Industrial Computer Vision
i.e. Machine Vision

02504 Computer Vision, Spring 2020

Rasmus A. Lyngby, Ph.D.

Who I am

2009	2012	2014	2018	2020
Swim Coach	**BSc**	**MSc**	**PhD**	**ProInvent**
Diploma Coach, Level 3 Aalborg Trænerakademi	Electronics and IT Aalborg University	Vision, Graphics, and Interactive Systems Aalborg University	Image Analysis and Computer Graphics Technical University of Denmark	Head of Machine Vision

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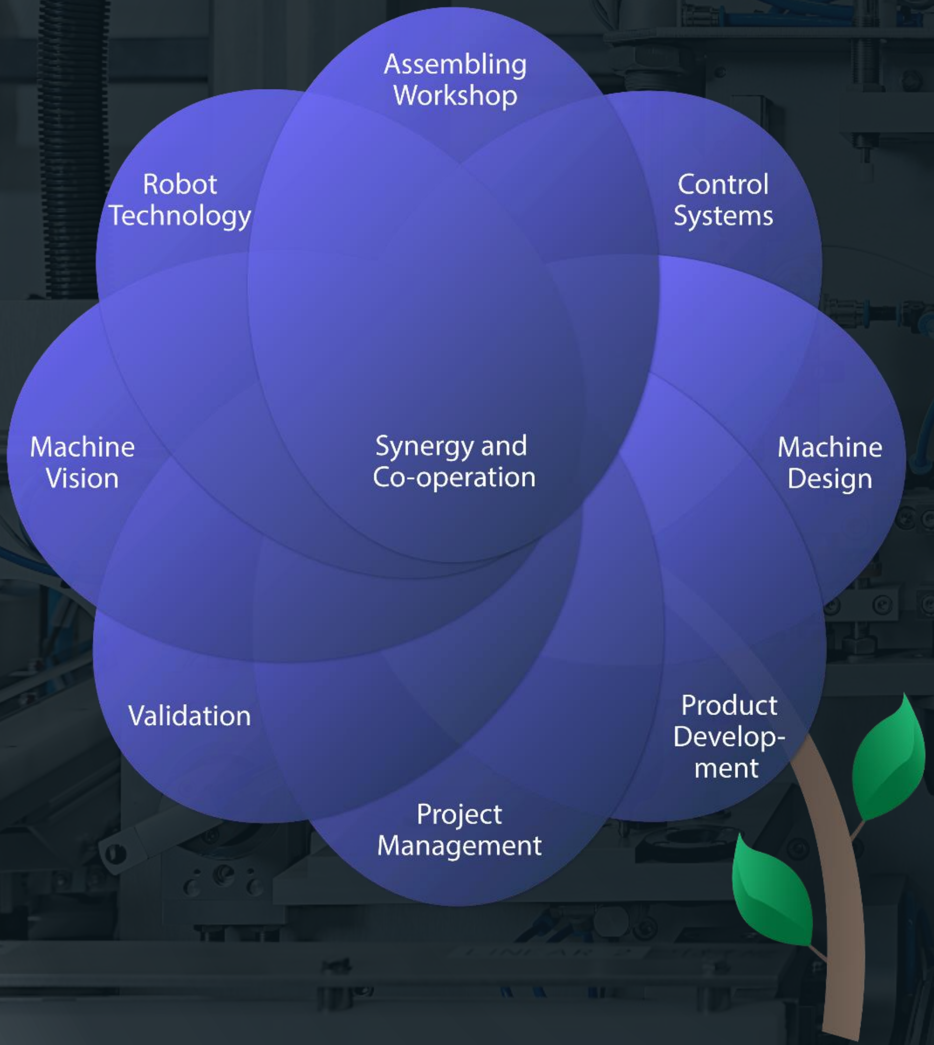
Who we are at ProInvent



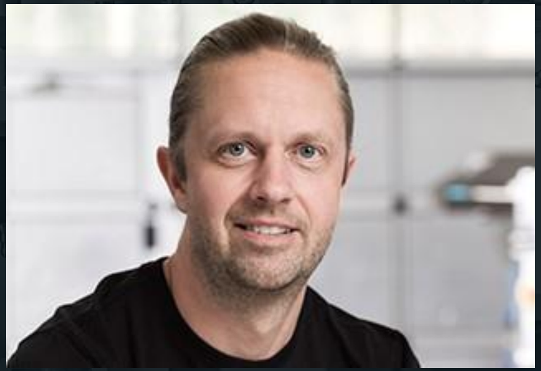
Our team

Rasmus Mortensen
Head of Machine Design

Henrik Søndergaard
Department Manager
Robotics & Automation

Rasmus Ahrenkiel Lyngby
Head of Vision

Peter Ahlberg
Senior Partner
Head of Project Management



Lasse Jensen
Head of Assembly

René Ferm Nyberg
Head of Product Development

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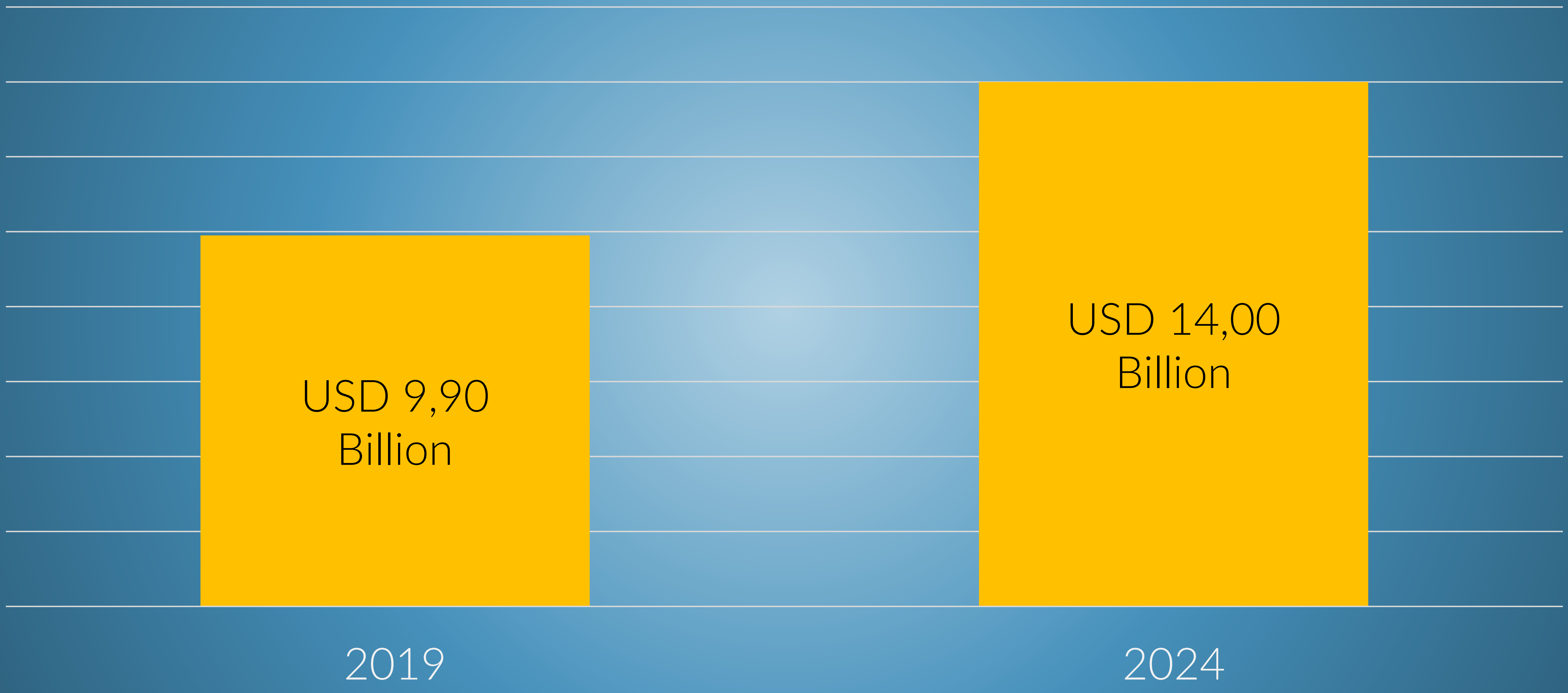
Projected Machine Vision Market Growth



Source: MarketsandMarkets Market Research Report 2919/12/02

Machine Vision vs. Computer Vision

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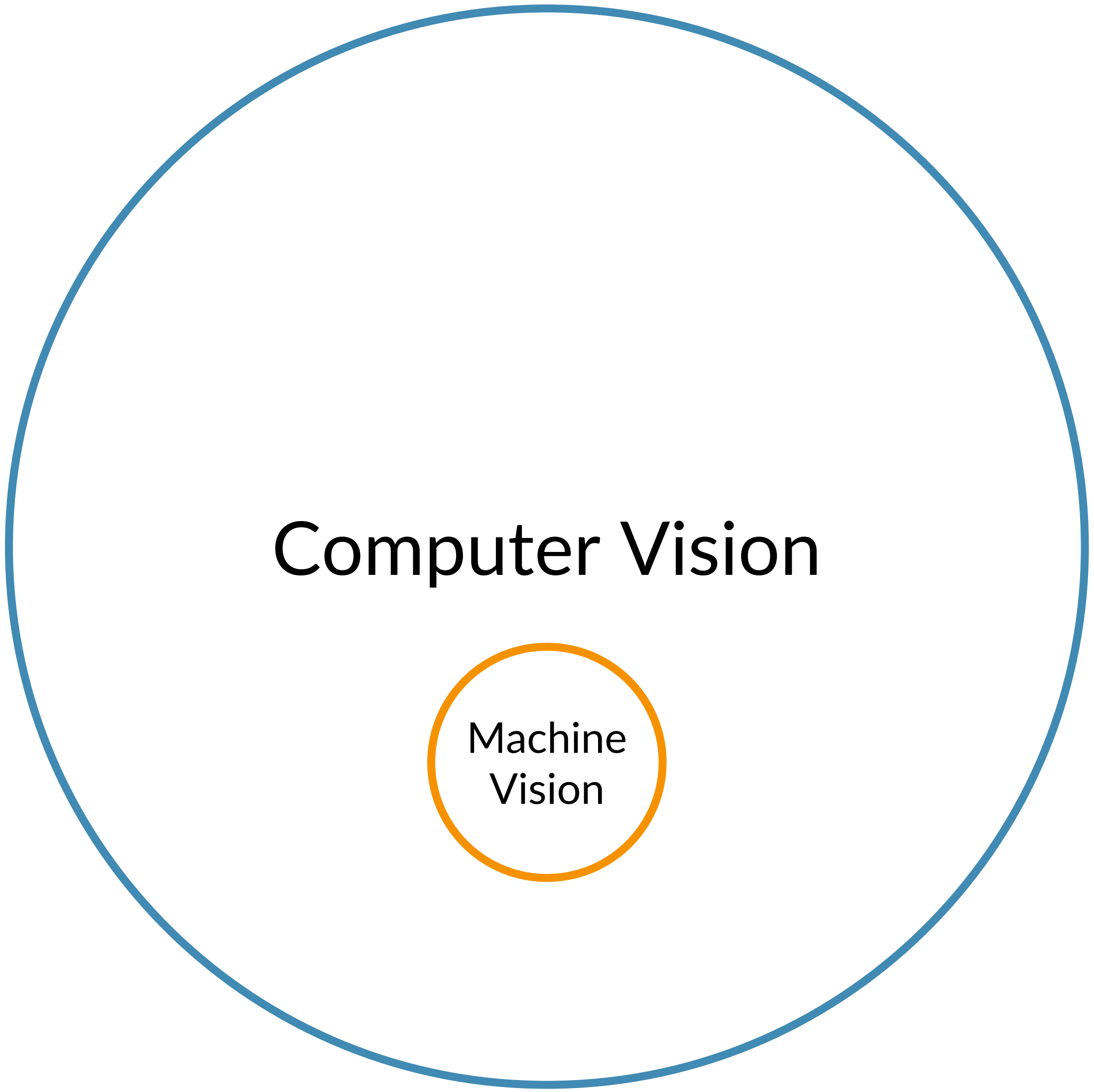
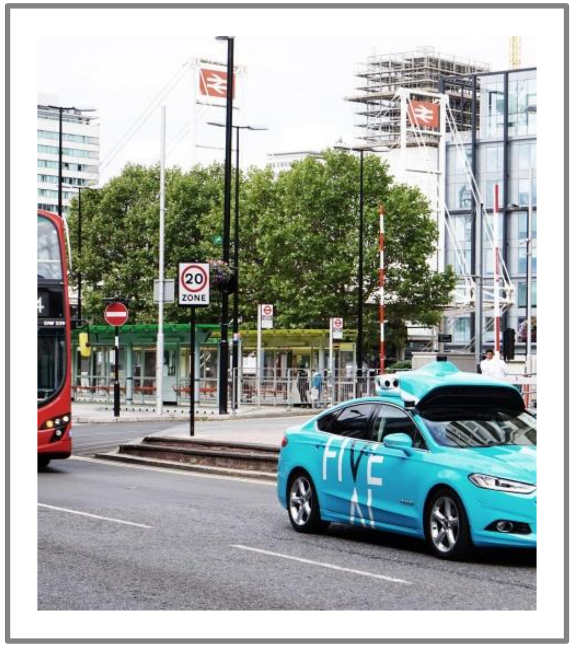
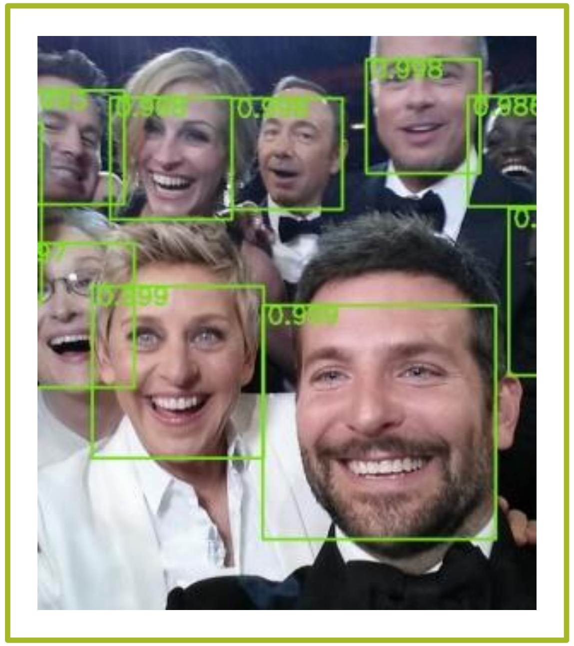

Computer Vision
Machine
Vision



Autonomous cars

Robots working “in the wild”



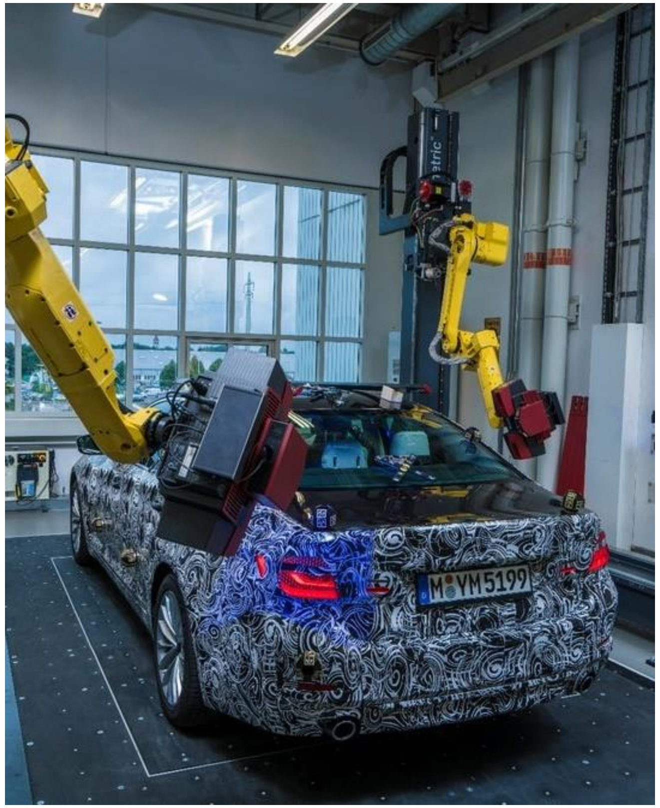
Computer Vision

In most Computer Vision applications, we are in limited control of the environment

Surveilance

Source: Willow Garage, FiveAI, Eniversity of Edinburgh

Product quality inspection



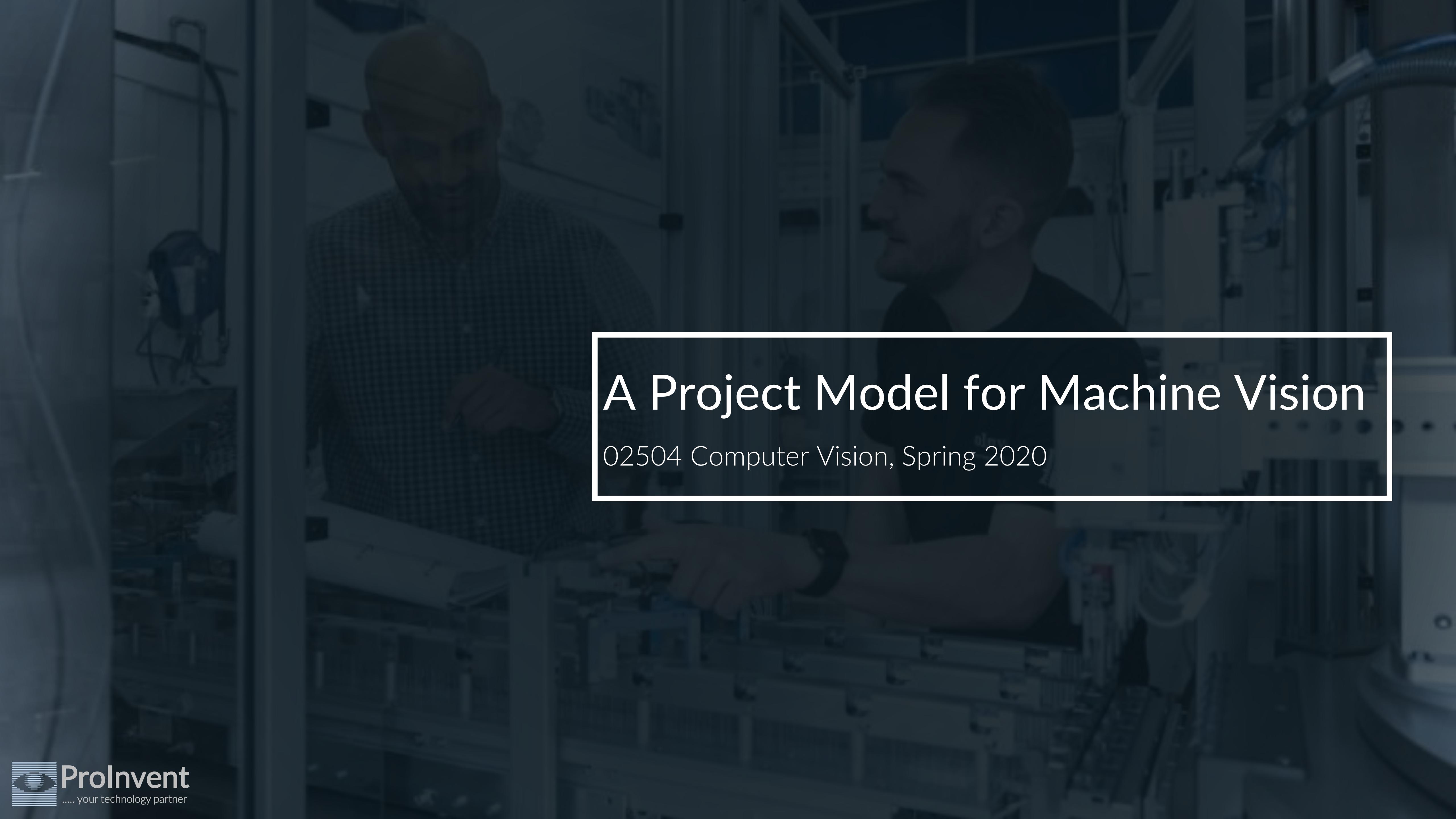
Advanced multi-ray, multi-wavelength quality inspection

