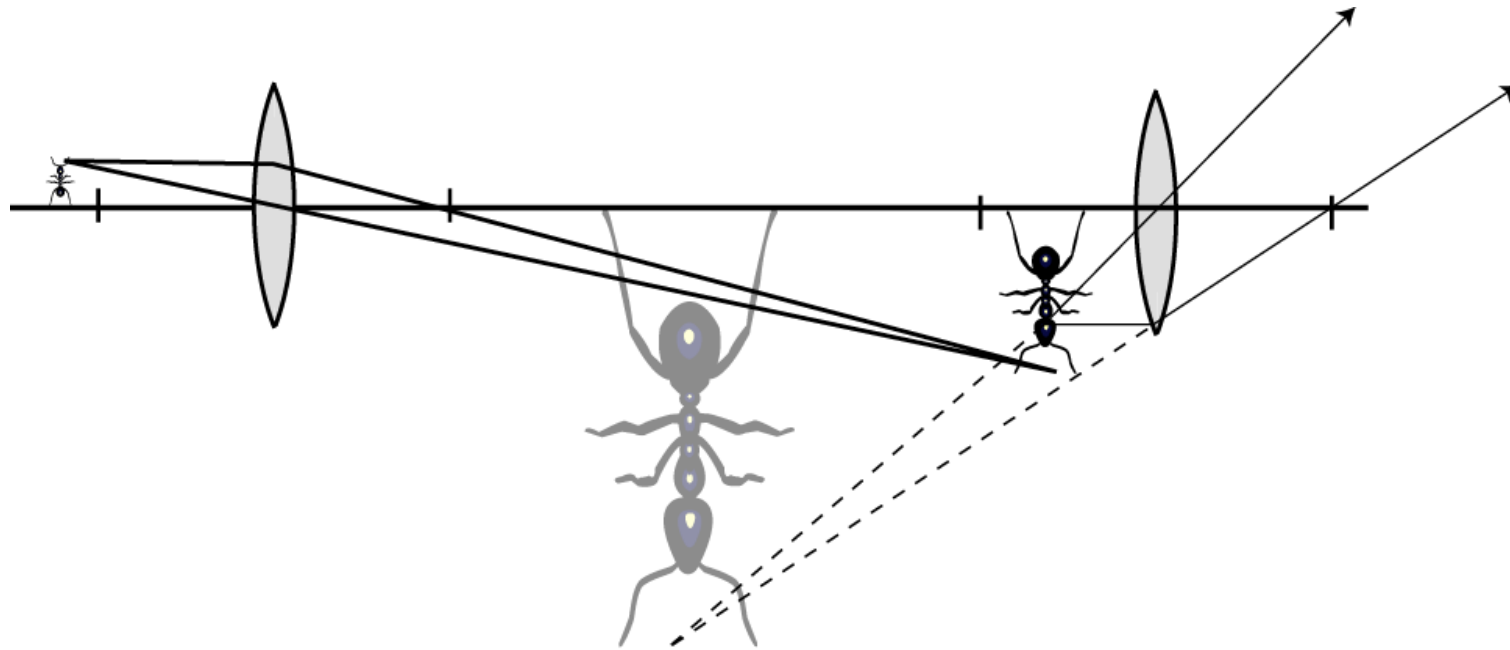
- Object is close to focus of objective lens.

被写界深度／Depth of Field

- 左：被写界深度が浅い／Left: Shallow (F4)
- 右：被写界深度が深い／Right: Deep (F20)

被写界深度／Depth of Field
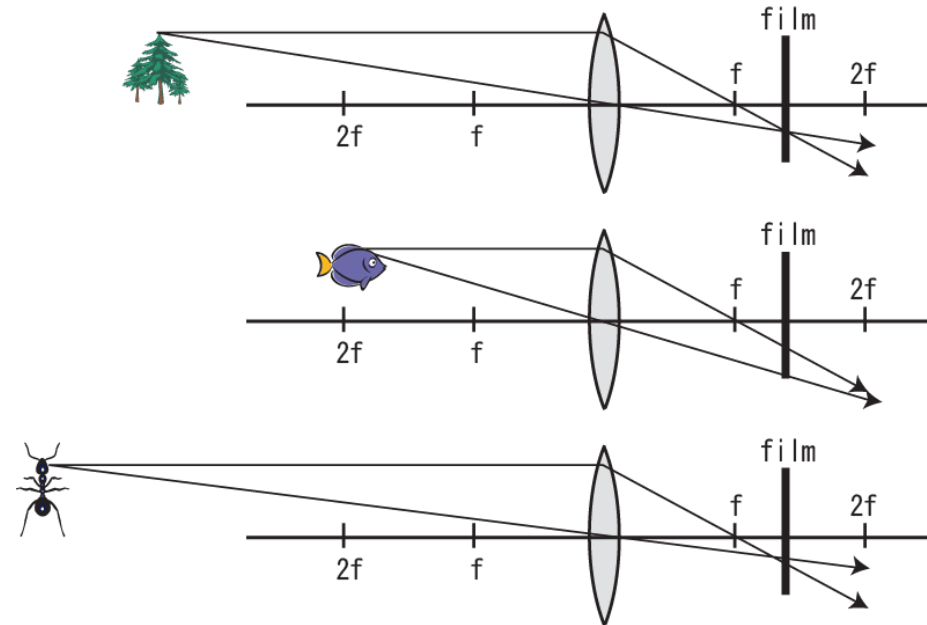
- 焦点の合う距離は一つだけ。他の距離ではすべてボケる.

  When distance between lens and film is fixed, object distance is fixed. Other objects always blur.

- しかし, ボケが人間に判別できないレベルの範囲であれば許容できる⇒この許容範囲のことを被写界深度と呼ぶ.

  Depth of Field=Acceptable distance

被写界深度／Depth of Field

- 被写界深度は，絞りと焦点距離に依存
  - Depth of field is related to aperture & focal length
- 絞り／Aperature（＝レンズの実質的な大きさ/lens size）
  - Large aperature = Shallower Depth of Field
  - Minimum Aperature = Pinhole Camera
    - 応用：視力の良くなるアイマスク
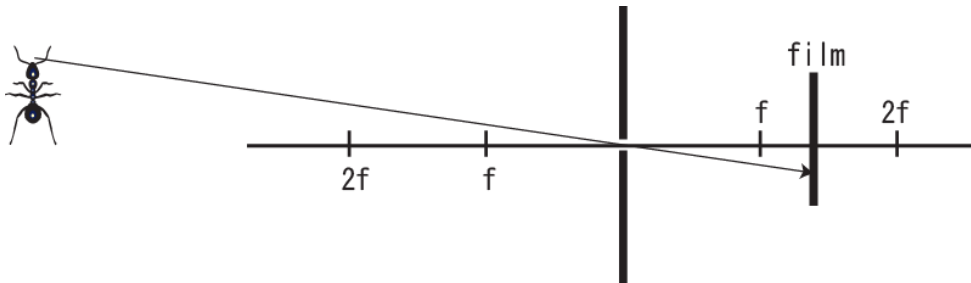
- 焦点距離／Focal Length
  - 短い（＝広角）ほど深い（極端な例：魚眼レンズ）

ピントが合って見える範囲　絞り

https://www.nikon-image.com/enjoy/phototech/manual/04/04.html
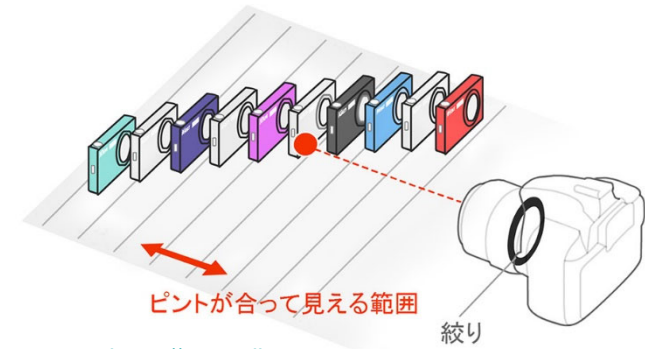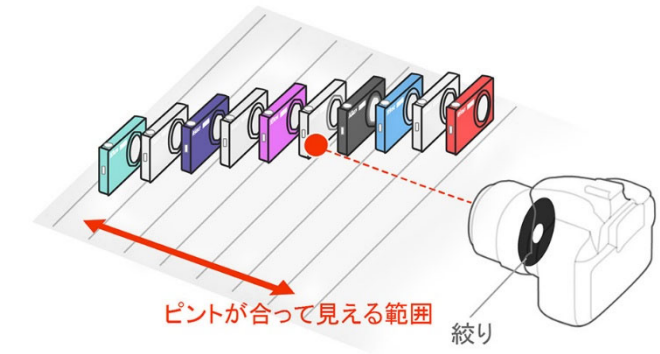
ピンホール＝被写界深度無限
Pinhole makes the depth much larger.

- （左）普通に撮影（スマートフォン）/ Photo by ordinary smartphone.
- （中）アルミホイル＋穴でピンホール化 / Pinhole by aluminum foil.
- （右）遠くも近くもピントが合った写真になる/ Photo again.

被写界深度：コンパクトカメラの大問題
Depth of field as an issue of compact-size camera.

