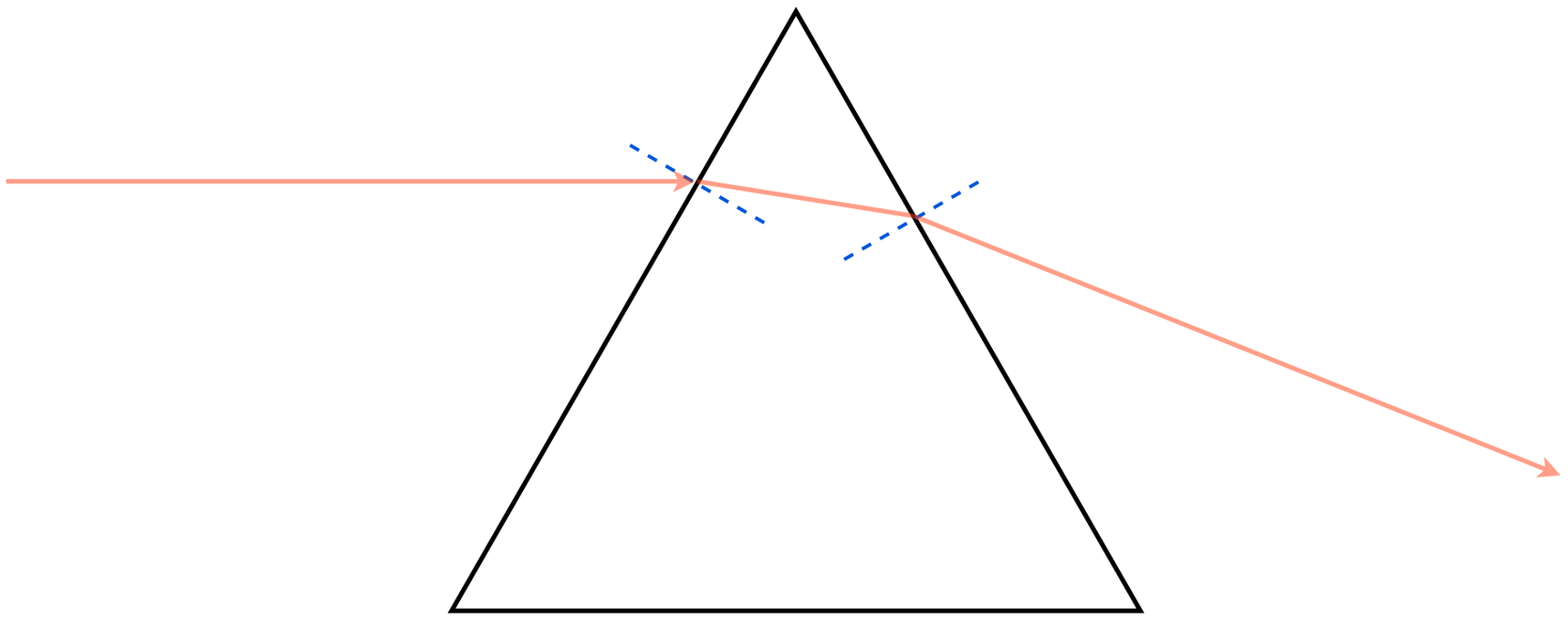
Lenses

- Refraction
- Refraction - converging lens
- Refraction - diverging lens
- Images in convex (converging) lenses
- The human eye
- Images in concave (diverging) lenses
- The lens & mirror equation
- Image formation - summary

Refraction

- Light refracts as it passes between different materials.
- Moving into a more optically dense material causes refraction towards the normal line, as one part of the wave is slowed down before the other.



Light refracts towards the wider end of a triangular prism.

