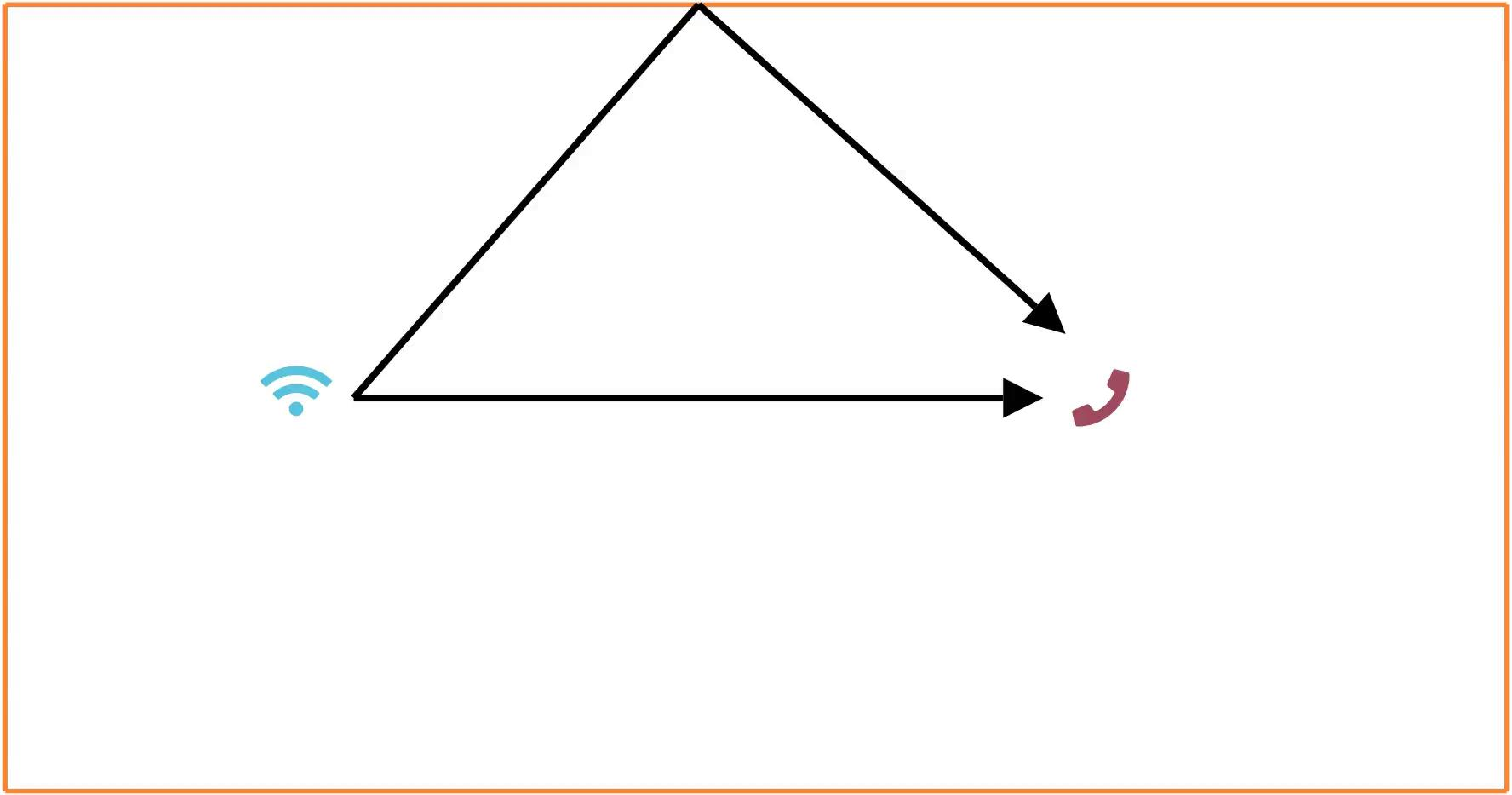
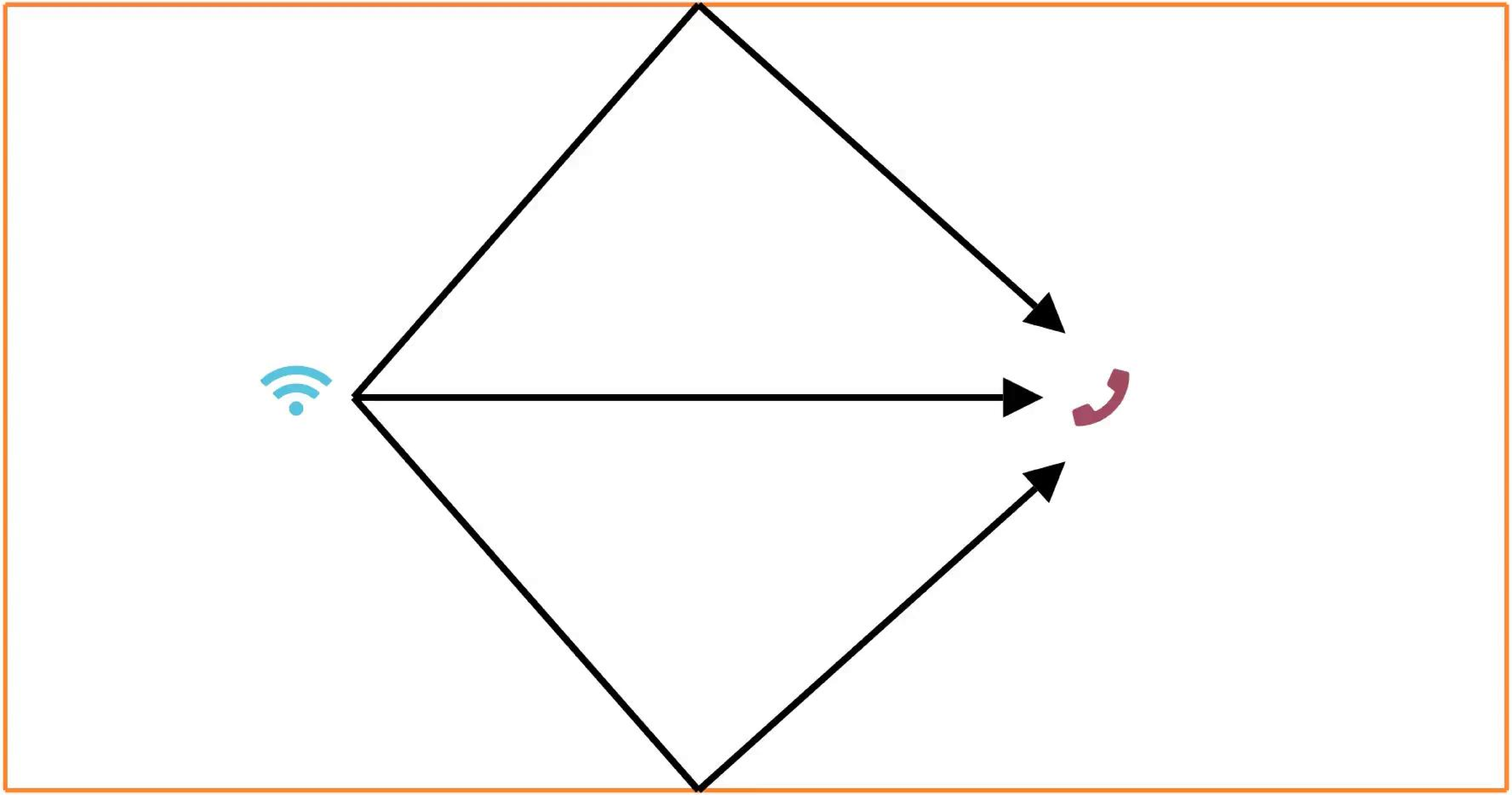
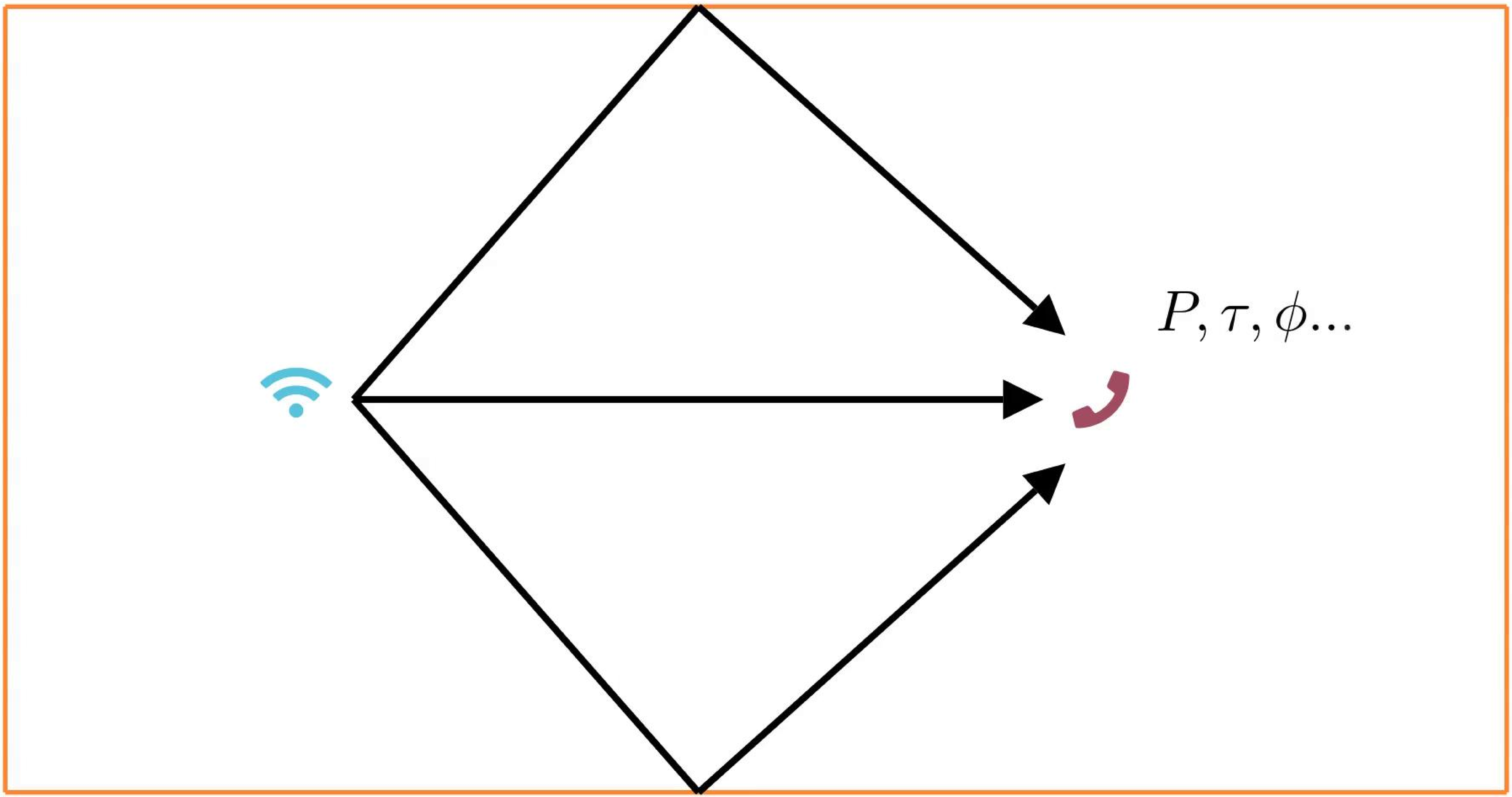
Min-Path-Tracing: A Diffraction Aware Alternative to Image Method in Ray Tracing

Jérome Eertmans






$P, \tau, \phi...$

How to find all paths?

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Multiple methods exist!

Outline:

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1. Image-based method

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2. Our method

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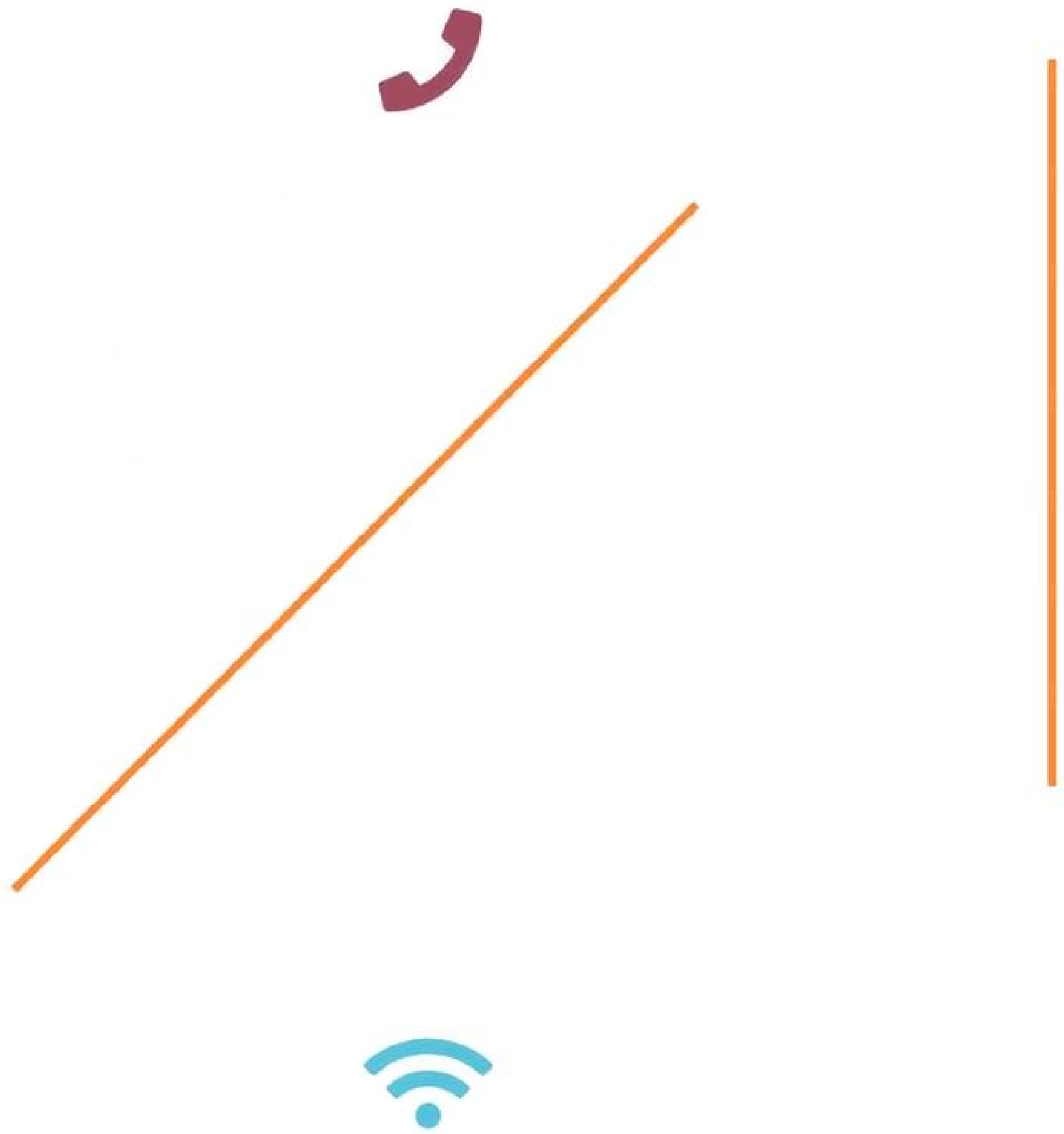
2. Our method
3. Future & Applications