- レンズが小さい＝ピンホールに近い＝被写界深度を浅く出来ない。
- Small lens = close to pinhole = shallow depth is difficult.

被写界深度・焦点の「後処理」/ Synthetic Refocusing

https://www.lytro.com/renng-thesis.pdf
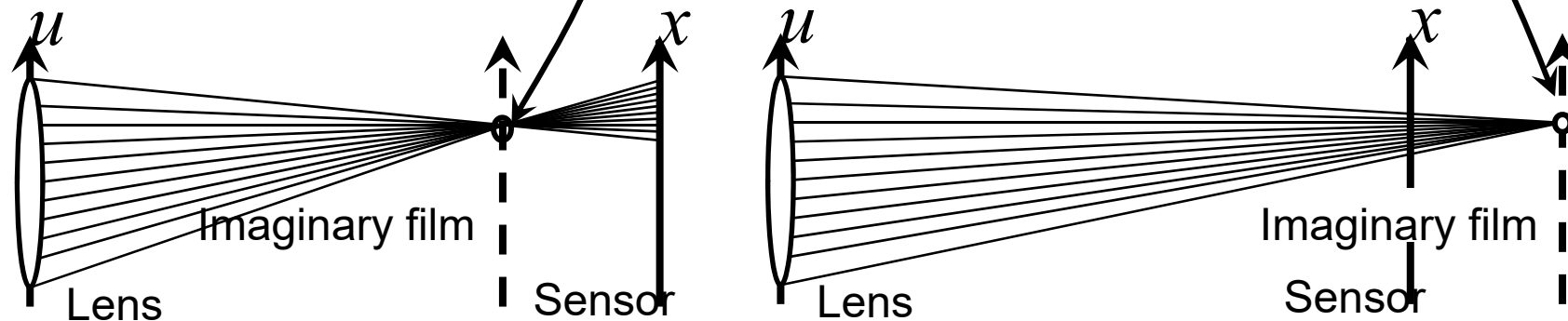
- 到来する光線を方向も含めて記録できればピントを合わせる距離の後処理可能
- If incident light "direction" is recorded, refocusing after the shoot is possible

Synthetic Refocusing (idea)
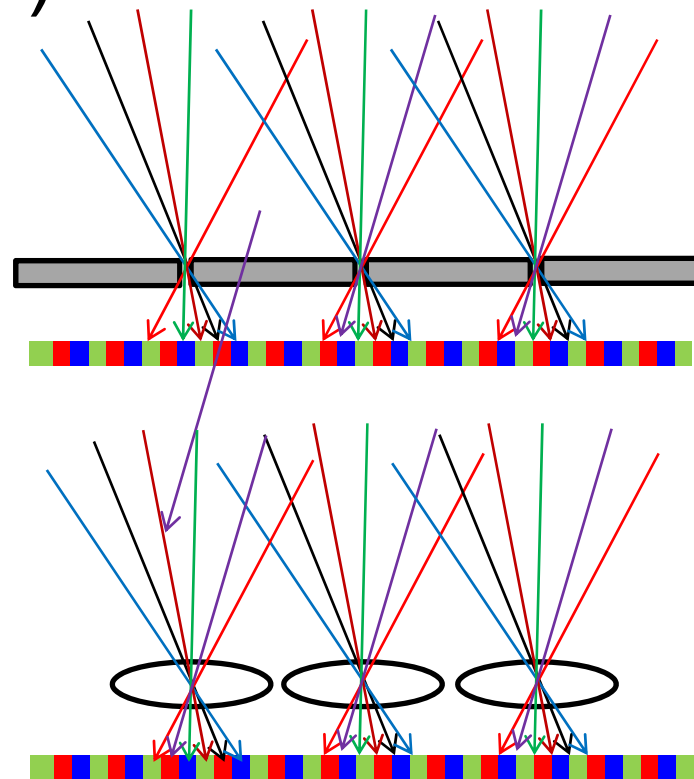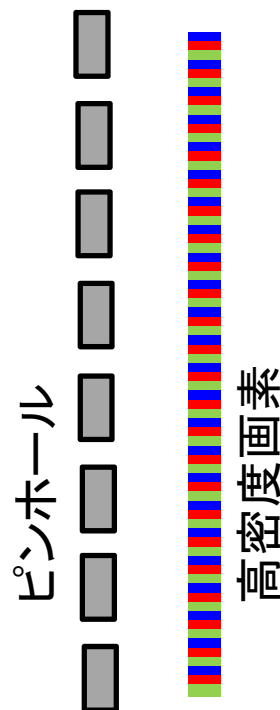
ピンホール（個数＝実現すべき画素数）＋より高密度な画素で「方向も含めた」光線群を記録。/ Pinhole + high-resolution sensors can record incident light and its direction.

- 実際には多数のレンズを用いる。/ Normally micro lens are used.
- 複数のカメラで実現等、多くのバリエーション。/ Multiple cameras are also used.

製品：Lytro(2012)

https://www.lytro.com/renng-thesis.pdf
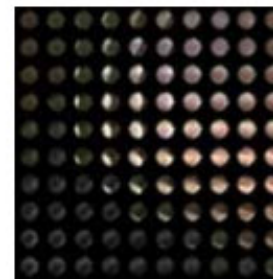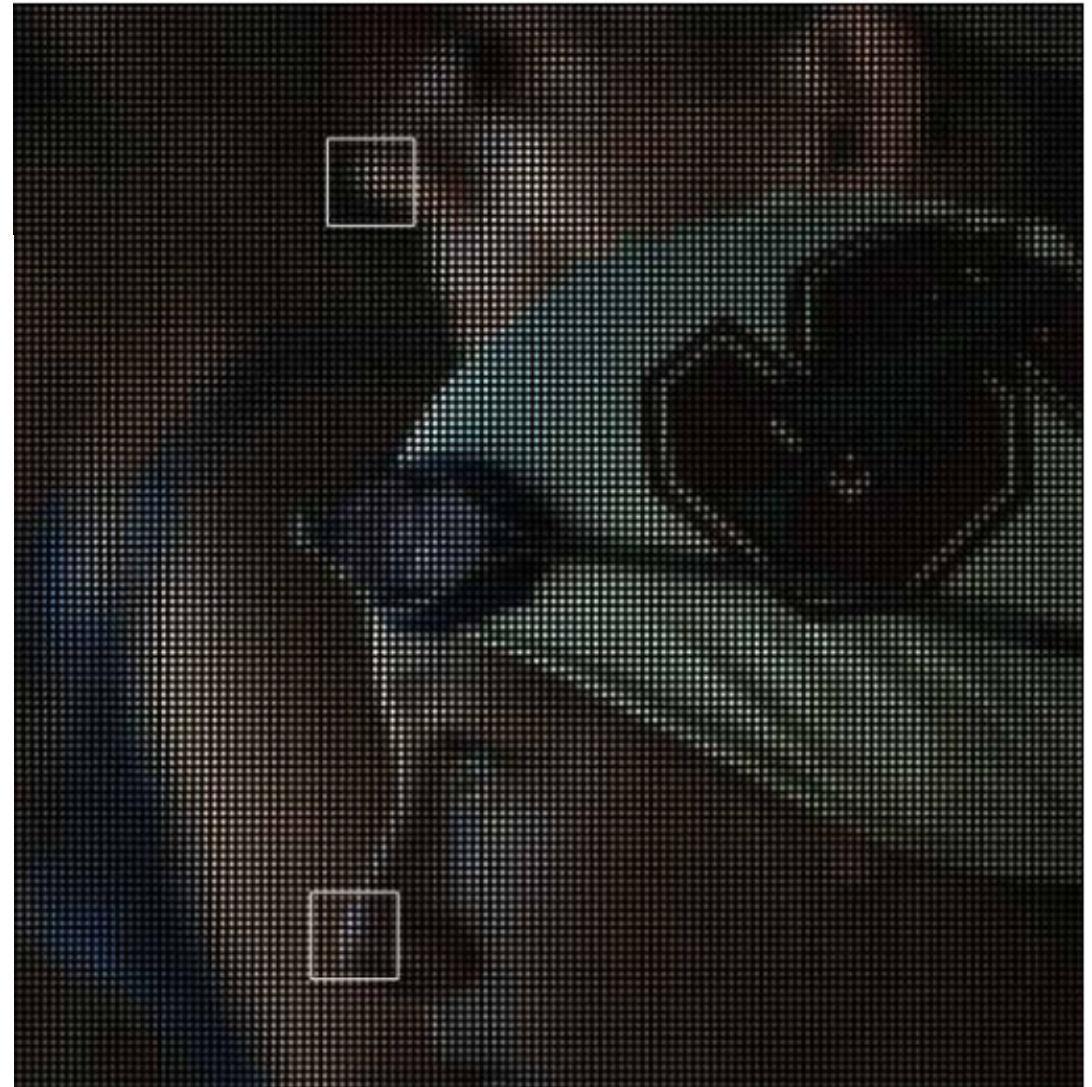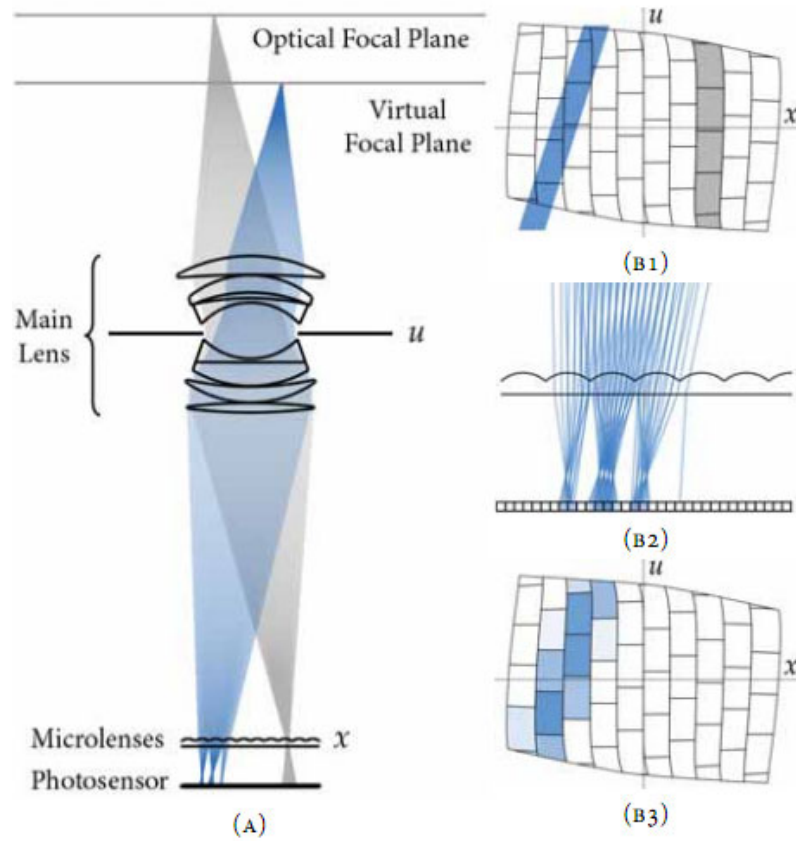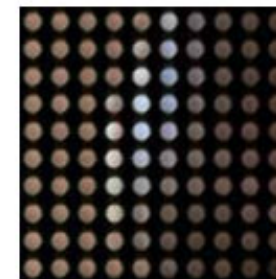
製品：Lytro(2012)