Refraction

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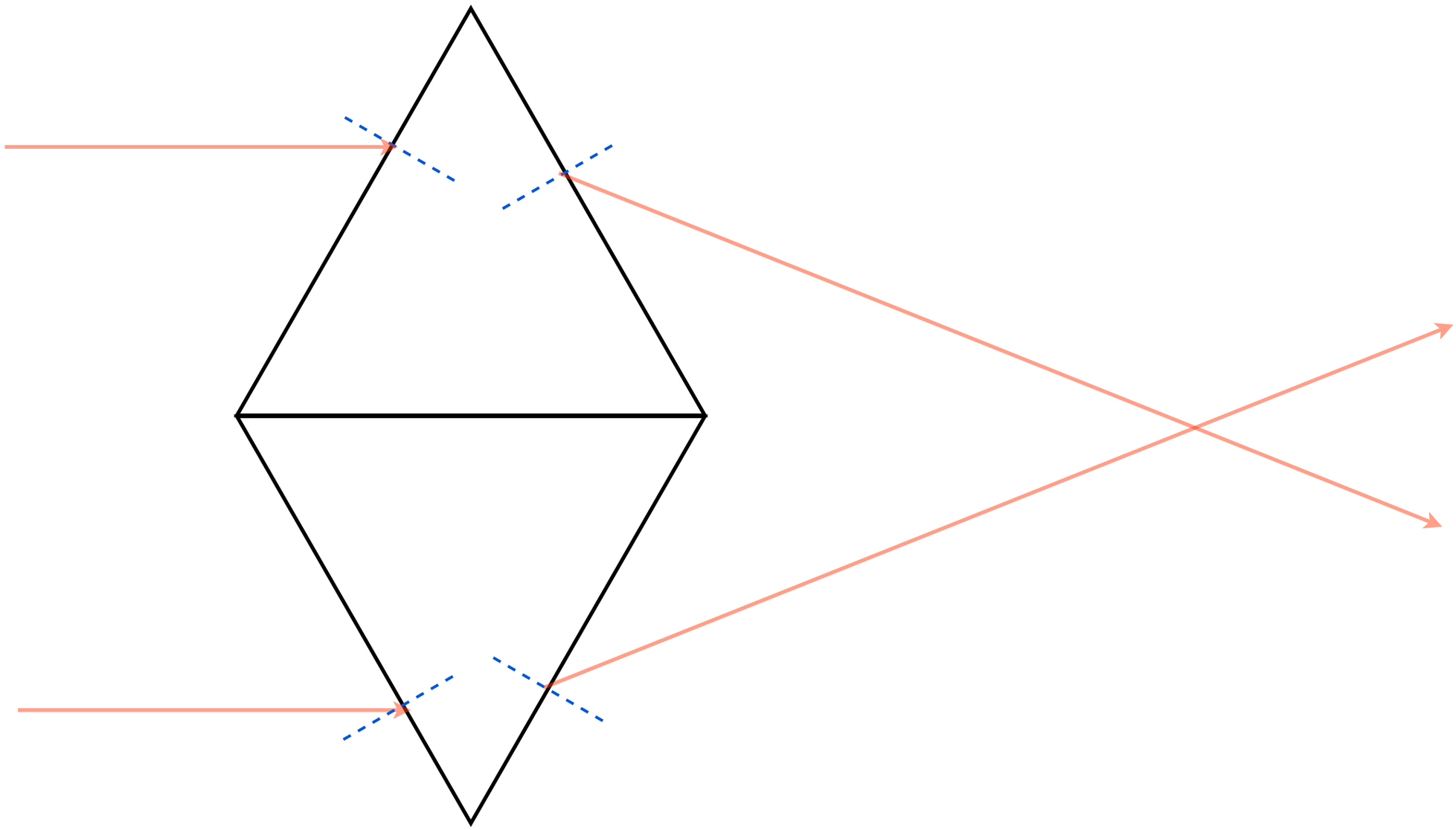
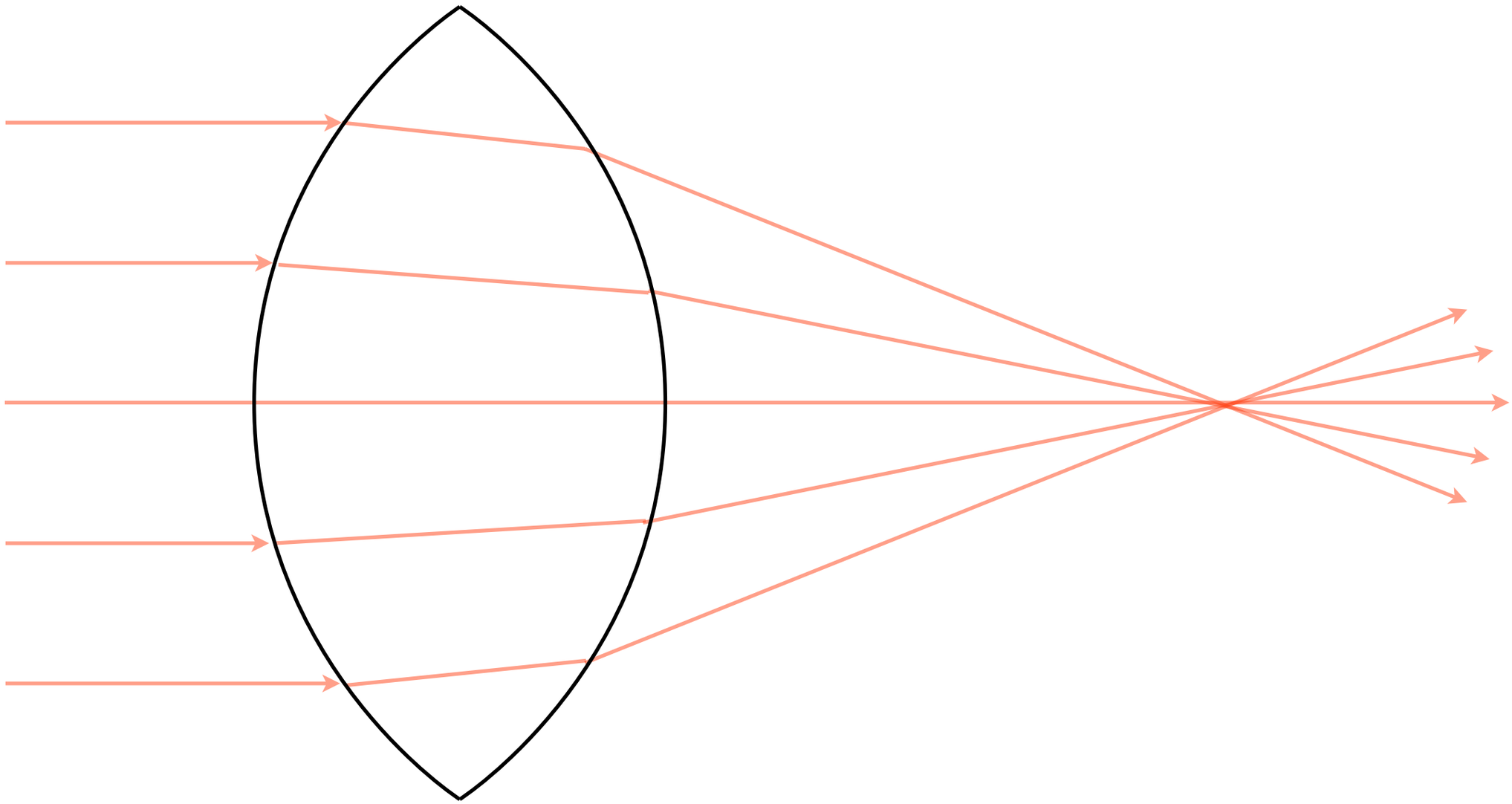