Industrial robots for geometrical tolerancing

Machine Vision

In most Machine Vision applications, we are <u>in almost full</u> control of the environment

Source: Metrology News, Cognex, New Atlas



A Project Model for Machine Vision

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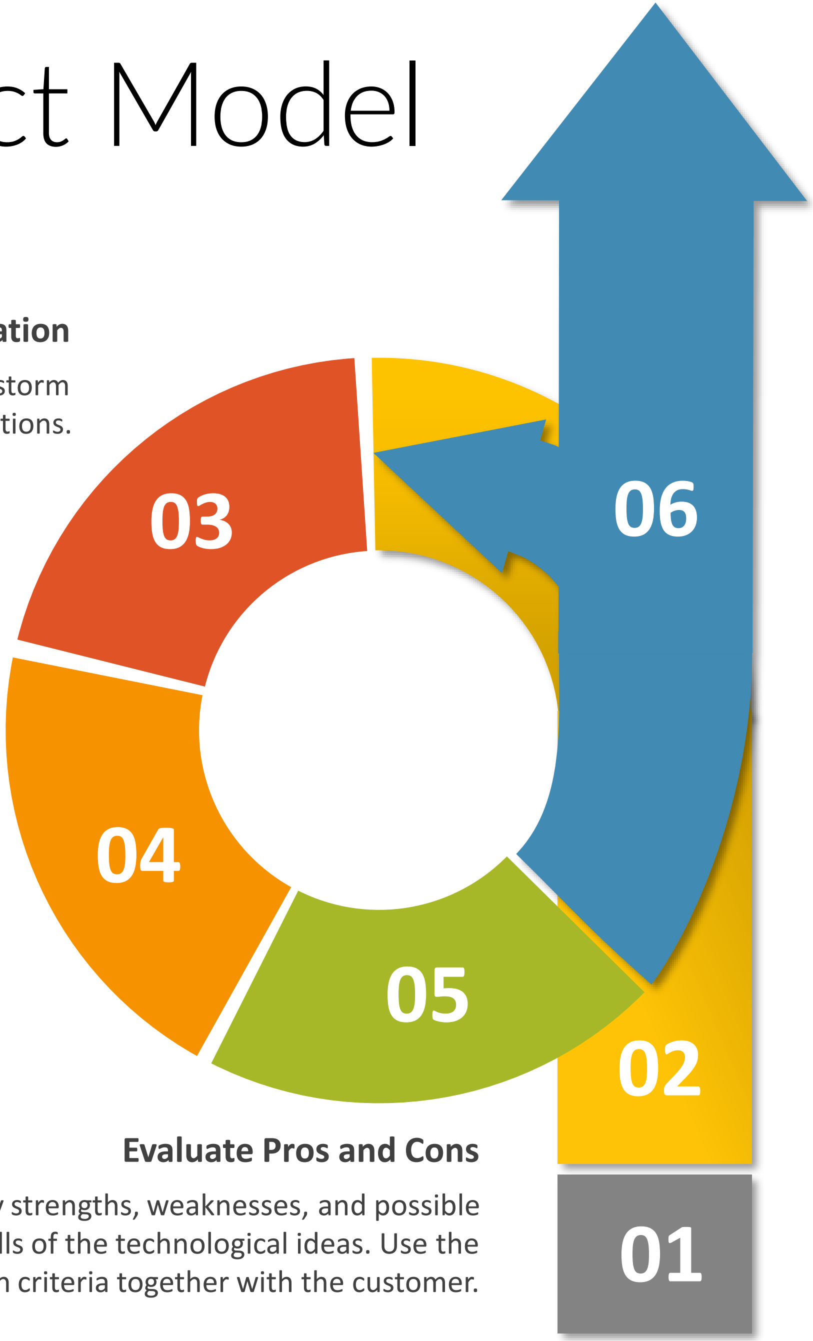
The Pre-Project Model



Conceptualization

The key idea generation process. Brainstorm individually and in groups to generate solutions.

Fast Prototyping

Test the key concept idea either through calculation, mock-up, or both. Likely to generate new ides.

Evaluate Pros and Cons

Identify strengths, weaknesses, and possible pitfalls of the technological ideas. Use the evaluation criteria together with the customer.

Basic Design

Generate a trustworthy design which “visualizes” the final concept.

Evaluation Criteria

Pick and choose concept evaluation criteria together with the customer.

Investigation

Gathering of information on customer supply chain and analyze data.

Designing a Machine Vision System

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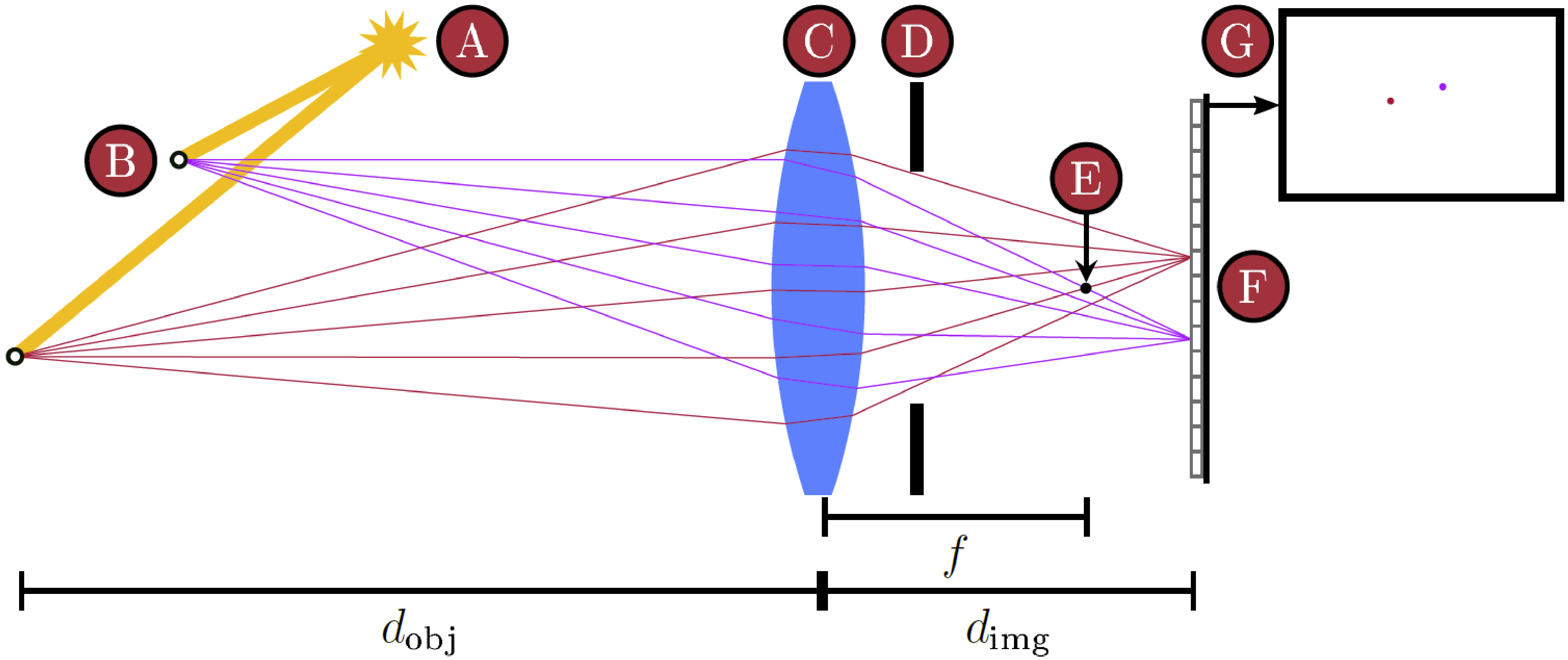
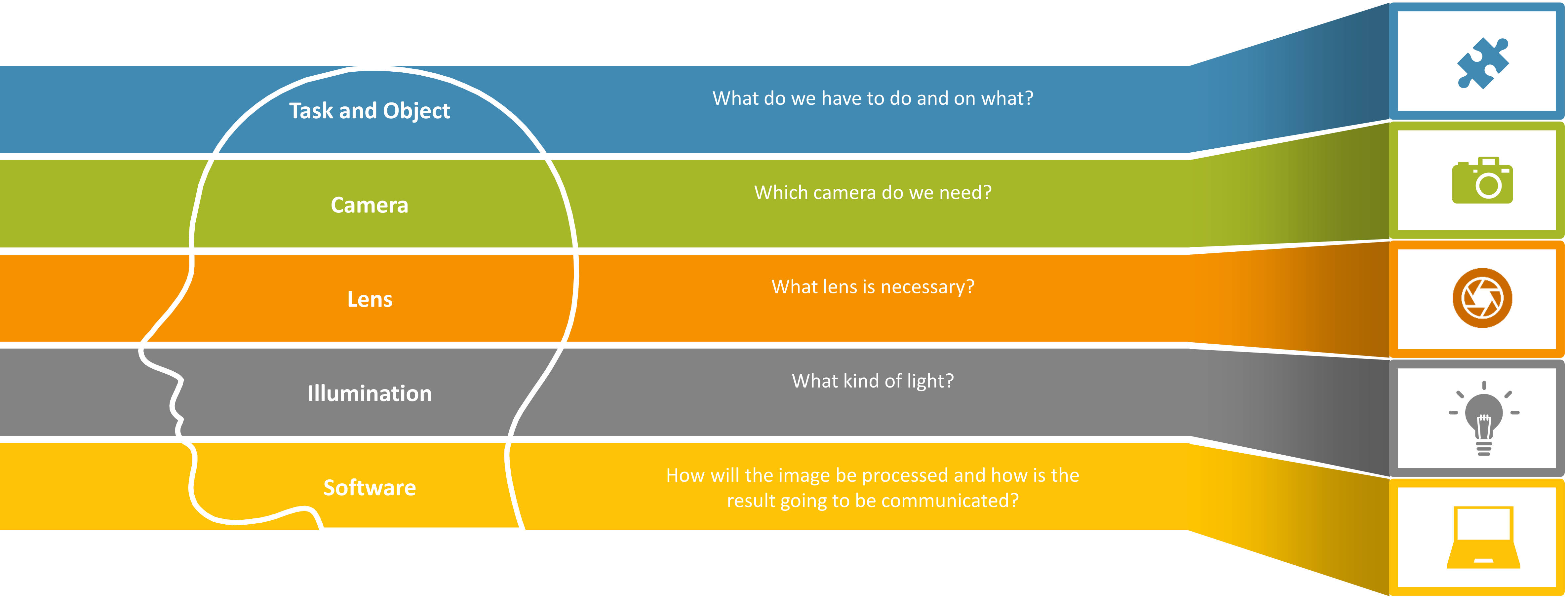
Elements in a Machine Vision system



Lyngby, R. A. (2019). Autonomous Optical Inspection of Large Scale Freeform Surfaces. Kgs. Lyngby, Denmark: Technical University of Denmark. DTU Compute PHD-2018, Vol.. 486

Elements in a Machine Vision system



Task and Object

- What are we going to do?
  - Geometrical measurement
  - Inspection
  - Detection
  - Reading
- What is our feature size?
- How is the shape of the workpiece?
- What material is the workpiece made of?

Feature size

Source: inspect world of vision

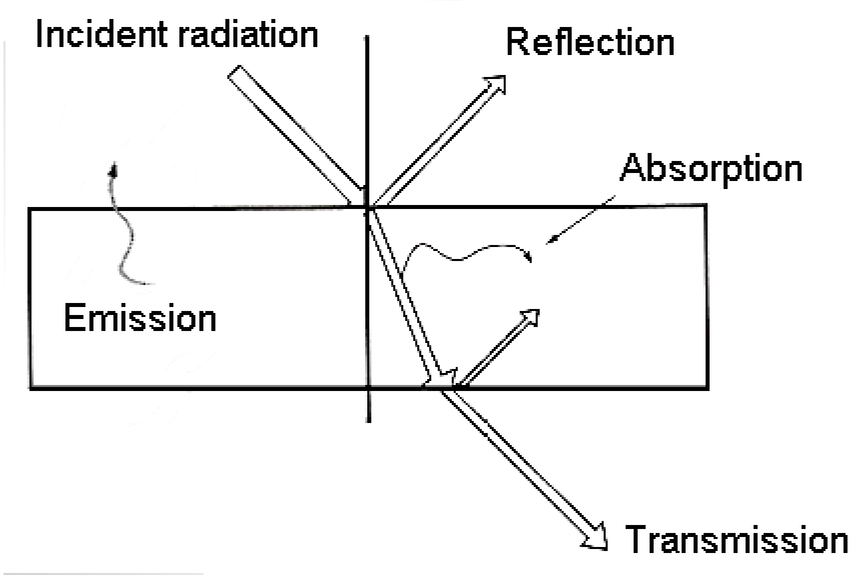
Material

- For dielectric medias:

$$\frac{I_0}{I_R} + \frac{I_0}{I_T} + \frac{I_0}{I_A} = 1$$

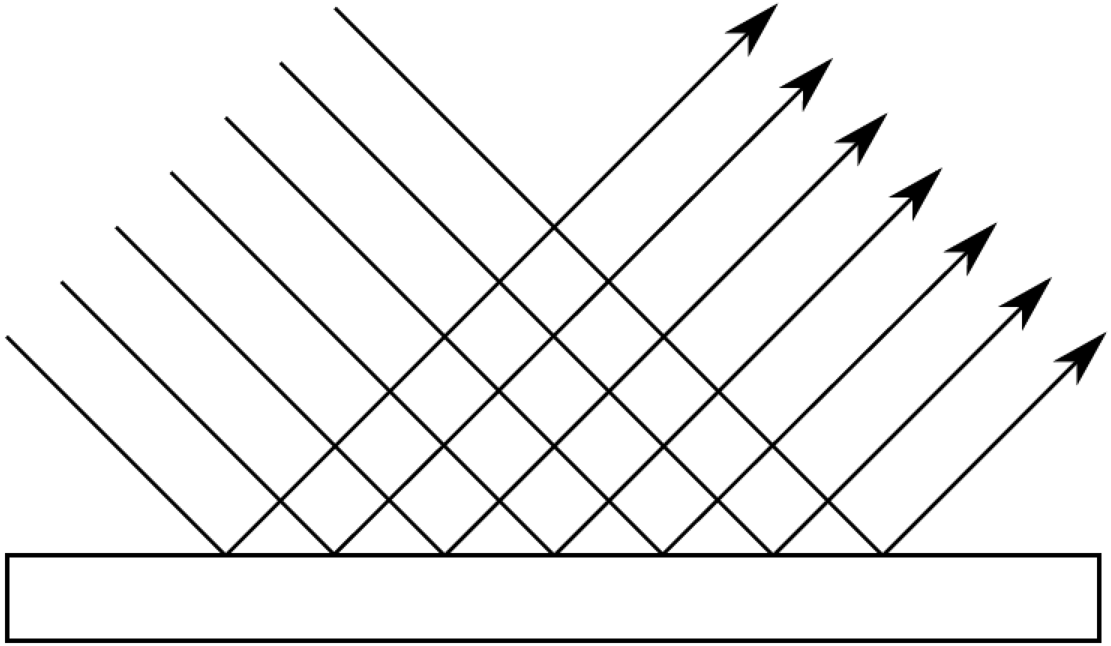
- Where:

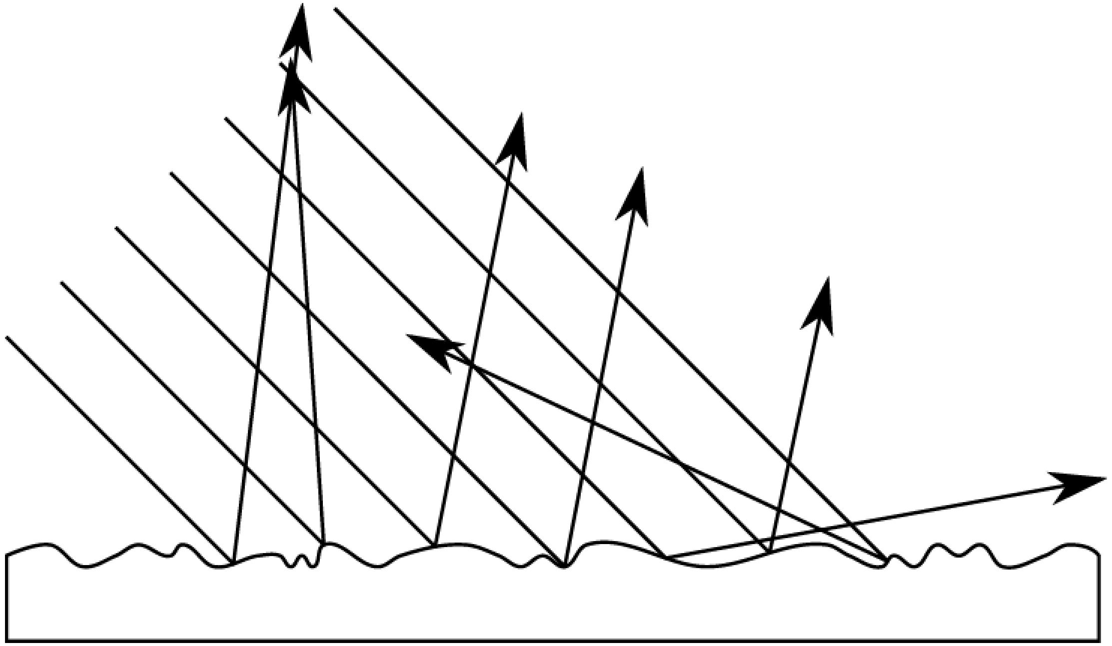
  I_0: Incoming irradiance $[W/m^2]$
  I_R: Reflected radiance $[W/sr/m^2]$
  I_T: Transmitted radiance $[W/sr/m^2]$
  I_A: Absorbed radiance $[W/sr/m^2]$



Source: Hyll, C. (2012). Infrared Emittance of Paper: Method Development, Measurements and Application (Doctoral dissertation, KTH Royal Institute of Technology).