Lytro Illum review
https://www.youtube.com/watch?v=bUd7xXhmugM

屈折率、曲率と焦点距離／
Refraction factor, curvature and focal length
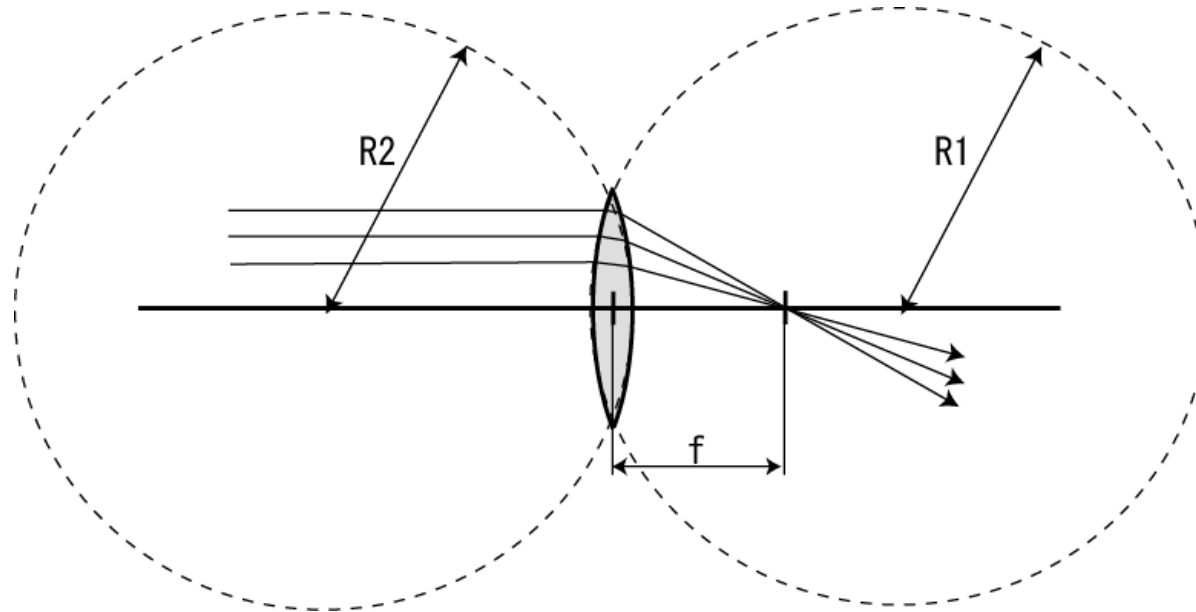
- 球面レンズの場合の近似式／For spherical lens

$$\frac{1}{f} = (N-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{(N-1)^2 d}{NR_1 R_2}$$

- f:焦点距離, N:ガラスの屈折率, R1,R2:レンズの曲率半径, d:レンズの厚み
- 薄いレンズでは第二項は無視することが多い。

What happens if N=2？
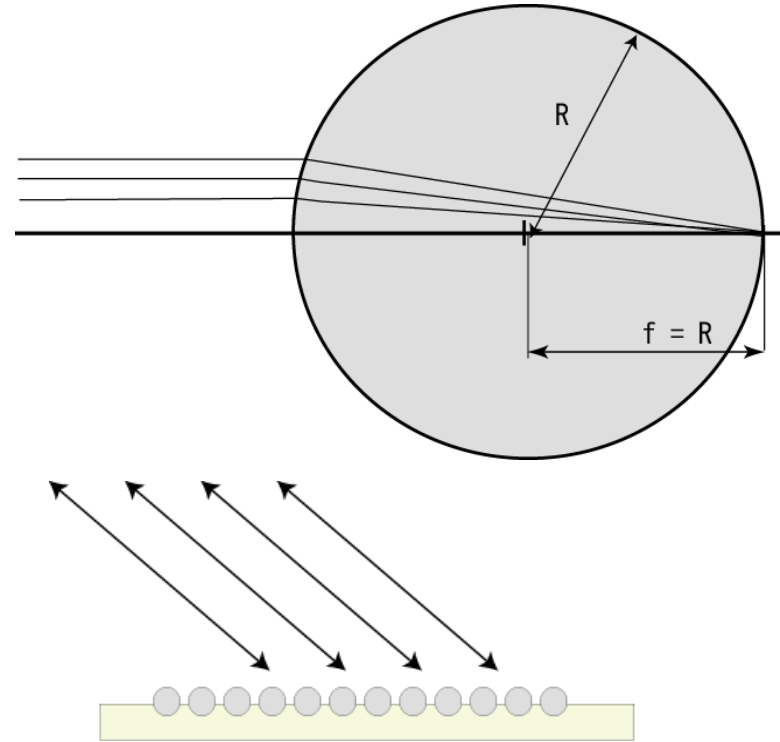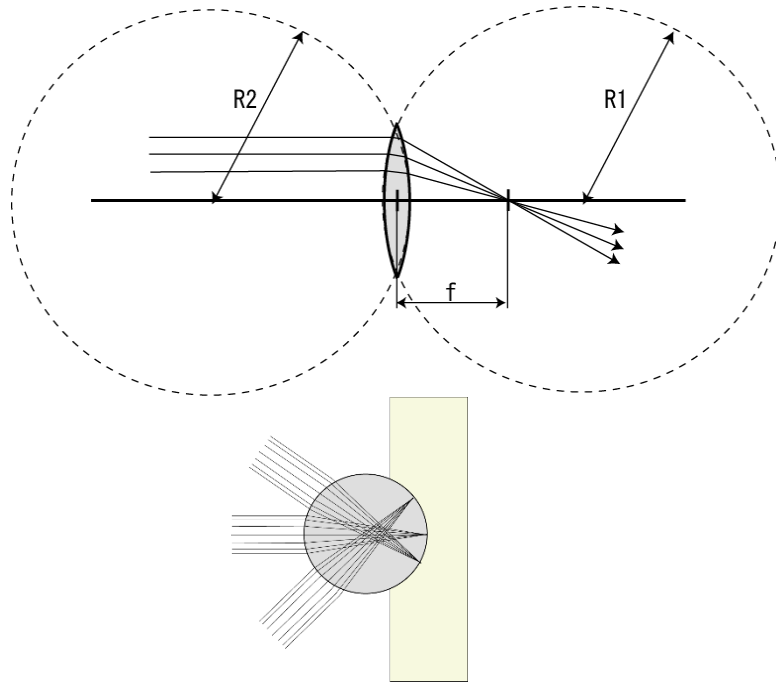
- N=2, R1=R2=R, d=2Rを代入

$$\frac{1}{f} = (N-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{(N-1)^2 d}{NR_1 R_2} = (2-1)\left(\frac{1}{R} + \frac{1}{R}\right) - \frac{(2-1)^2 2R}{2R^2} = \frac{1}{R}$$

$$\therefore f = R$$

- 球面の反対側表面に焦点を結ぶことを意味する
- Meaning focal point is just at the back side of the lens

