SFU SIMON FRASER UNIVERSITY
ENGAGING THE WORLD

Sensors Overview

CMPT 419/983
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Outline

- Sensors Overview
  - More details in Siegwart, Nourbakhsh, Scaramuzza, “Introduction to Autonomous Mobile Robots,” MIT Press 2011

Classification of sensors

- Proprioceptive: measurements of internal values
  - Motor speed, heading
- Exteroceptive: measurements of the environment
  - Distance measurements, light intensity, sound

- Passive: measure of signals from the environment
  - Temperature sensors, cameras
- Active: send a signal to the environment and measure the response
  - Ultrasonic sensors, Laser rangefinders
  - May affect the environment

Sensor Performance

- **Dynamic range**: ratio between maximum and minimum input values that can be measured accurately
- **Resolution**: smallest difference in signal that can be detected
- **Linearity**
- **Bandwidth** or frequency: how often a measurement is made

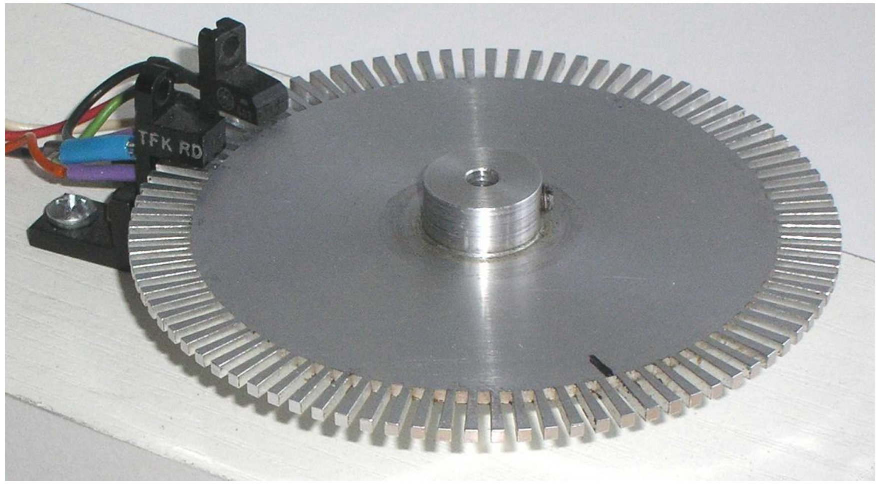
Sensor Performance

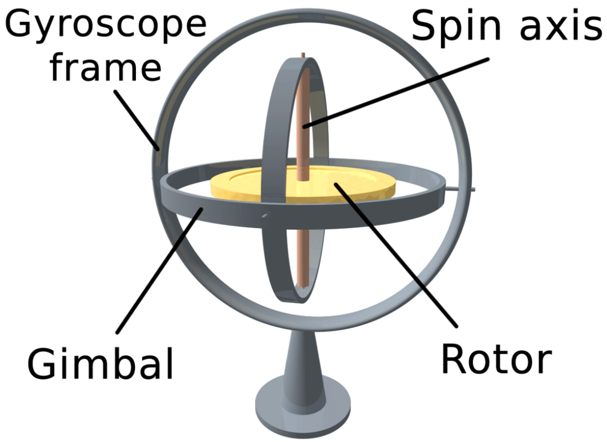
- **Sensitivity**: ratio of output change to input change
  - May vary with input signal, if sensor is nonlinear
  - Cross-sensitivity: sensitivity to unrelated factors in the environment
- **Error**: different between sensor measurement and true value
- **Accuracy**: absolute error relative to true value as a percentage
- **Precision**: consistency/reproducibility of measurements

- Sensor models: probabilistic description of sensor measurements
  - Will discuss more in localization and mapping lectures

Types of sensors

- Encoders
- Heading sensors
- Accelerometers and IMU
- Beacons
- Active ranging
- Cameras