Specular vs Diffuse reflection





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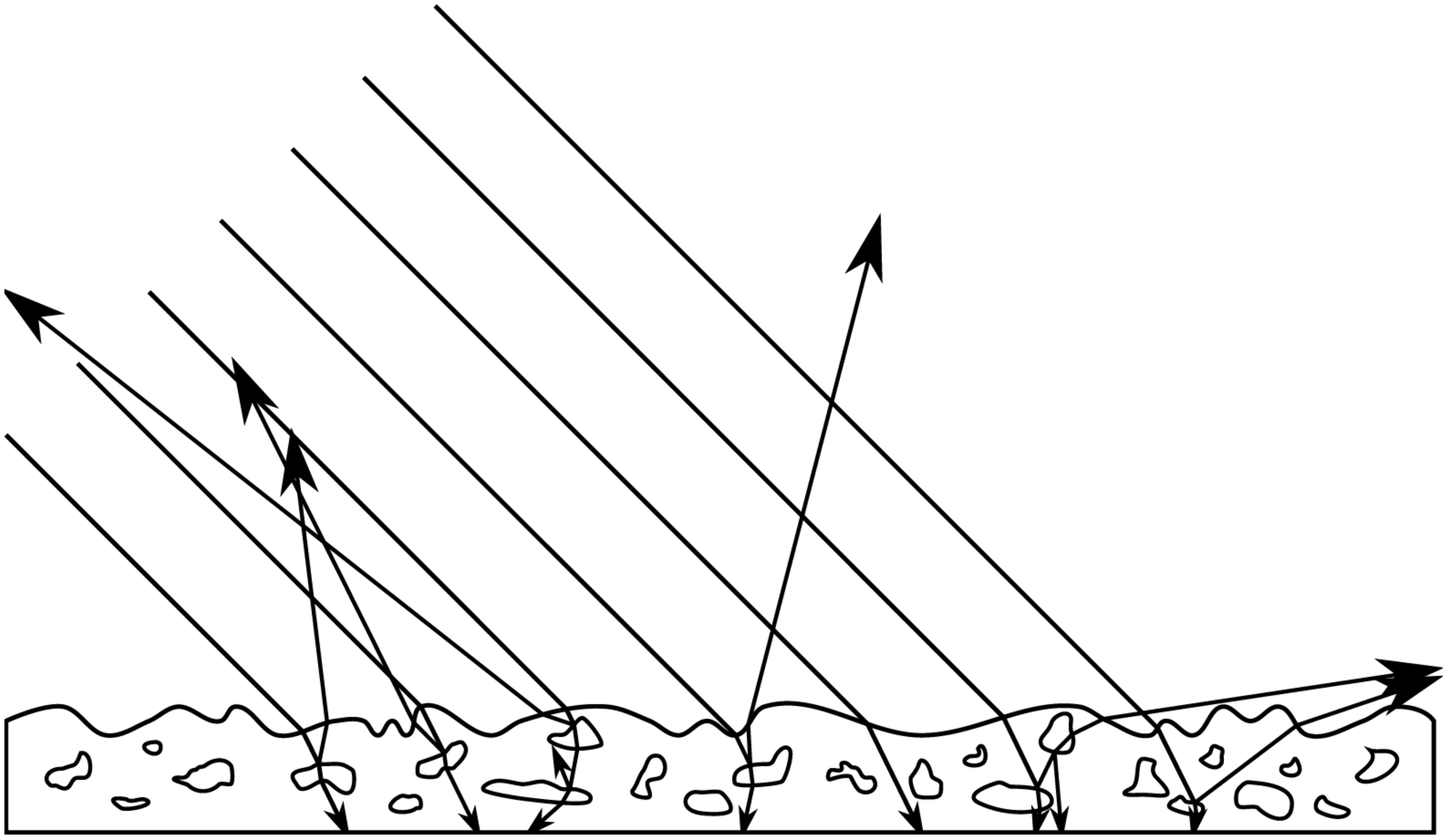
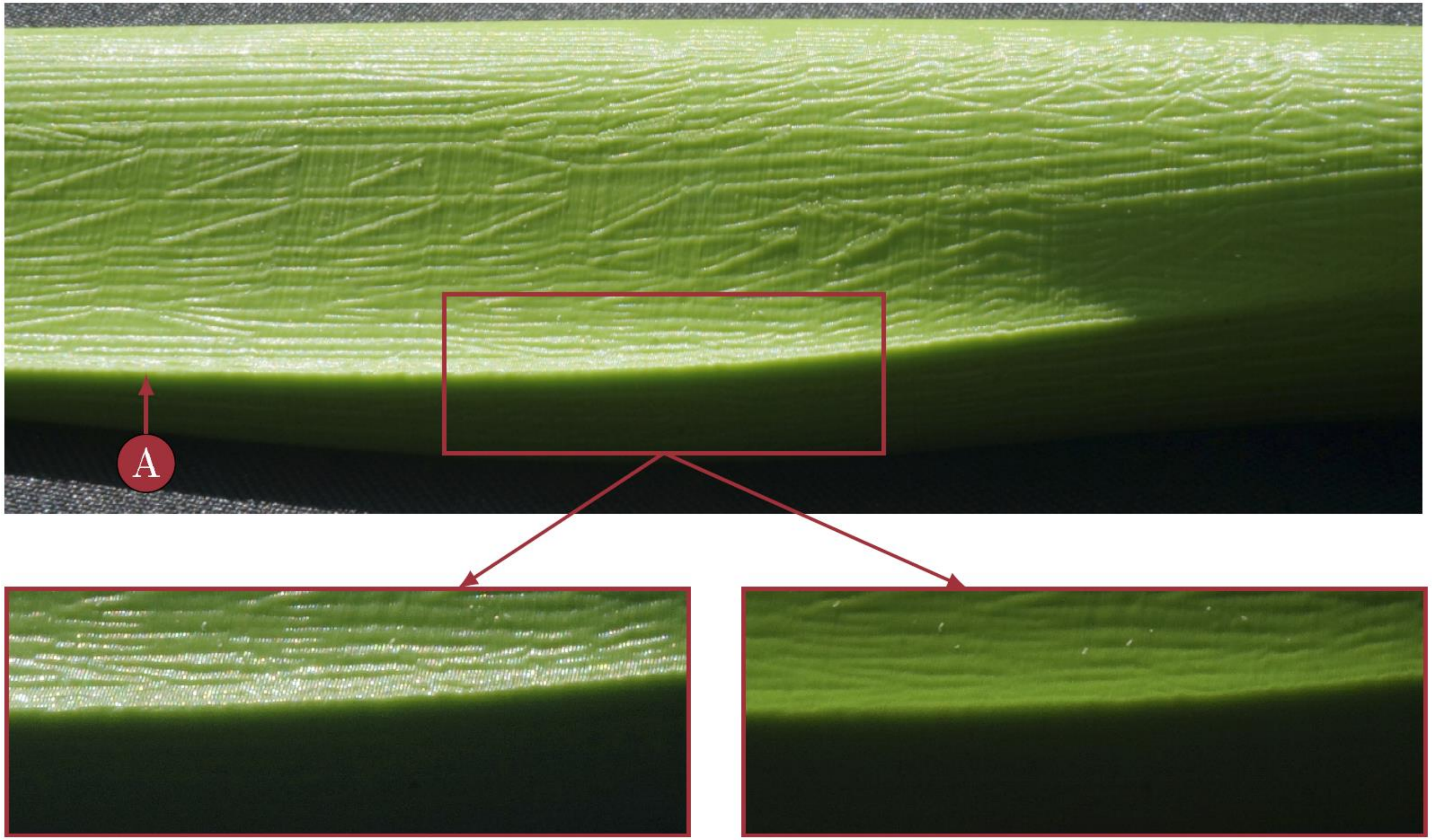
Sources: Lyngby, R. A. (2019). Autonomous Optical Inspection of Large Scale Freeform Surfaces. Kgs. Lyngby, Denmark: Technical University of Denmark. DTU Compute PHD-2018, Vol.. 486

Subsurface scattering



Sources: Lyngby, R. A. (2019). Autonomous Optical Inspection of Large Scale Freeform Surfaces. Kgs. Lyngby, Denmark: Technical University of Denmark. DTU Compute PHD-2018, Vol.. 486

Example



Sources: Lyngby, R. A. (2019). Autonomous Optical Inspection of Large Scale Freeform Surfaces. Kgs. Lyngby, Denmark: Technical University of Denmark. DTU Compute PHD-2018, Vol.. 486

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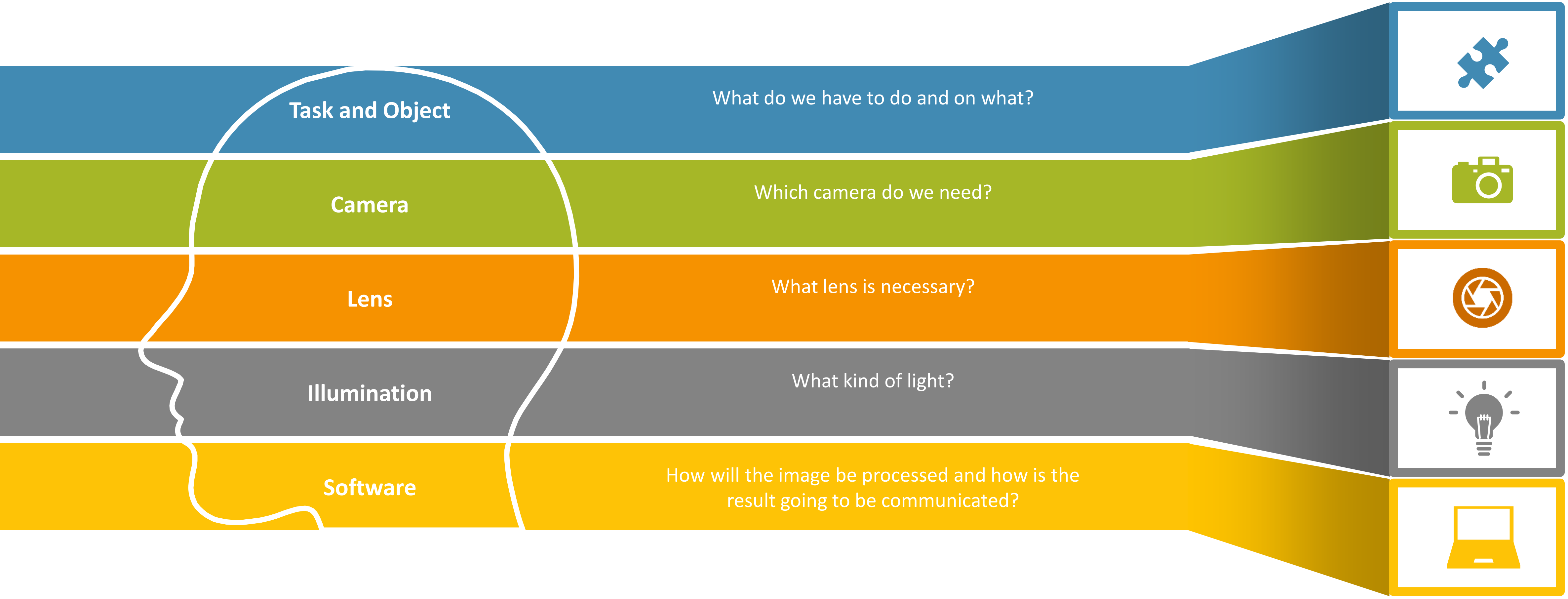
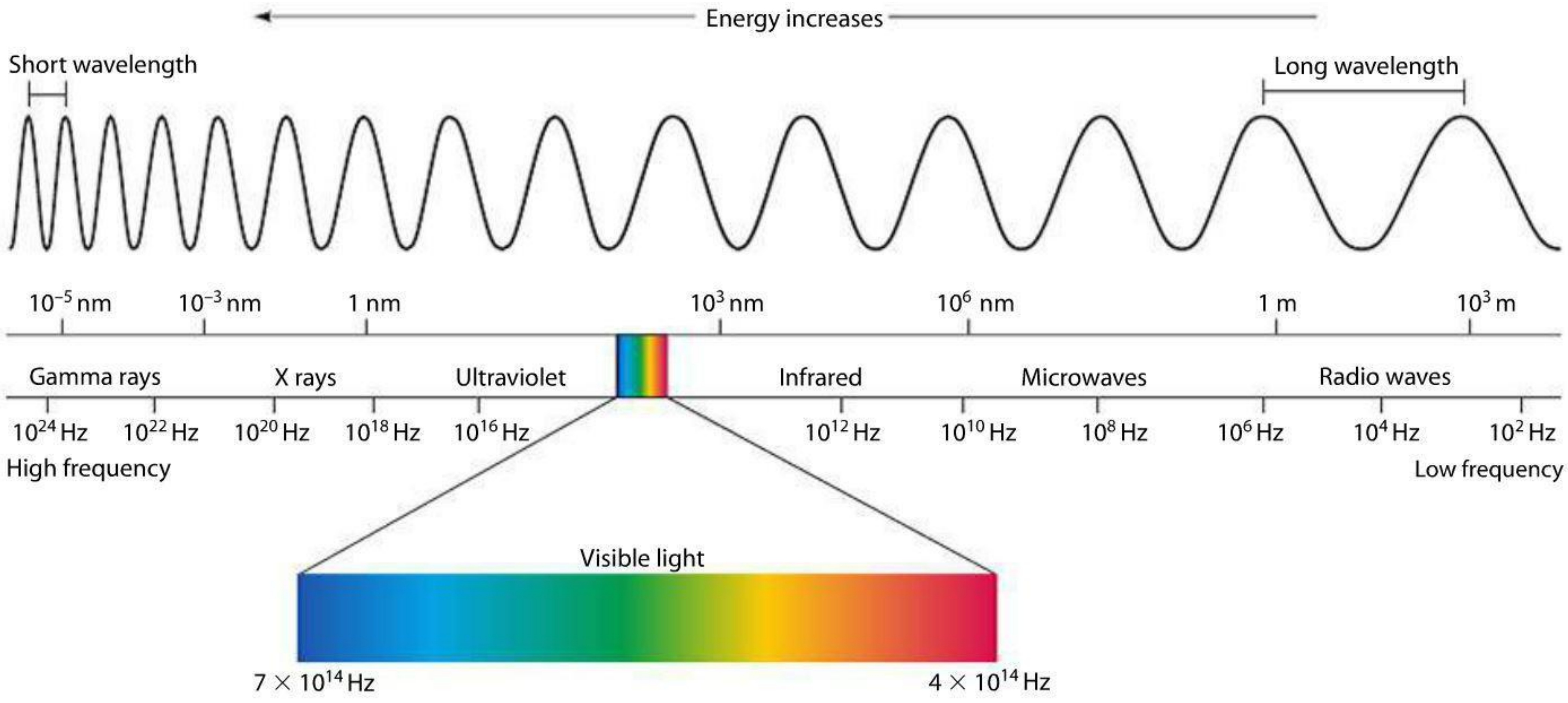
Elements in a Machine Vision system