再帰性反射材／Retro-reflector

Retroreflector (Wikipedia)
https://en.wikipedia.org/wiki/Retroreflector
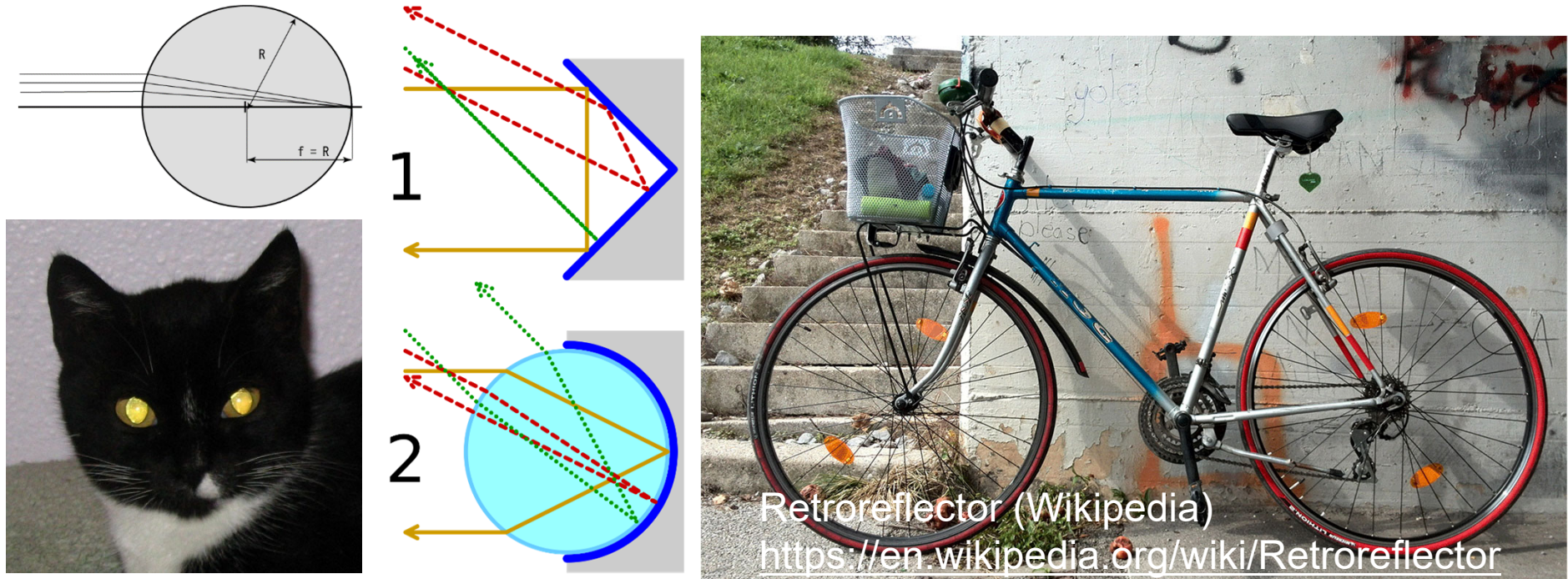
- 屈折率2のガラスビーズは，光が来た方向に帰る
  glass beas with refractive index=2 works as retro-reflector.

  - 球面内側表面での「鏡面」反射は本質ではない．拡散反射しても再帰性反射は生じる（赤目現象と同じ．当然鏡面反射の方が強い反射光を得られるが）

- コーナーキューブタイプも多用される。
  Corner cube is also used.

再帰性反射材／Retro-reflector

Smartphone
LED
Figure
Retro-reflector
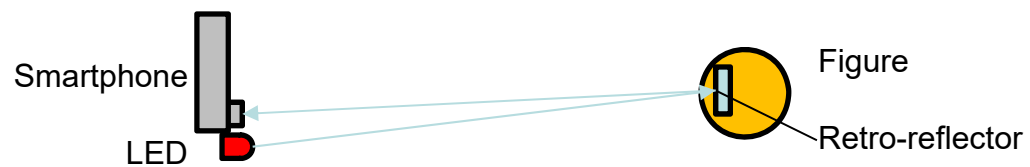
1m away

2m away

TODAY's TOPIC

- 光学素子／Optical Elements
- 光学の基礎／Basics of Optics
- 3次元イメージング／ 3D Image Sensing

3次元イメージング／3D Image Sensing

- 3D Display requires 3D data acquisition
    - 照度差ステレオ法／ Photometric Stereo
    - モワレ法／ Moire Fringe Analysis
    - 光切断法／ Light Section
    - 光レーダー法／Optical Radar
    - タイムオブフライト／ Time of Flight
    - レンズ焦点法／ Shape from Focus
    - パッシブステレオ法／ Passive Stereo
    - 視体積交差法／ Visual Cone Intersection

照度差ステレオ法／Photometric Stereo
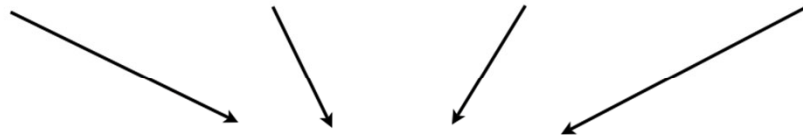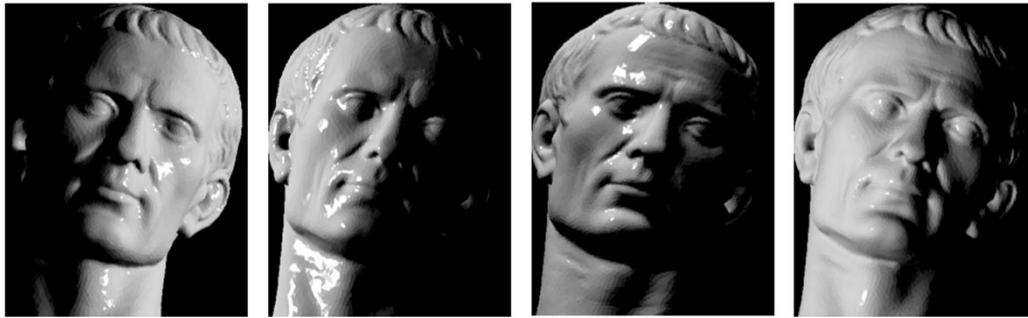
Photometric stereo
https://en.wikipedia.org/wiki/Photometric_stereo

- Prepare 3 or more light sources.
- Object's gradient is calculated by Luminance change
- Shape is calculated by integrating gradient.
- Object surface's characteristics are commonly necessary.
- Single image version is known as shape from shading.
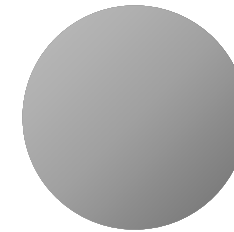
モワレ法／Moire Fringe Analysis

Moire pattern (Wikipedia)
https://en.wikipedia.org/wiki/Moir%C3%A9_pattern

- Project stripes
- See the projected image through the other stripes
  （do the same calculation in PC）
- Depth is converted to density.

Observation
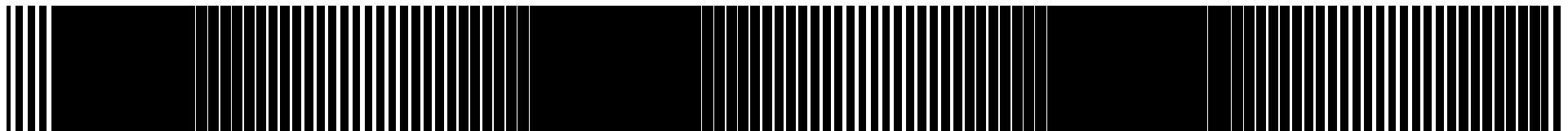
Projection
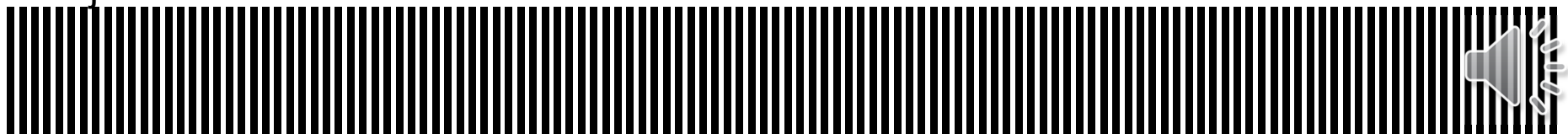
光切断法／Light-section method
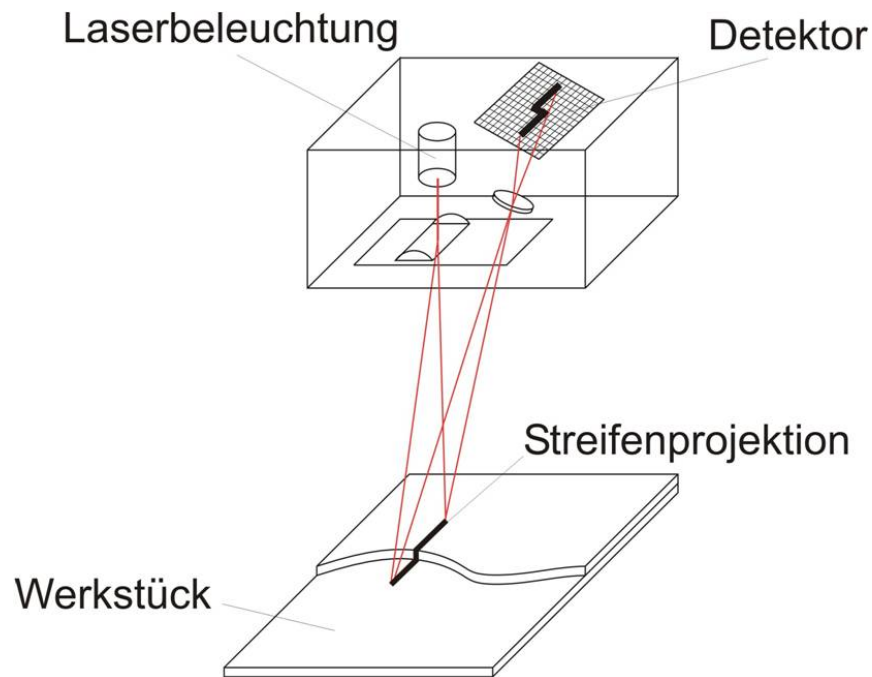
Light section (Wikipedia)
https://en.wikipedia.org/wiki/Light_section