1. Image-based method



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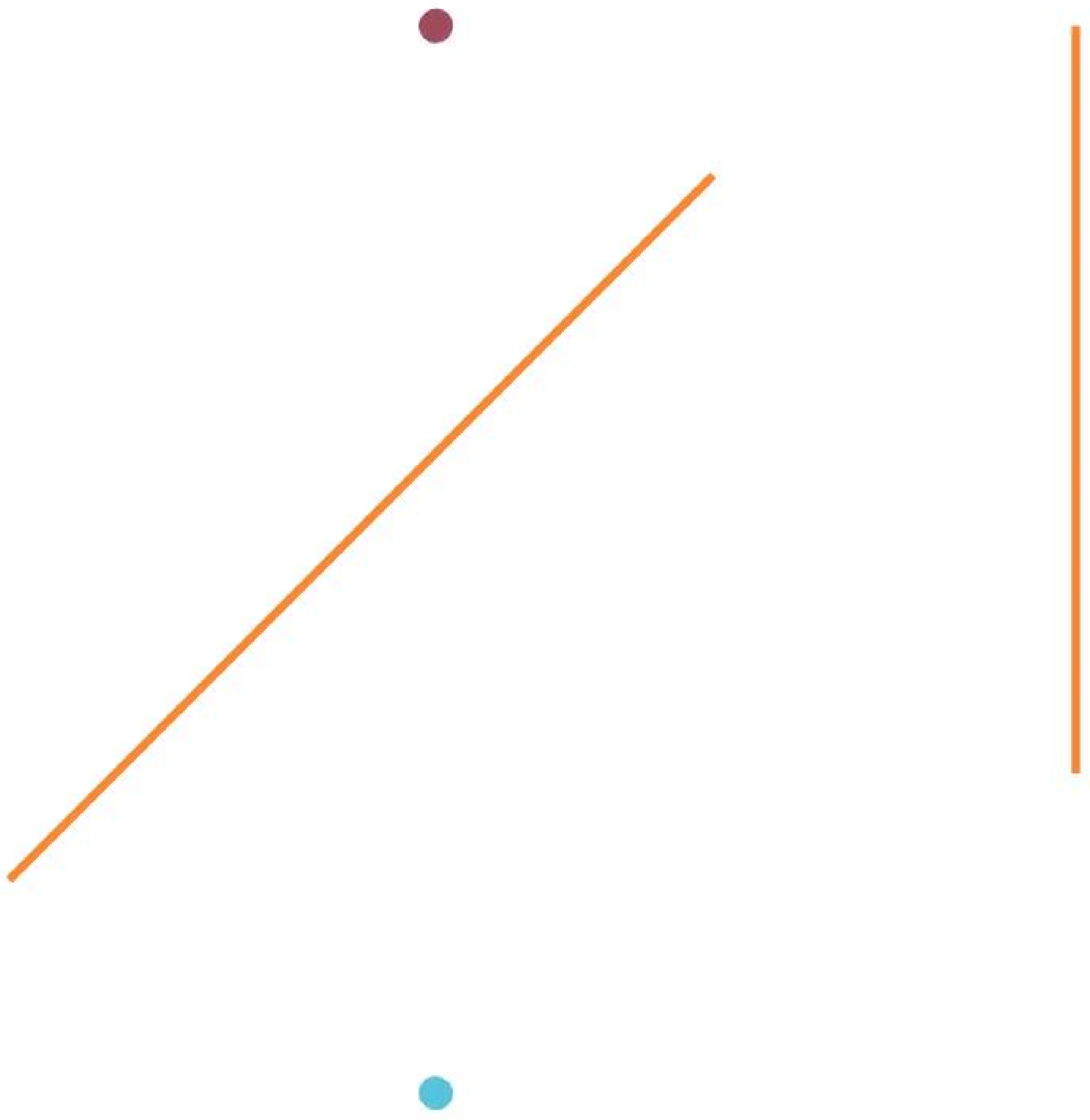

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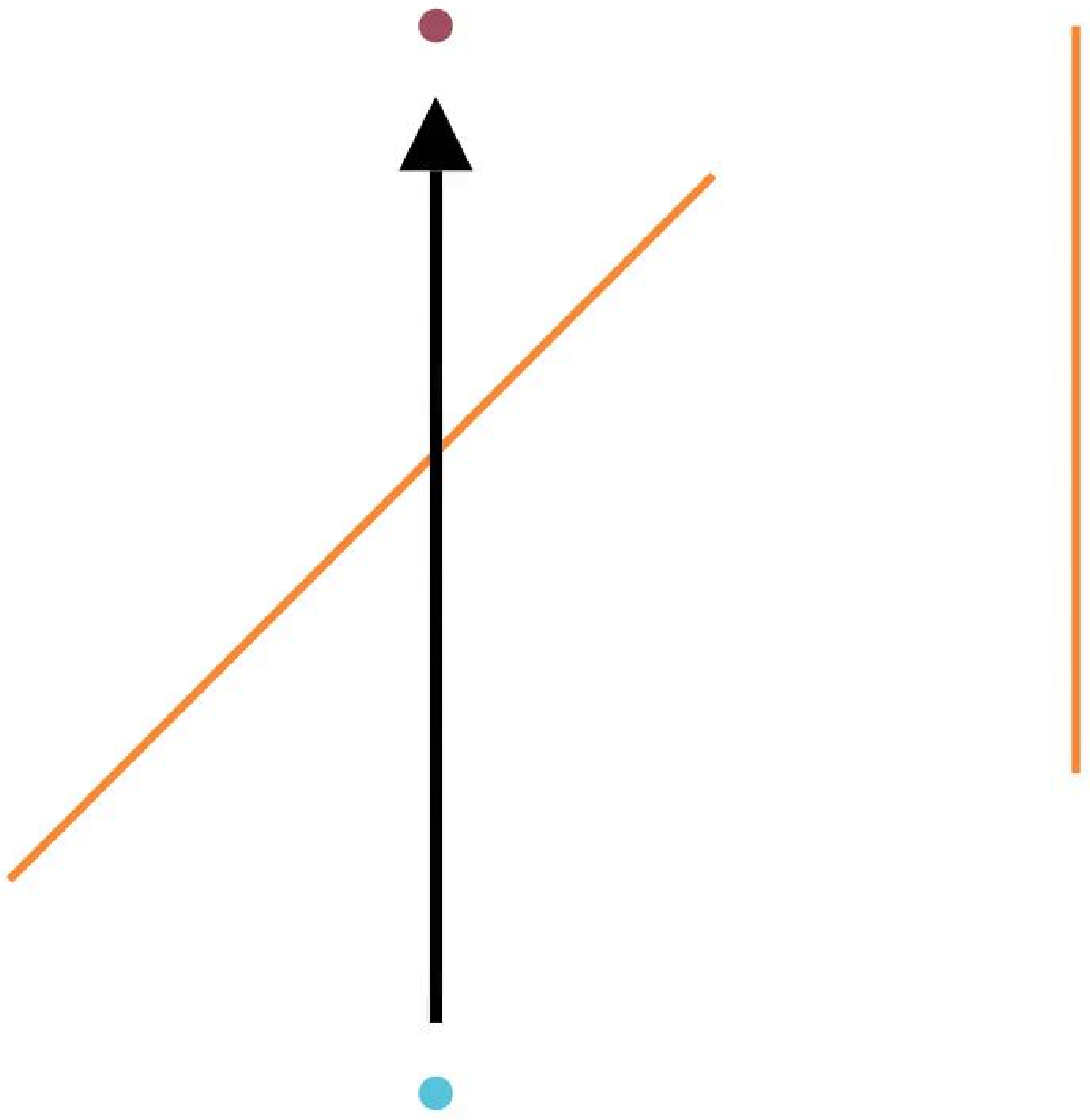

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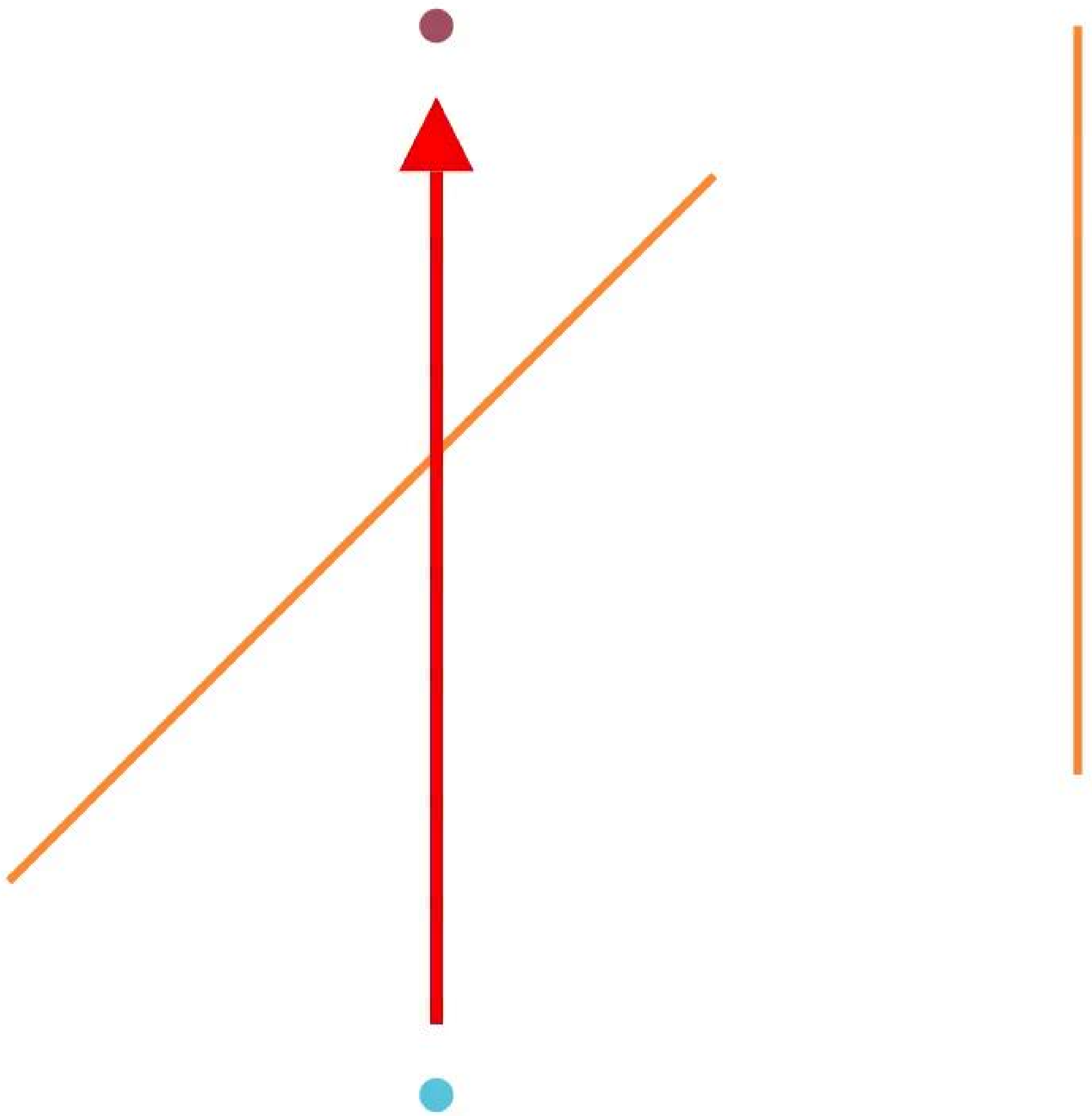

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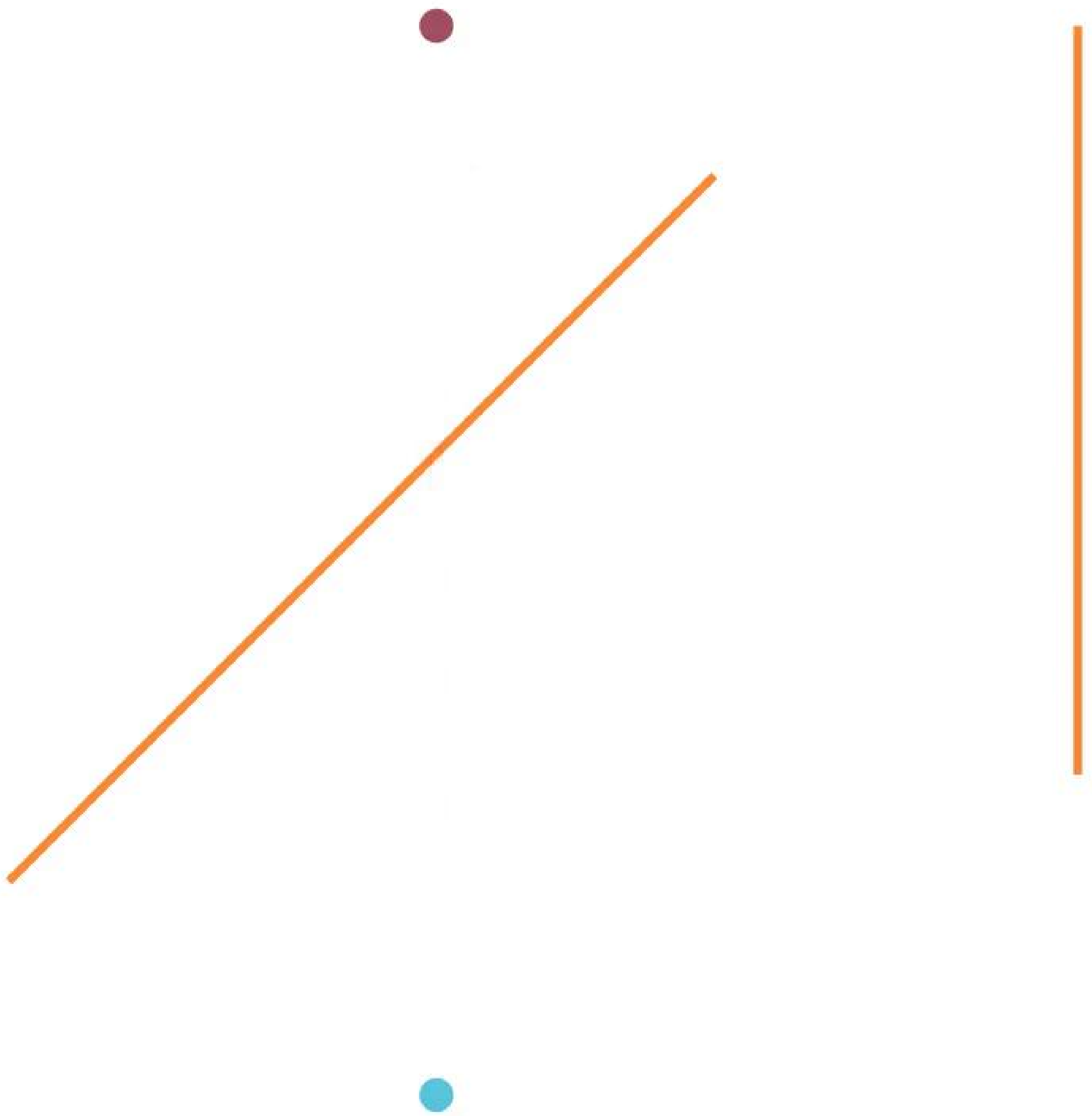