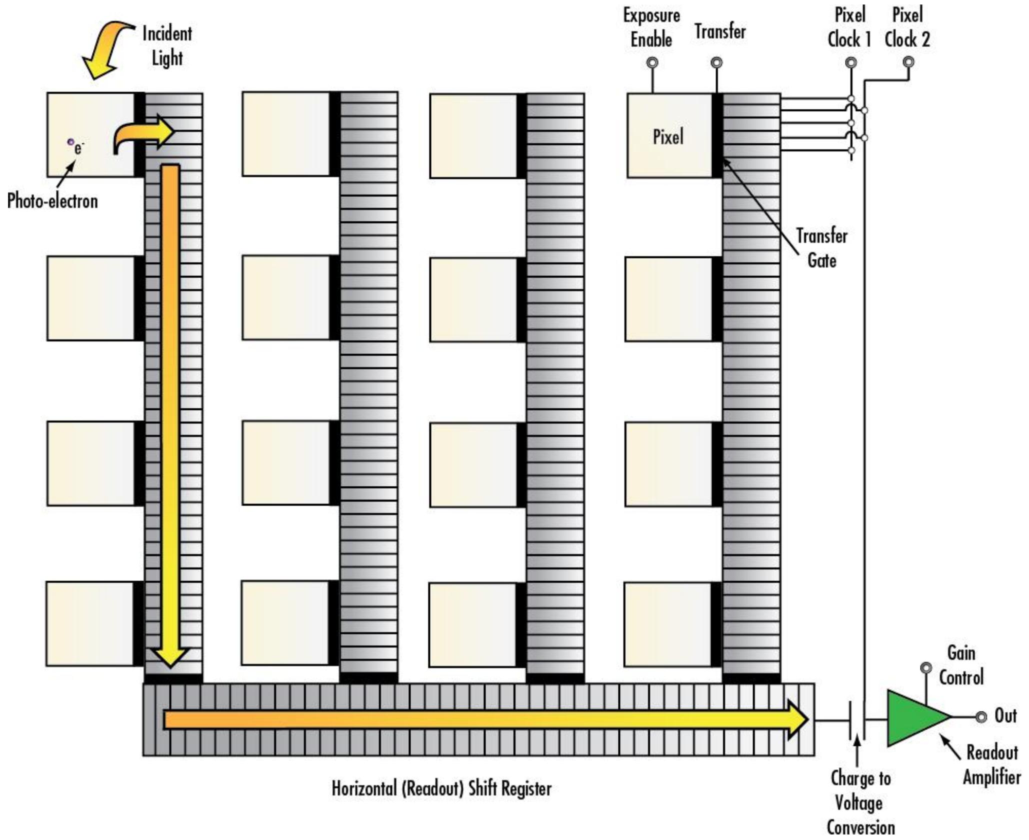
The electromagnetic spectrum



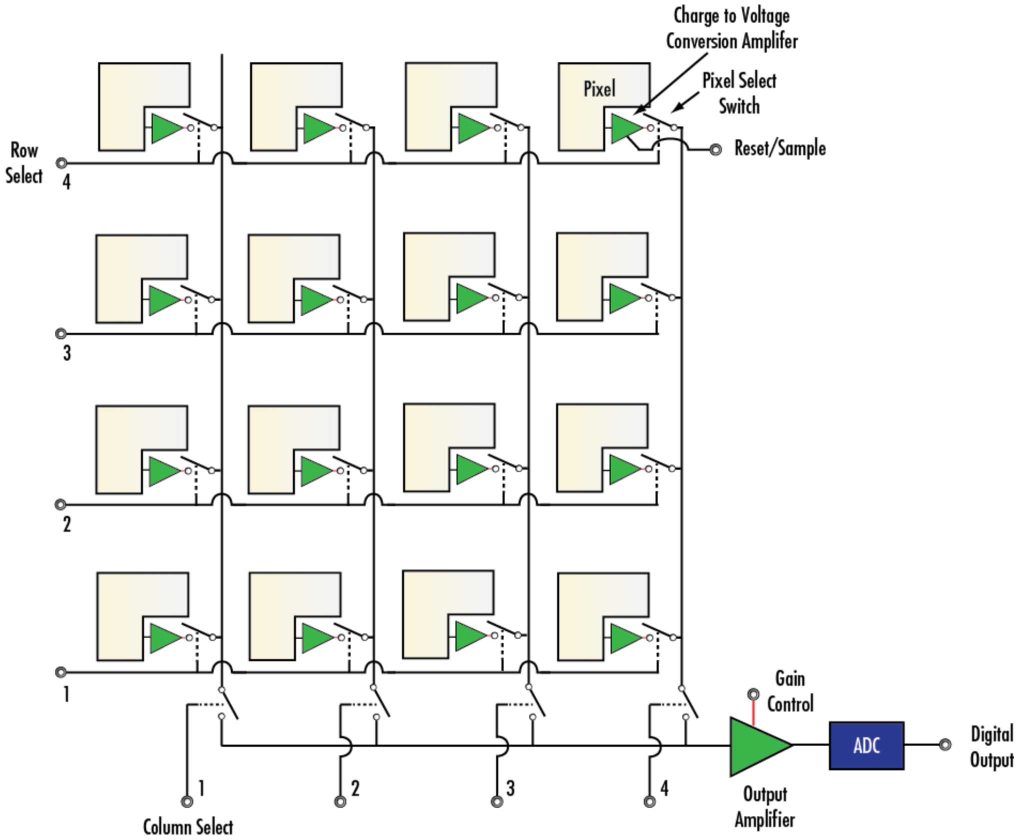
Sources: O'Connor, B., & Secades, C. (2013). Review of the use of remotely-sensed data for monitoring biodiversity change and tracking progress towards the Aichi Biodiversity Targets.

Image sensor types

CCD sensor

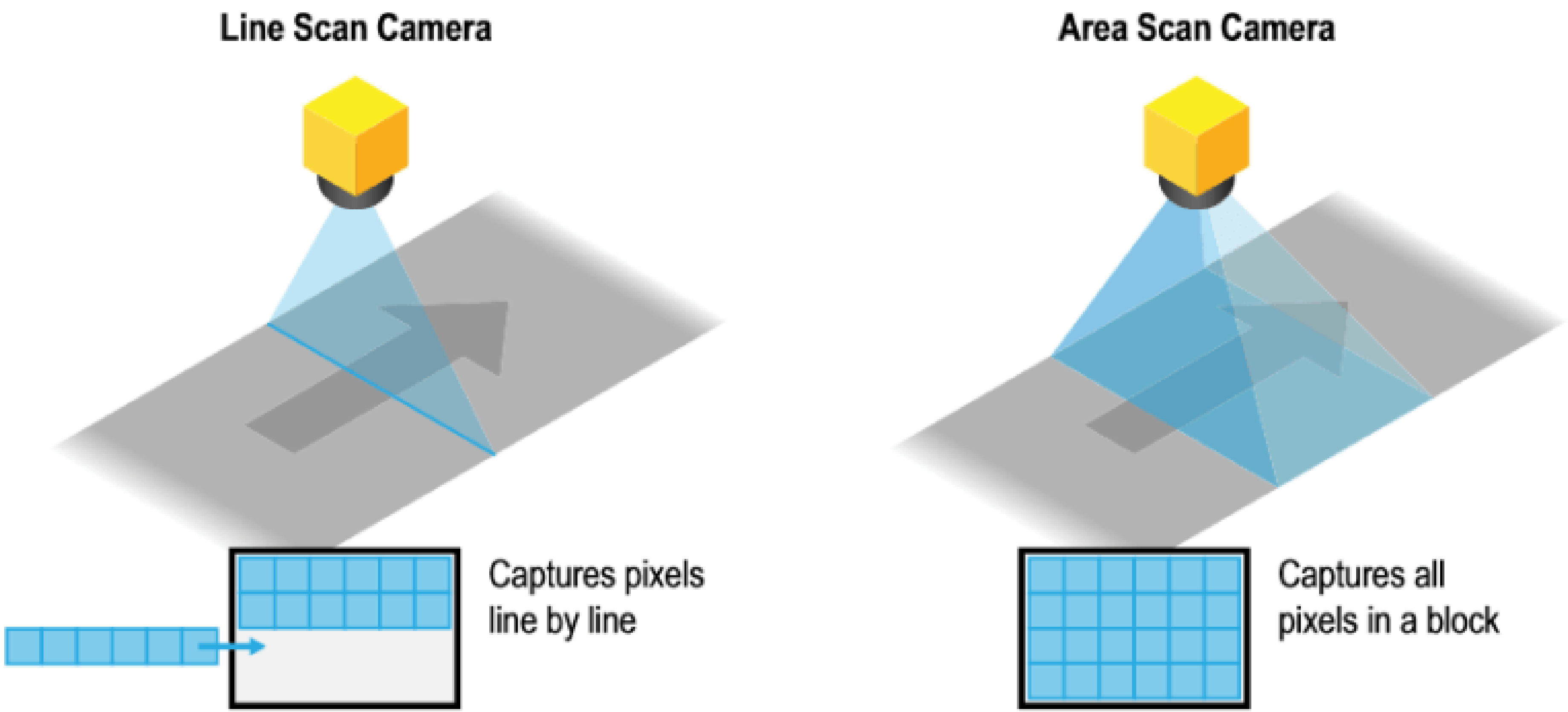


CMOS sensor

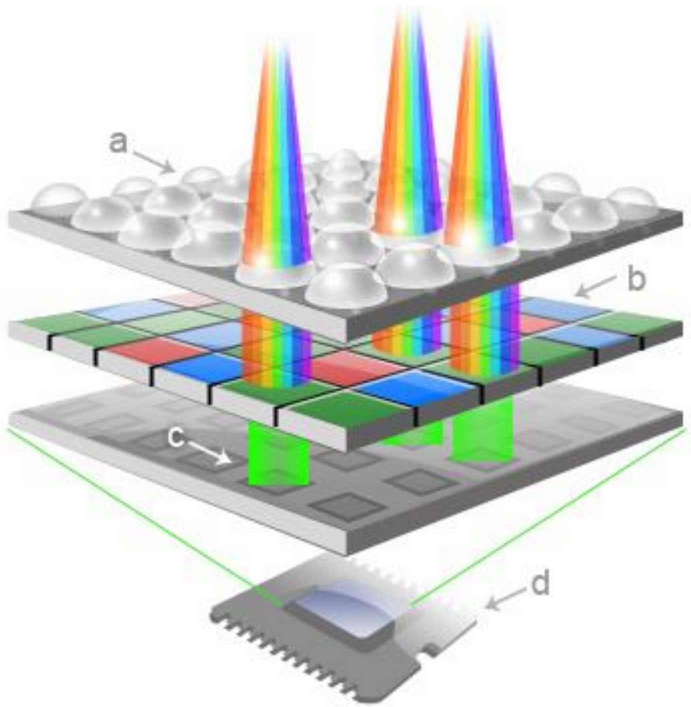


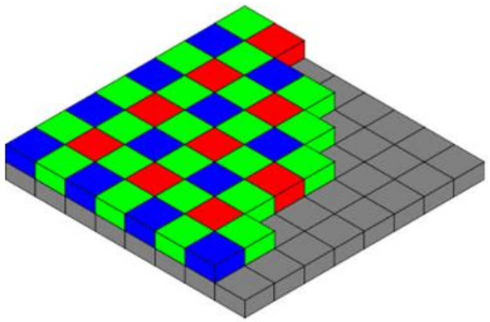
Source: Edmund Optics

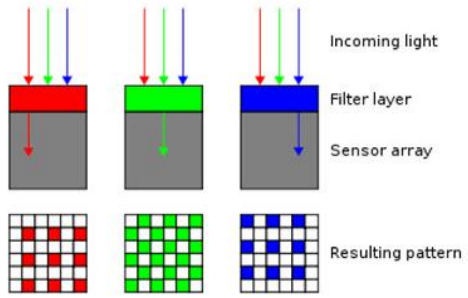
Camera types



Color camera

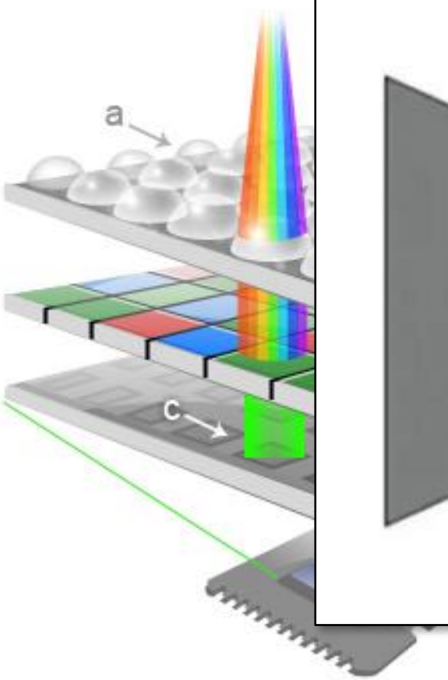


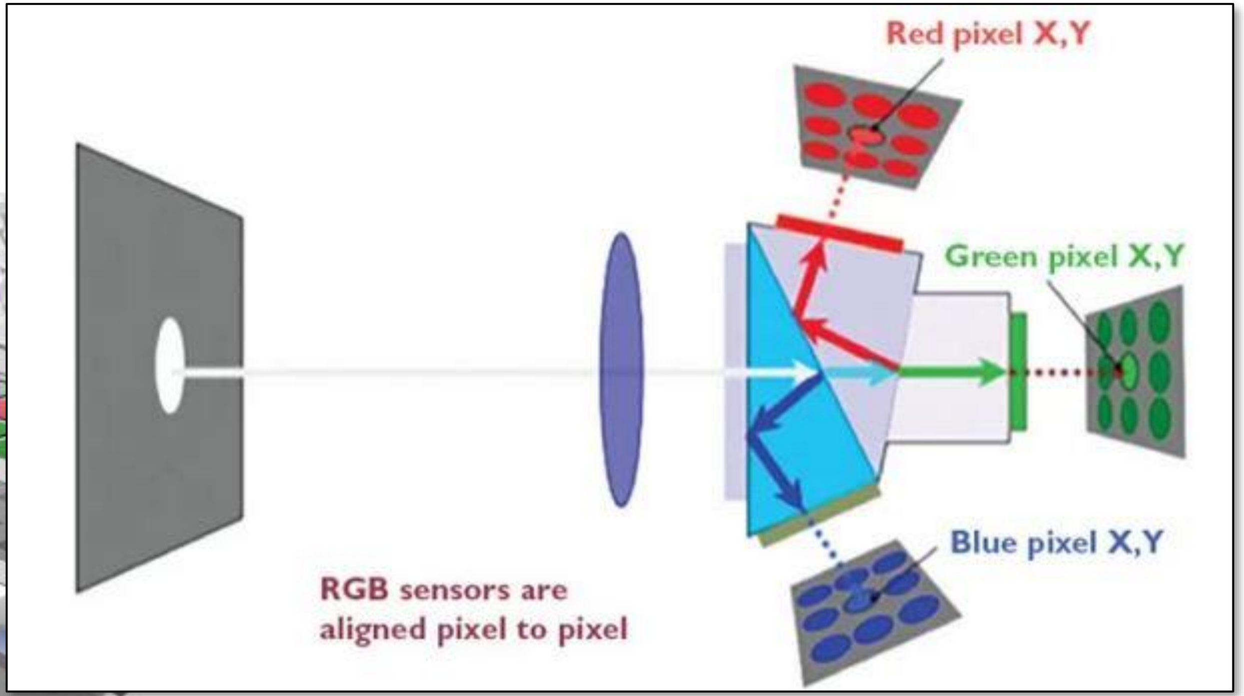


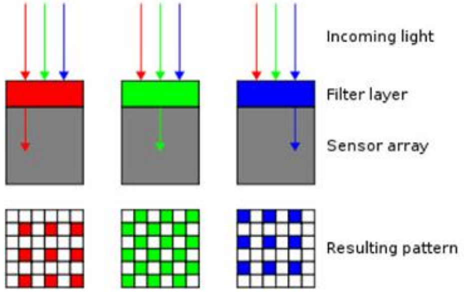


Source: Accu-Scope, JTH Online

Color camera



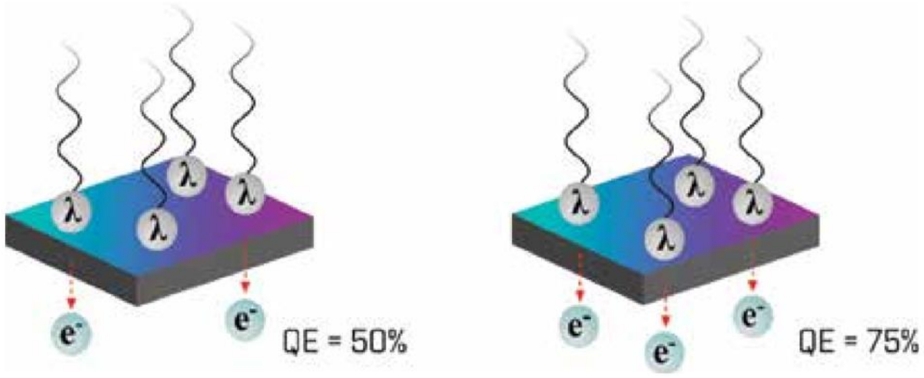


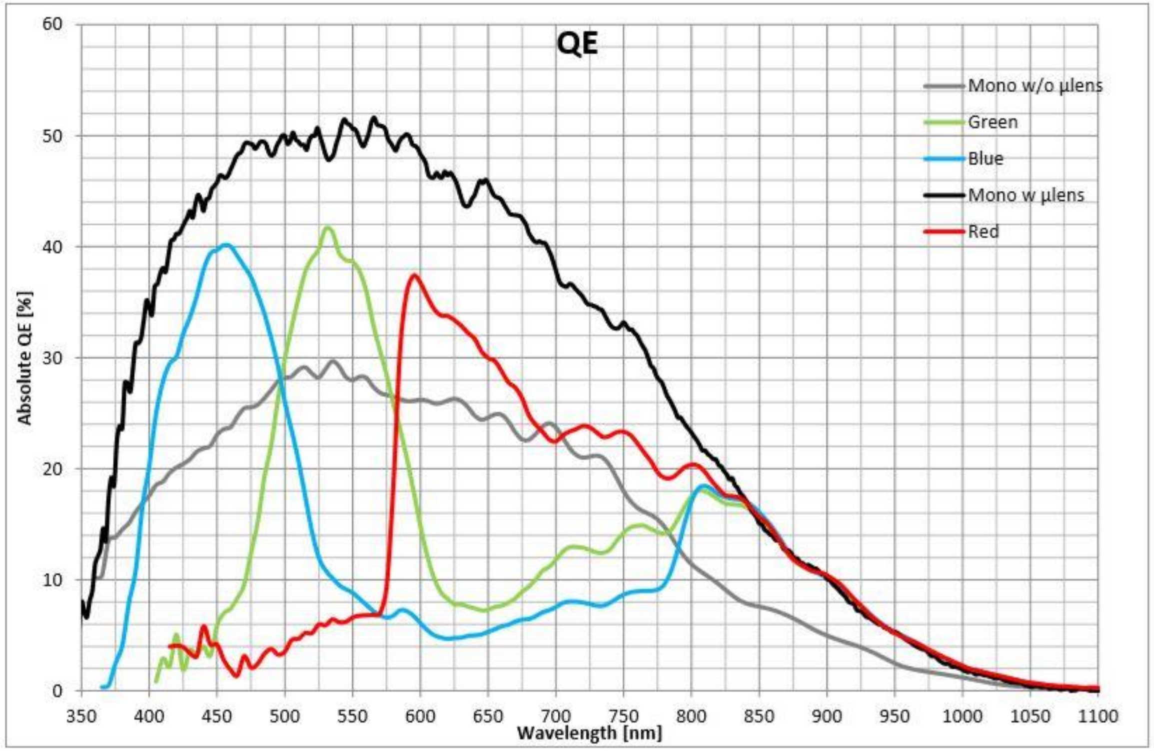


Source: Accu-Scope, JTH Online

Quantum Efficiency

- The percent of photons converted to electrons at a specific wavelength



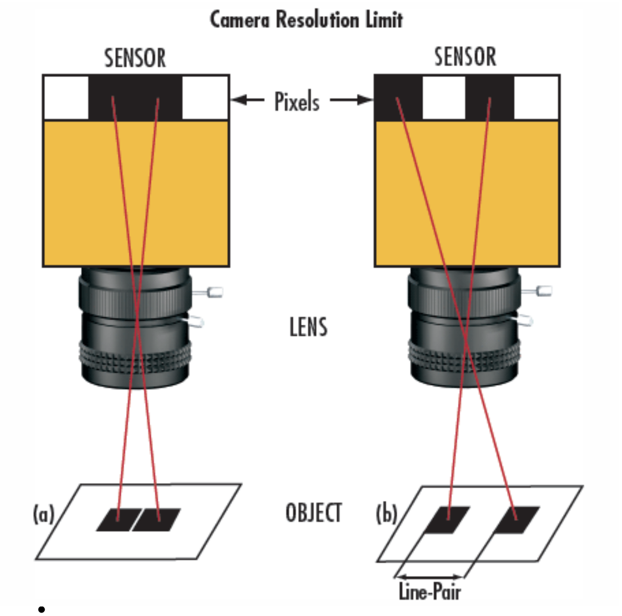


Source: Trisys, Edmund Optics

Sensor resolution

- The highest frequency which can be resolved by a sensor, the Nyquist frequency, is effectively two pixels or one line pair
- Needed resolution:

$$R = \frac{W_{\mathbf{FoV}}}{W_{\mathbf{obj}}}(2n_{\mathrm{p}}) = \frac{W_{\mathbf{FoV}}}{W_{\mathbf{obj}}} n_{\mathrm{lp}}$$