Inline Color 3D Scanner Light Section Method
https://www.youtube.com/watch?v=dd3ayqJGVvo
カラー光切断法
https://www.youtube.com/watch?v=dN3lxPWgCzc

- Project line image and Capture from different position.

- Disparity = distance

- Coded pattern is projected for fast acquisition.

Real-time Projection & 3D retrieval (Song Zhang et al., 2006)

https://www.youtube.com/watch?v=83WwqWiqCmc

Note: stripe-pattern projection method was devised *before* video projector became common.

Xbox Kinect（ver.1）(2012) Projection pattern

IR projector & camera

RGB camera

Kinect v1 (Wikipedia)
https://en.wikipedia.org/wiki/Kinect

How Microsoft Kinect works with Infrared
https://www.youtube.com/watch?v=dTKlNGSH9Pc

光レーダー法／Optical Radar

- Put laser beam to target.
- Use reflection time and phase-lag
- Use rotating mirror for scanning
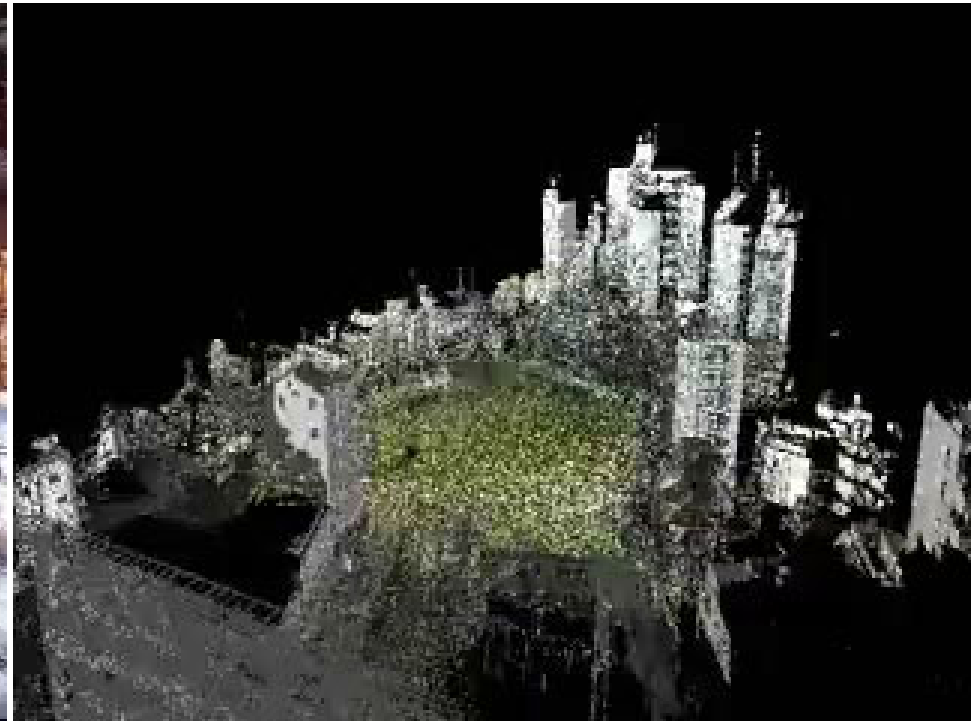- (good) Most accurate
- (bad) Most expensive, requires time for scan

タイムオブフライト／Time of Flight (ToF)

Time-of-Flight Classification

- **Optical Time of Flight** – round trip estimation of an light wave emitted from the sensor to the targeted object, and then reflected from the object back to the sensor

Direct Time-of-flight

$$d = \frac{c \cdot \Delta t}{2}$$

Indirect Time-of-flight

$$d = \frac{c \cdot \varphi}{4 \cdot \pi \cdot fm}$$
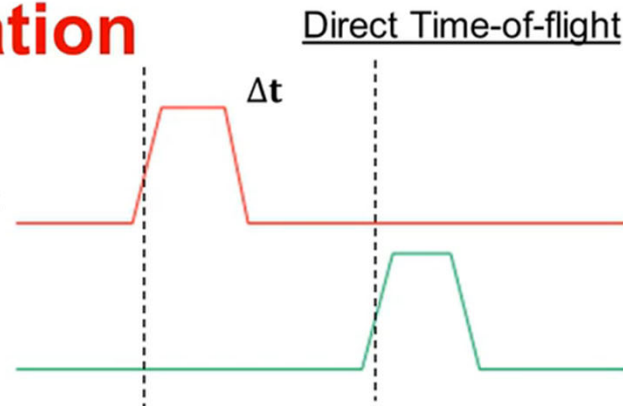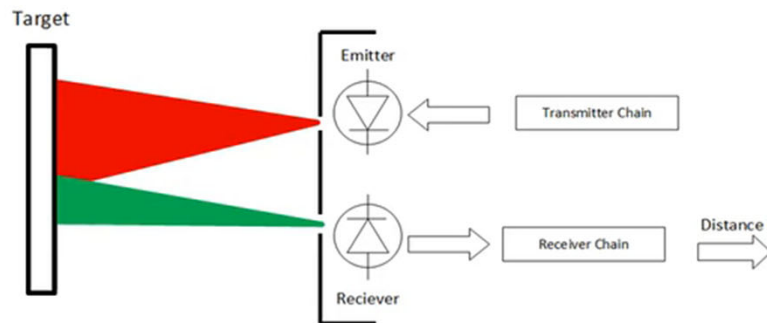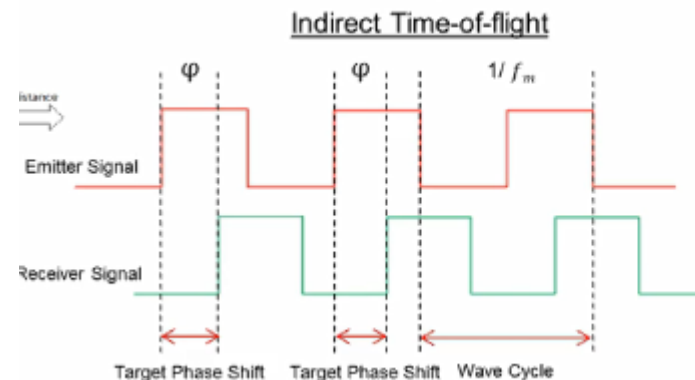
- https://www.youtube.com/watch?v=TpjnooXhOmY
- Similar to optical radar.
- Each CMOS image sensing element has timer