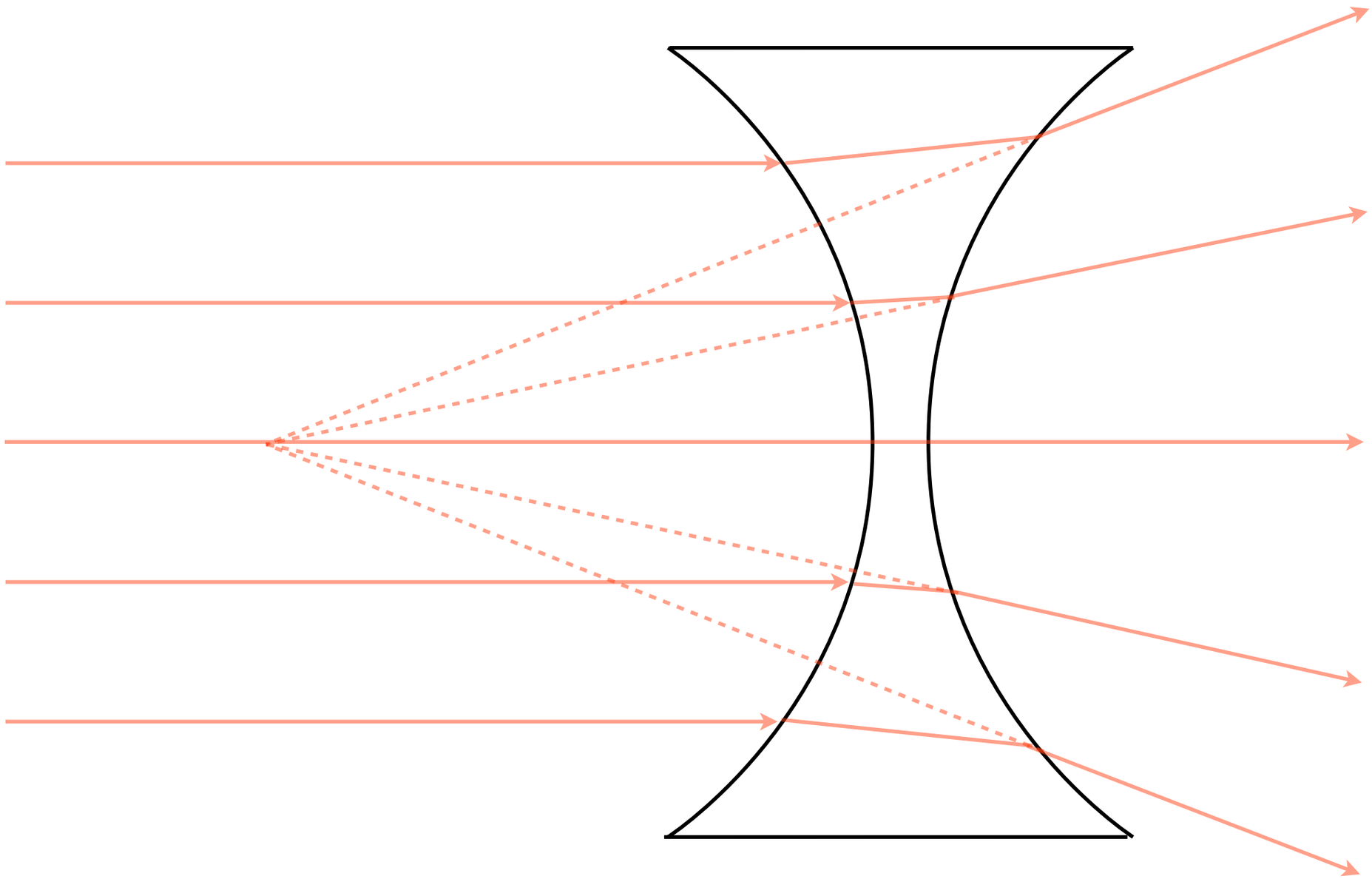
Refraction - converging lens

- Using a smoothly curved **biconvex** lens results in a clear **focal point**.
- All horizontal rays will refract & pass through the focal point.
- The focal point will be closer with a tighter curvature of the lens.