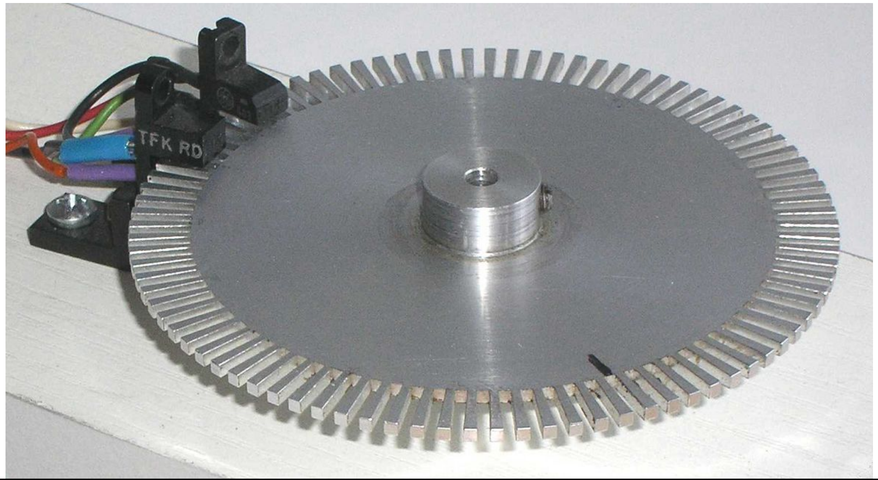


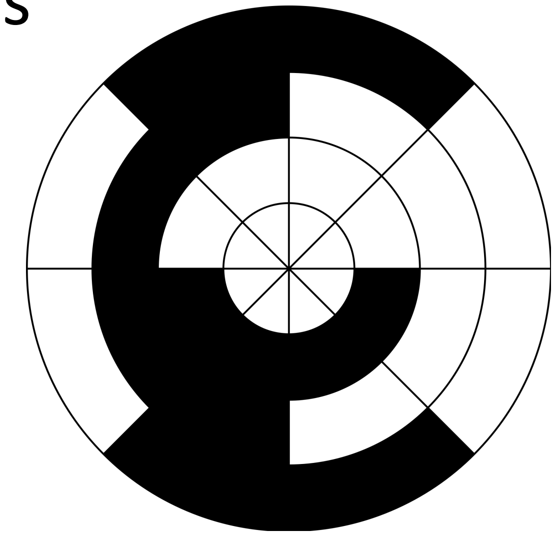


Encoders

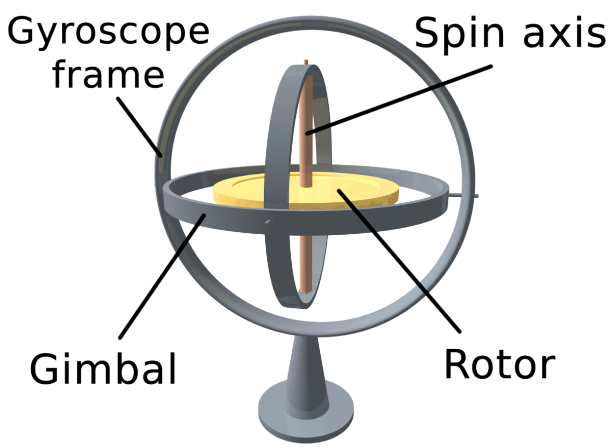
- Measures position by shining light through slits and counting number of interruptions

- Converts motion into a sequence of digital pulses
  - Proprioceptive
  - Can (kind of) be used for localization