TEXAS INSTRUMENTS

Xbox Kinect（ver.2）(2014) adopted ToF

IR projector & camera

RGB camera

Kinect v2 (Wikipedia)
https://en.wikipedia.org/wiki/Kinect

Bill Heiland 2015

Kinect V1 Vs Kinect V2
https://www.youtube.com/watch?v=Zx2E19IV2zs

レンズ焦点法／Shape (depth) from Focus

A:最も高いところで

B:中間で

C:最も低いところで

抽出合成

深度合成画像

断面イメージ図

https://www.keyence.co.jp/ss/products/microscope/beginner/technology/depth-composition.jsp
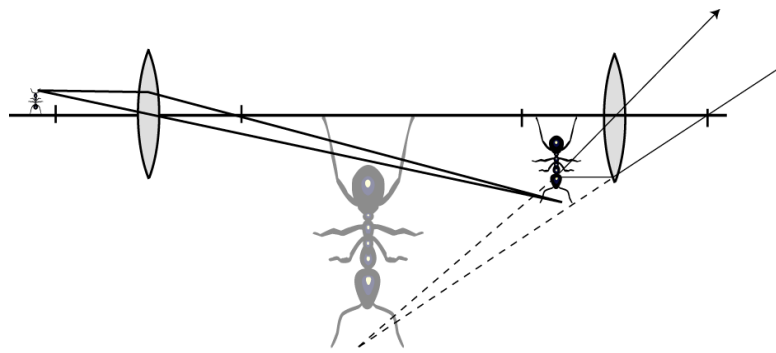
First Experiment in Depth from Focus
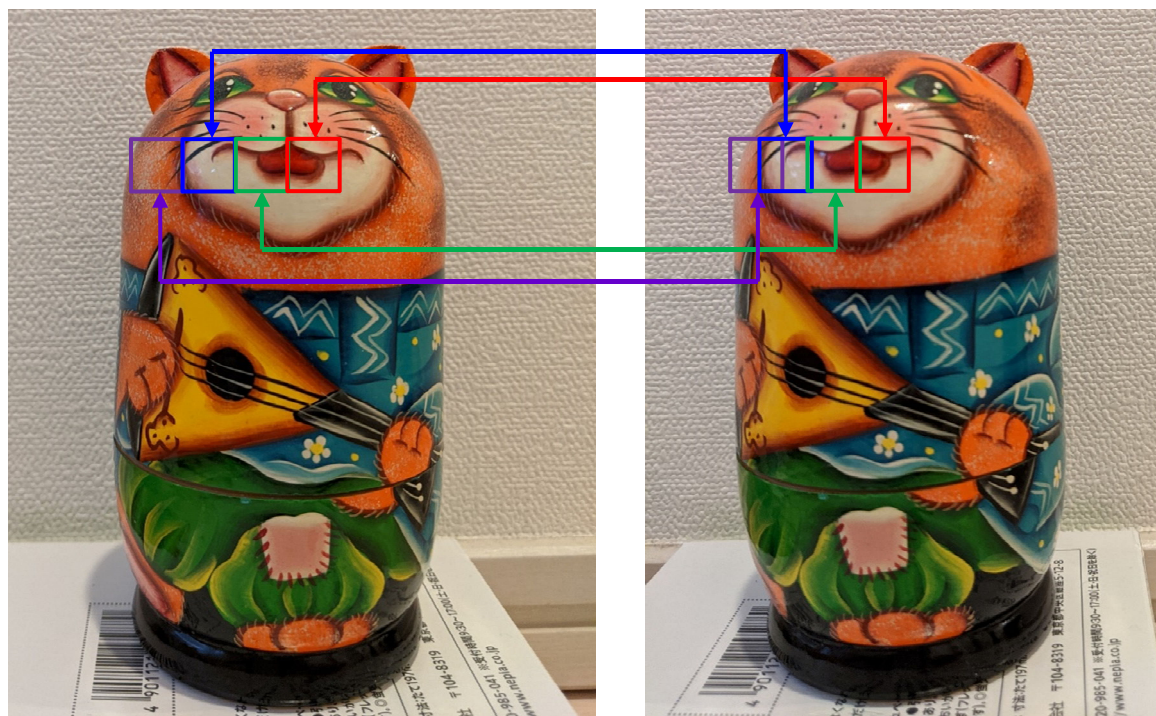https://www.youtube.com/watch?v=YkjCZTAzlsA&t=180s

- Shift the lens and move focus distance
- Use different focus levels to obtain a sequence of object images.
- Quite rough, when used for scenary.(focal depth is large)
- Quite accurate, when used in microscopy. (focus is severe)
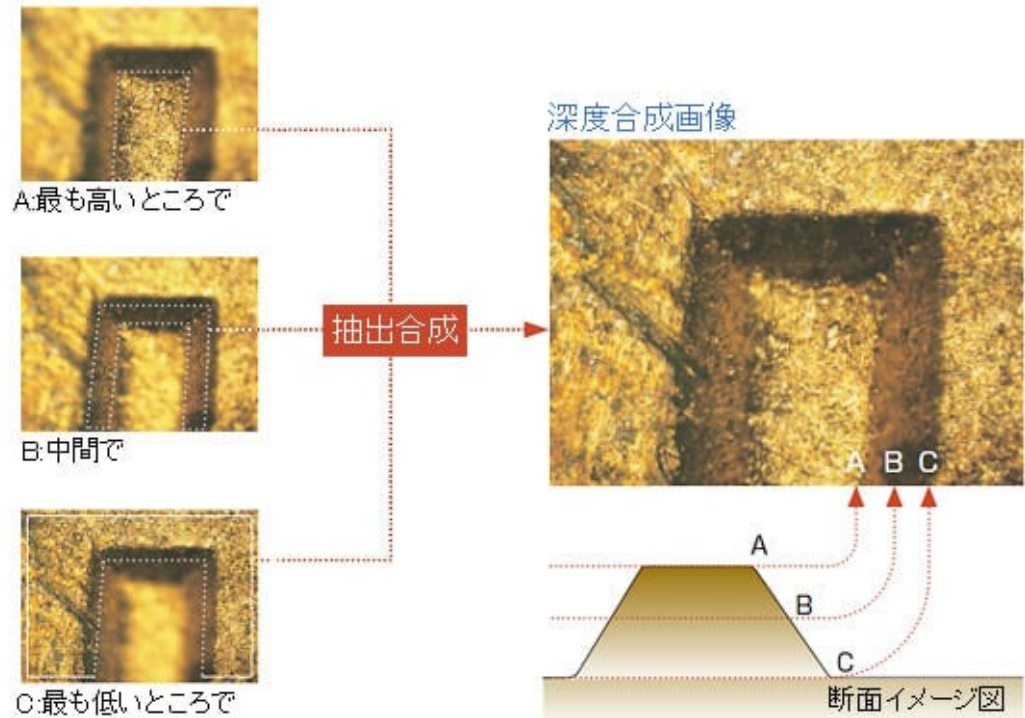
パッシブステレオ法／Passive Stereo

- Two or more cameras
    - Just like we do with our two eyes.
    - Use disparity. Triangular Method.
    - (bad) Disparity measurement requires huge calculus.
    - (bad) Mis-calculation of the disparity occasionally.
    - (good) Can be used outdoors.

Passive Stereo example

https://www.stereolabs.com/zed/
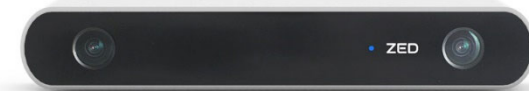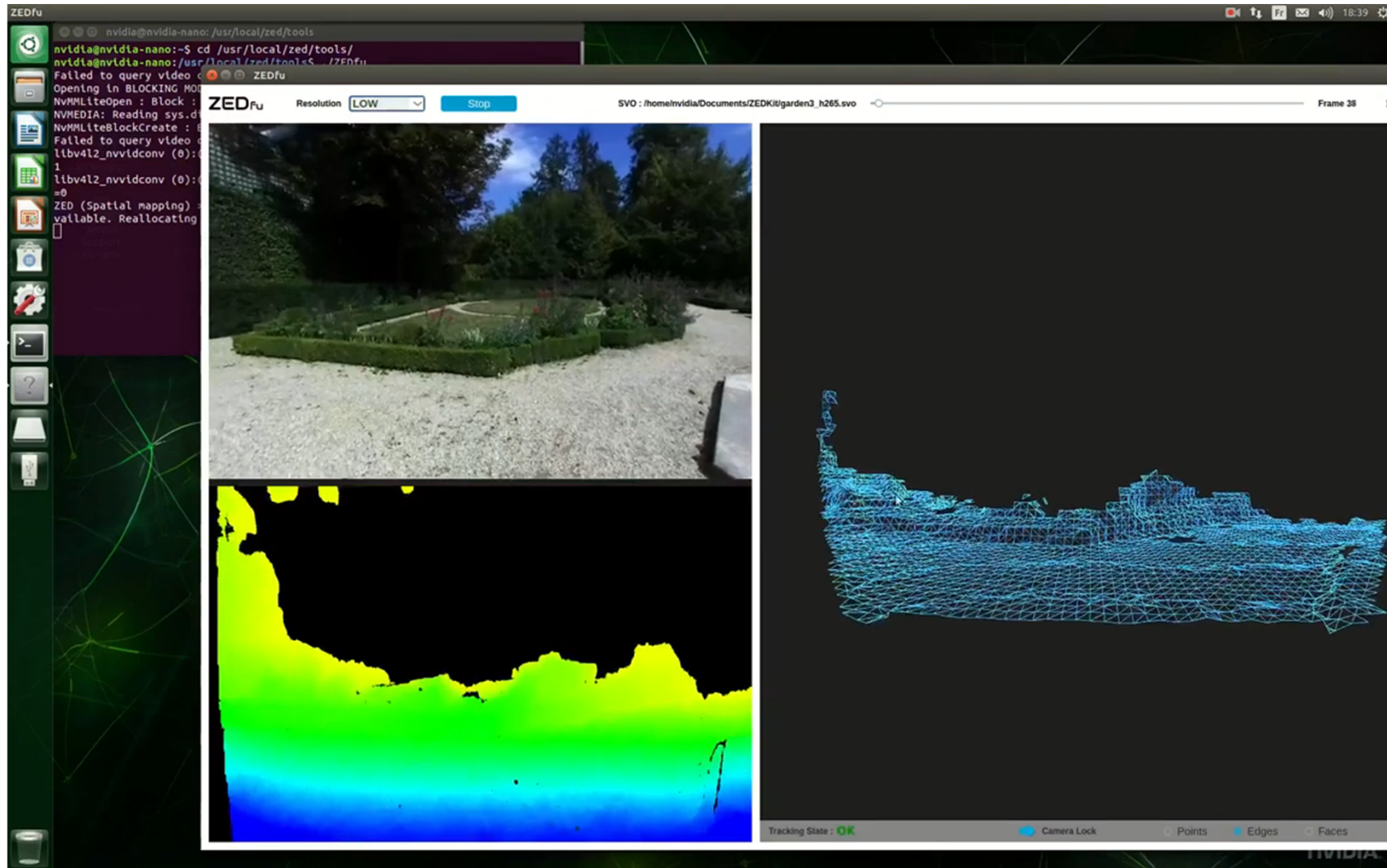
https://www.youtube.com/watch?v=c7UQ6BQJncM
3D Mapping on Jetson Nano with ZED Camera