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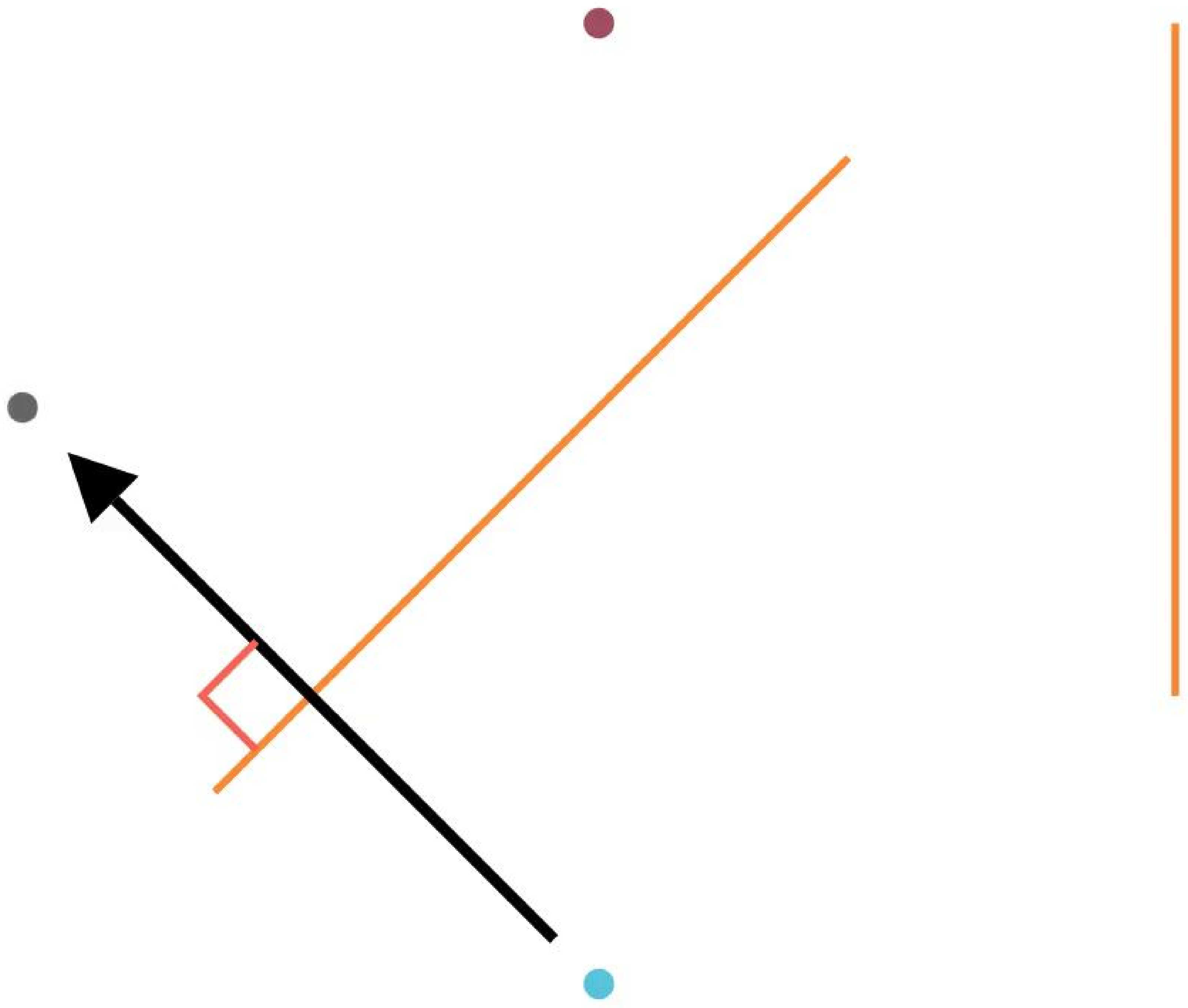

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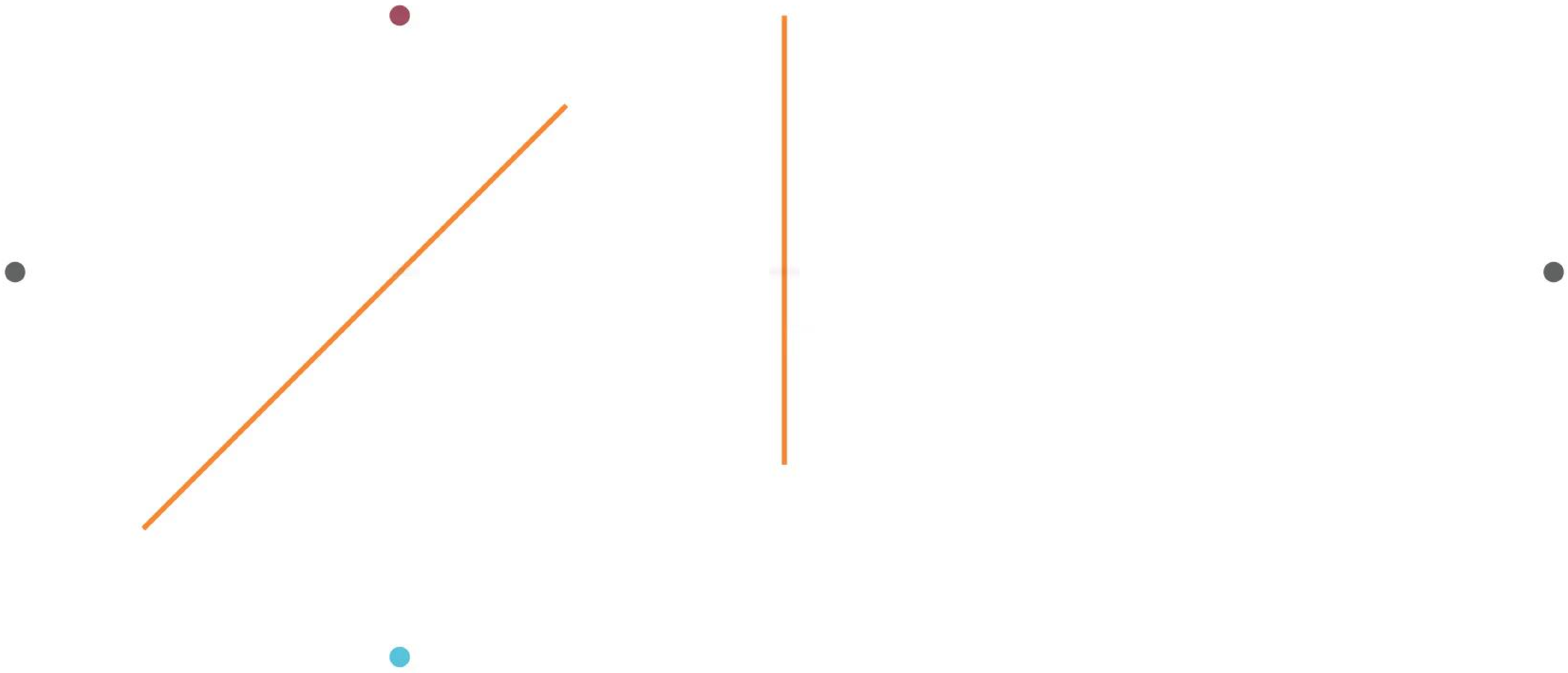

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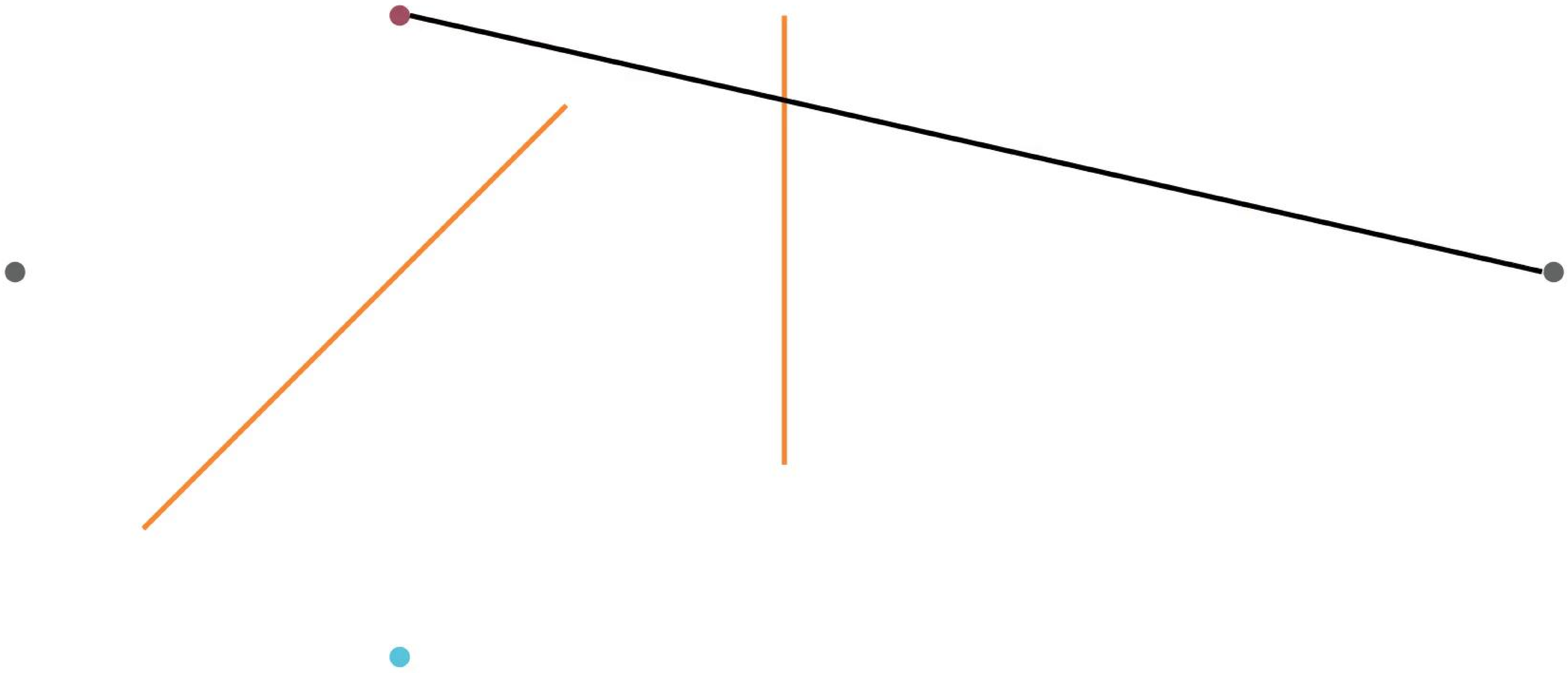

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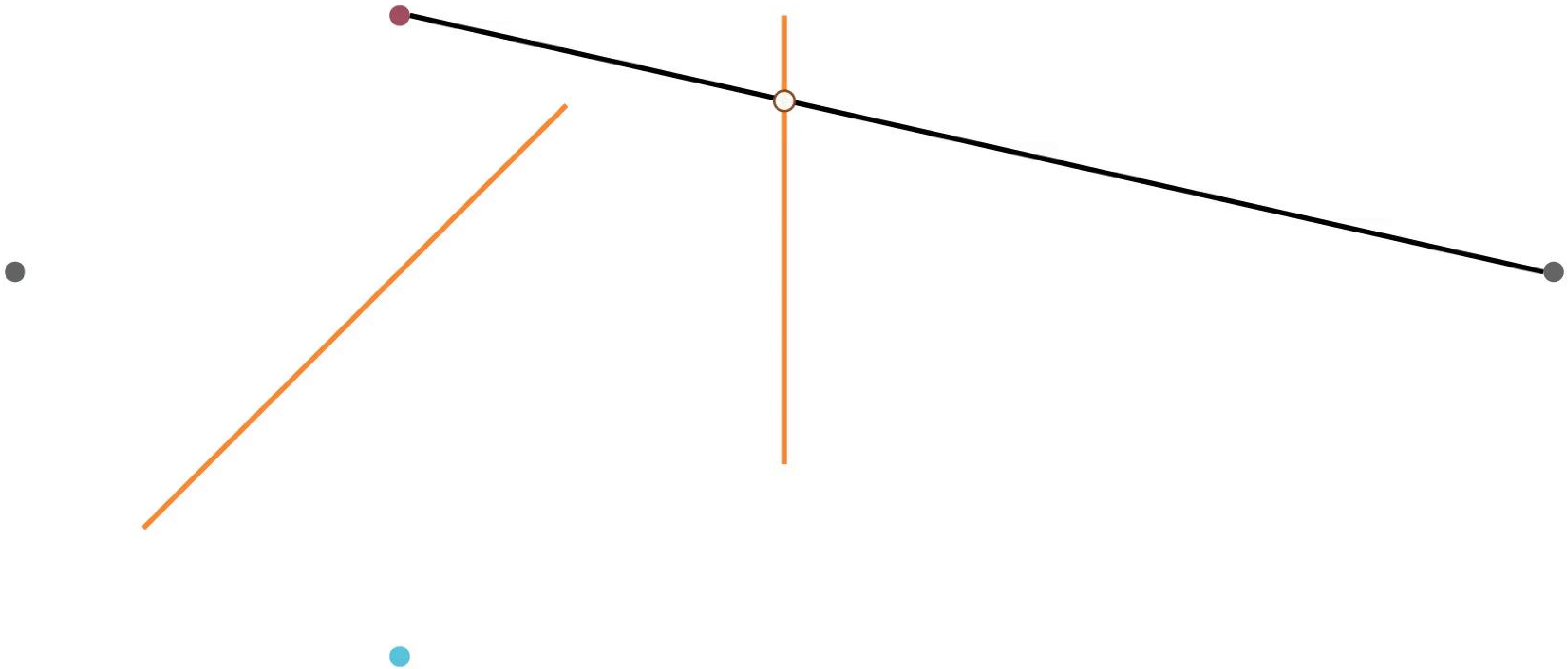

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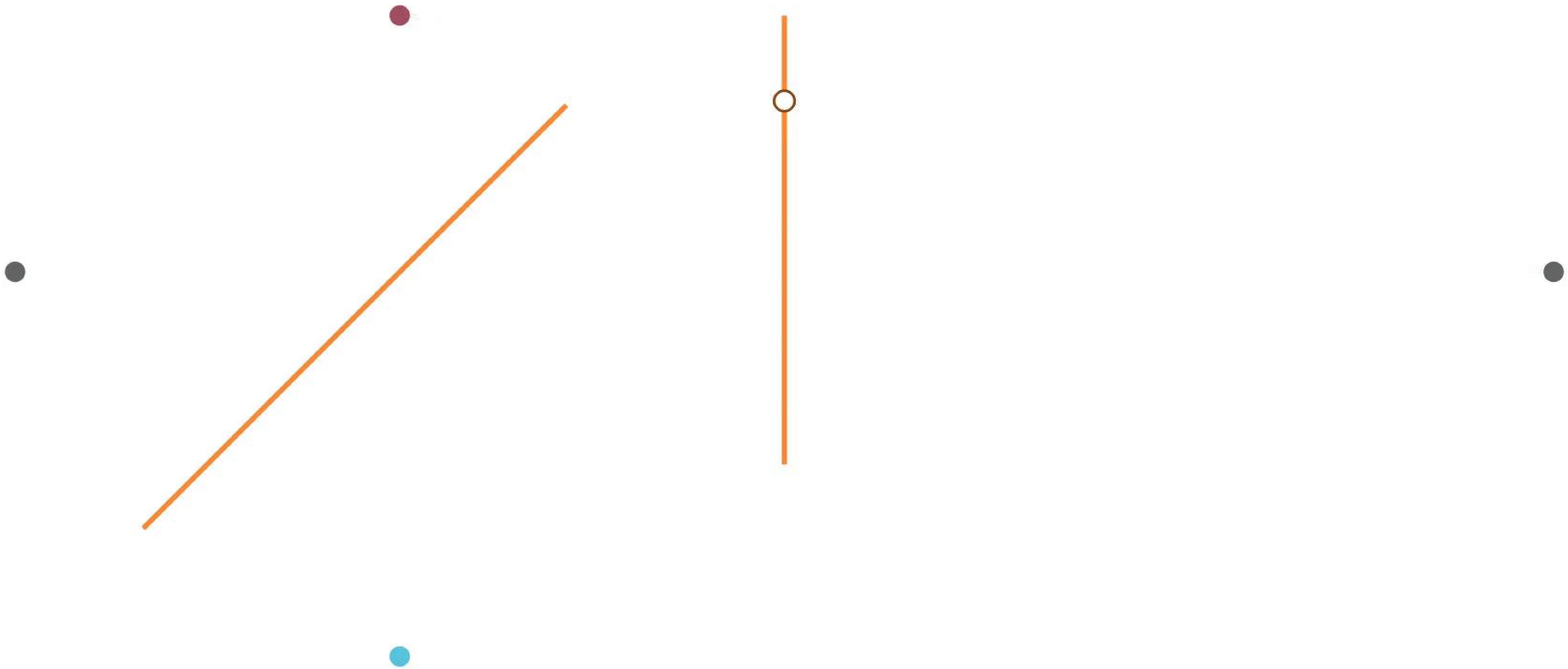