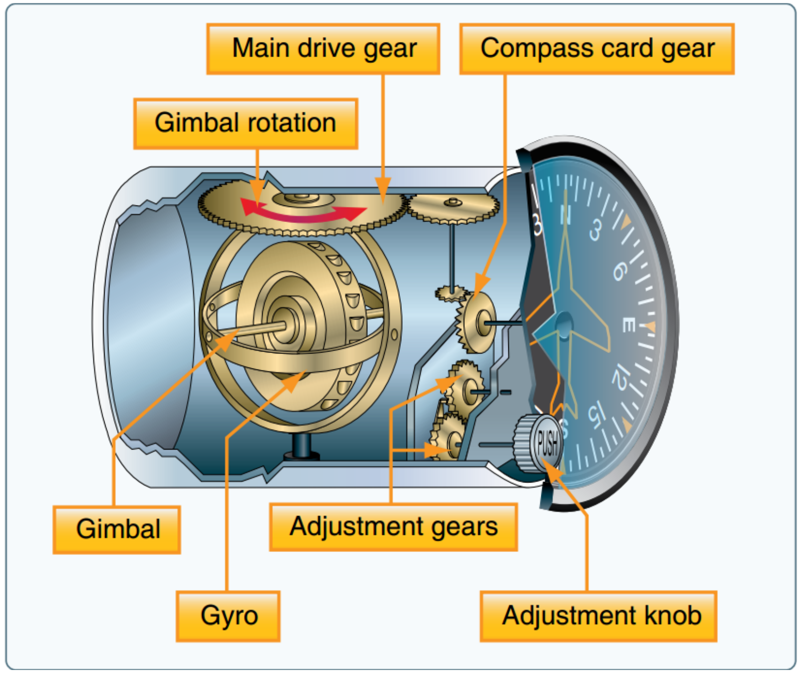




Heading Sensors

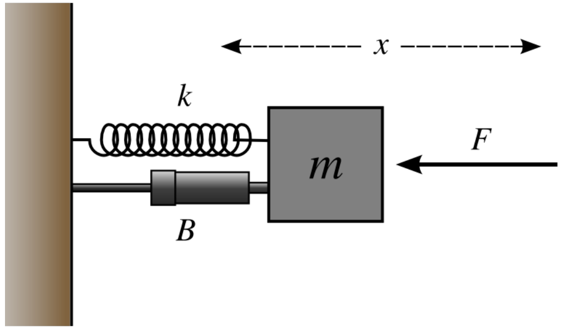


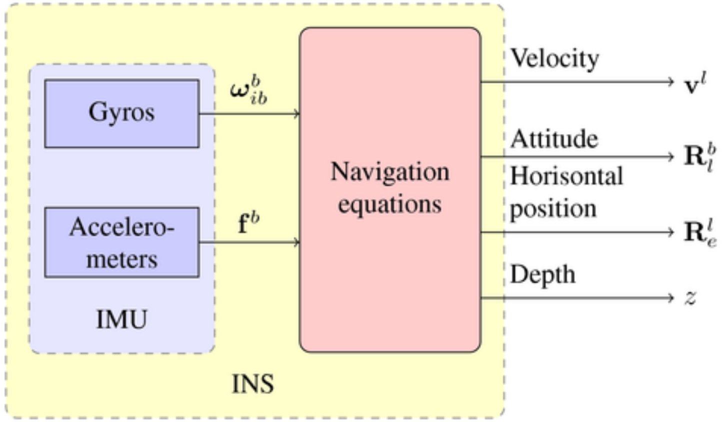
- Measures orientation or heading
  - Gyroscope: proprioceptive
    - Mechanical: up to three gimbals freely rotate without affecting axis of rotation of rotor
    - Optical: pair of lasers fired into circular optical fibre in opposite directions; rotations cause Doppler shift
  - Compass: exteroceptive
- Can be combined with velocity measurements to obtain position estimate



Accelerometer and Inertial Measurement Unit (IMU)

- Accelerometer: Measures external forces acting on the sensor
  - Mechanical accelerometer: $F_{\text{applied}} = m\ddot{x} + c\dot{x} + kx$
    - $\Rightarrow a_{\text{applied}} = \frac{kx}{m}$ in steady state
    - Measure x, obtain a_{applied}
  - Modern accelerometers:
    - Micro Electro-Mechanical Systems (MEMS)
    - Capacitative: capacitance changes with force
    - Piezoelectric: voltage changes with force





- Inertial measurement unit (IMU)
  - Sensor package that measures position, orientation, and their rates
  - Combines gyroscopes and accelerometers
  - Sometimes synonymous with inertial navigation system (INS), but an INS contain an IMU and post-processes IMU data for navigation

Beacons

- A device or structure with precisely known position

- Stars, lighthouses, landmarks
- GPS, motion capture systems
- Required for accurate measurement of position
  - Used in combination with IMU