- Where:
  $W_{\mathbf{FoV}}$: Width of the Field-of-View [mm]
  $W_{\mathbf{obj}}$: Width of the object [mm]
  n_{p}: Number of pixels on the object
  n_{lp}: Number of line pairs on the object
- n_{lp} is often at least five times the minimum feature size

Source: Edmund Optics

Shutter types: Global and Rolling

Source: reddit /r/educationalgifs

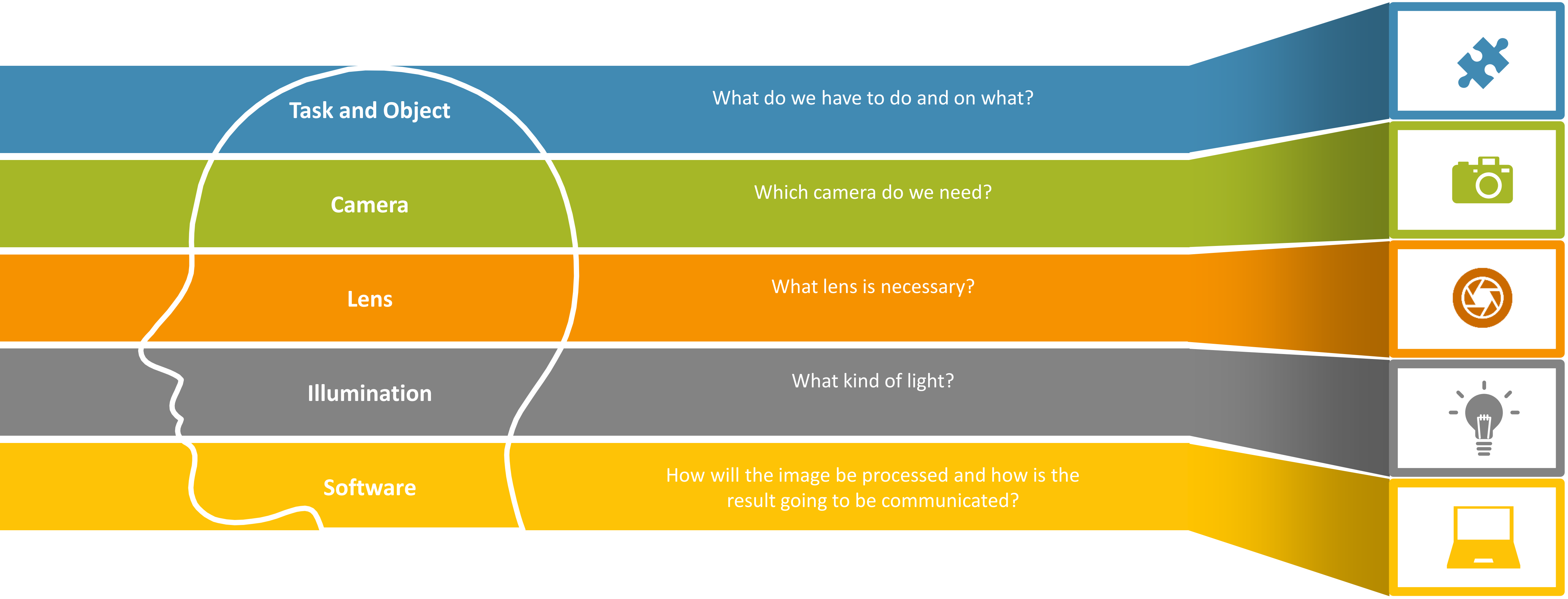
Shutter speed for moving objects

- Maximum shutter time:

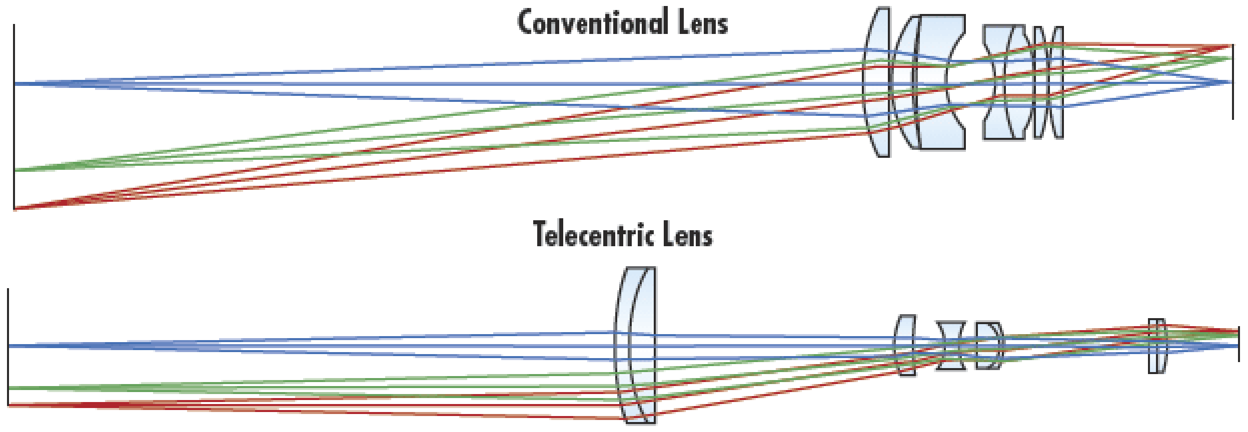
$$S_{\mathbf{max}} = \frac{W_{\mathbf{obj}}}{n_{\mathbf{lp}} v_{\mathbf{obj}}}$$

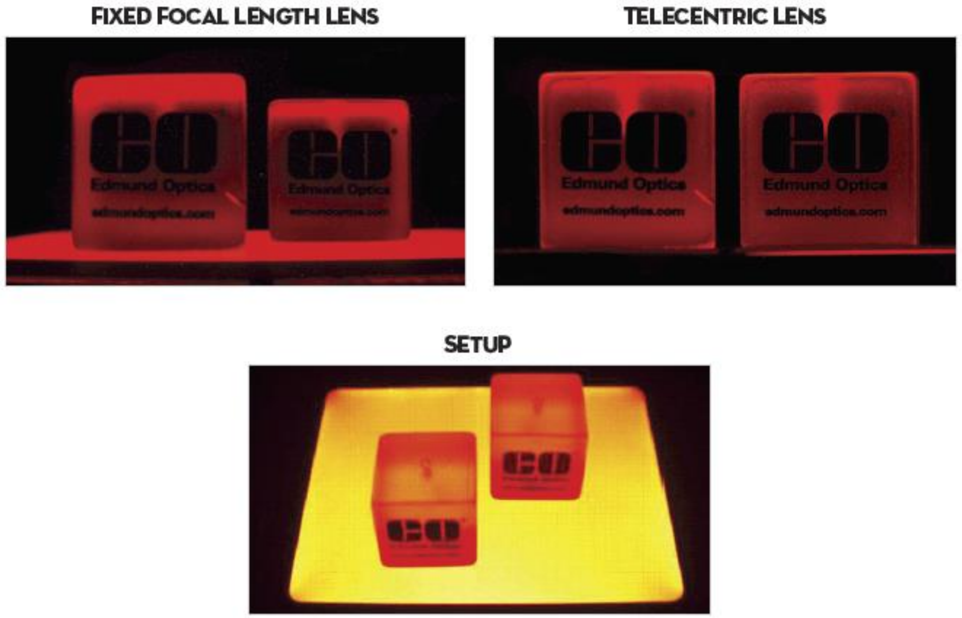
- Where:
  $v_{\mathbf{obj}}$: Velocity of the object $[m/s]$
- Use global shutter for moving objects

Elements in a Machine Vision system



Lens types





Source: Edmund Optics

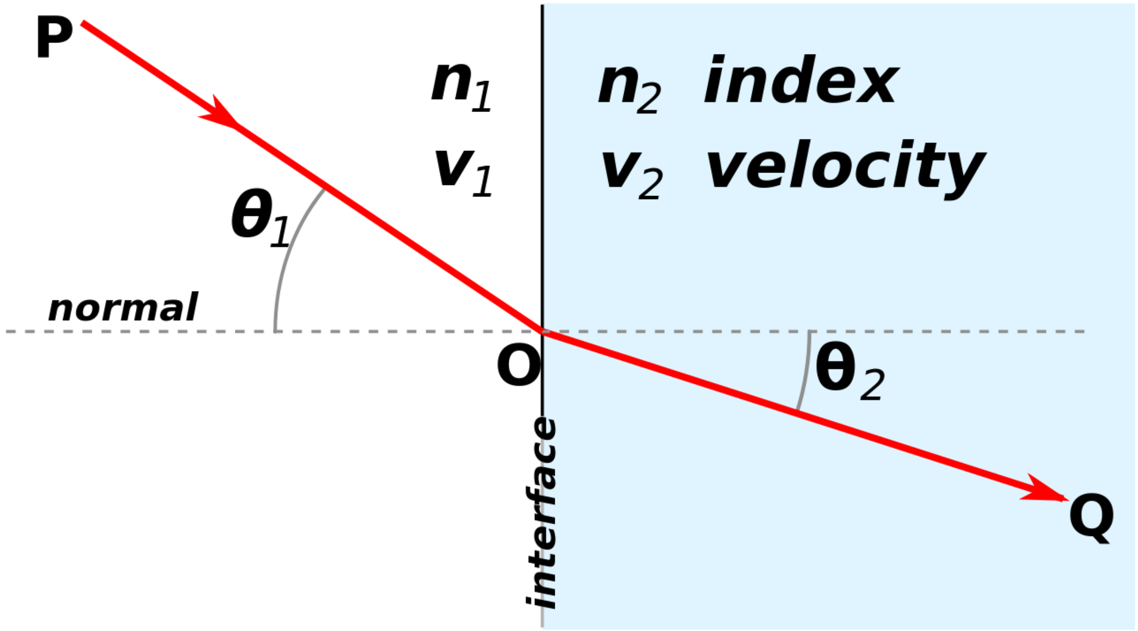
Snell's law

Index of refraction:

$$n = \frac{c}{v}$$

Snell's law:

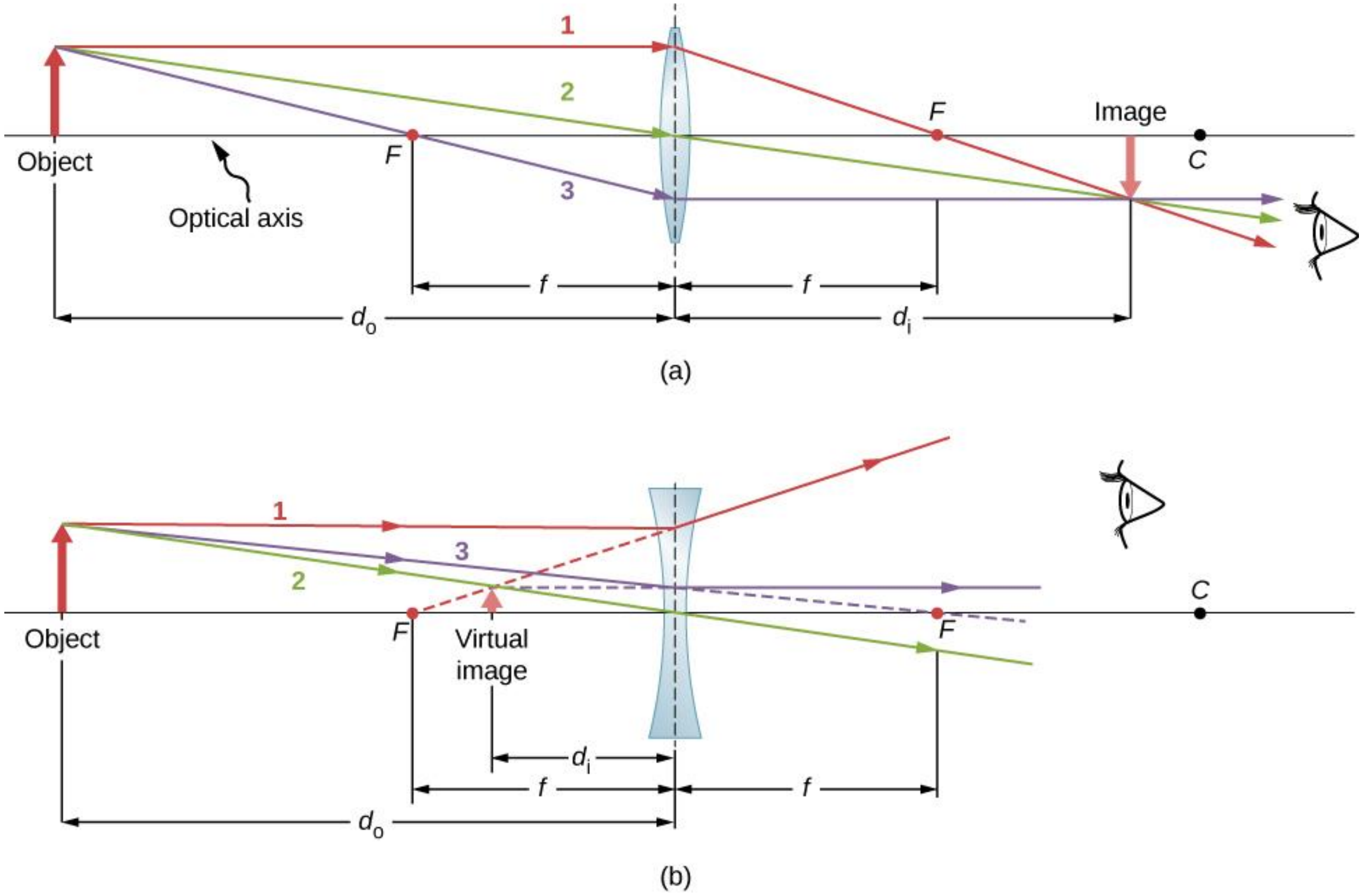
$$\frac{\sin(\theta_2)}{\sin(\theta_1)} = \frac{v_2}{v_1} = \frac{n_1}{n_2}$$



Source: Wikimedia

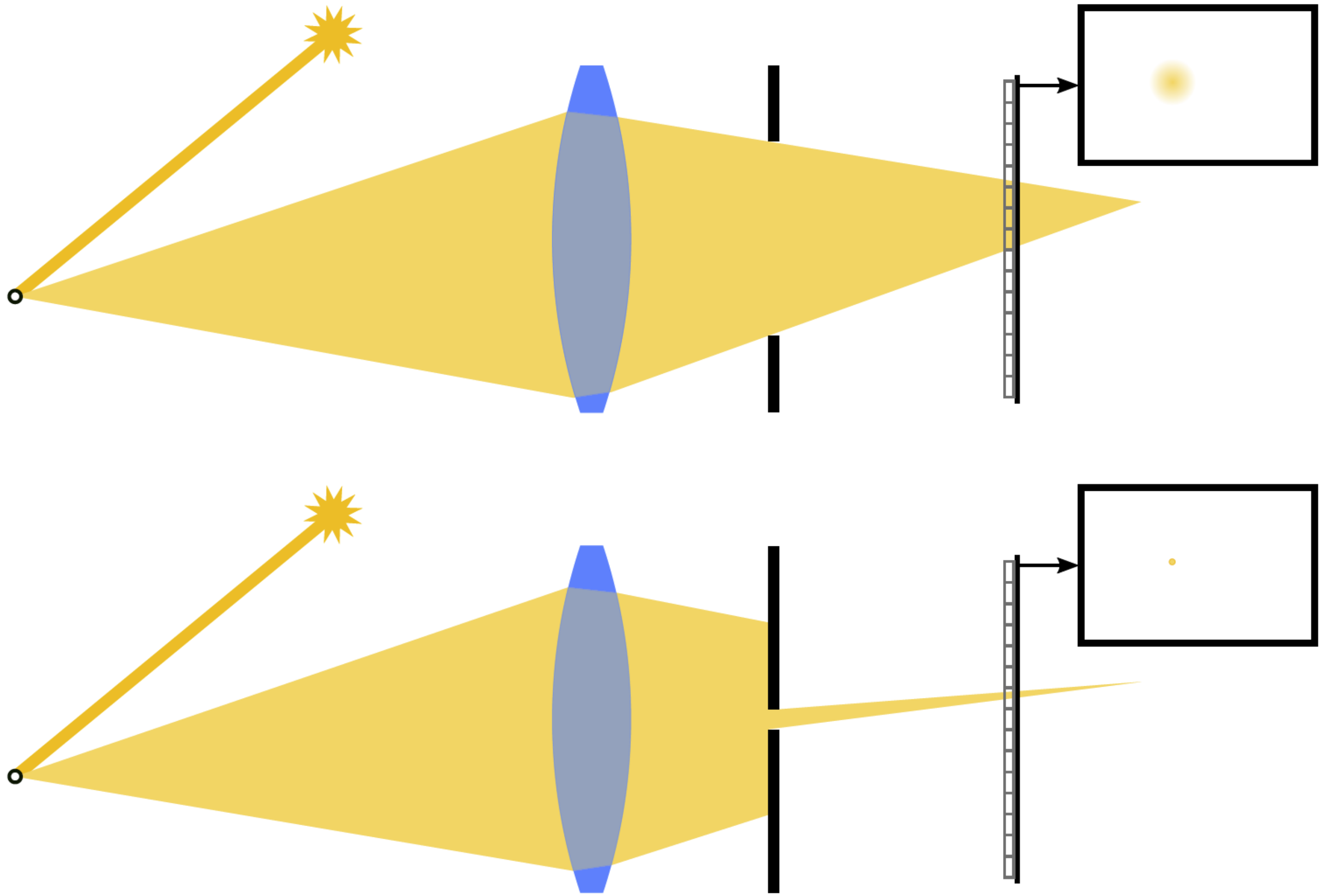
The thin lens model

- A lens is thin if its turning radius is much larger than its width
- $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
- If $d_o \gg d_i$ then: $\frac{1}{d_i} \approx \frac{1}{f} \Leftrightarrow f \approx d_i$