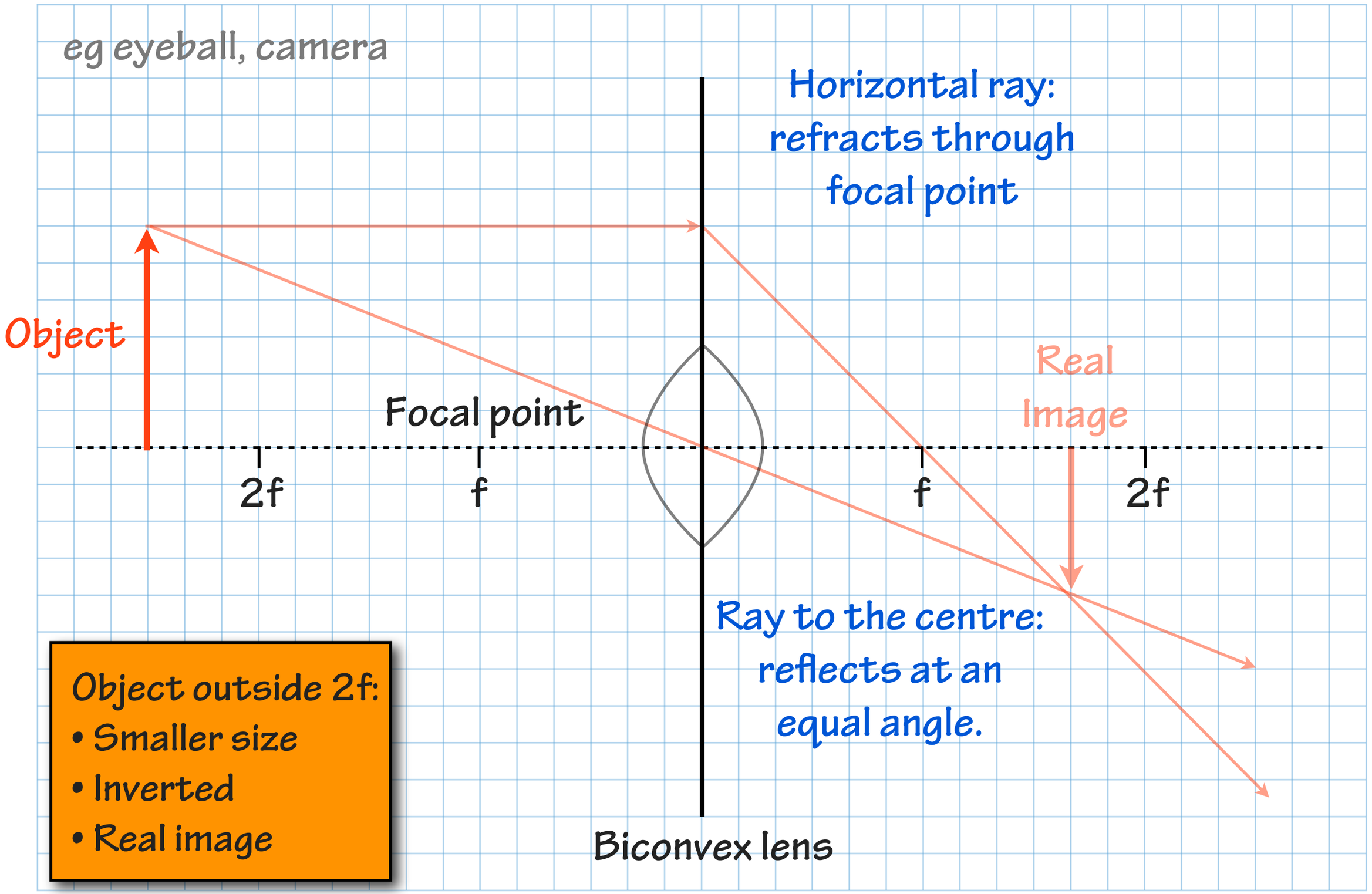
Refraction - diverging lens

- A **biconcave lens** creates a divergence of light rays.
- All horizontal rays will refract & exit as if they came from a **virtual focal point**.