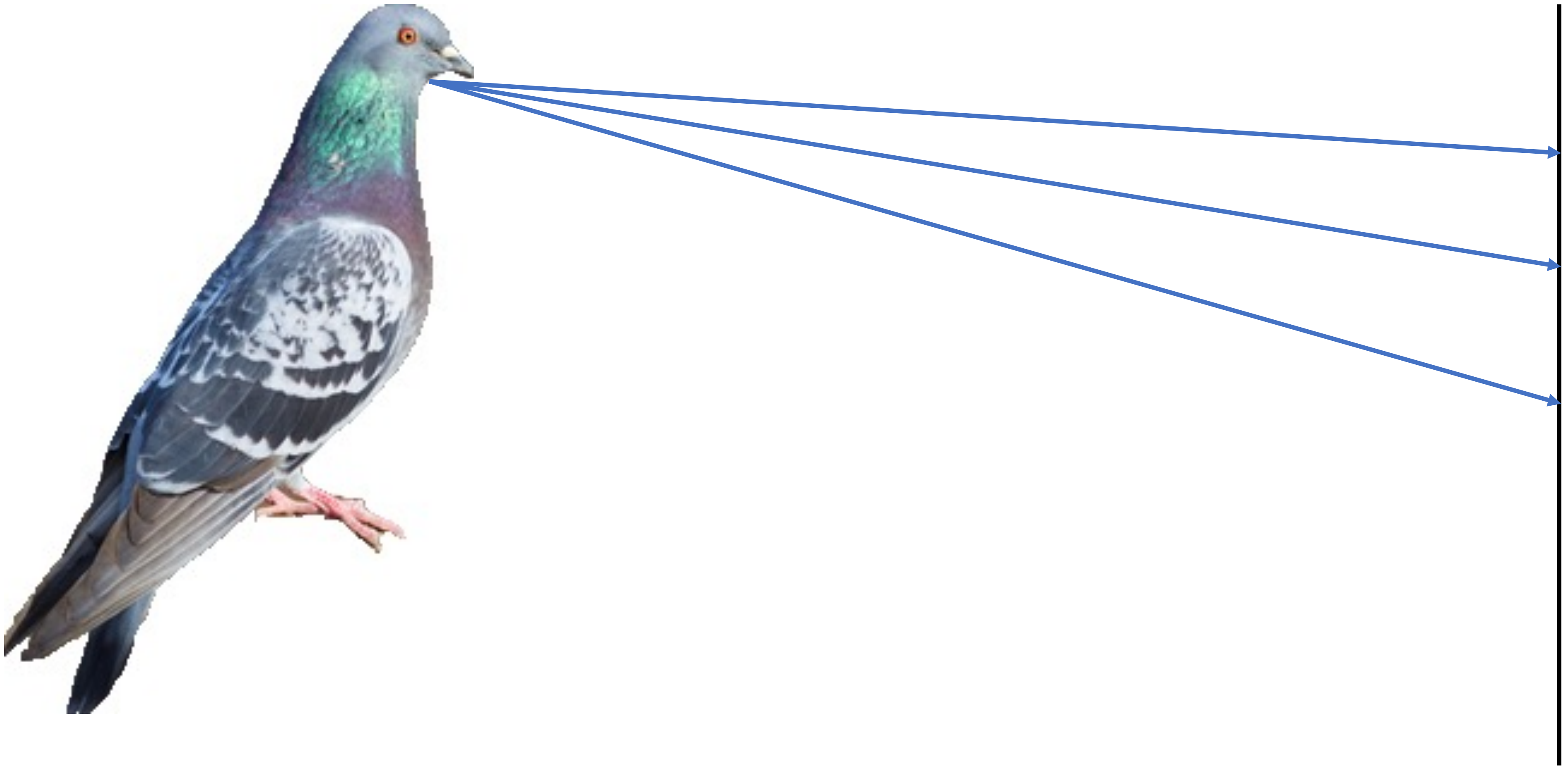
Active Ranging

- Measures distances to nearby objects

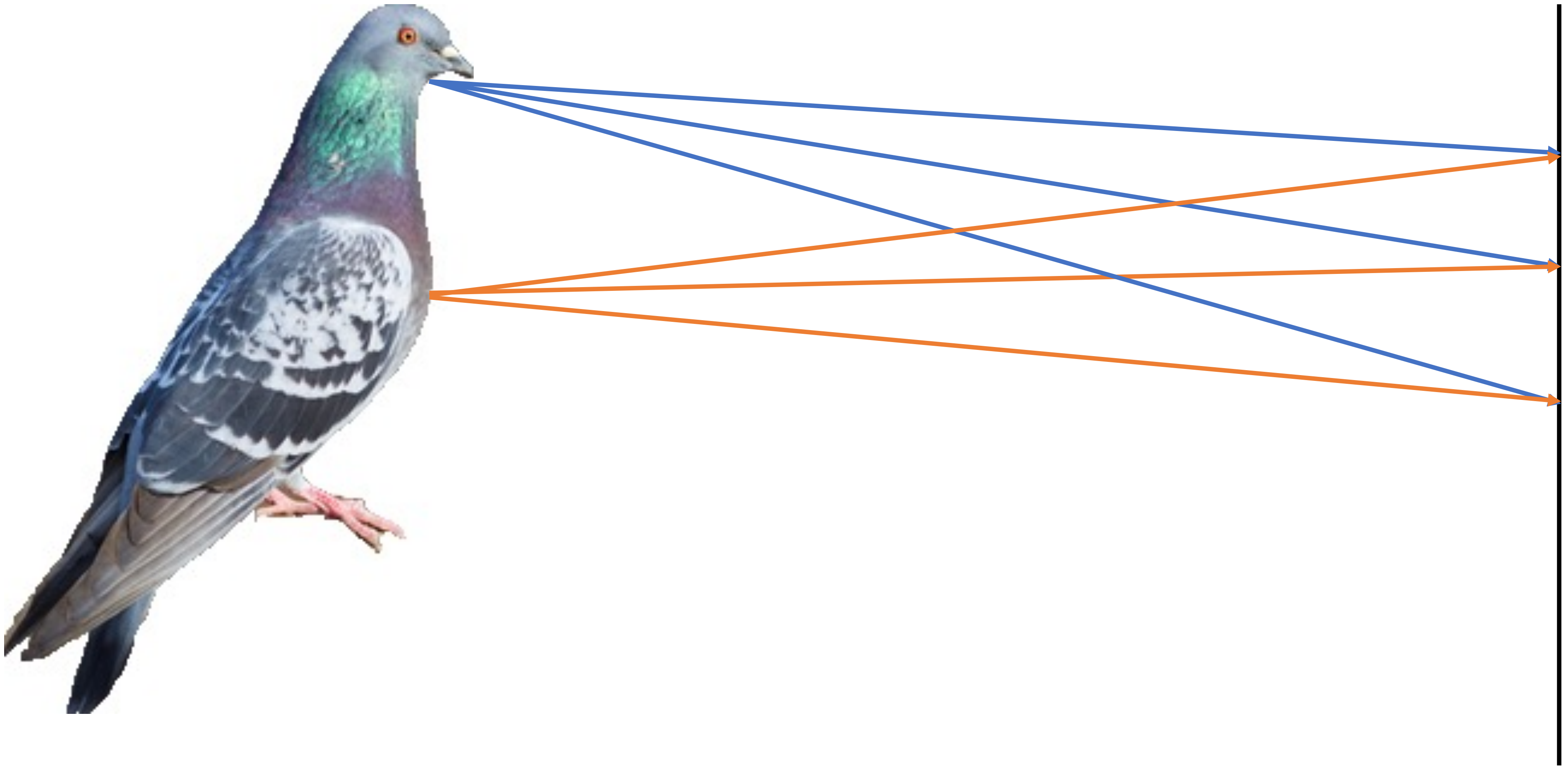
- Time-of-flight active ranging sensors
  - Travel distance: $d = ct$, where c is the speed of wave propagation and t is time of flight
  - Sonar: uses sound waves, $c = 343\ \mathrm{m/s}$
  - Lidar/radar: uses light waves, $c = 300\ \mathrm{m/\mu s}$
    - In general, longer wavelength → longer range, but cannot detect small features