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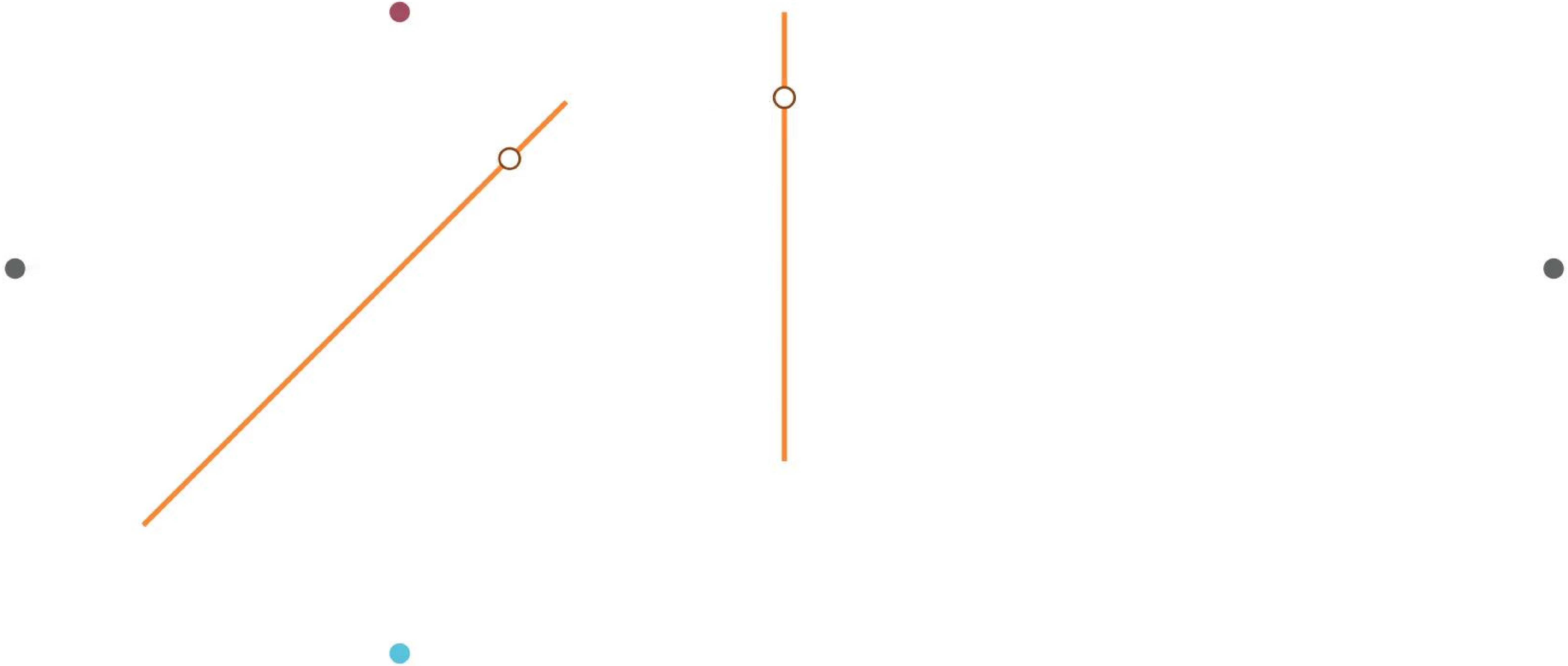

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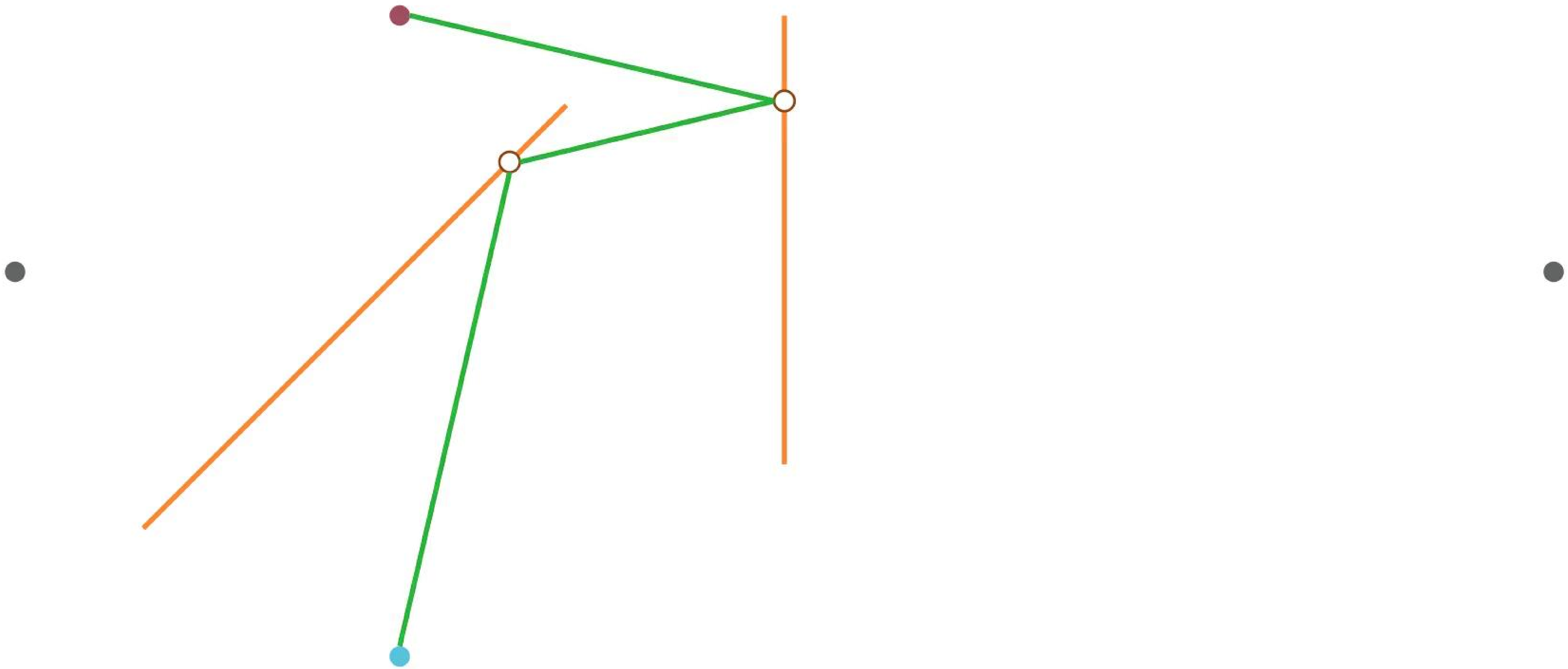

Summary:

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Pros

- Simple
- Fast - $\mathcal{O}(n)$

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Pros
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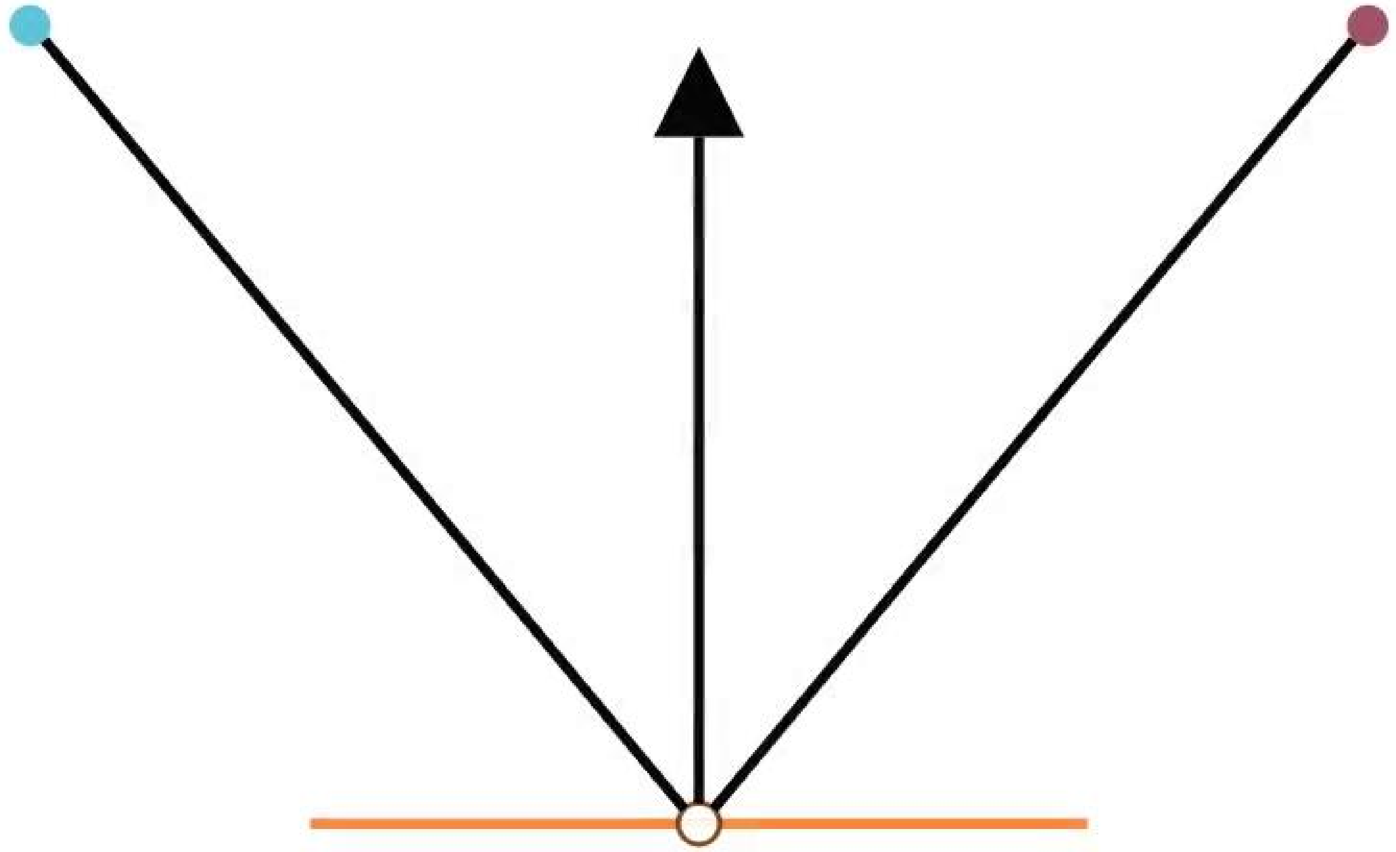
- Fast - $\mathcal{O}(n)$

Cons
- Limited to planar surfaces
- Specular reflection only

2. Our method



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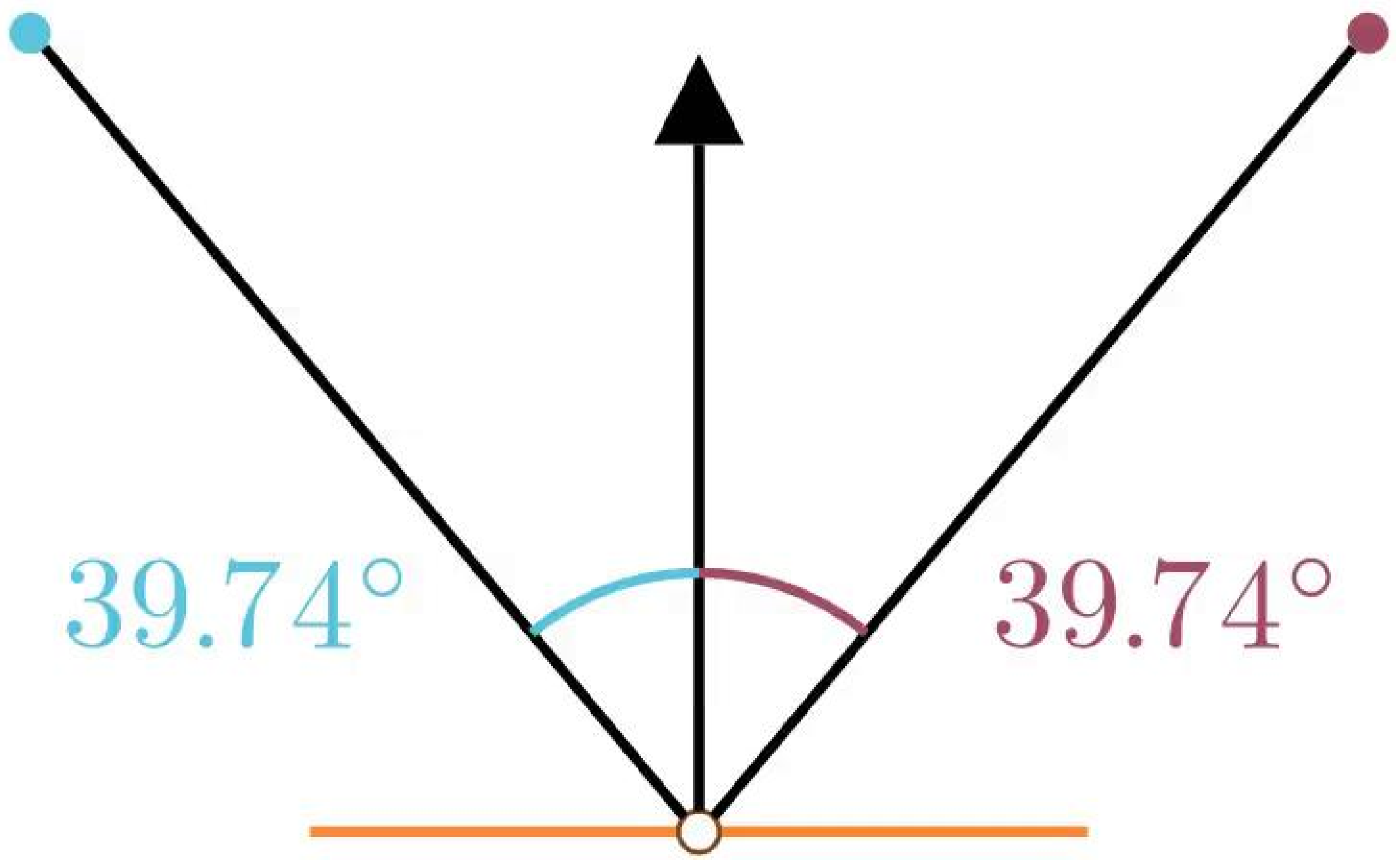