Images in convex (converging) lenses (1)

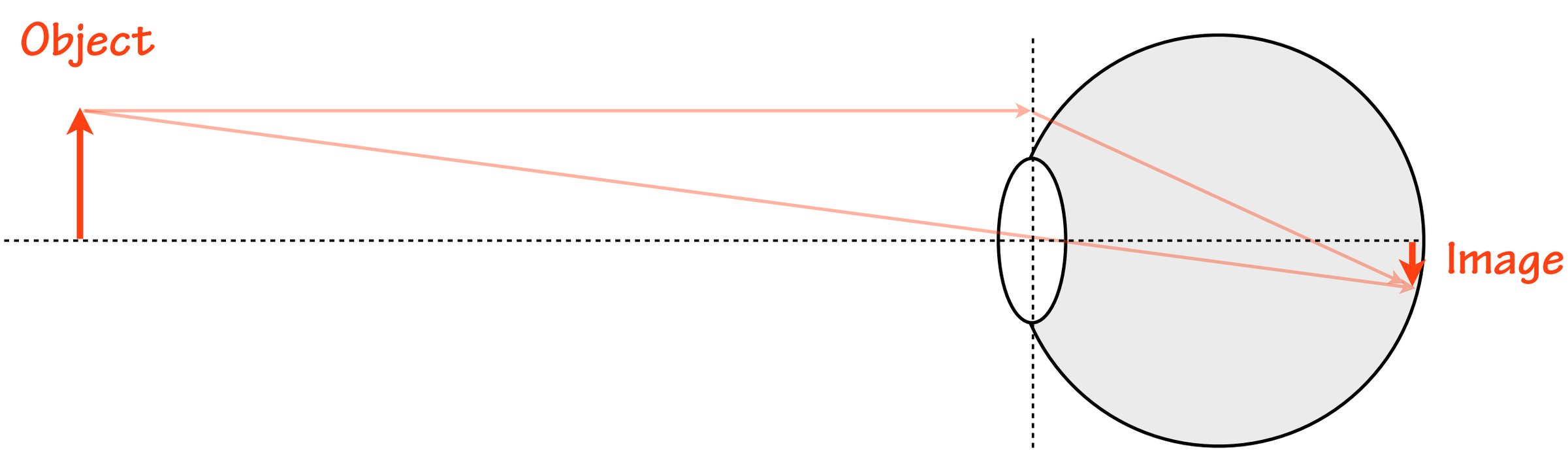
eg eyeball, camera



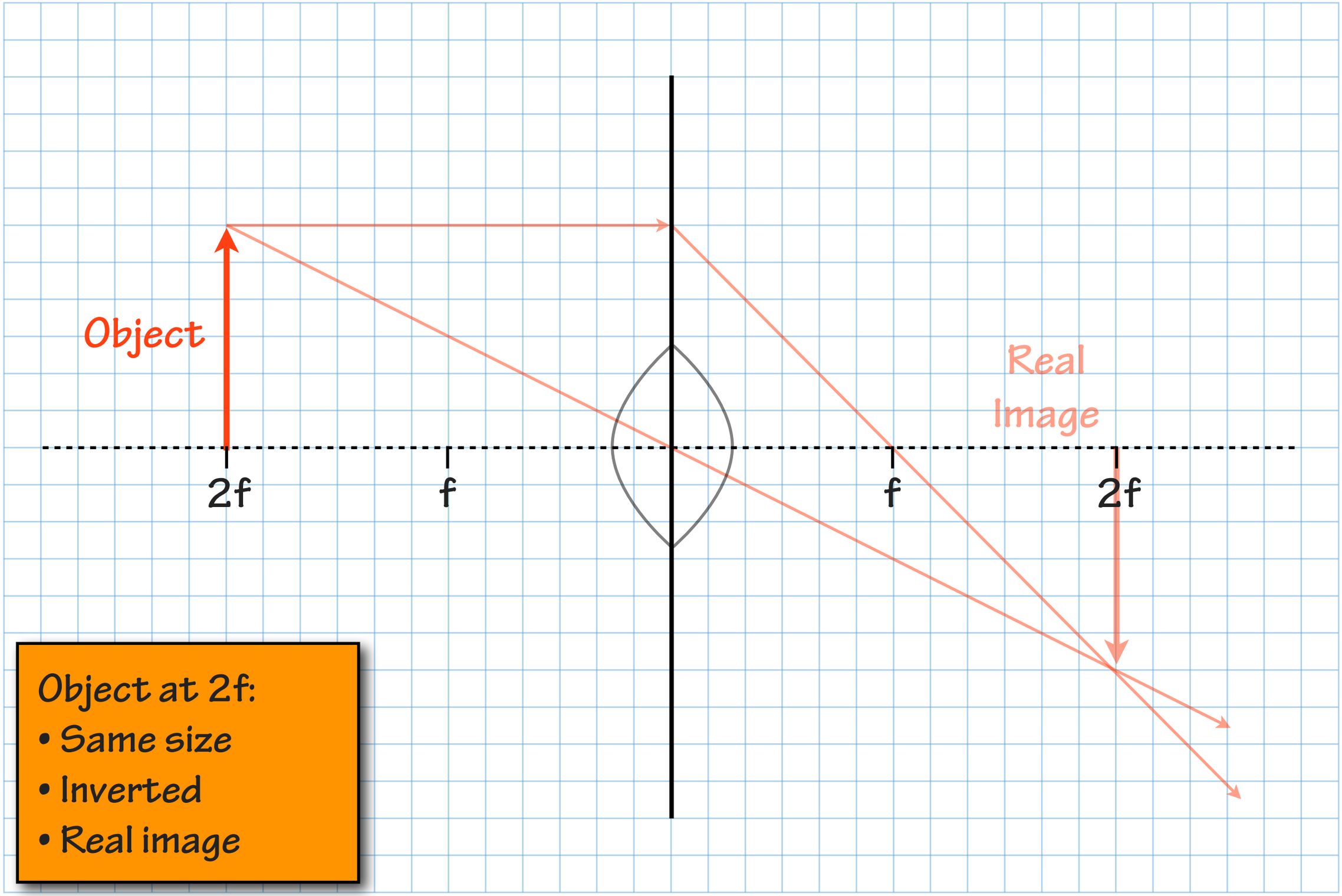
Object outside 2f:
- Smaller size
- Inverted
- Real image