Source: LibreText

Aperture



Lyngby, R. A. (2019). Autonomous Optical Inspection of Large Scale Freeform Surfaces. Kgs. Lyngby, Denmark: Technical University of Denmark. DTU Compute PHD-2018, Vol.. 486

f-number (or f-stop)

The f-number N is given by:

$$N = \frac{f}{D}$$

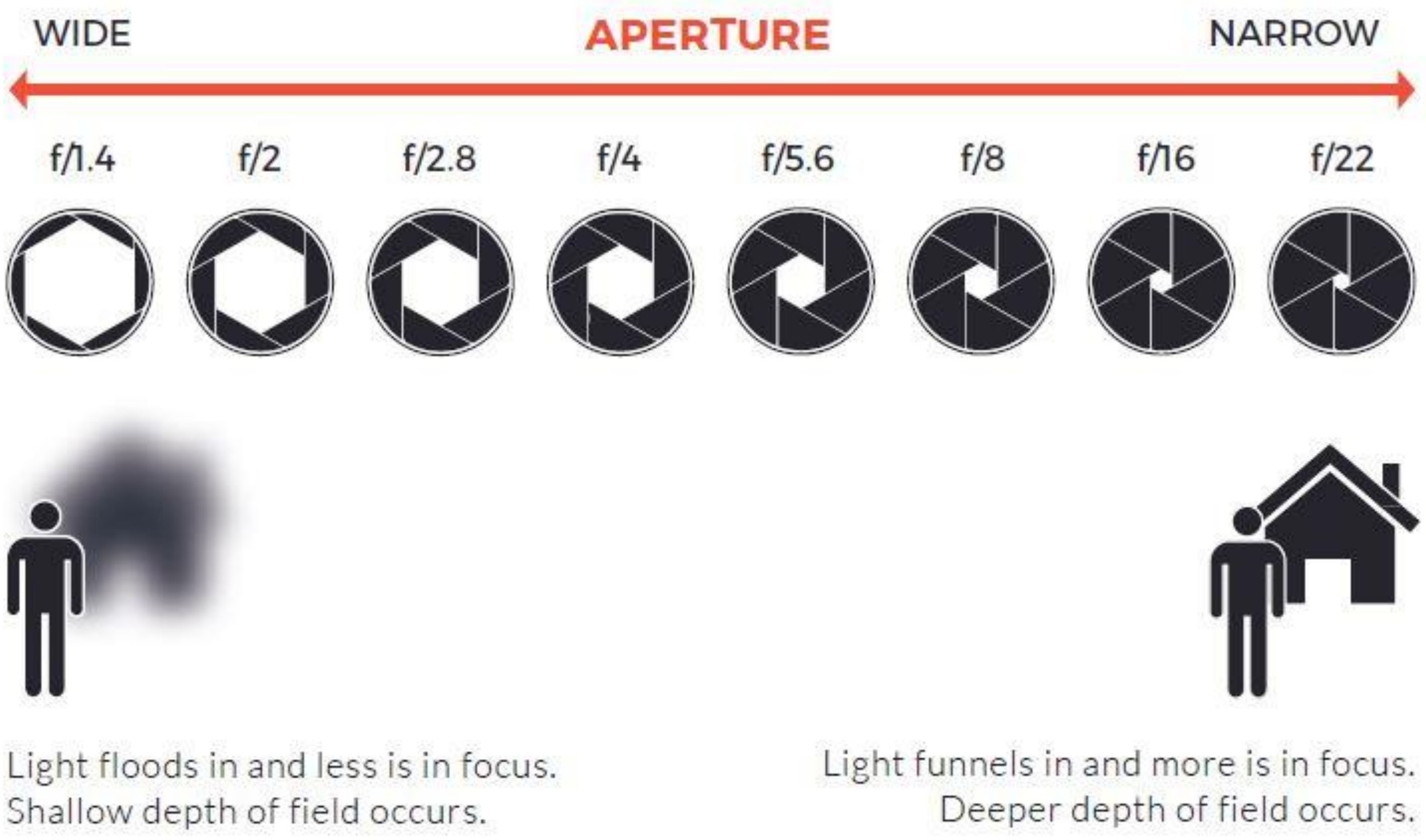
Where:

f: Focal length [mm]
D: Pupil diameter [mm]

Usually, the f-number is written:

f/N (or $f/\#$)

which form an expression for the entrance pupil diameter



Source: Creative Photography, Skylum

f-number (or f-stop)

The f-number N is

N =

Where:

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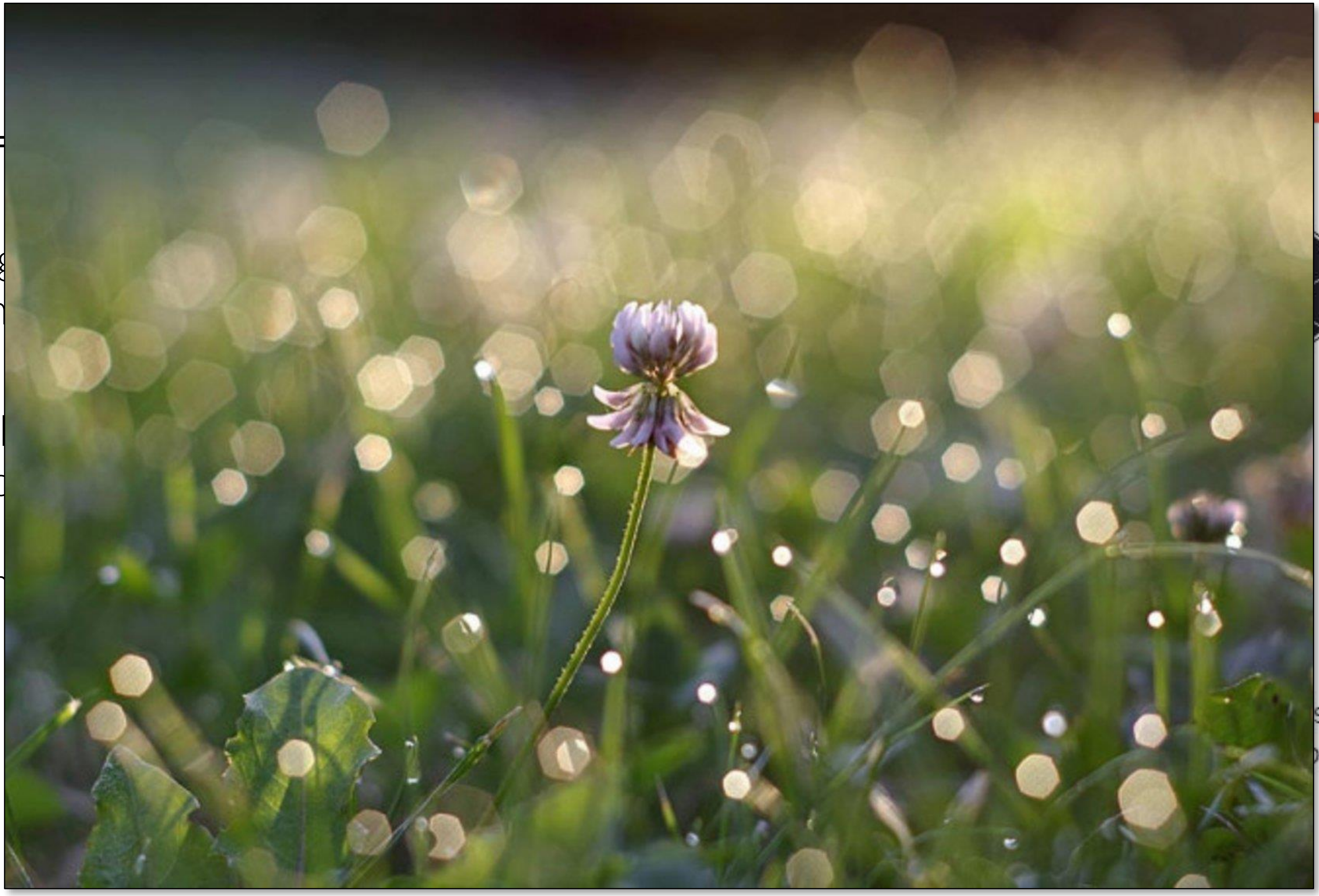
D: Pupil dian

Usually, the f-numb

f/N (c

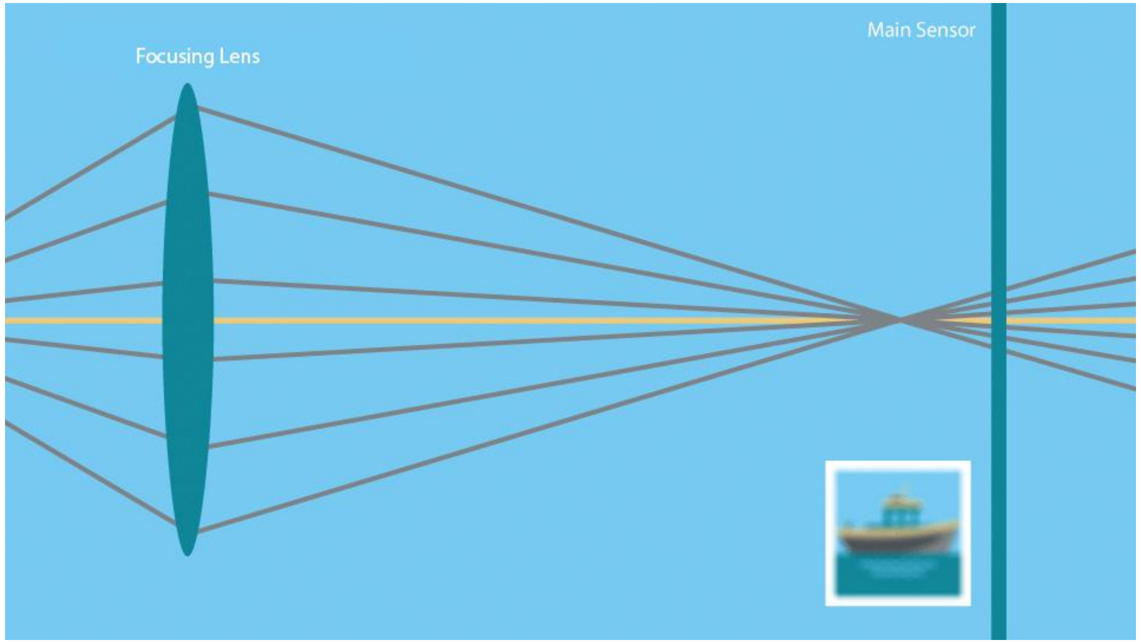
which form an exp

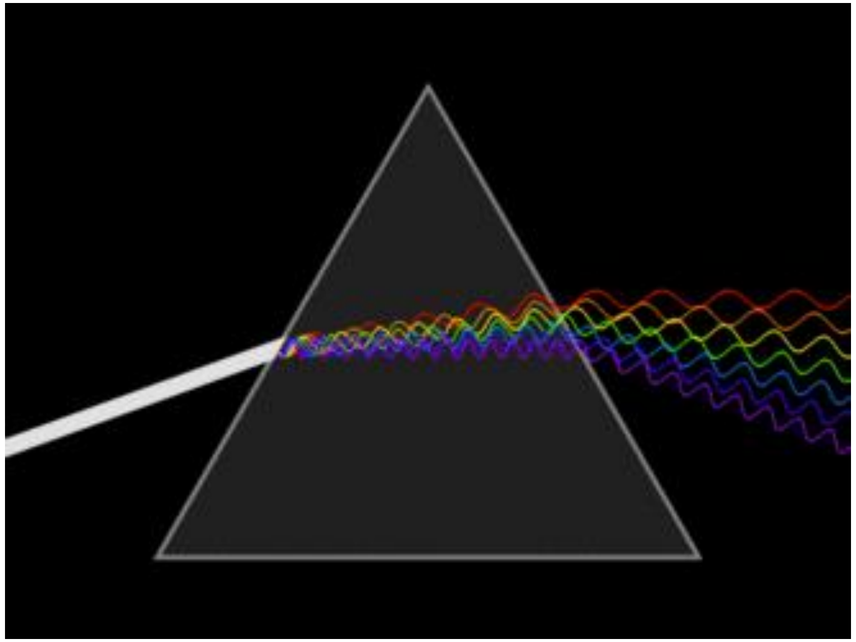
entrance pupil dian



Source: Creative Photography, Skylum

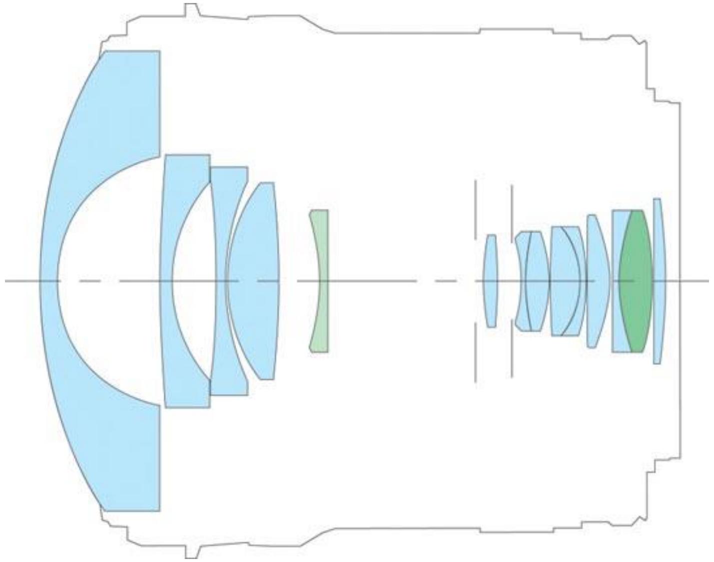
Issues with having only one lens element

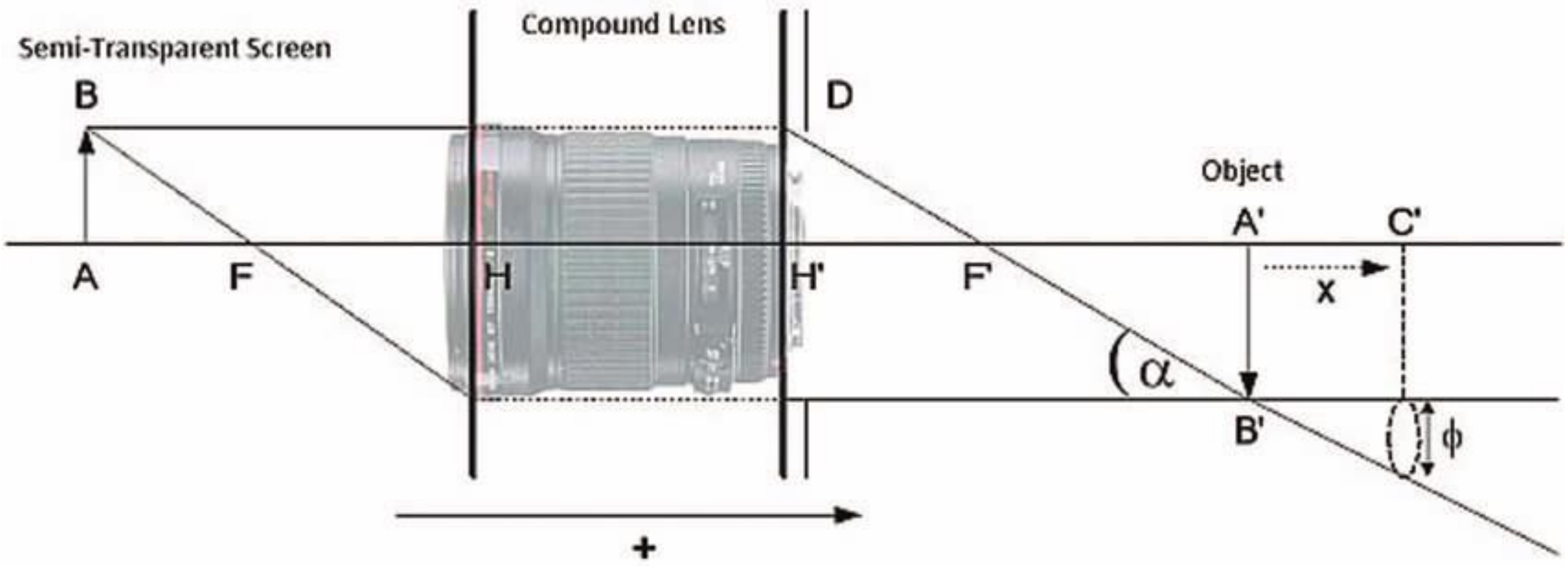




Source: B&H Photo Video, Wikipedia

Compound and complex lenses





Source: Lertrusdachakul, Intuon & Fougerolle, Yohan & Laligant, Olivier. (2011). Dynamic (de)focused projection for three-dimensional reconstruction. Optical Engineering. 50. 113201-1;113201. 10.1117/1.3644541.