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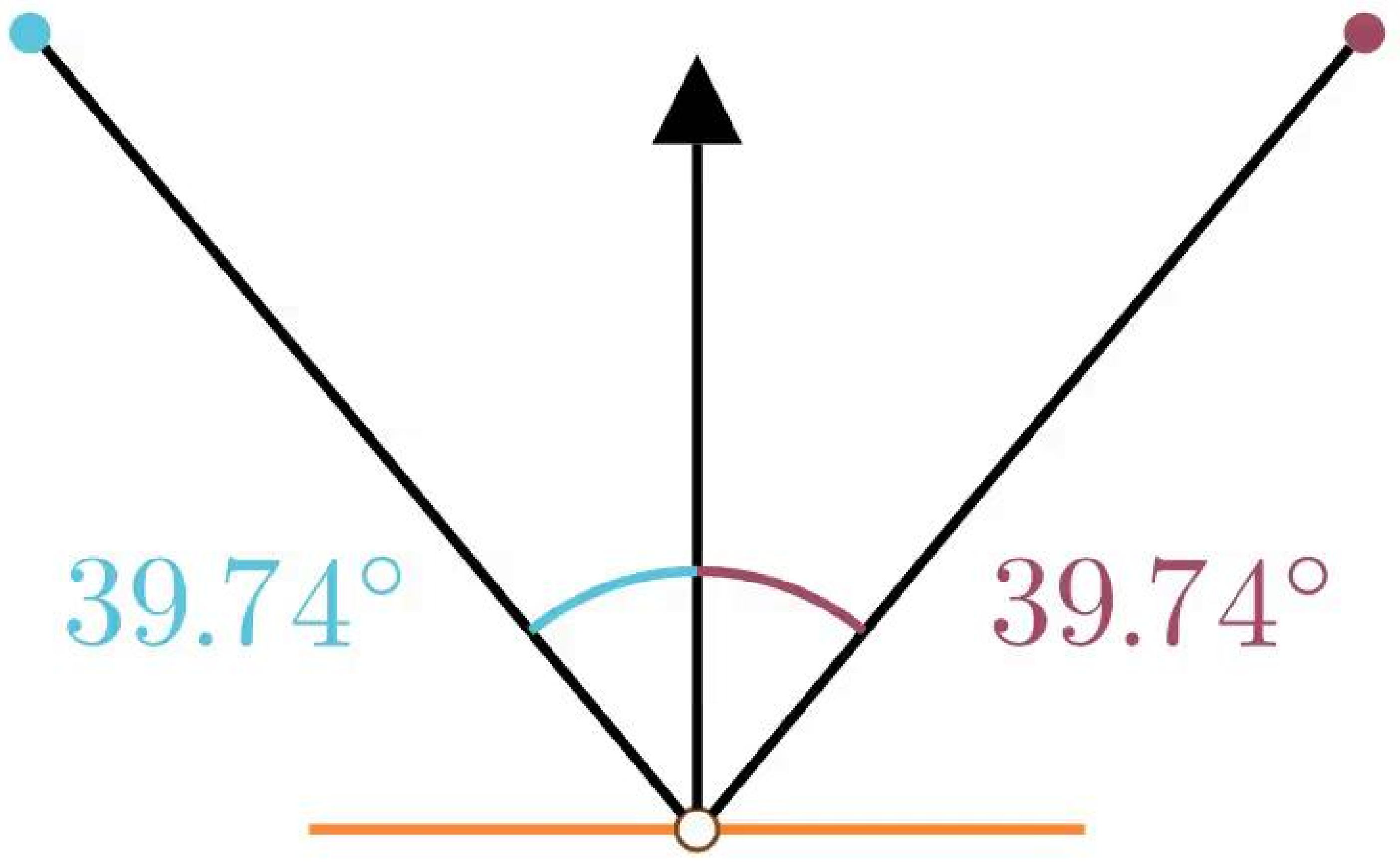

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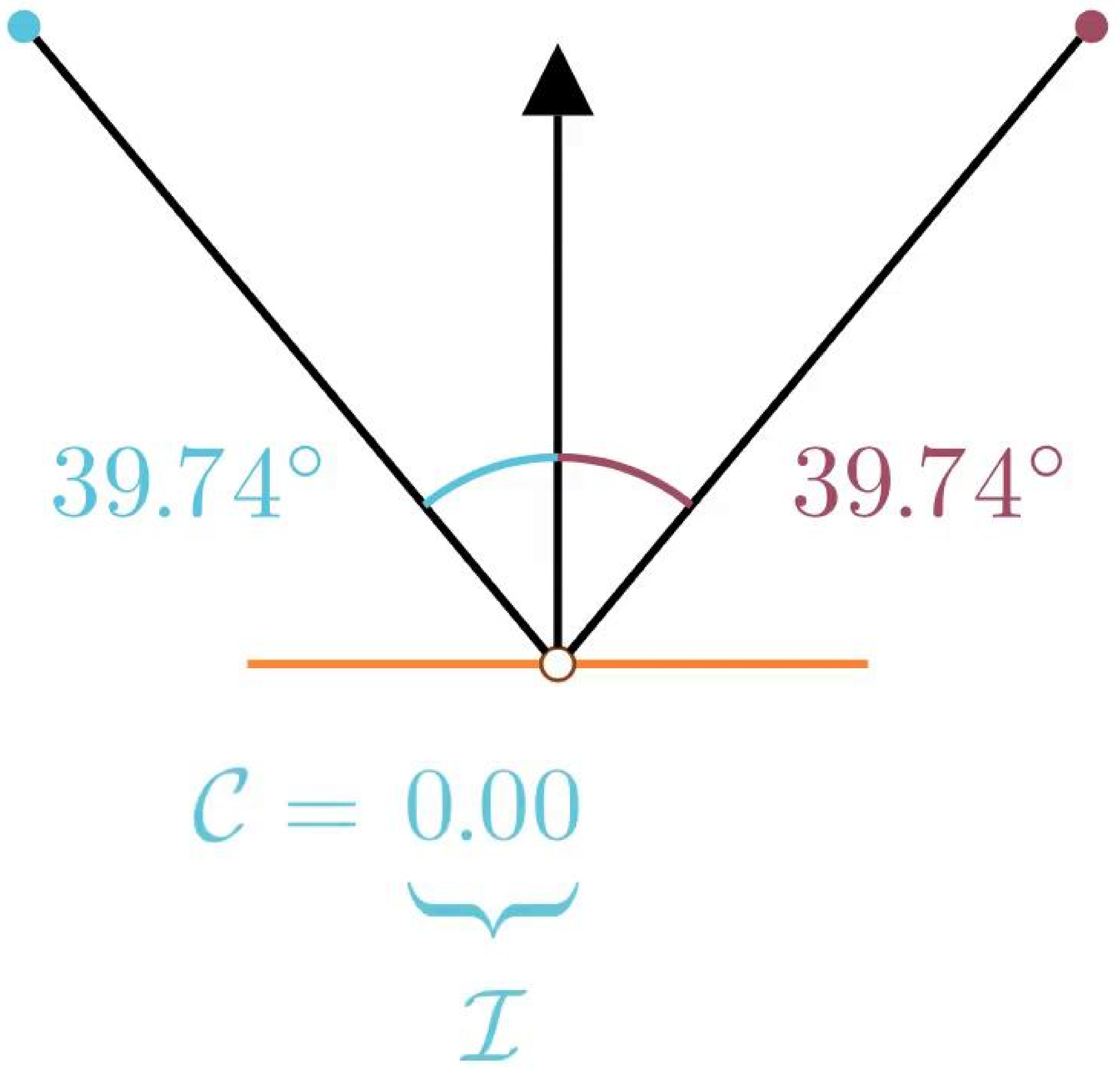

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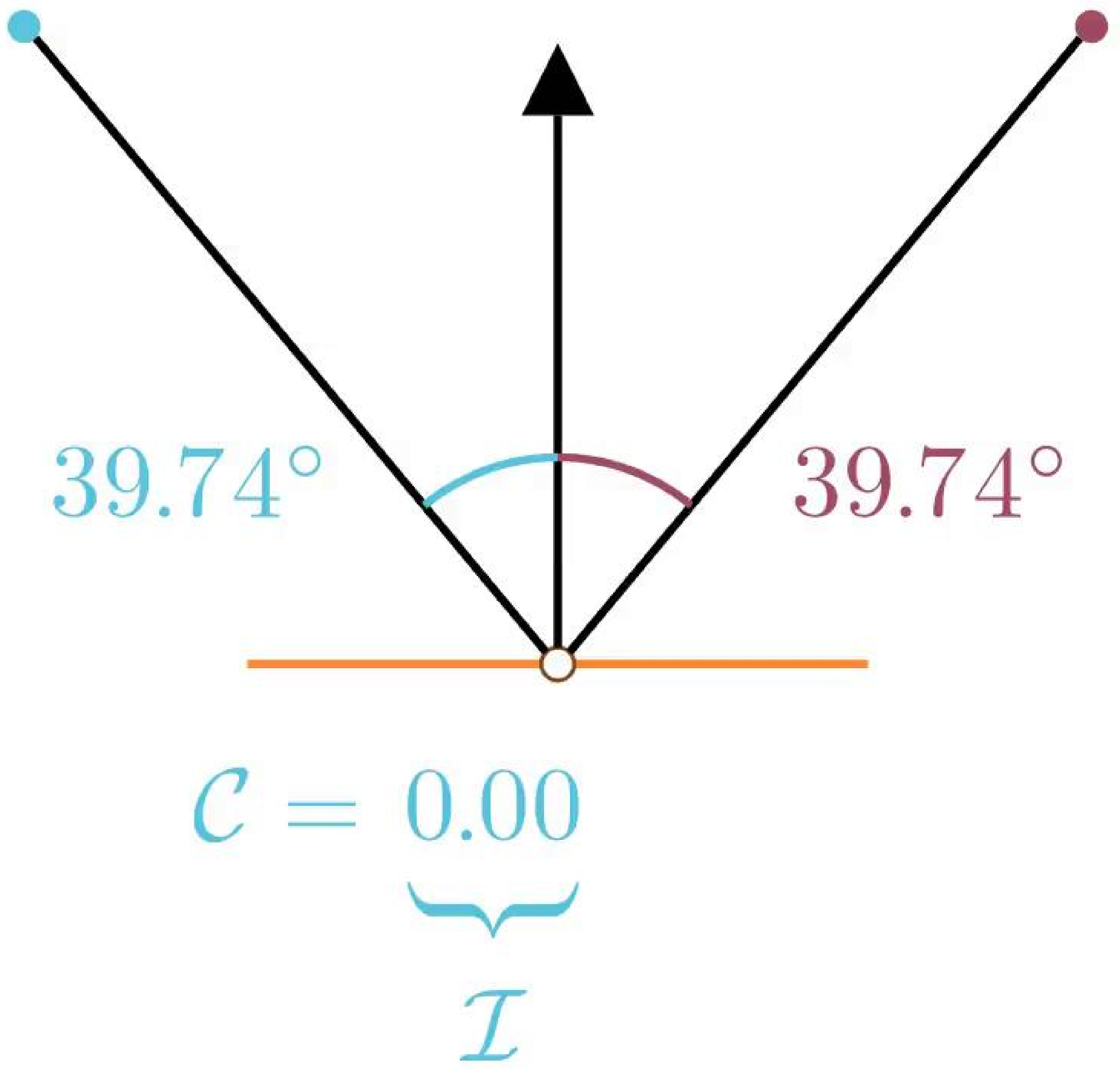

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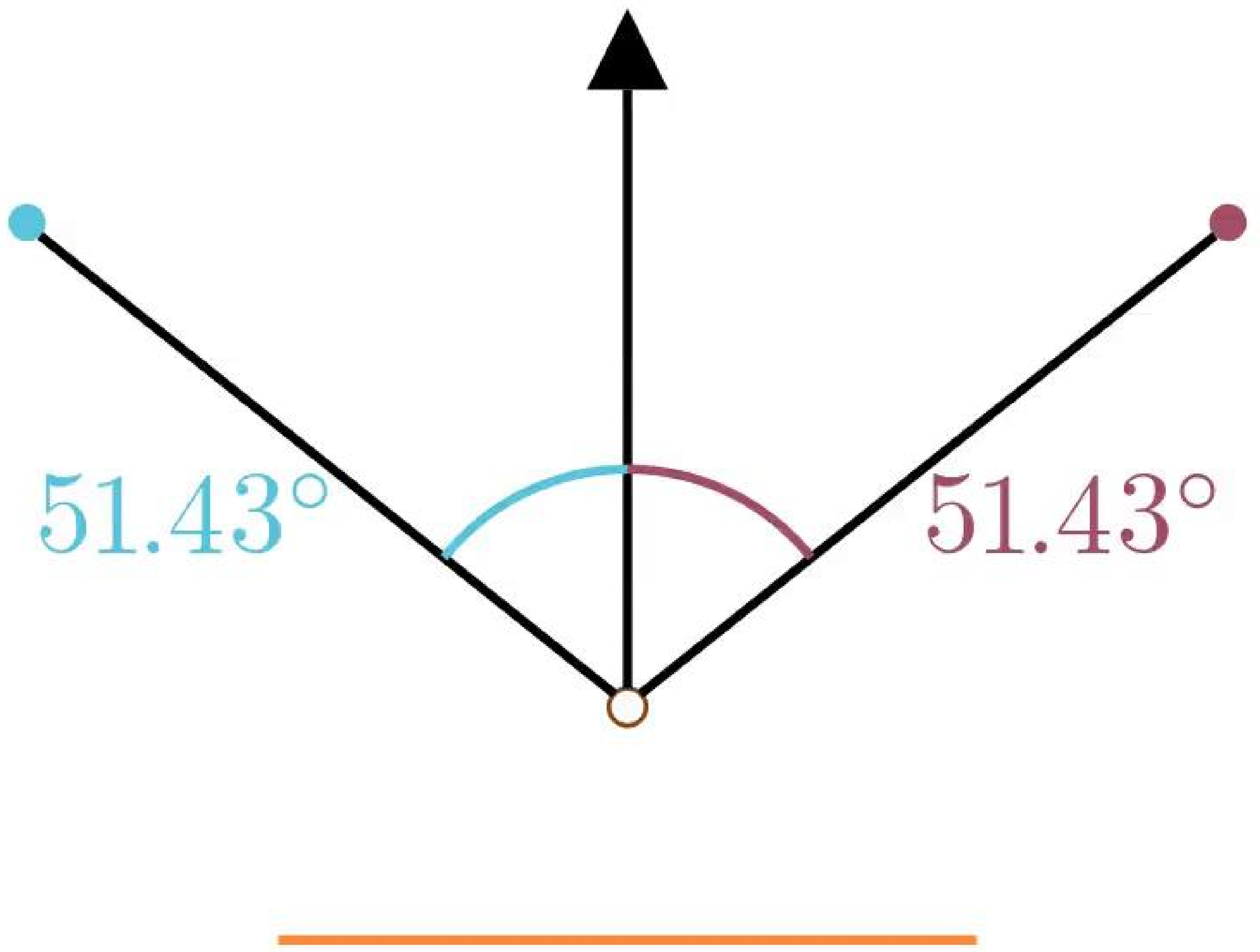

$$\mathcal{C} = \underbrace{0.00}_{\mathcal{I}}$$

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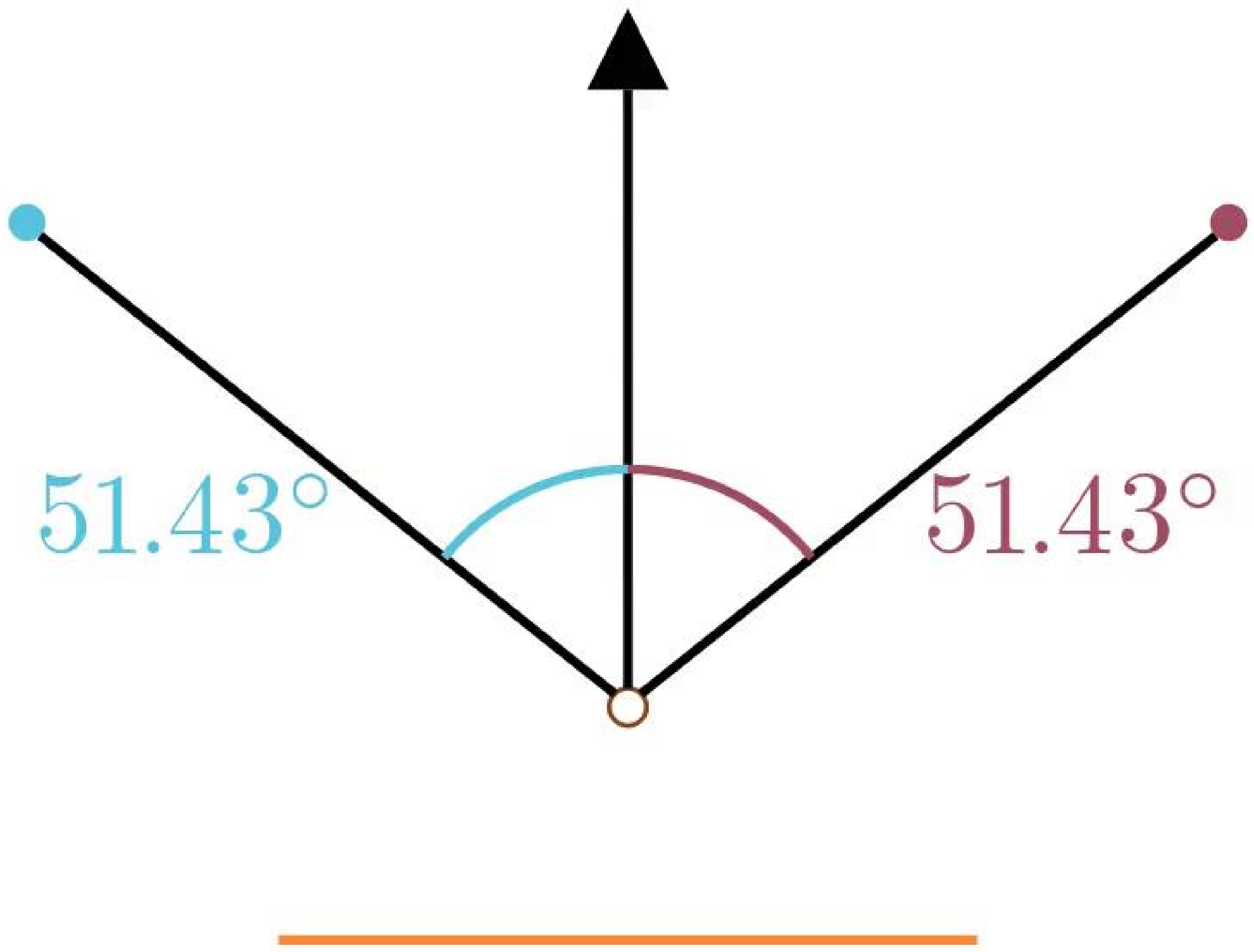

$$\mathcal{C} = \underbrace{0.00}_{\mathcal{I}} + \underbrace{1.00}_{\mathcal{F}}$$