The human eye

- Real images are projected through the lens to the retina.
- The image distance is the depth of the eye-ball: about 2.5 cm.
- The image is inverted on the retina at the back of the eye.
- Changes to focus are the result of reshaping the lens.



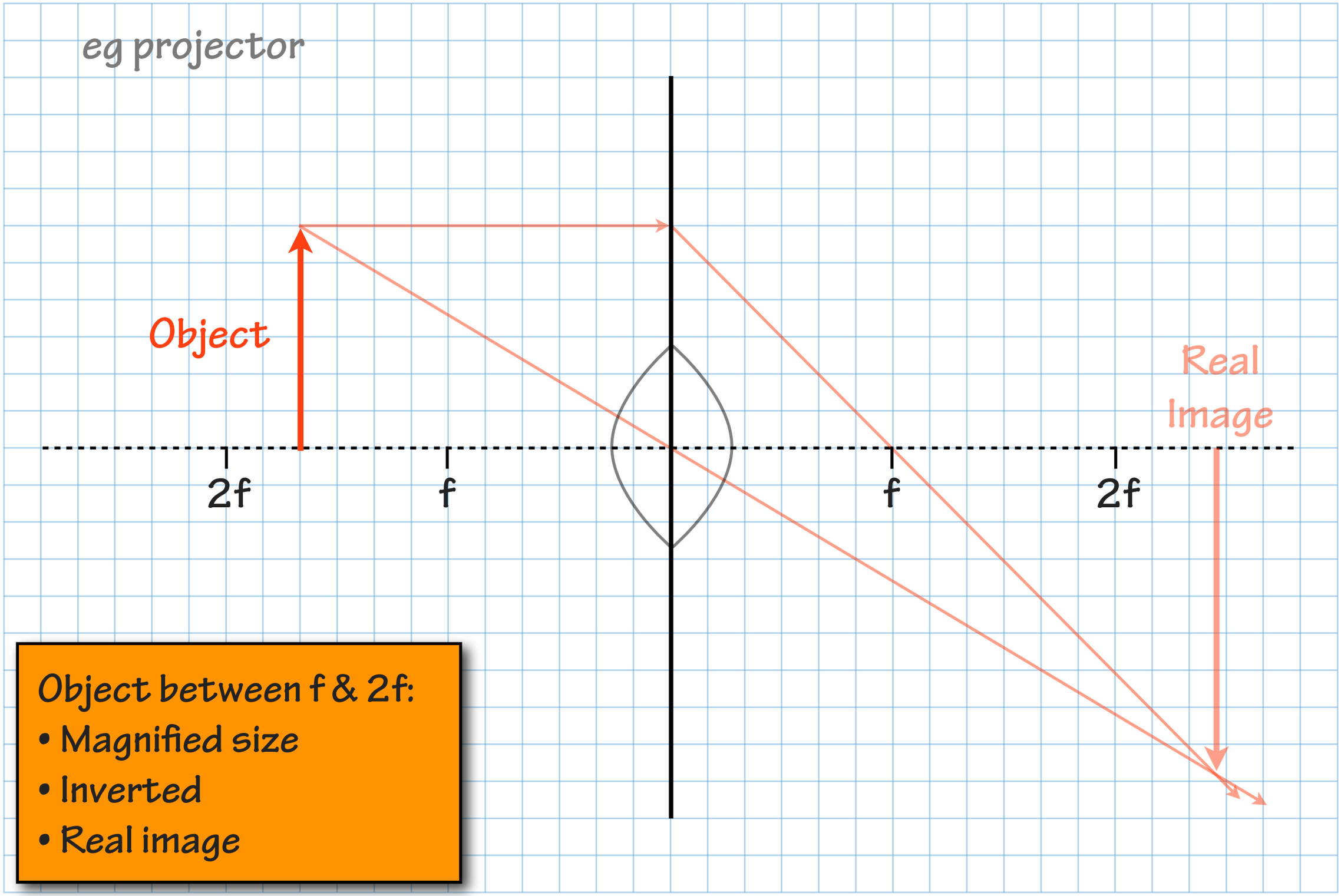
Images in convex (converging) lenses (2)