Selecting a lens

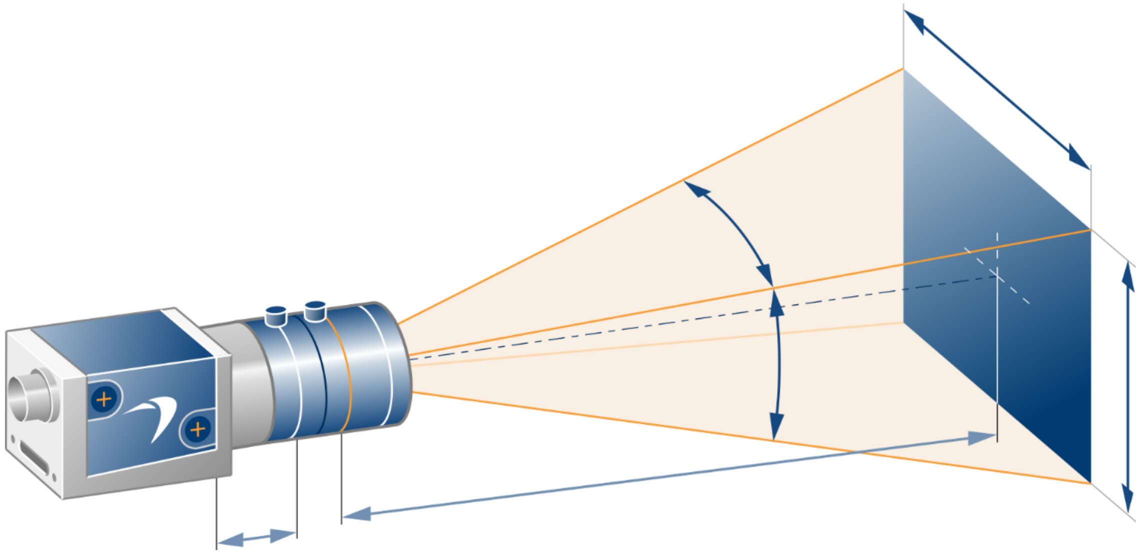
- Pinhole model:

$$\frac{2f}{w_{\mathrm{sen}}} = \frac{2D}{w_{FoV}}$$

$$\Updownarrow$$

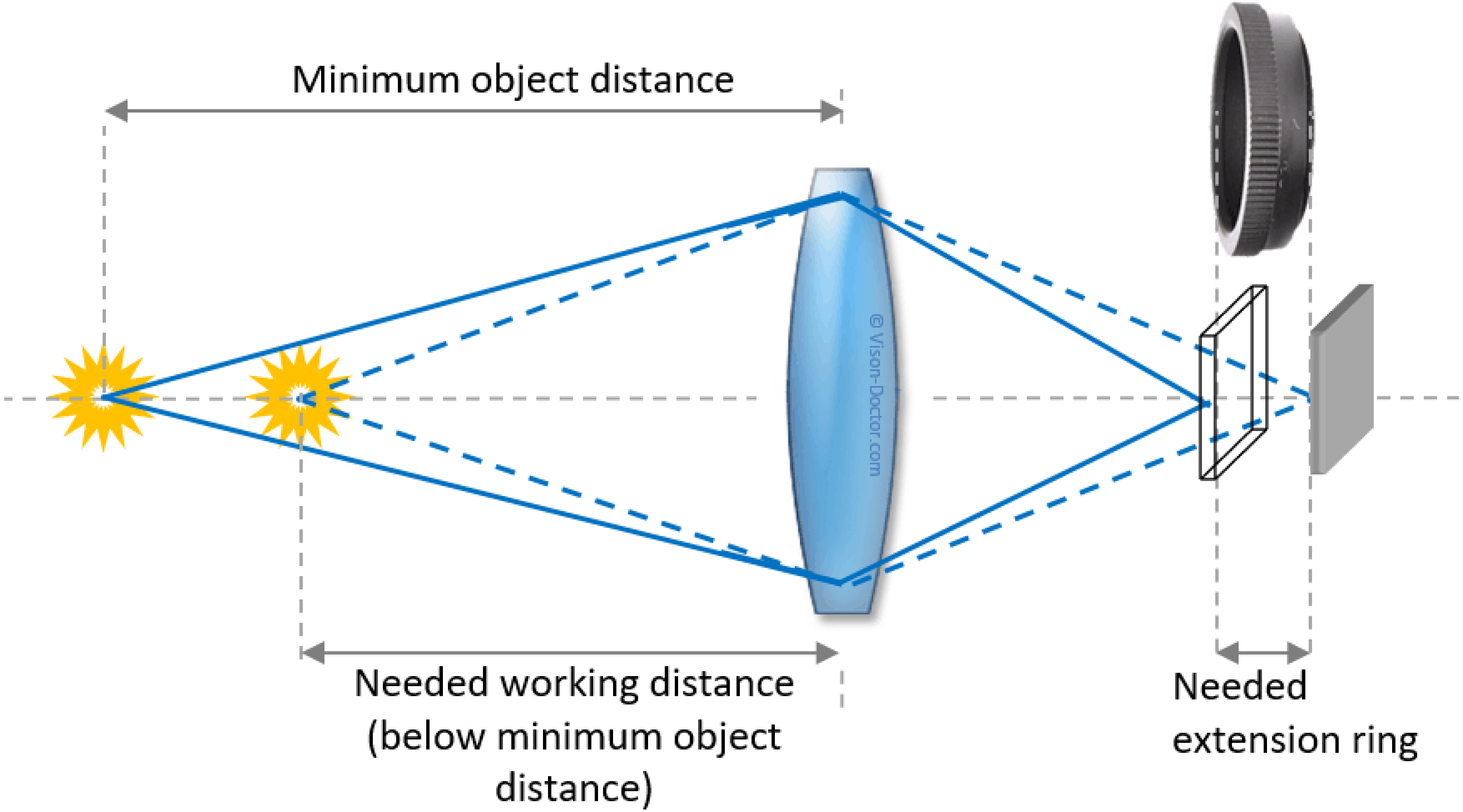
$$f = \frac{2D}{w_{FoV}} w_{\mathrm{sen}}$$

- Lens resolution should at least be equal to the sensor resolution



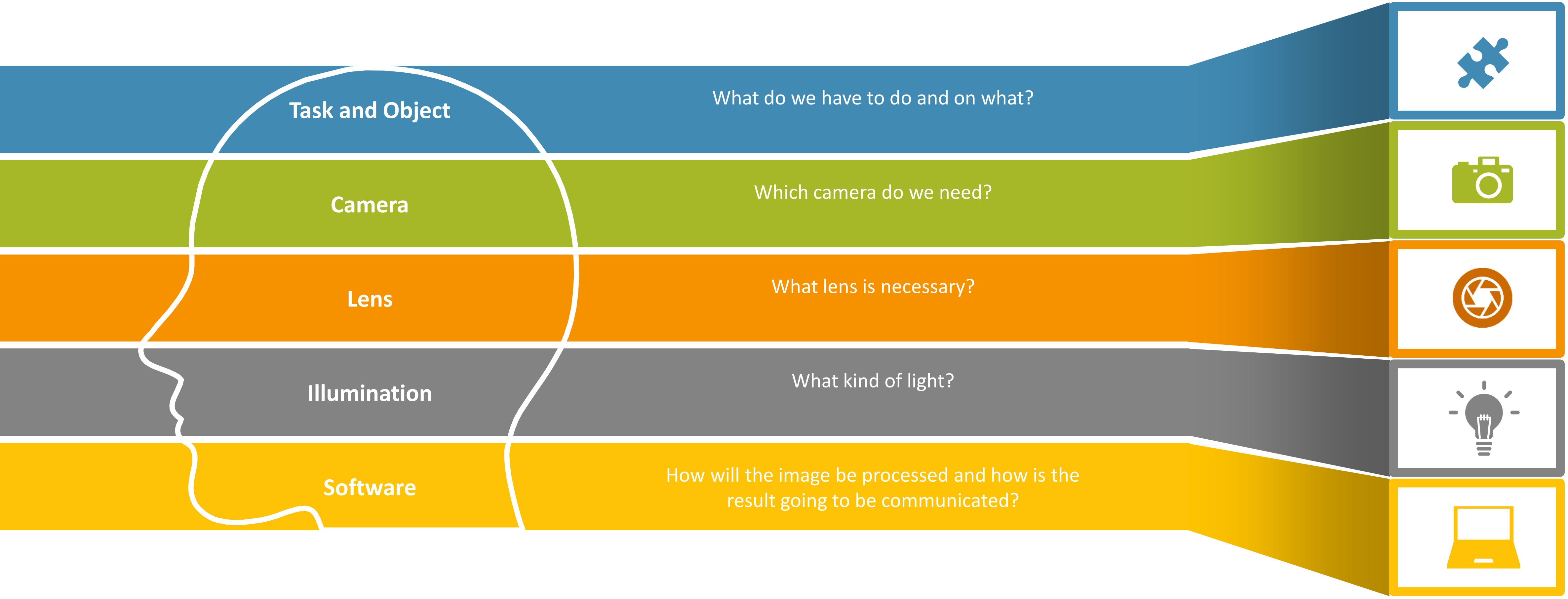
Source: Basler

Minimum Object Distance (MOD)