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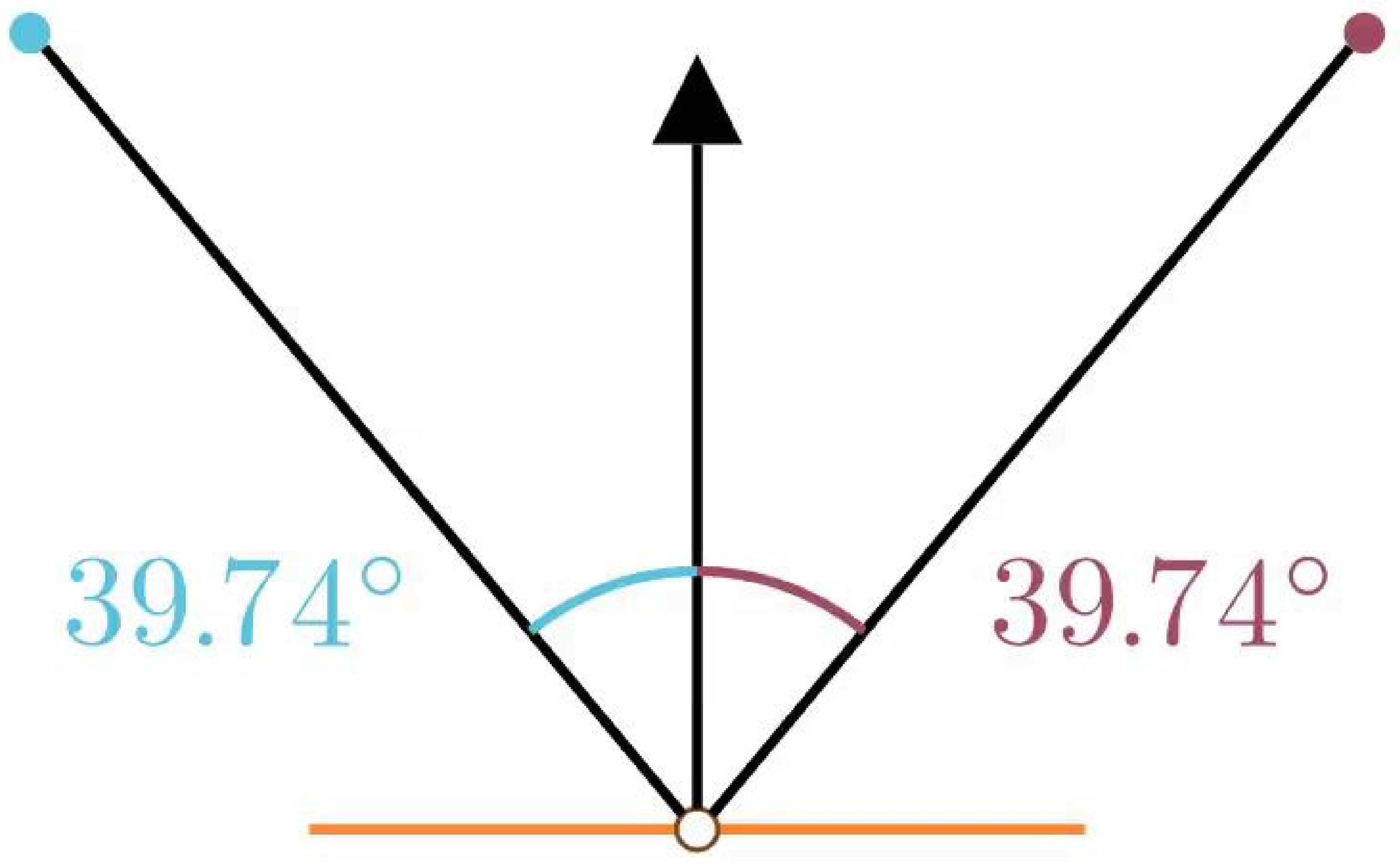

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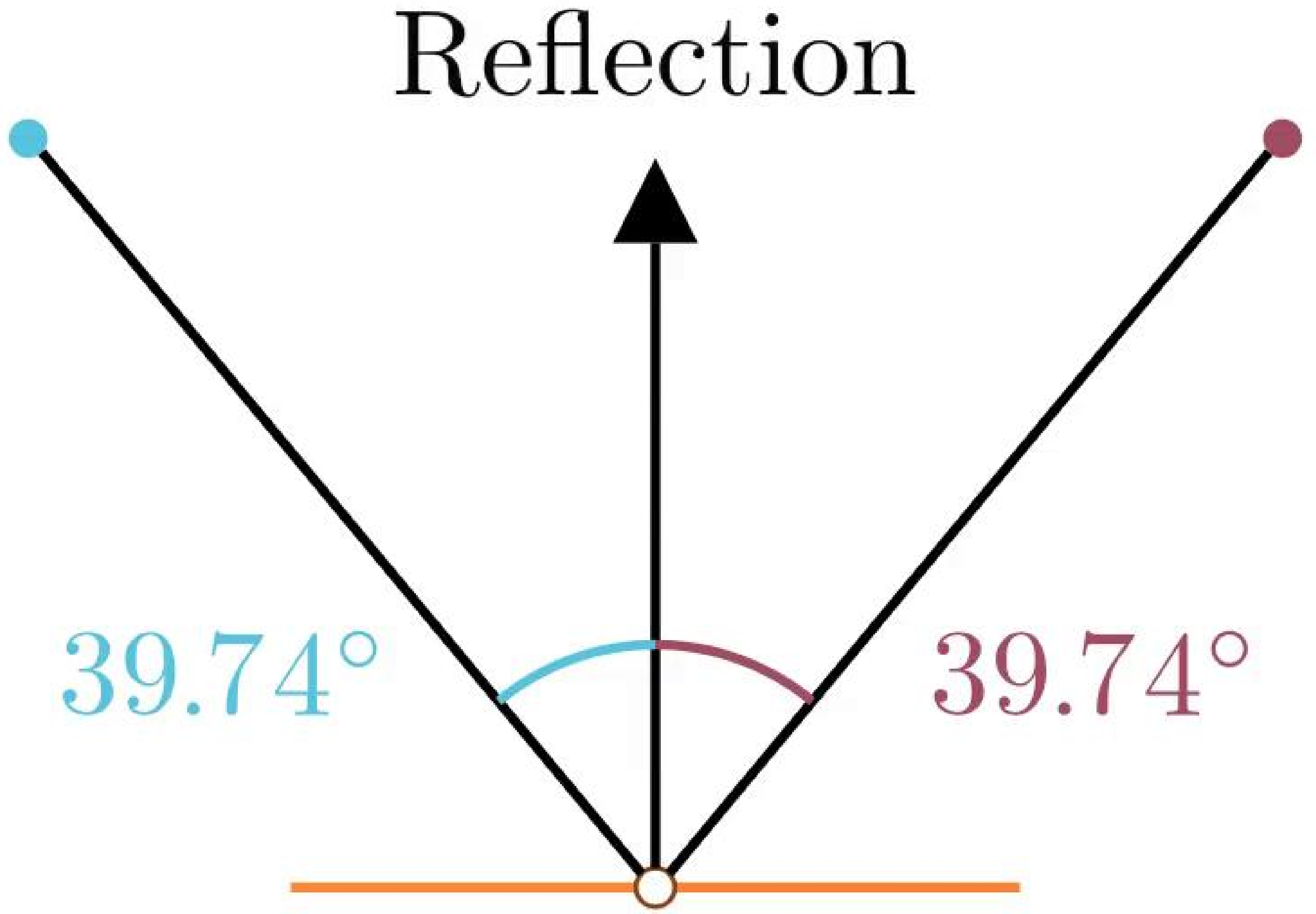
$$\mathcal{I} \sim \hat{\boldsymbol{r}} = \hat{\boldsymbol{i}} - 2\langle \hat{\boldsymbol{i}}, \hat{\boldsymbol{n}} \rangle \hat{\boldsymbol{n}}$$



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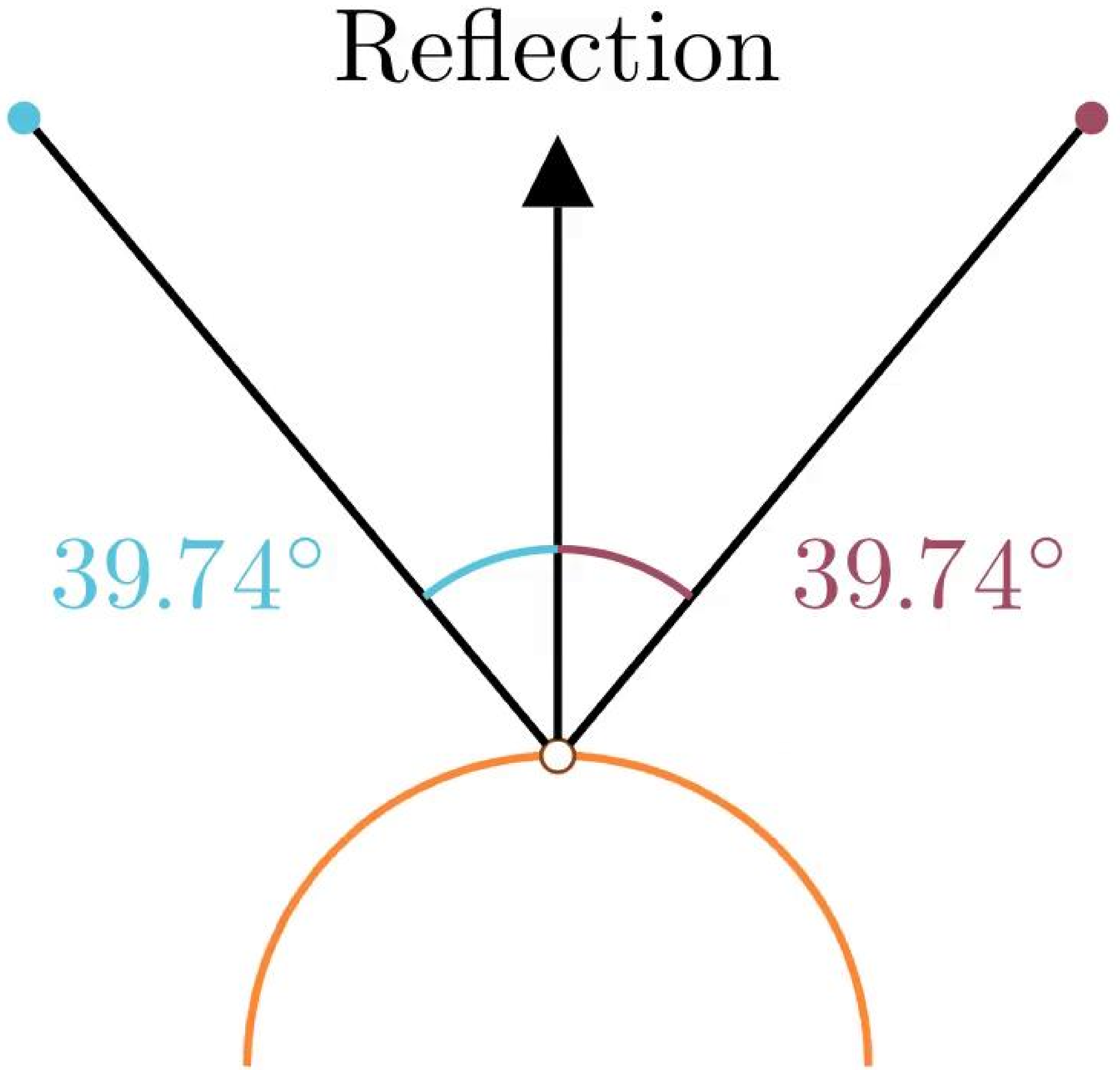

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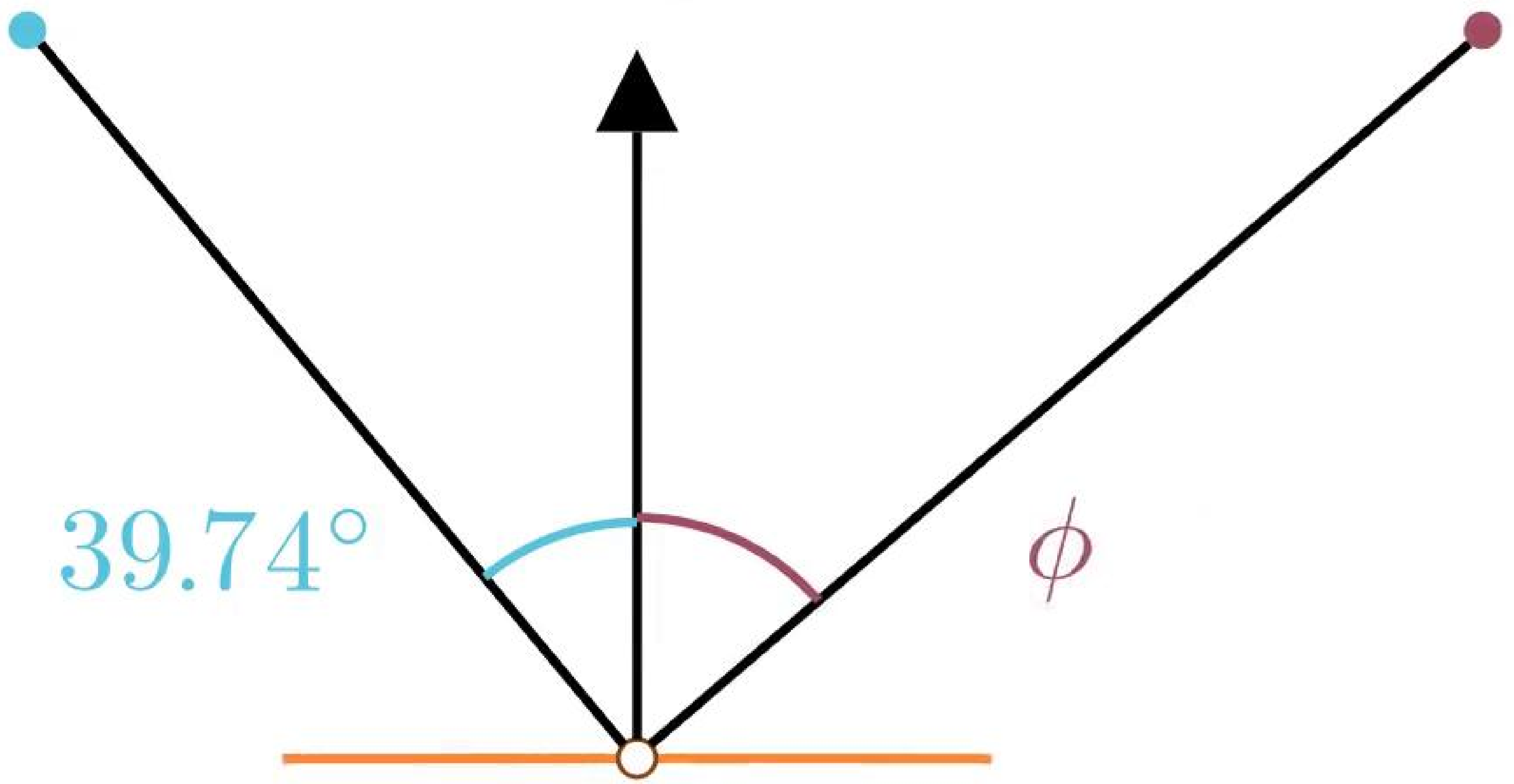
$\mathcal{I} \sim \boldsymbol{r} = f(\hat{\boldsymbol{n}}, \phi)$