Object at 2f:
- Same size
- Inverted
- Real image

Images in convex (converging) lenses (3)

eg projector

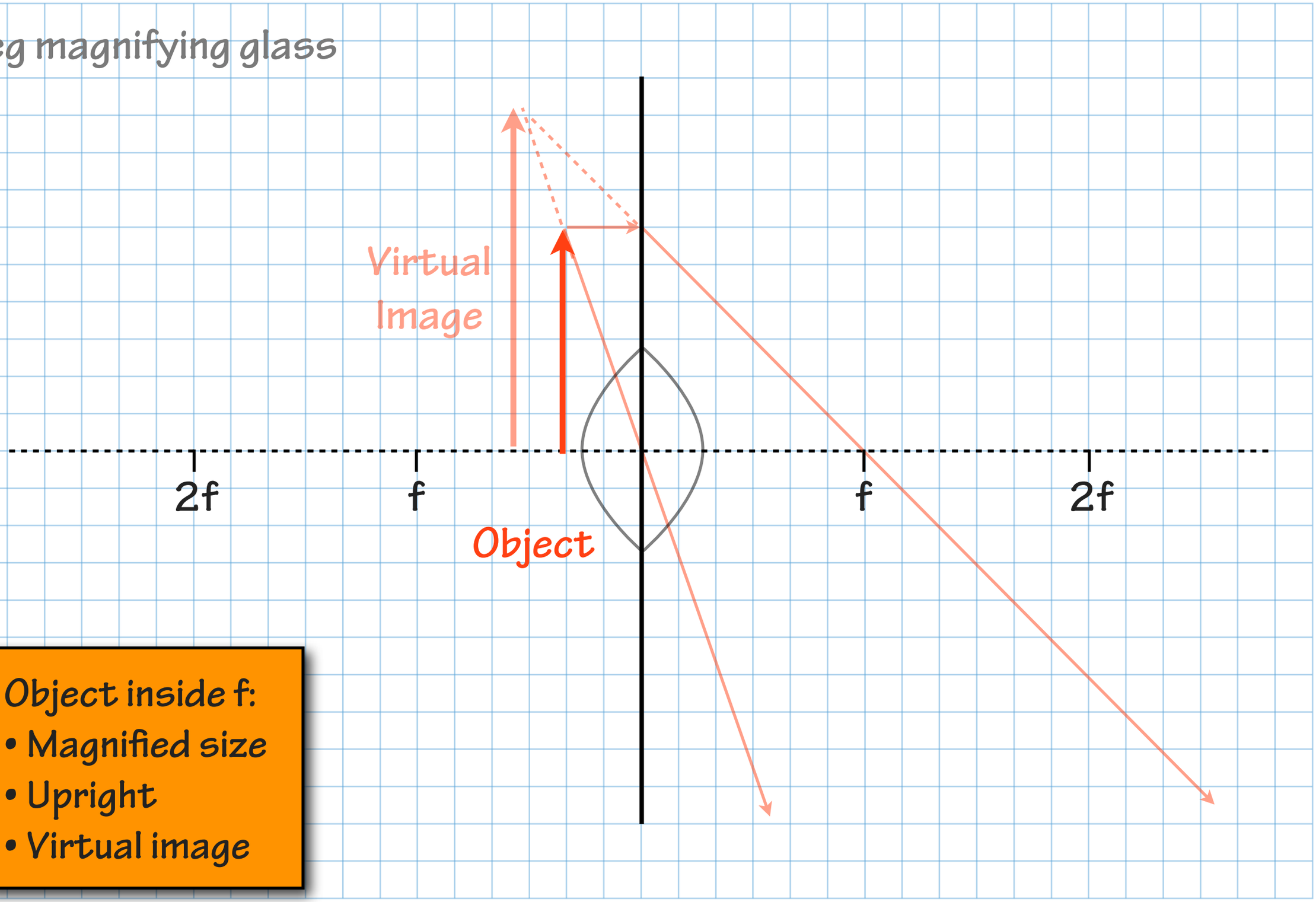


Object between f & 2f:

- Magnified size
- Inverted
- Real image

Images in convex (converging) lenses (4)