Passive Stereo example: LeapMotion

IR Stereo Cameras

モバイル機器に搭載される奥行きカメラ
depth sensing in mobile.
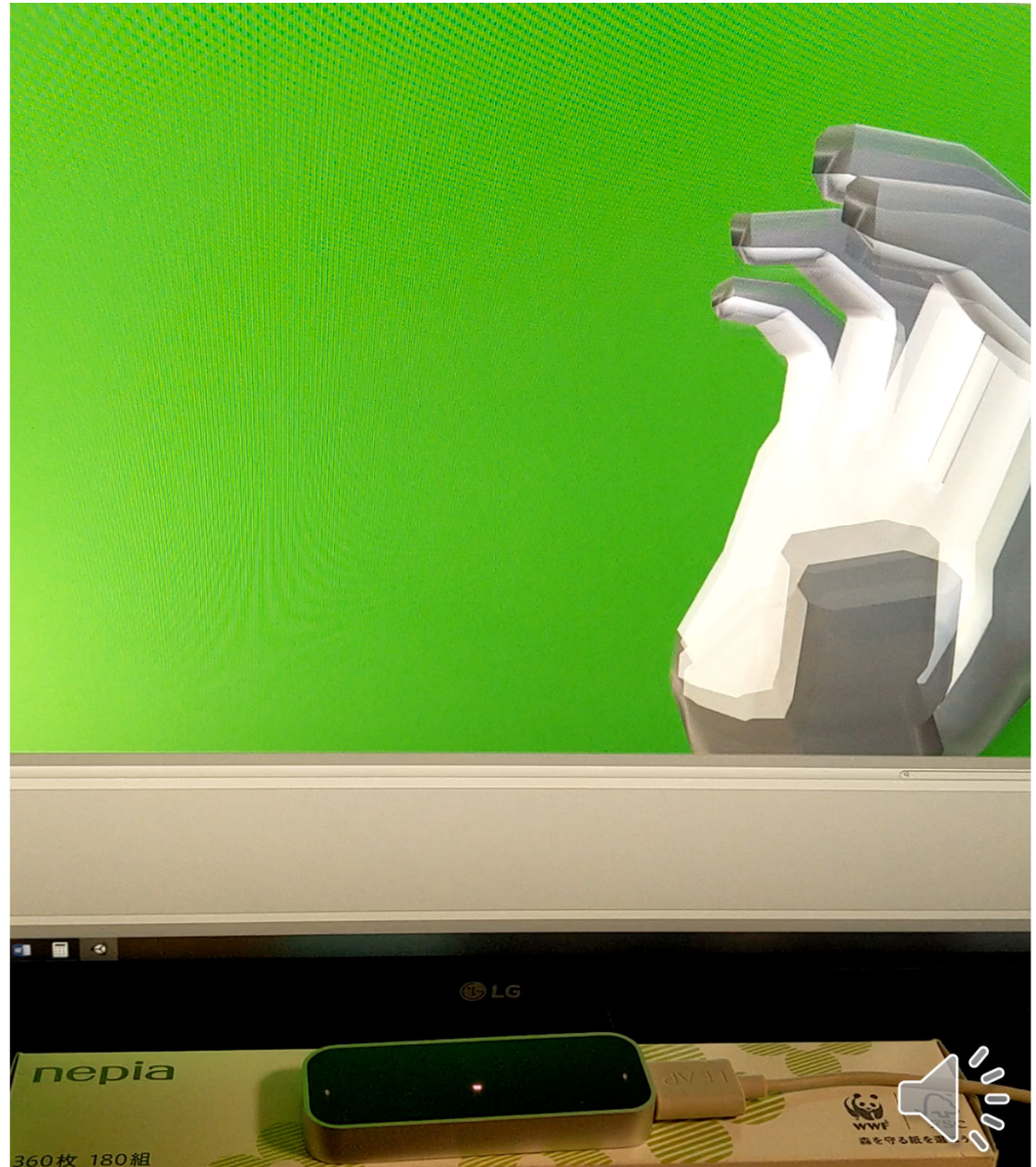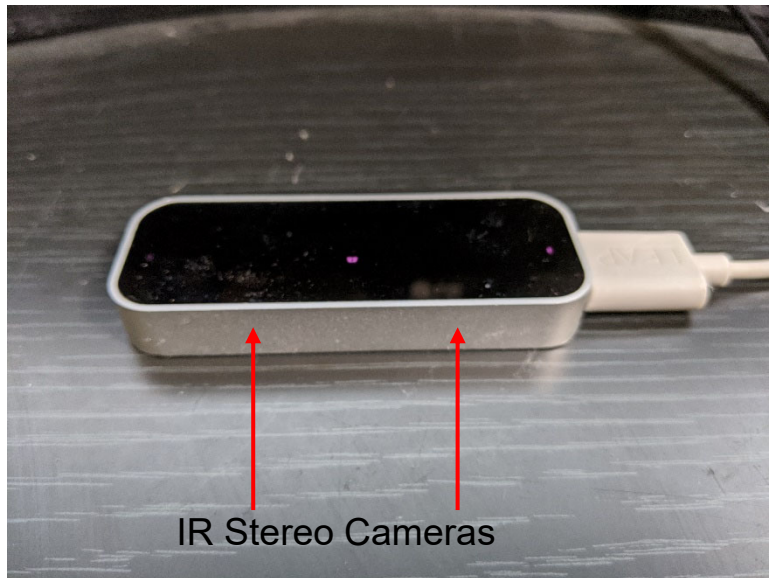

Google's Project Tango, 2014〜
- 第一世代：Laser, Structured Light (Prime Sense)
- 第二世代：Laser, Structured Light (Mantis Vision)
- 第三世代：IR, Time of Flight

https://www.youtube.com/watch?v=Qe10ExwzCqk
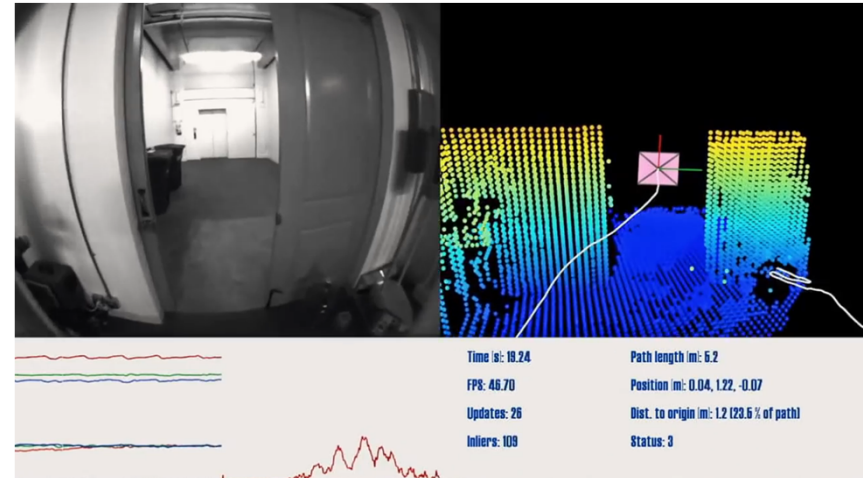
HTCOne M8, 2014〜
Dual camera for post processing

Huawei P10, 2017〜
Double lens camera for post processing

https://www.youtube.com/watch?v=sj3EhvFCY6c

https://www.digitaltrends.com/mobile/huawei-p10-vs-huawei-p10-plus/

スマートフォンでは奥行き計測そのものより画像の被写界深度を擬似的に浅くするために奥行き検出を必要とした。しかし画像処理技術のみで同レベルの処理を行うアプローチも成功（Google Pixel）