- Geometric active ranging sensors

Cameras



Cameras



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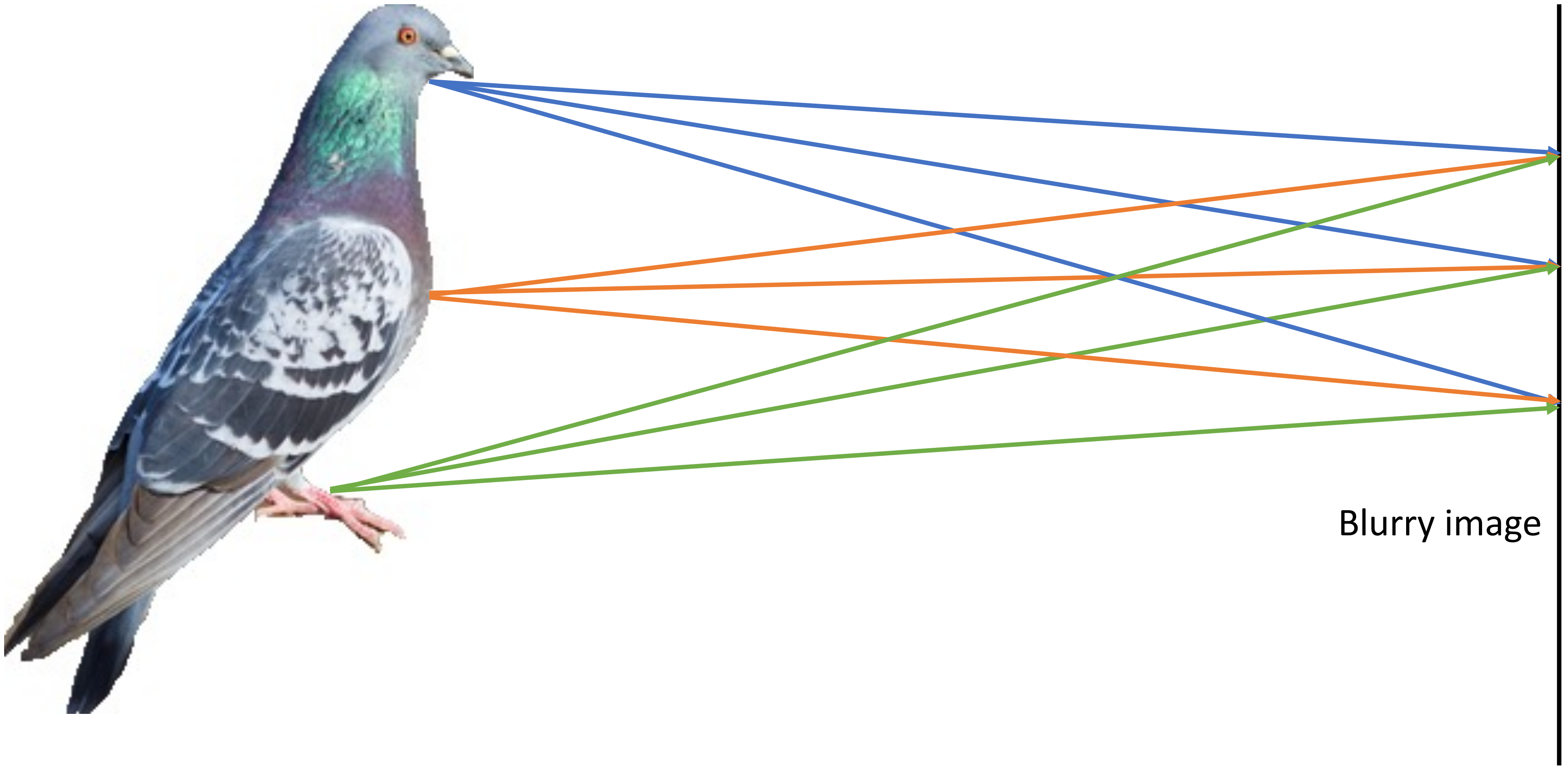
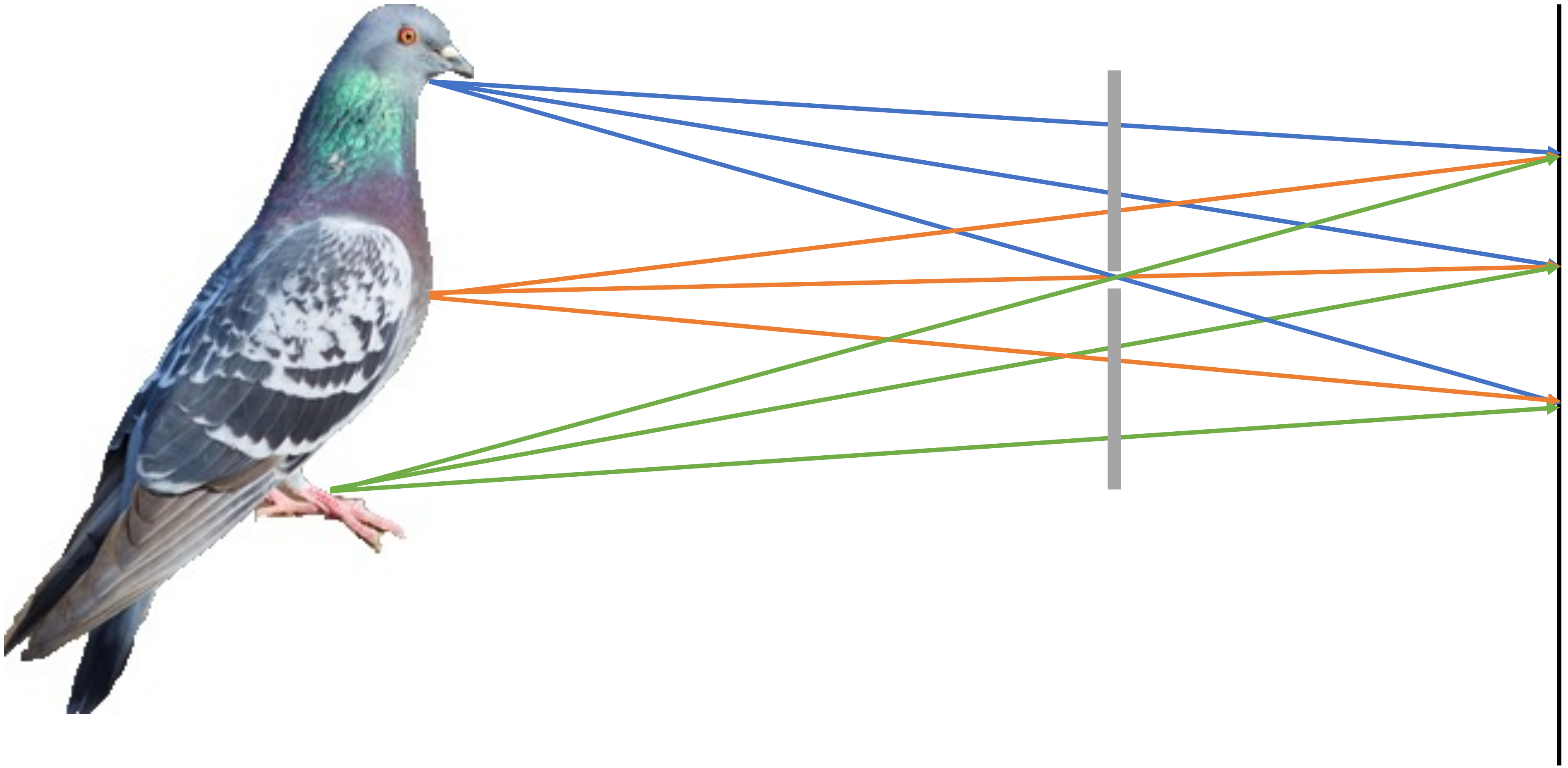
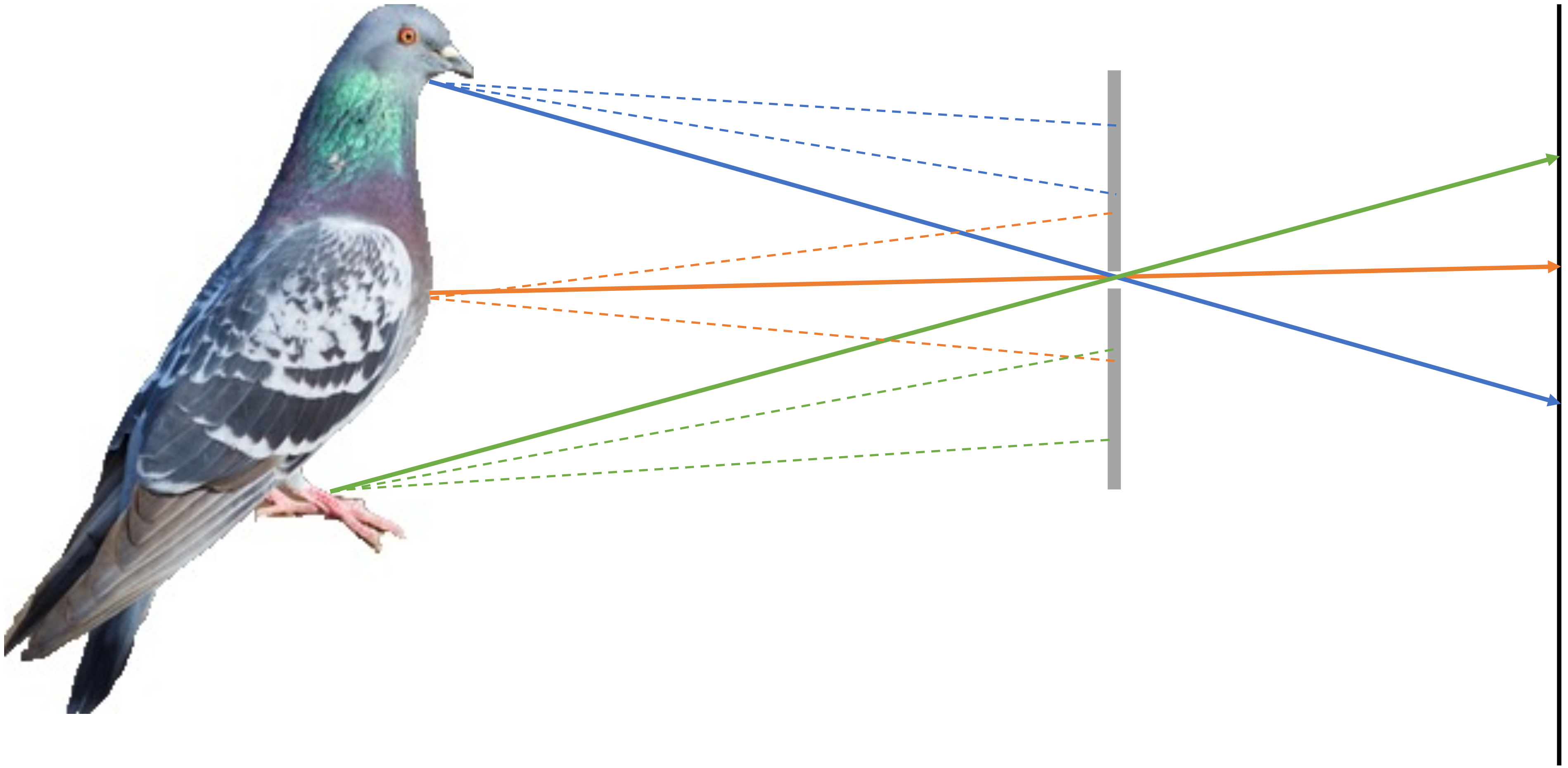