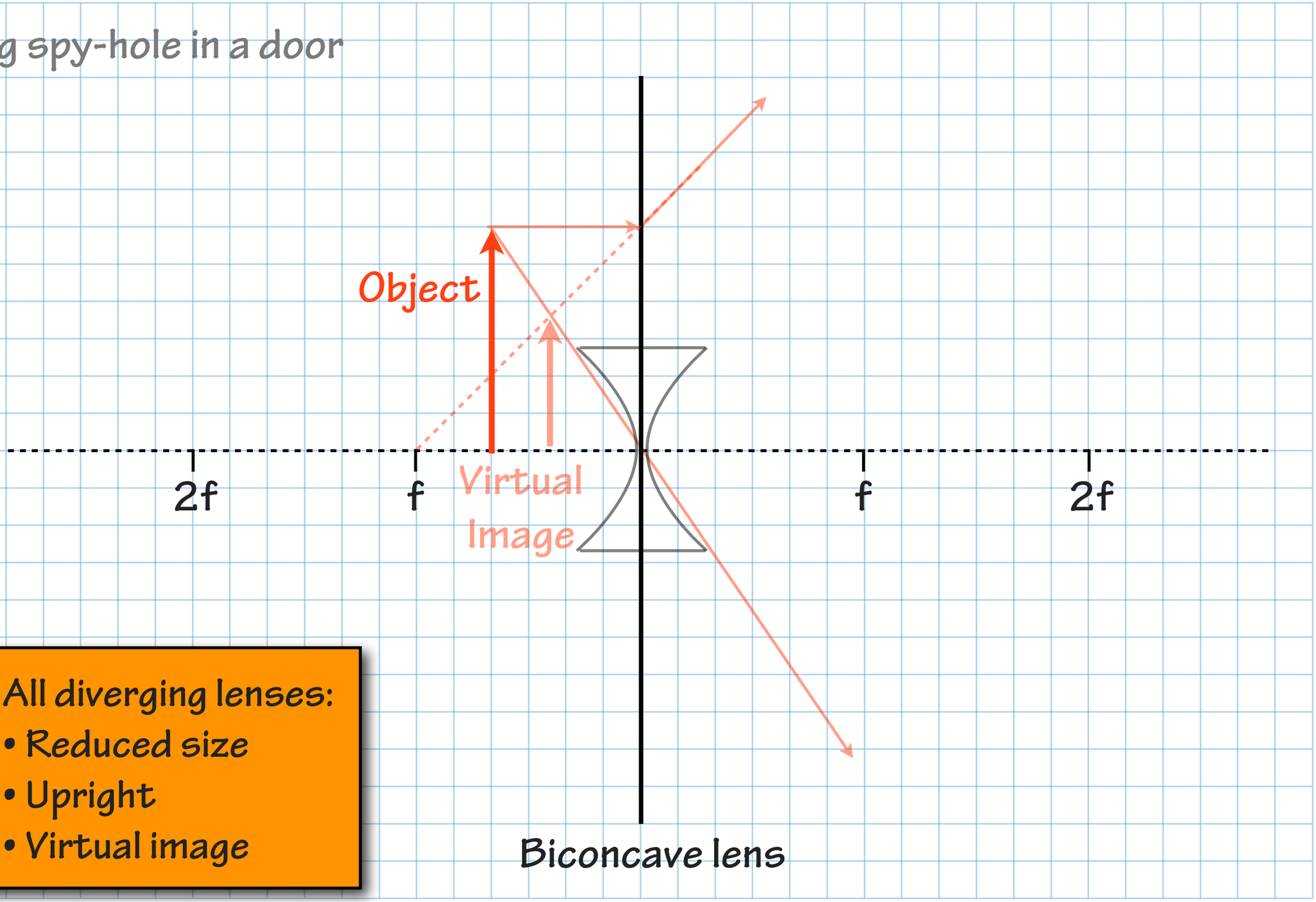
eg magnifying glass



Object inside f:
- Magnified size
- Upright
- Virtual image

Images in concave (diverging) lenses

eg spy-hole in a door



All diverging lenses:
- Reduced size
- Upright
- Virtual image

The lens & mirror equation

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$M = -\frac{v}{u}$$

u = object distance

f = focal length

Object

Real Image

v = image distance

2f

f

f

2f

Using the rule:

- Positive values of v & f are through the lens.
- (Converging lens is positive f.)
- Positive magnification is a virtual image.

Using lenses

- *eg. A 25 cm object is placed 15 cm in front of a converging lens with a focal length of 40 cm.*
- **Find the position, nature & size of the image formed.**

$f = 40\ cm$

$u = 15\ cm$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{40} = \frac{1}{15} + \frac{1}{v}$$

$$\frac{3}{120} - \frac{8}{120} = \frac{1}{v}$$

$$v = -\frac{120}{5} = -24\ cm$$

$$M = -\frac{v}{u}$$

$$M = -\frac{-24\ cm}{15\ cm}$$

$$M = +1.7$$

$$\text{Size} = 1.7 \times 25\ cm = 42\ cm$$

The image is virtual, upright, 42 cm.

Image formation - summary

- **Real images** form from the convergence of light rays.
- **Virtual images** form from the divergence of light rays - our eyes extrapolate the rays backwards to a point.
- Real images are always inverted - virtual images are upright.
- Objects outside the focal length of convex lenses form real images.
- Objects inside the focal point form magnified, virtual images.
- Objects closest to the focal point form the largest images.
- Images in concave lenses are always virtual and reduced in size.

Optical systems - microscopes & telescopes

- Compound microscopes & basic astronomical telescopes use a system of two lenses.
- The objective lens produces a real image just inside the focal point of the ocular / eyepiece lens.
- This forms a virtual image with the maximum magnification.