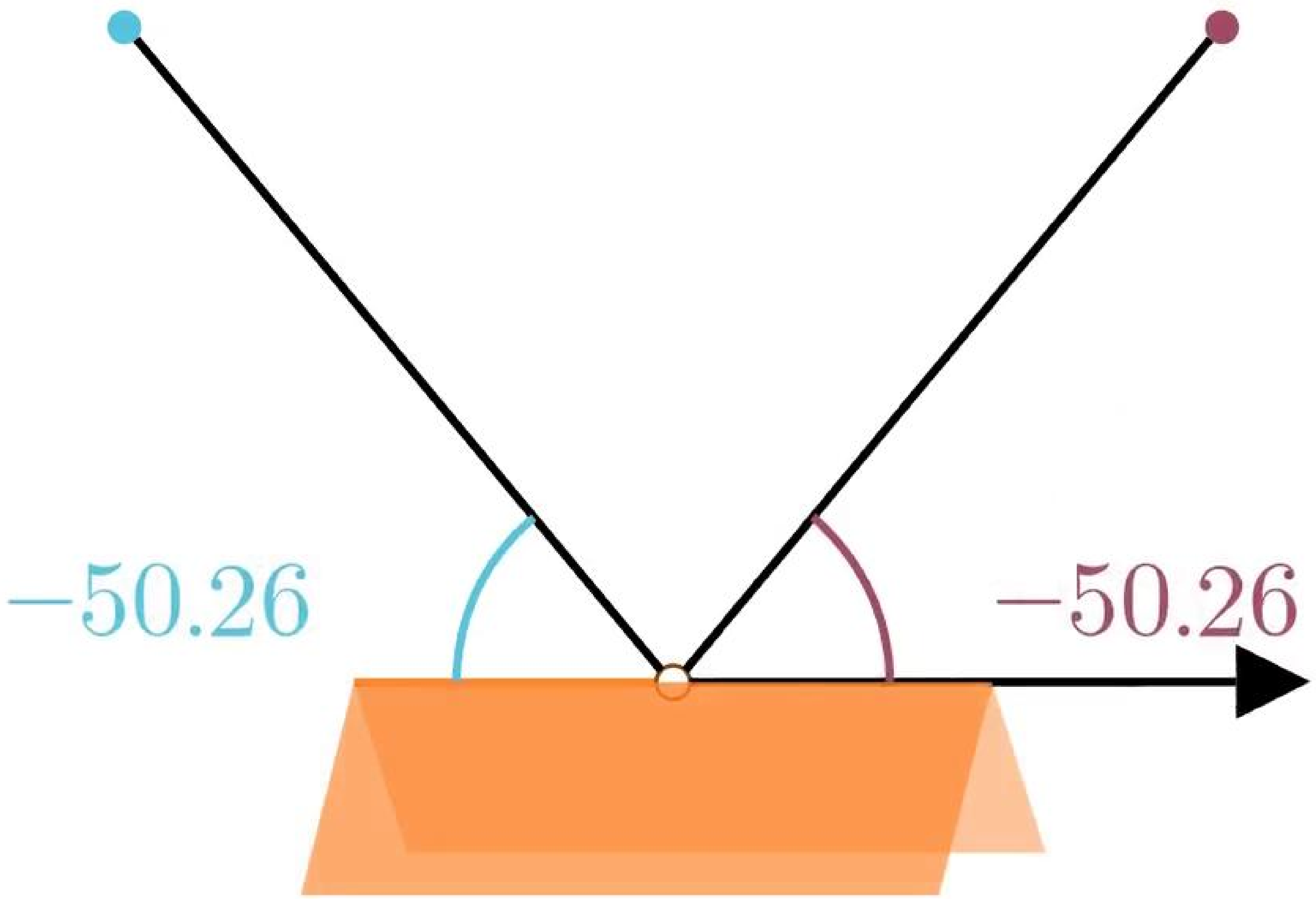
Reflection on metasurfaces



2. Our method

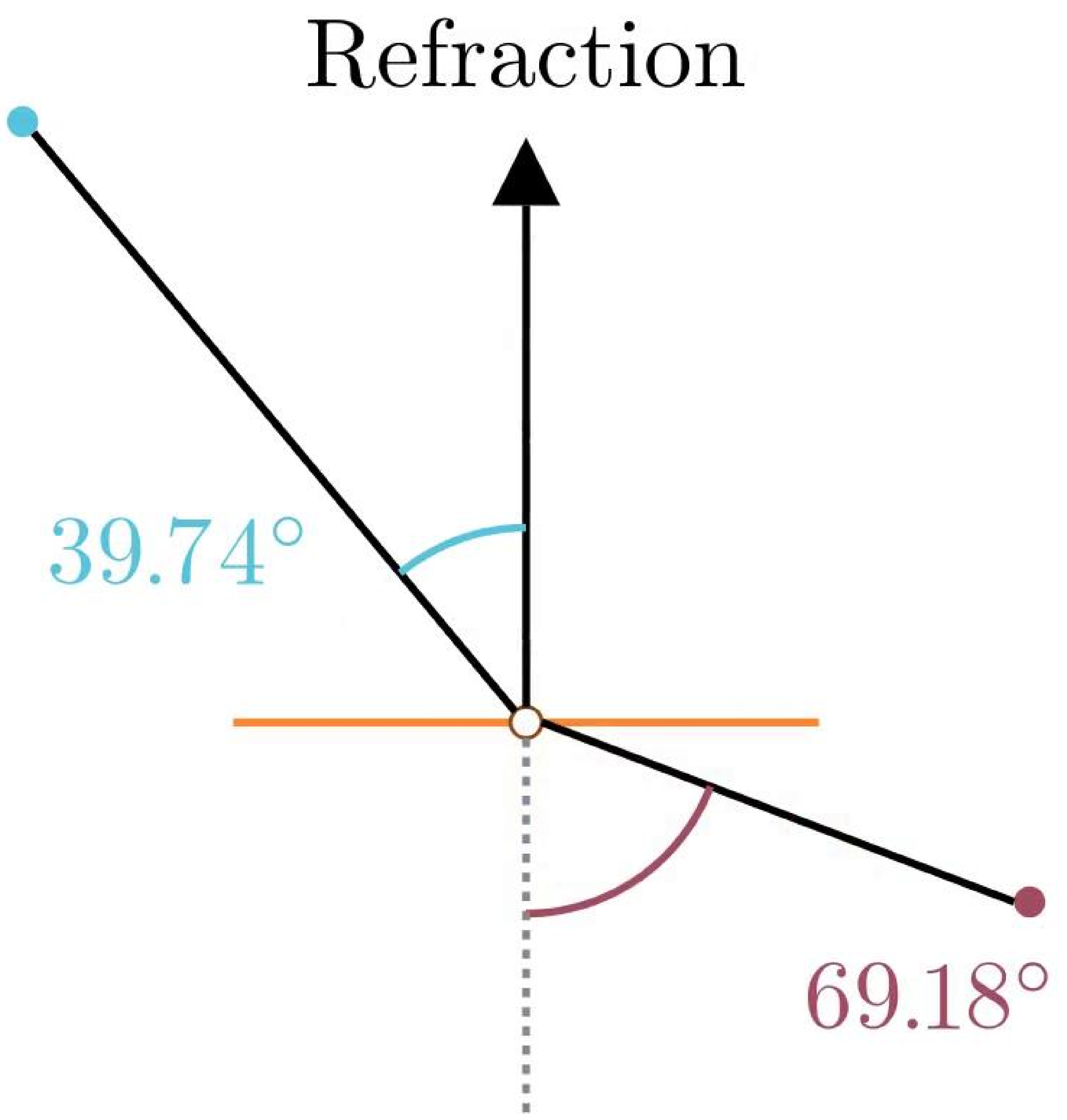
$$\mathcal{I} \sim \frac{\langle \boldsymbol{i}, \hat{\boldsymbol{e}} \rangle}{\|\boldsymbol{i}\|} = \frac{\langle \boldsymbol{d}, \hat{\boldsymbol{e}} \rangle}{\|\boldsymbol{d}\|}$$

Diffraction



2. Our method

$$\mathcal{I} \sim v_1 \sin(\theta_2) = v_2 \sin(\theta_1)$$



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$$\underset{\boldsymbol{\mathcal{X}} \in \mathbb{R}^{n_t}}{\text{minimize}} \; \mathcal{C}(\boldsymbol{\mathcal{X}}) := \|\mathcal{I}(\boldsymbol{\mathcal{X}})\|^2 + \|\mathcal{F}(\boldsymbol{\mathcal{X}})\|^2$$

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where n_t is the total number of unknowns

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$$\mathcal{C}(\boldsymbol{\mathcal{X}}) = 0$$

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$$\underset{\boldsymbol{\mathcal{X}} \in \mathbb{R}^{n_t}}{\text{minimize}}\ \mathcal{C}(\boldsymbol{\mathcal{X}}) := \|\mathcal{I}(\boldsymbol{\mathcal{X}})\|^2 + \|\mathcal{F}(\boldsymbol{\mathcal{X}})\|^2$$

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$$\mathcal{C}(\boldsymbol{\mathcal{X}}) \leq \epsilon$$

2. Our method

If we know a mapping s.t. $(x_k, y_k) \leftrightarrow t_k$

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If we know a mapping s.t. $(x_k, y_k) \leftrightarrow t_k$

$$\underset{\boldsymbol{\mathcal{T}} \in \mathbb{R}^{n_r}}{\text{minimize}}\ \mathcal{C}(\boldsymbol{\mathcal{X}}(\boldsymbol{\mathcal{T}})) := \|\mathcal{I}(\boldsymbol{\mathcal{X}}(\boldsymbol{\mathcal{T}}))\|^2$$

where n_r is the total number of (2d) reflections

$$\mathcal{C}(\boldsymbol{\mathcal{X}}(\boldsymbol{\mathcal{T}})) \leq \epsilon$$

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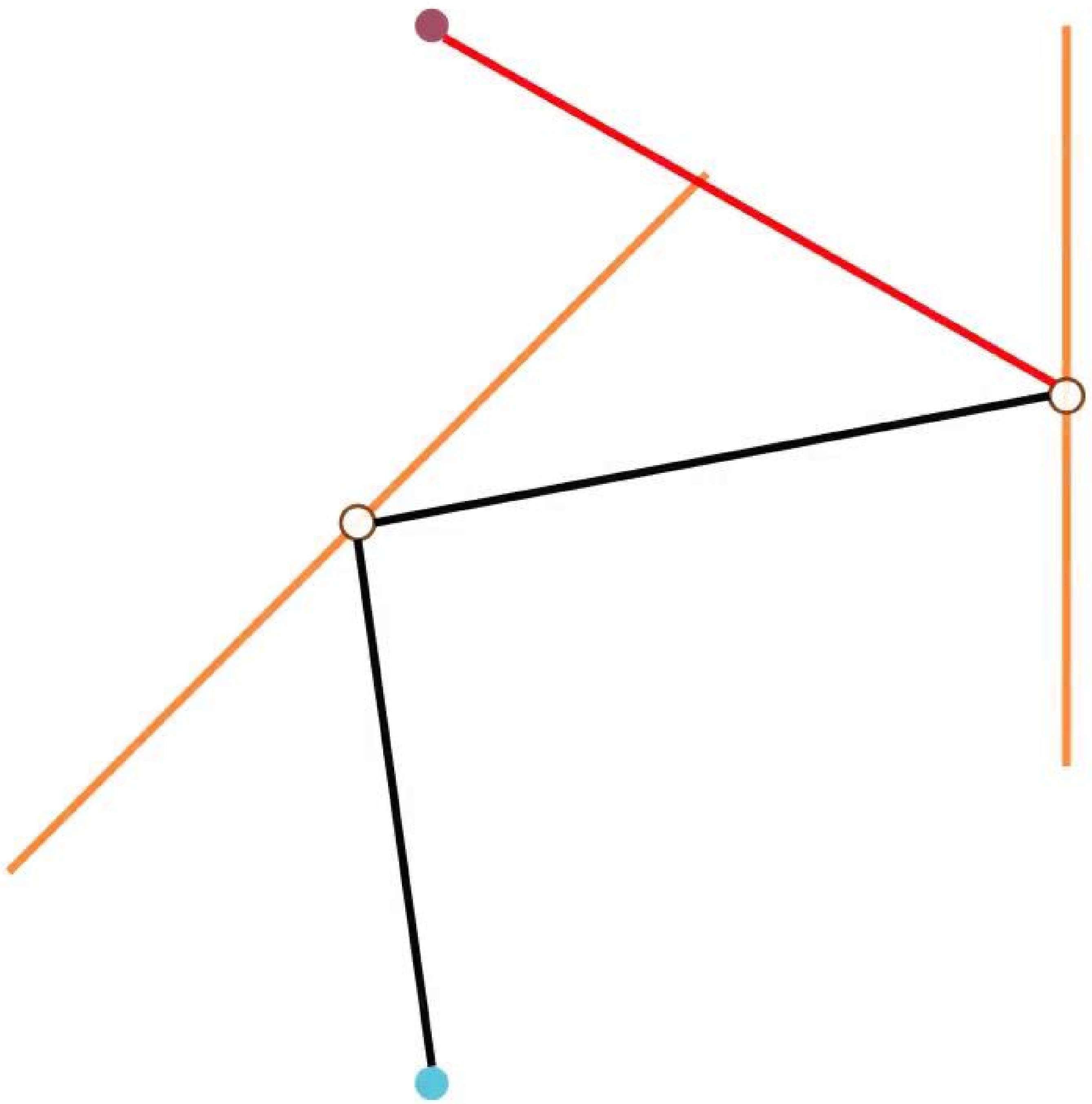