視体積交差法／Visual Cone Intersection, Visual Hull

box

viewpoint

silhouette

viewpoint1

http://vision.gel.ulaval.ca/~visualhull/
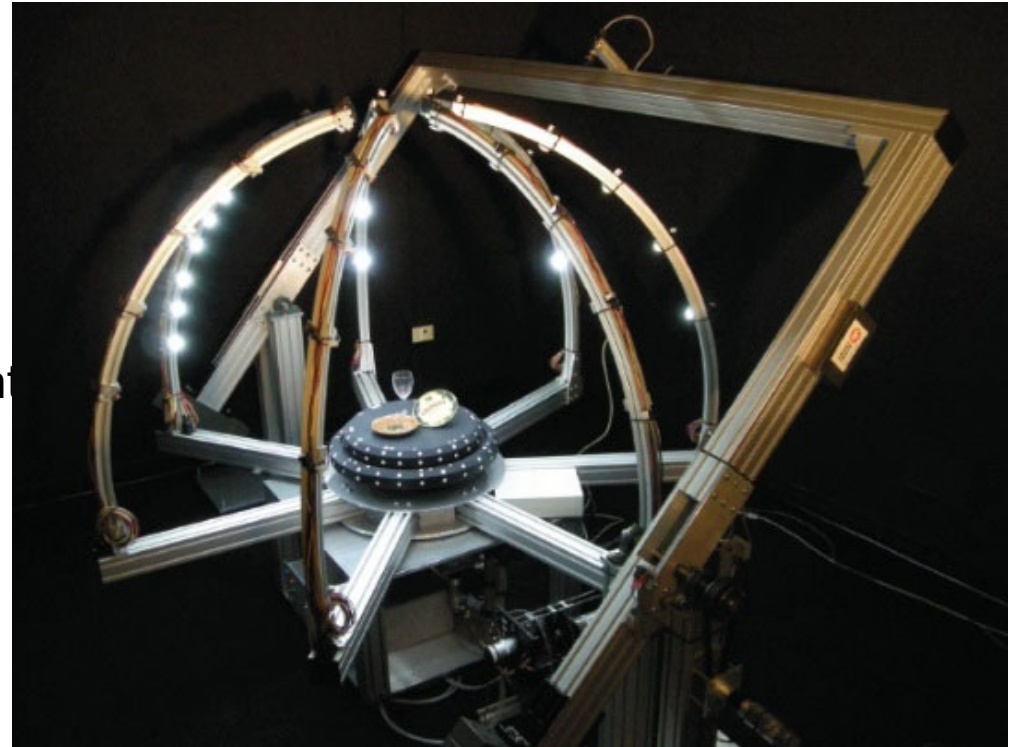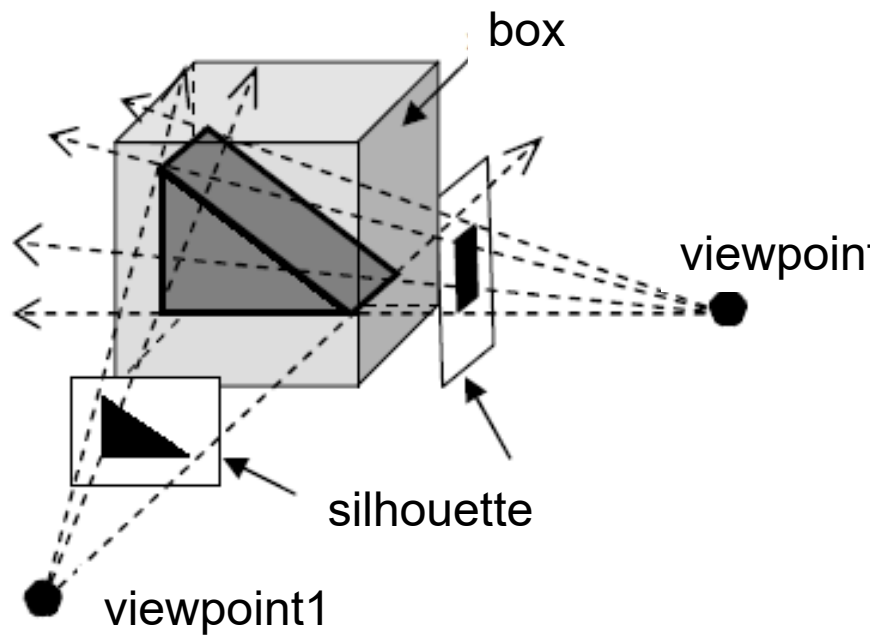
- Simple method when image can be captured from all-round.
- "trim" the box by using silhouettes.
- (bad) Concave part cannot be reconstructed.

Visual Hull

- https://www.youtube.com/watch?v=Lw9aFaHobao

- Image-based visual hulls

- Multiple cameras from ceiling enables 3D reconstruction.

TODAY's SUMMARY

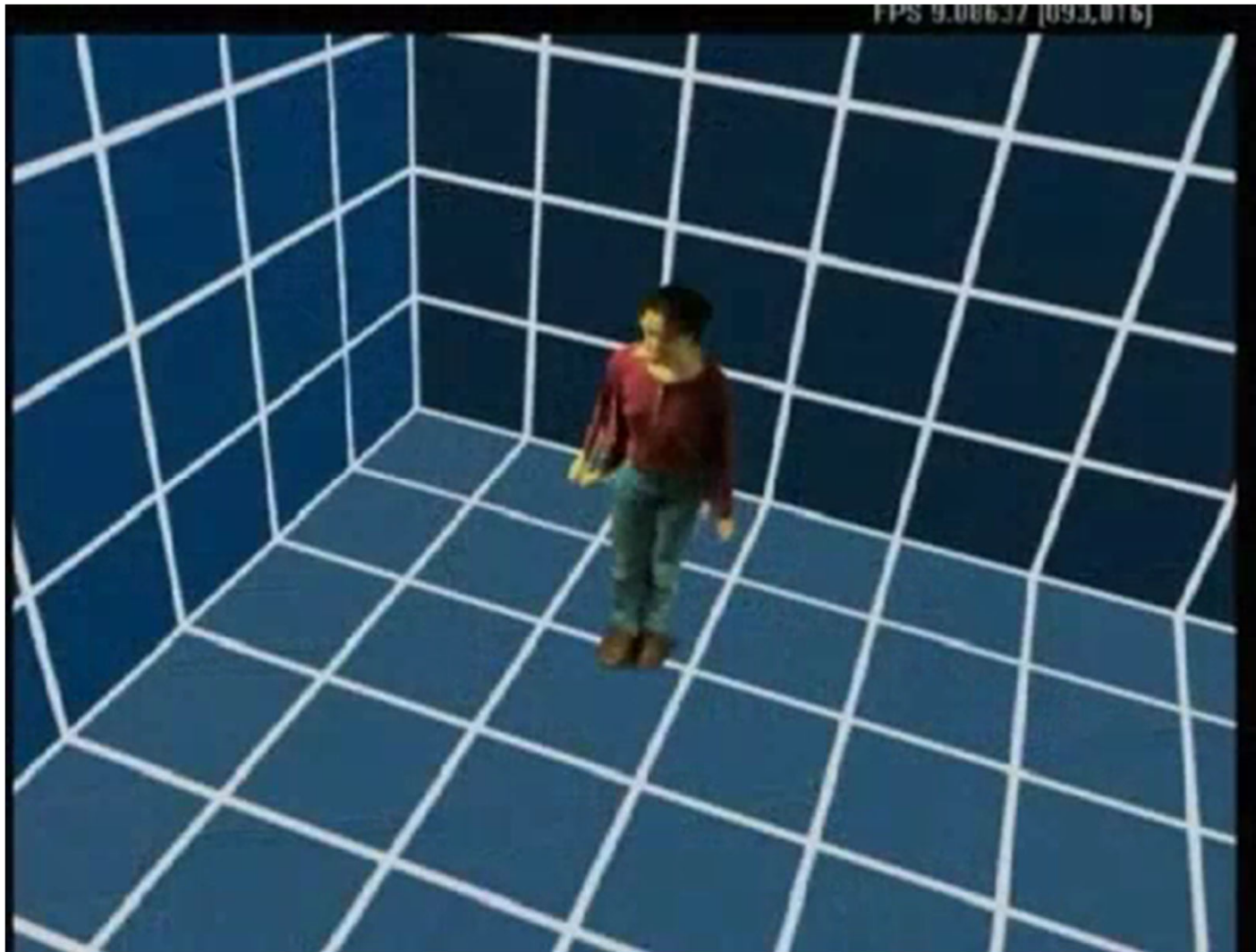- Basics of Optics
  - Lens
  - Real Image, Virtual Image
  - Refraction Image, Reflection Image
  - Mirror (flat, elliptic, hyperbolic, parabolic)
- 3D Image Sensing
  - True 3D reconstruction
    - Optical Radar, Time of Flight, Moire Fringe Analysis, Photometric Stereo, Light Section, Shape from Focus, Passive Stereo, Visual Cone Intersection
  - Practical Approach for interactive system

小テスト／Mini Test 次回開始までに提出

以下の全てに100字以内程度で解答せよ／Answer all questions within 50 words

1. フレネルレンズについて説明せよ Explain fresnel lens.
2. ハーフミラーについて説明せよ Explain half mirror
3. 偏光板について説明せよ Explain polarization plate
4. 実像について説明せよ Explain real image.
5. 虚像について説明せよ Explain virtual image
6. 再帰性反射材について説明せよ Explain retroreflector.
7. モワレ法について説明せよ Explain moire fringe analysis
8. 照度差ステレオ法について説明せよ Explain photometric stereo method
9. 光切断法について説明せよ Explain light section method.
10. タイムオブフライトについて説明せよExplain time of flight method
11. レンズ焦点法について説明せよ Explain shape from focus
12. パッシブステレオ法について説明せよ Explain passive stereo method
13. 視体積交差法について説明せよ Explain visual cone intersection method.