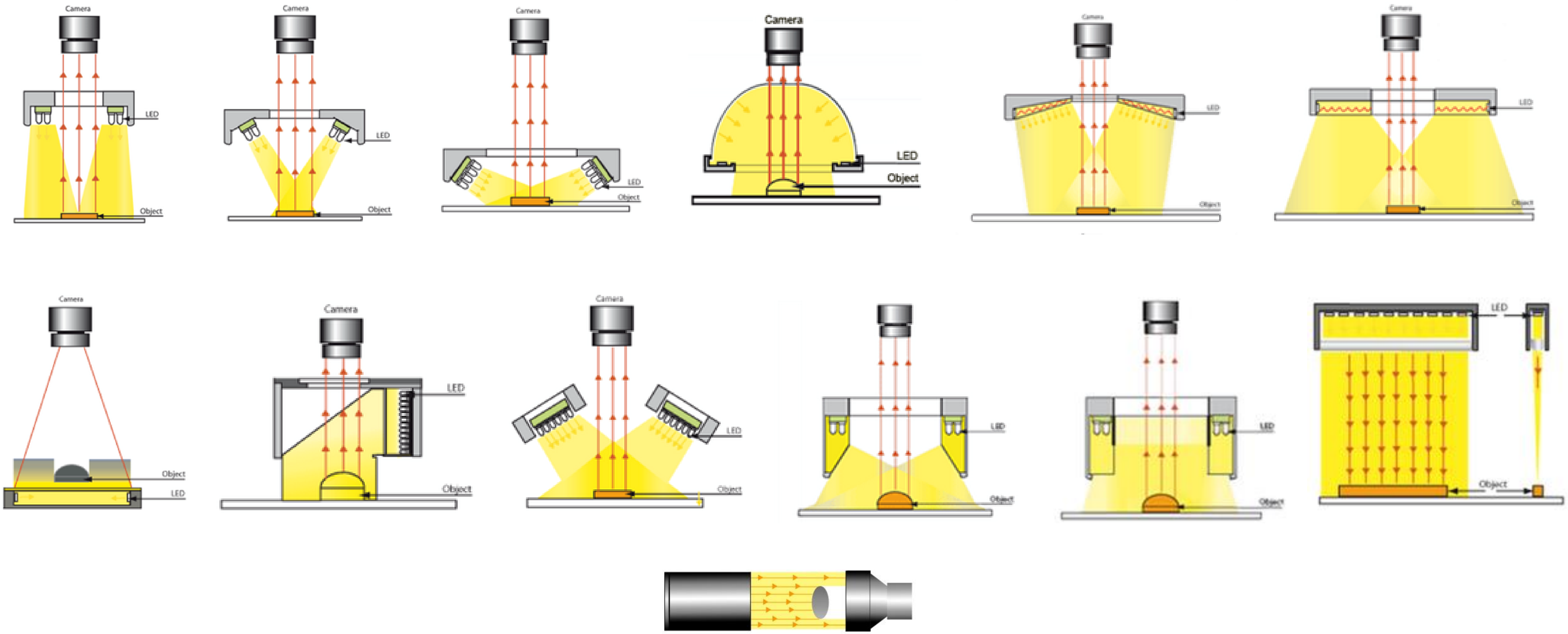


Source: Vision Doctor

Elements in a Machine Vision system

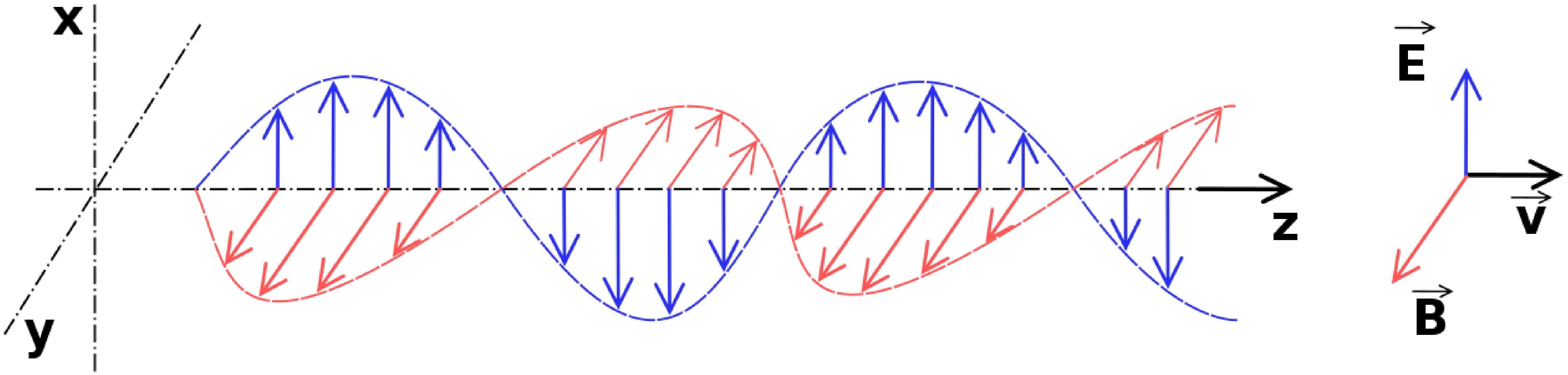


Light types



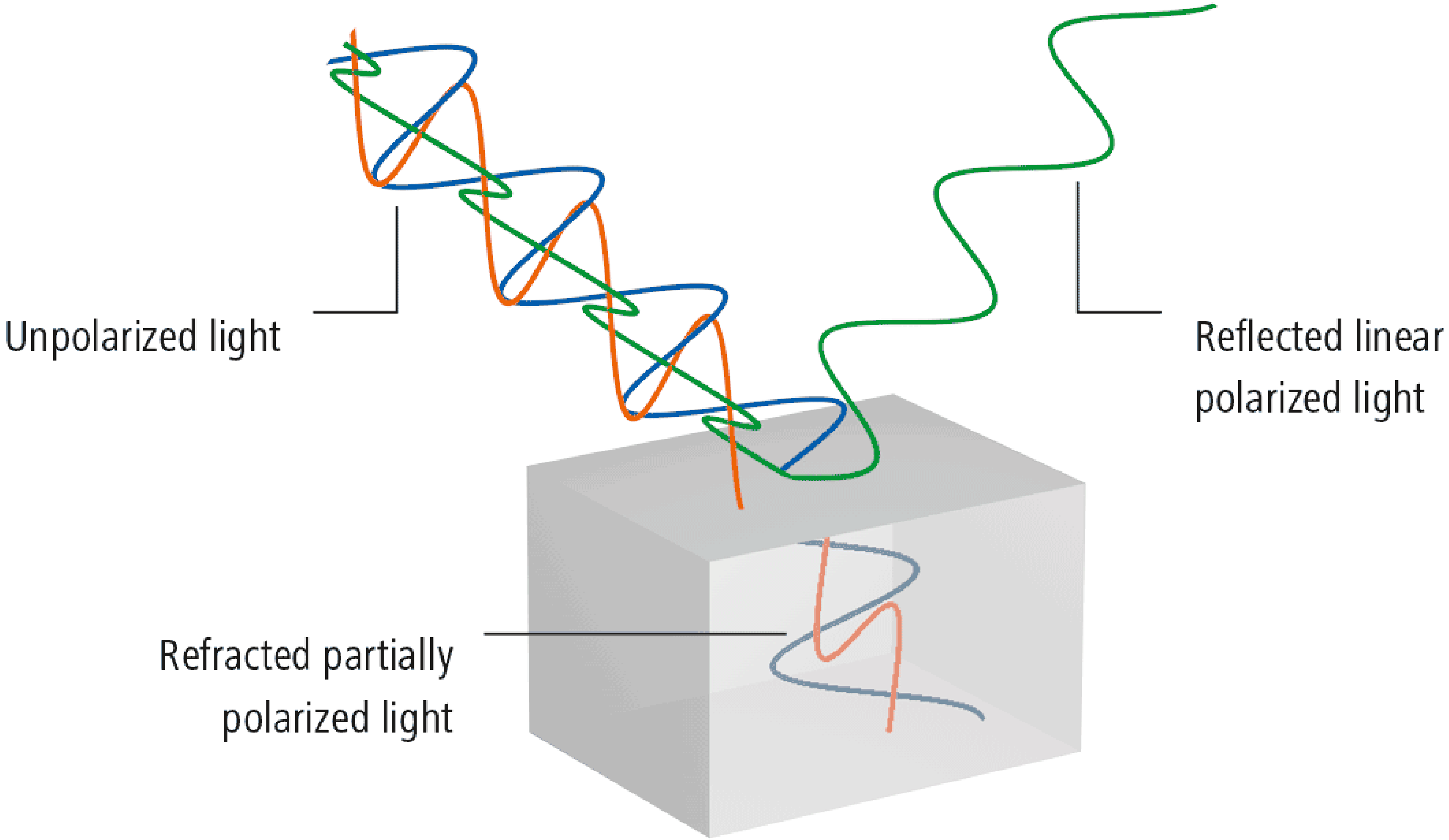
Source: Vital Vision

Light polarization



Source: Physics Stackexchange, Baumer

Light polarization



This happens <u>only</u> for dielectric medias

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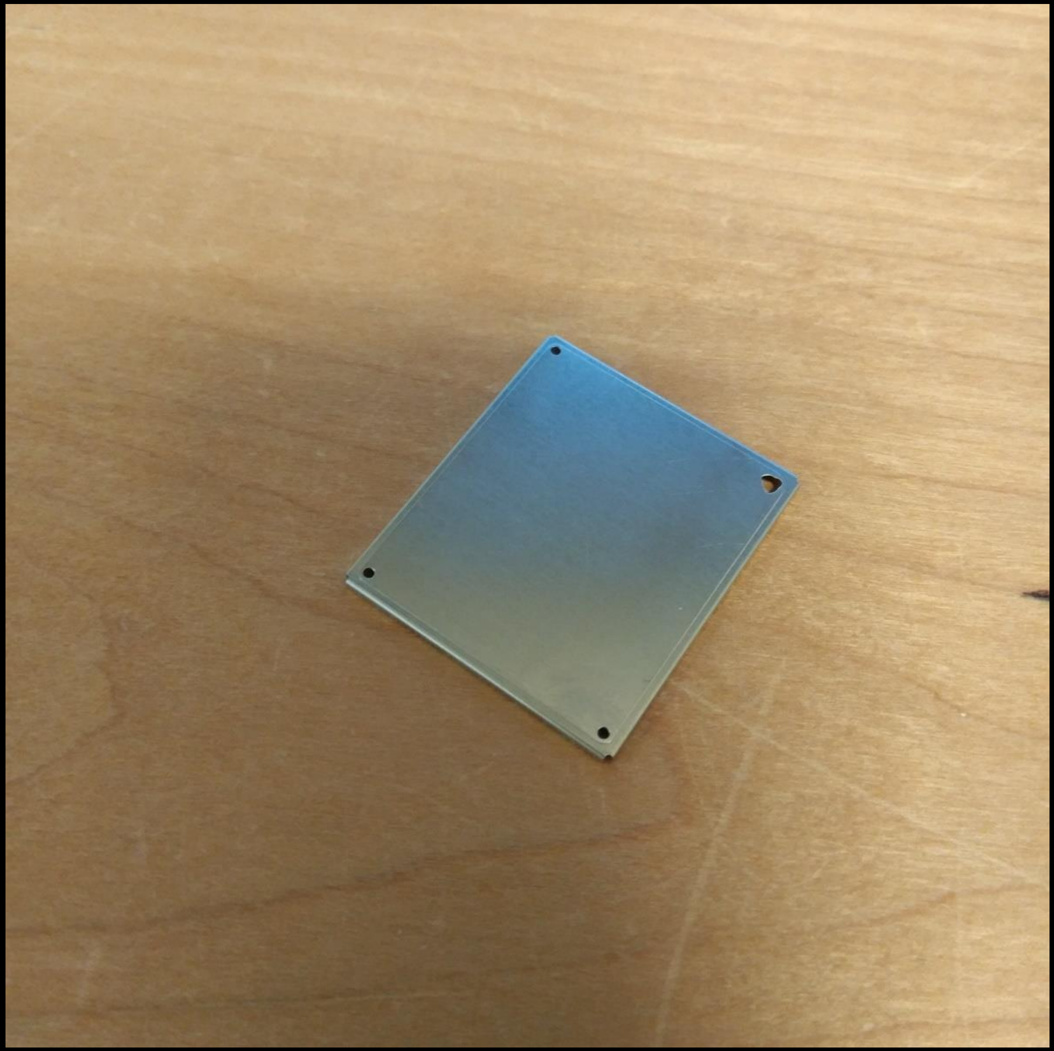
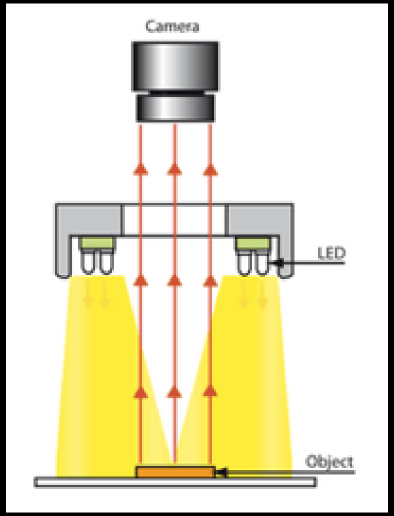
Source: Physics Stackexchange, Baumer

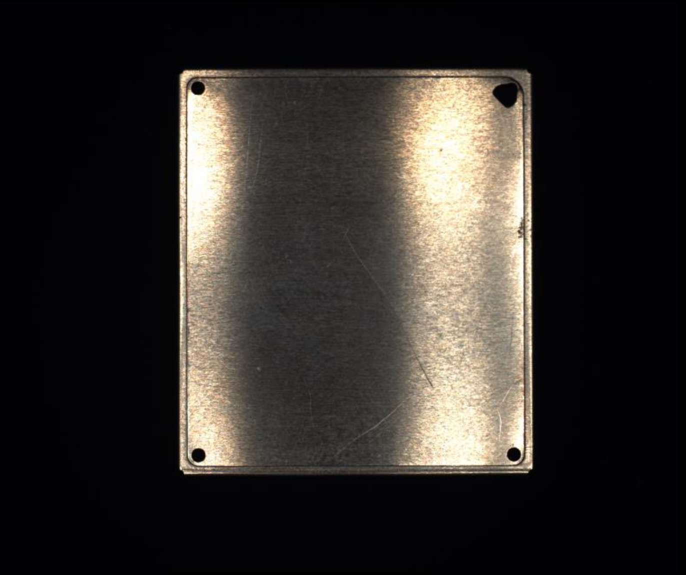
Example objects



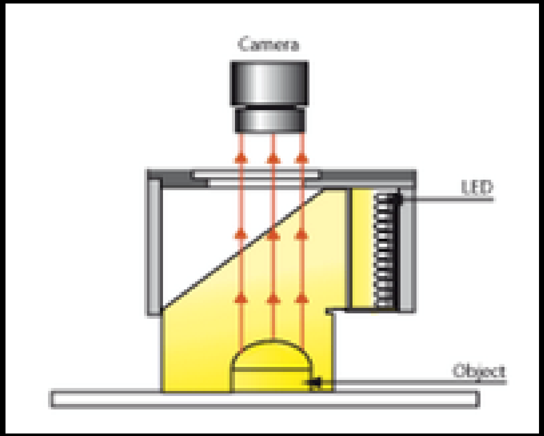
Front light


Camera
LED
Object

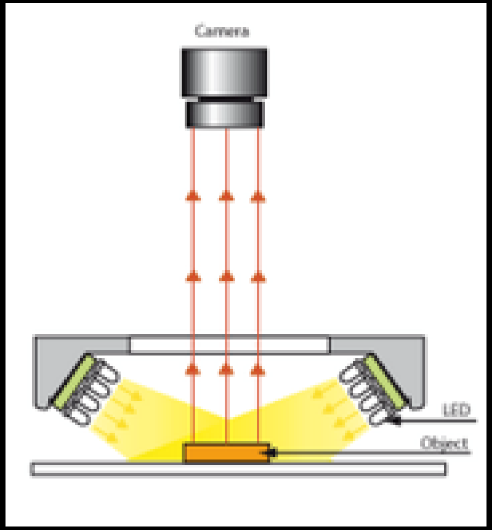

Kingston
TECHNOLOGY
Lock
micro SD
ADAPTER
CHINA

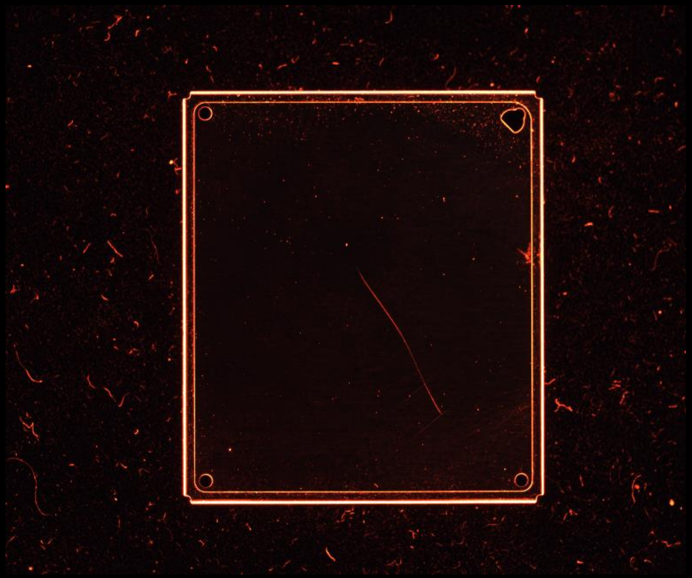


Co-axial front light



Narrow angle light (dark field)





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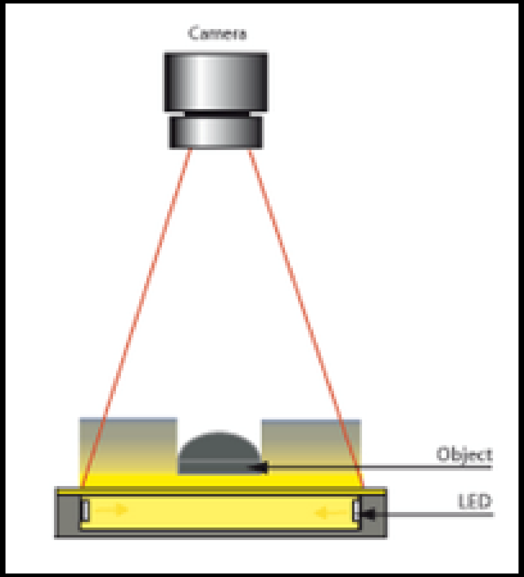
Back light



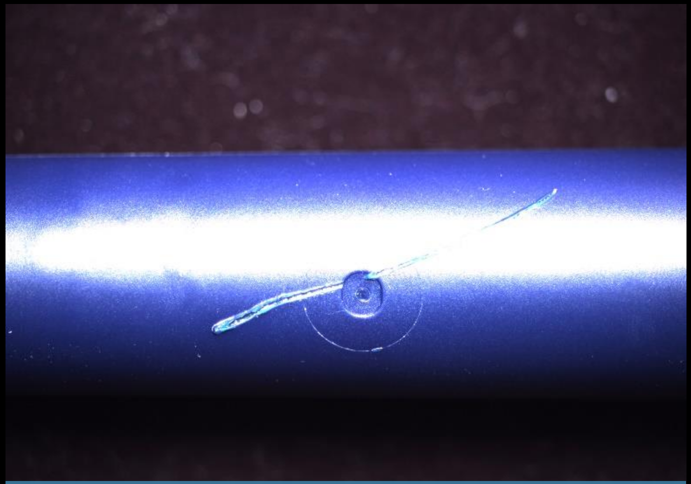
Polarized light source and polarizing filter

No filter

Filter at 0°

Filter at 90°

Polarized light source and polarizing filter



No filter

Filter at 0°

Filter at 90°

Polarized light source and polarizing filter

No filter

Filter at 0°

Filter at 90°

Elements in a Machine Vision system

Task and Object — What do we have to do and on what?

Camera — Which camera do we need?

Lens — What lens is necessary?

Illumination — What kind of light?

Software — How will the image be processed and how is the result going to be communicated?

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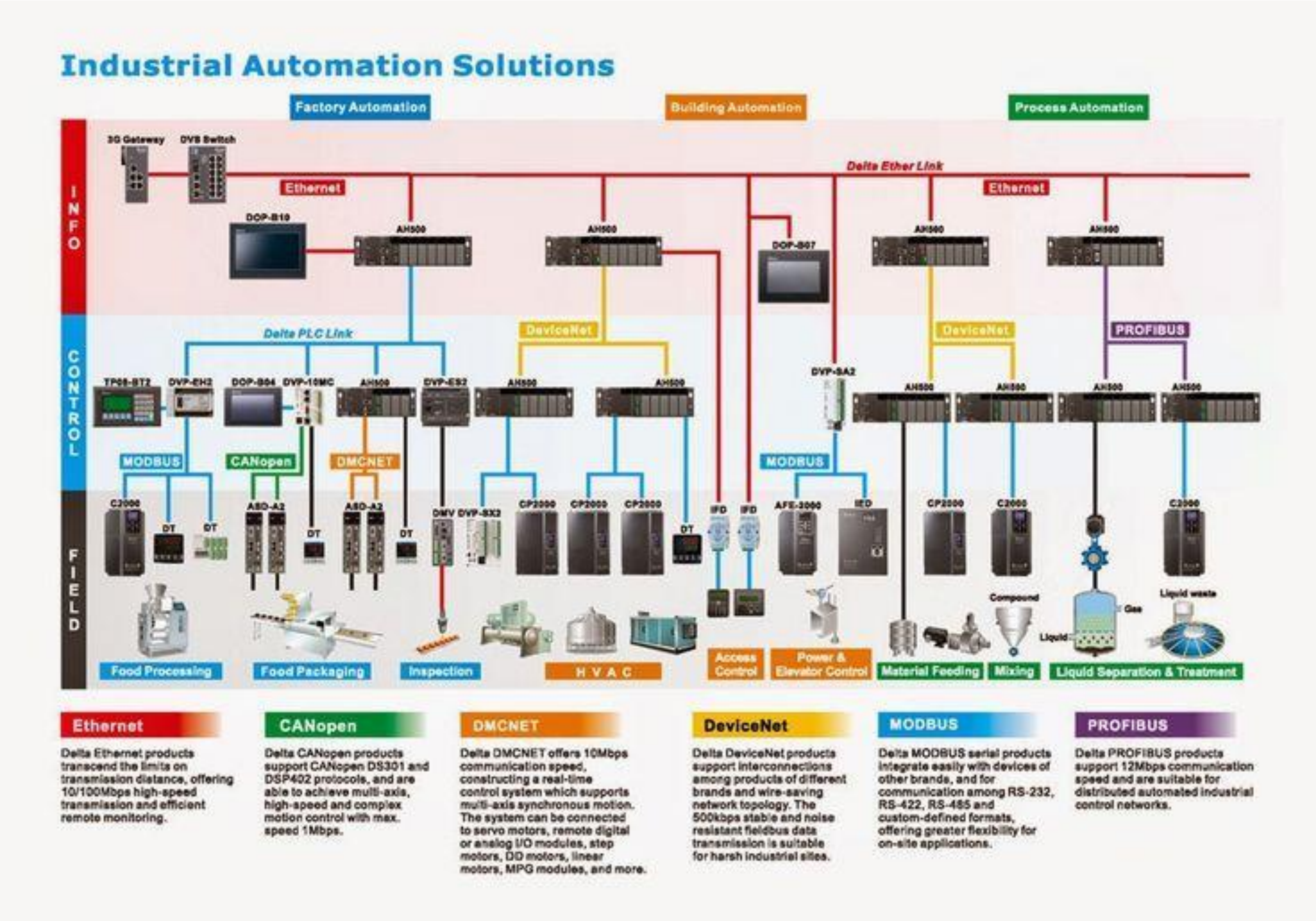
Software suits

Communication protocols



Source: Pinterest

Applications

02504 Computer Vision, Spring 2020

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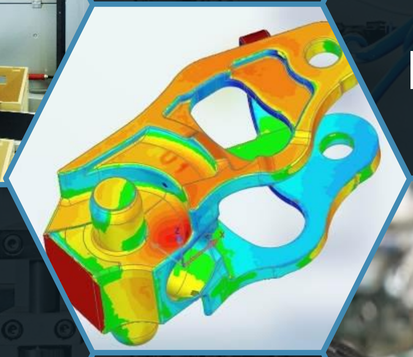
Machine vision application areas

Robot Guidance



Automatic Quality Inspection

Geometrical Metrology

Process Control

Text/Code Reading

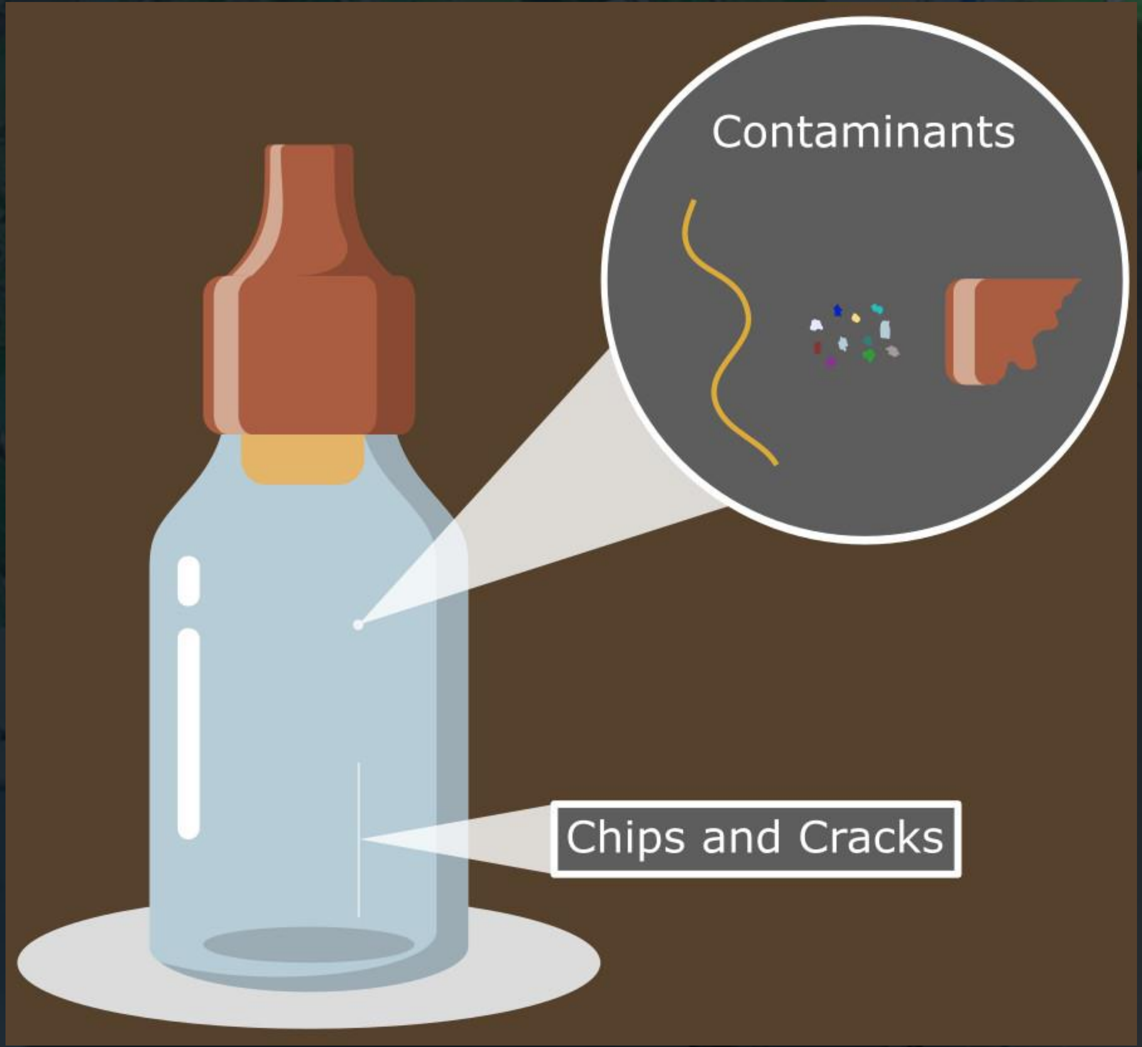
Benefits of Machine Vision

Fast inspection

Improved precision

Reduced cost

Quality control for pharmaceuticals



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