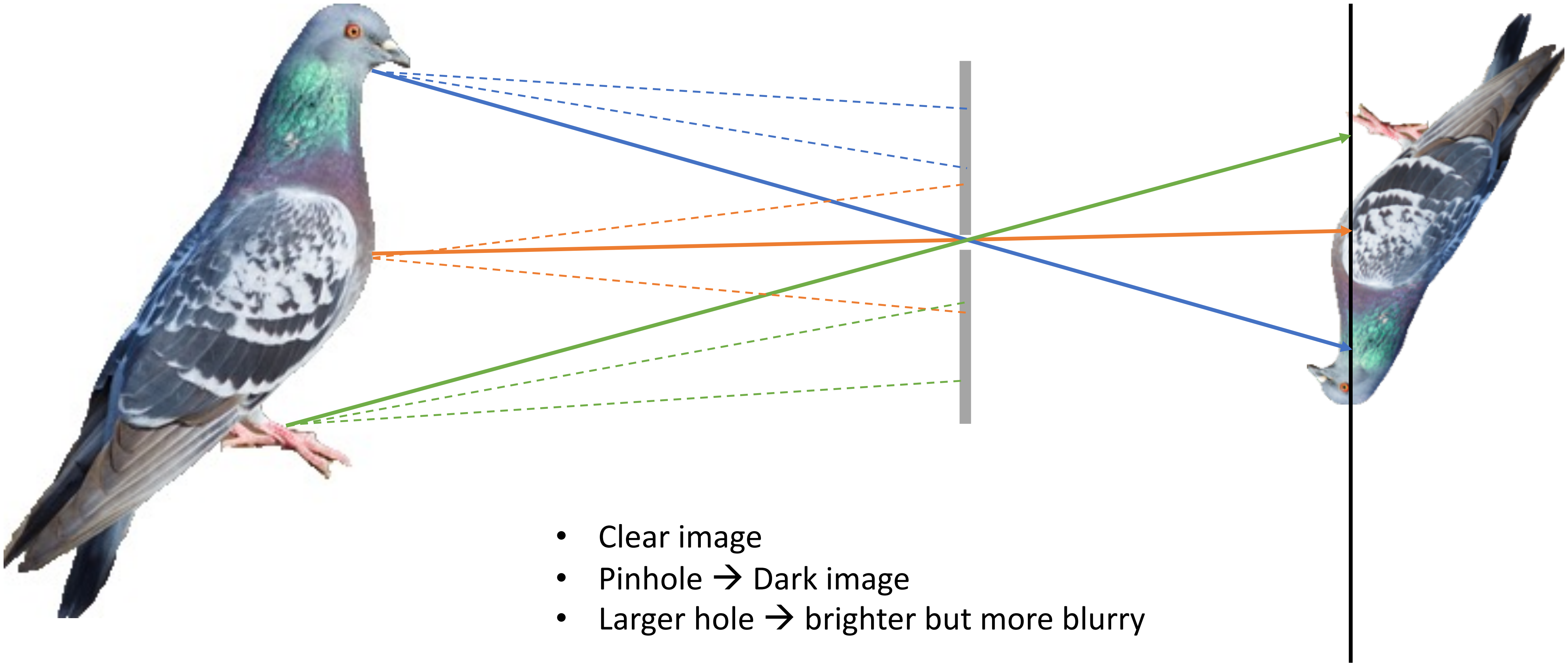
Pinhole Camera



Pinhole Camera



Pinhole Camera

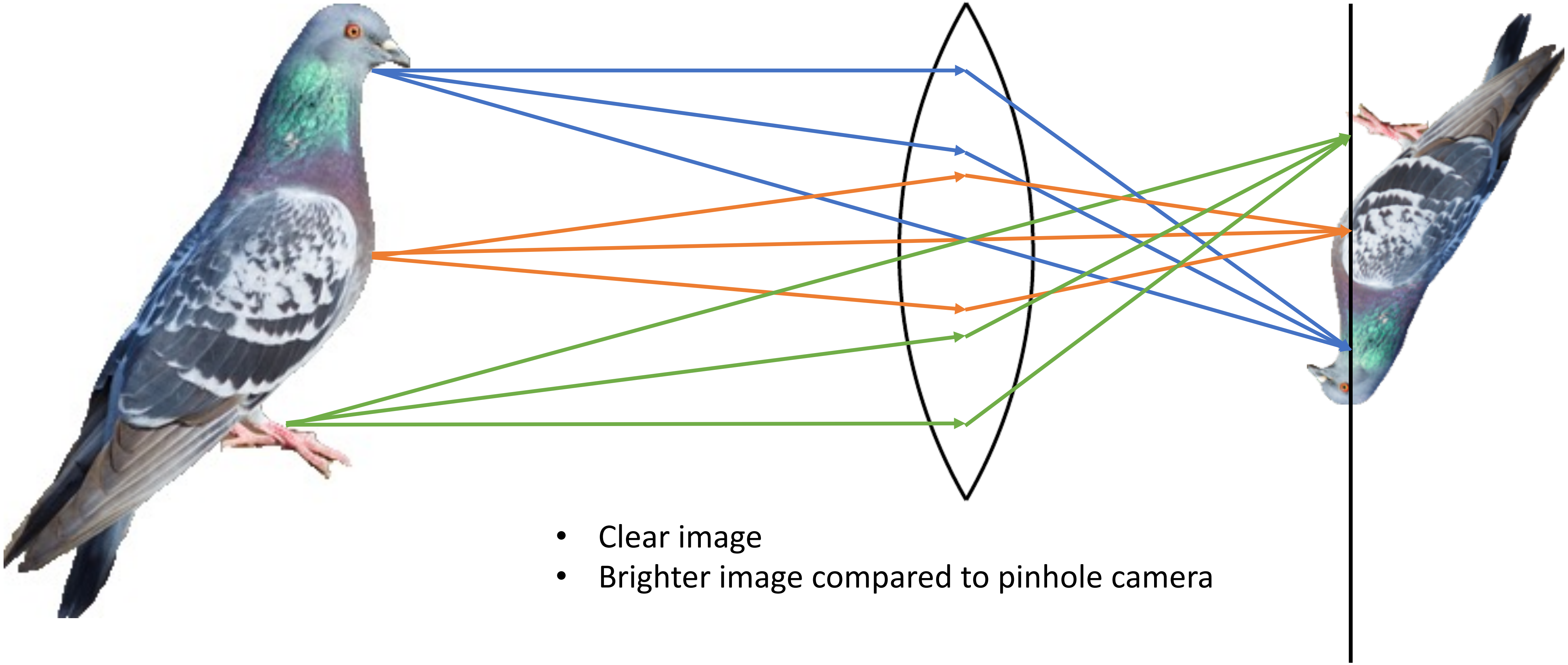


- Clear image
- Pinhole → Dark image
- Larger hole → brighter but more blurry

Solar Eclipse

- Gaps between leaves act as pinholes
- The shape of the sun is projected on the screen (ground)

Lenses



- Clear image
- Brighter image compared to pinhole camera

3D Scene Reconstruction From 2D Images

- Depth from focus
- Stereo vision: two images taken at different locations at the same time
- Structure from motion: two images of the same object taken at different times

Image Processing and Understanding

- Pixel data need to be converted into useful features

- Common operations
  - Image filtering, enhancement, compression
  - Geometric feature extraction
    - corner, edge, plane, etc.

- Deep learning computer vision techniques

Example: Self-Driving Car