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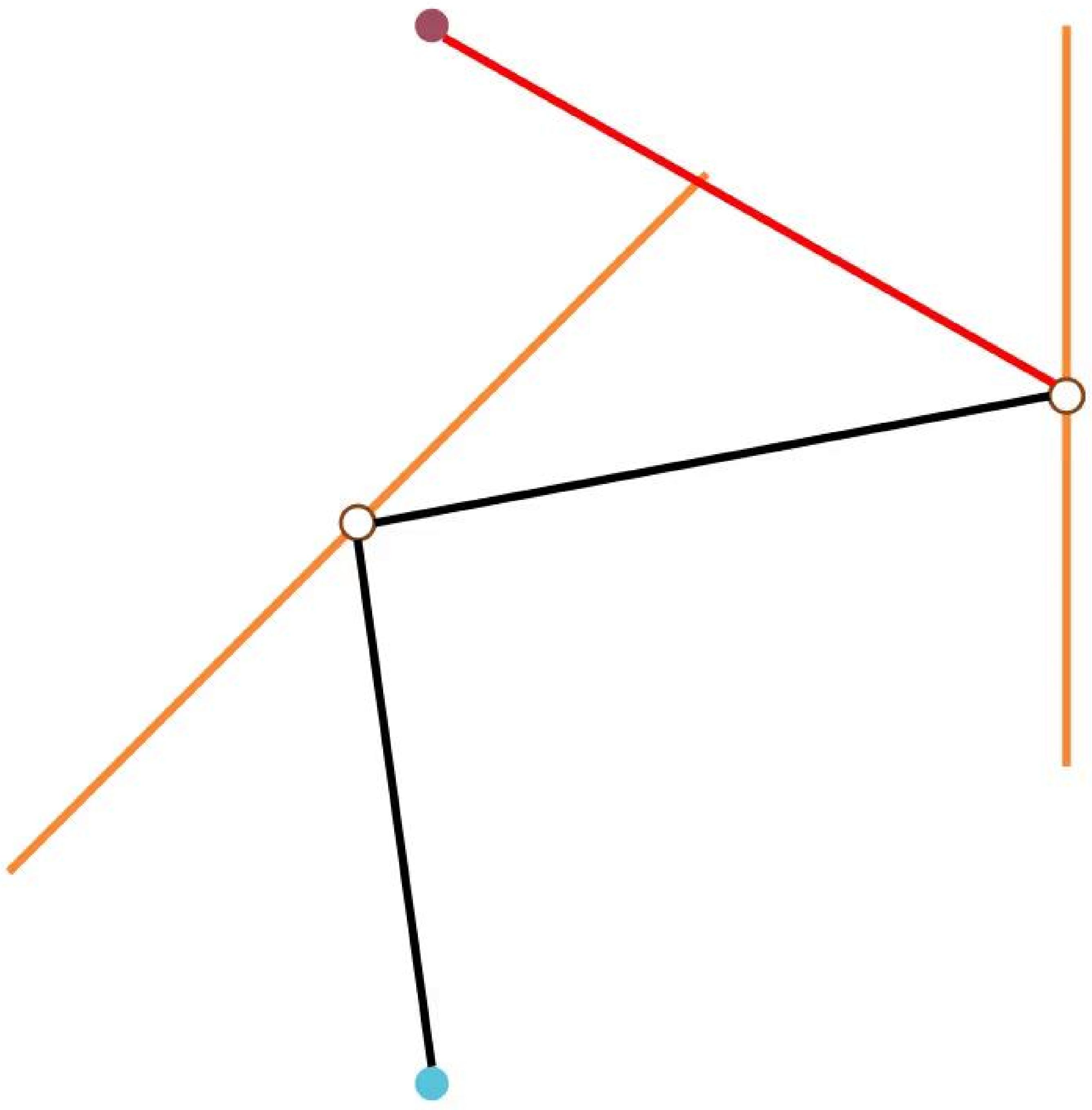

$$\mathcal{C} = \|[\mathcal{I}_1(t_1, t_2); \mathcal{I}_2(t_1, t_2)]\|^2$$

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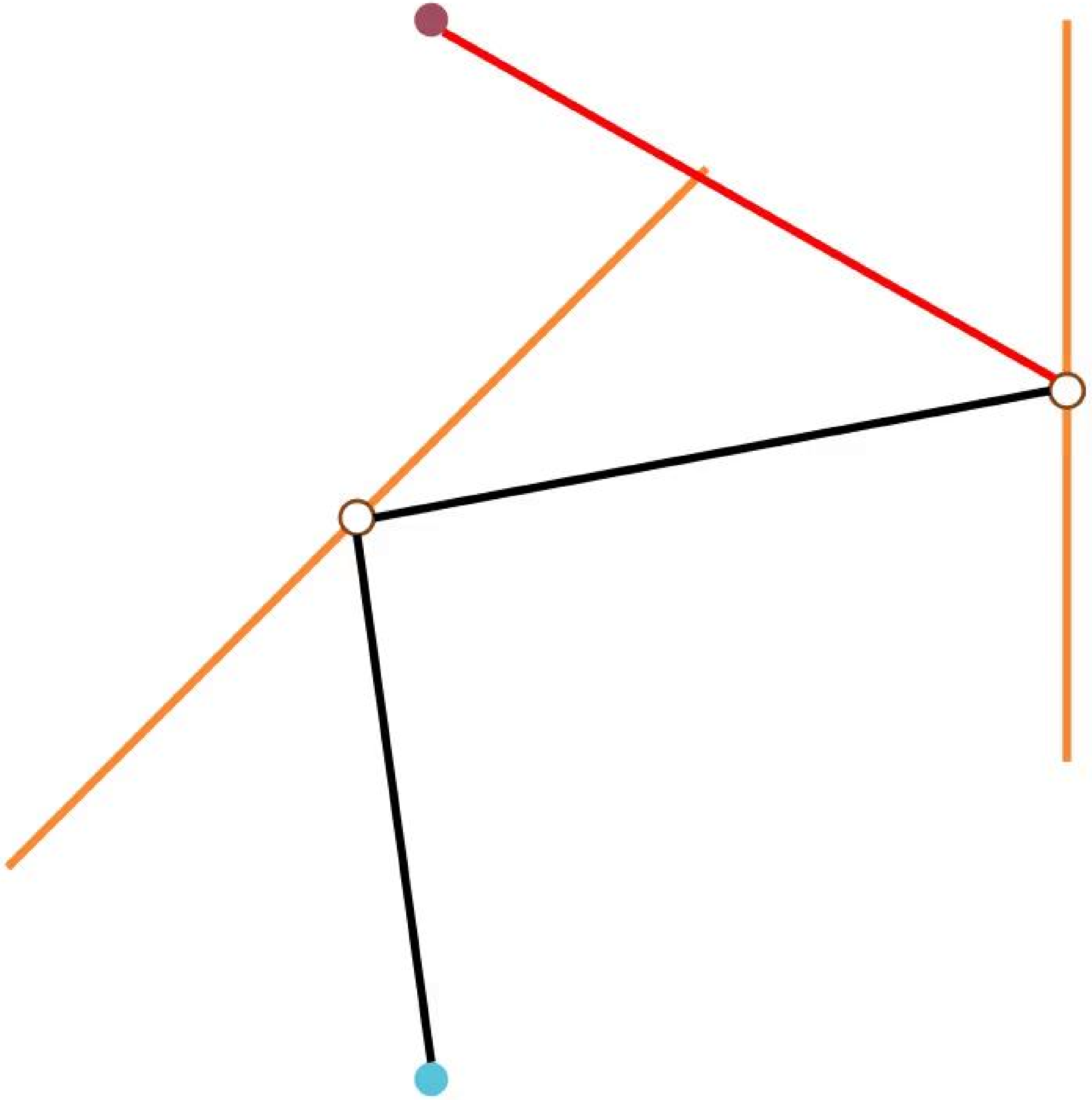

$$\mathcal{C} = \left(-t_1 + t_2 + \frac{(t_2 - 4)\sqrt{(t_1 - 5)^2 + (t_1 - t_2)^2}}{\sqrt{(t_2 - 4)^2 + 9}}\right)^2 + \left(t_1 + \frac{3\sqrt{(t_1 - 5)^2 + (t_1 - t_2)^2}}{\sqrt{(t_2 - 4)^2 + 9}} - 5\right)^2 + \left|t_1 + \frac{(t_1 - 5)\sqrt{(t_1 - 2)^2 + (t_1 + 1)^2}}{\sqrt{(t_1 - 5)^2 + (t_1 - t_2)^2}} - \frac{\sqrt{2}\left(\sqrt{2}(t_1 - 2) - \sqrt{2}(t_1 + 1)\right)}{2} - 2\right|^2 + \left|t_1 + \frac{(t_1 - t_2)\sqrt{(t_1 - 2)^2 + (t_1 + 1)^2}}{\sqrt{(t_1 - 5)^2 + (t_1 - t_2)^2}} + \frac{\sqrt{2}\left(\sqrt{2}(t_1 - 2) - \sqrt{2}(t_1 + 1)\right)}{2} + 1\right|^2$$

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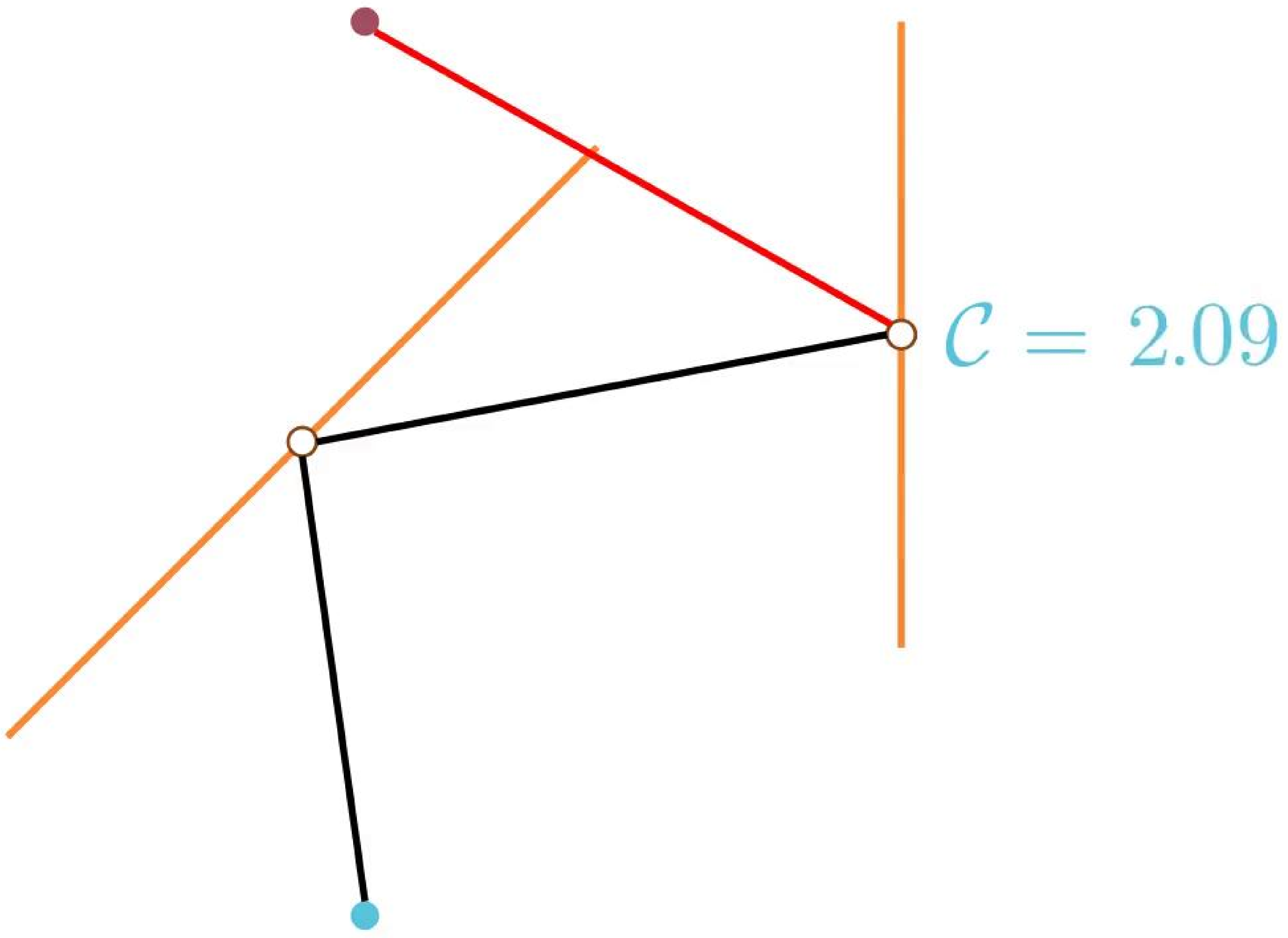

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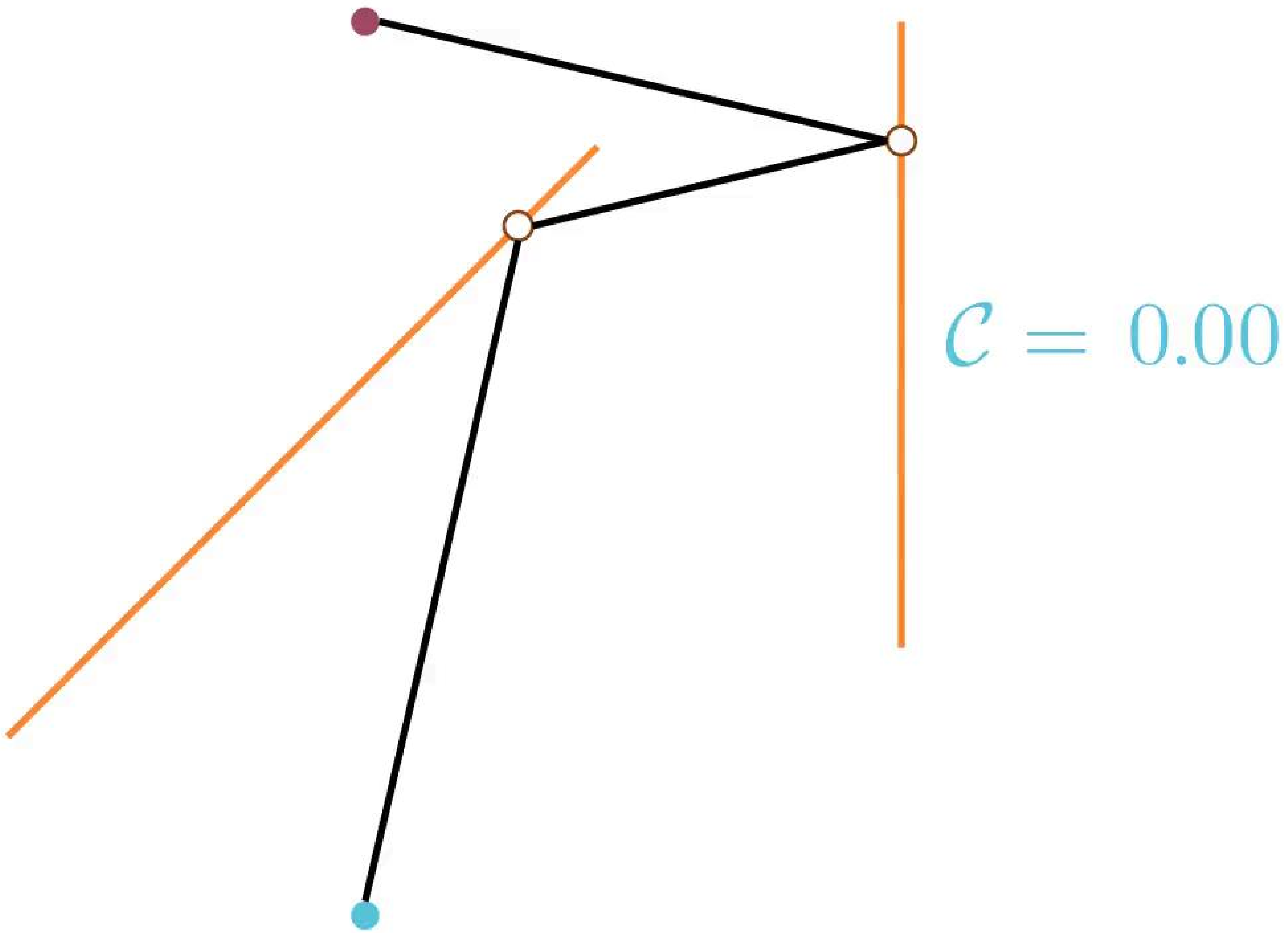
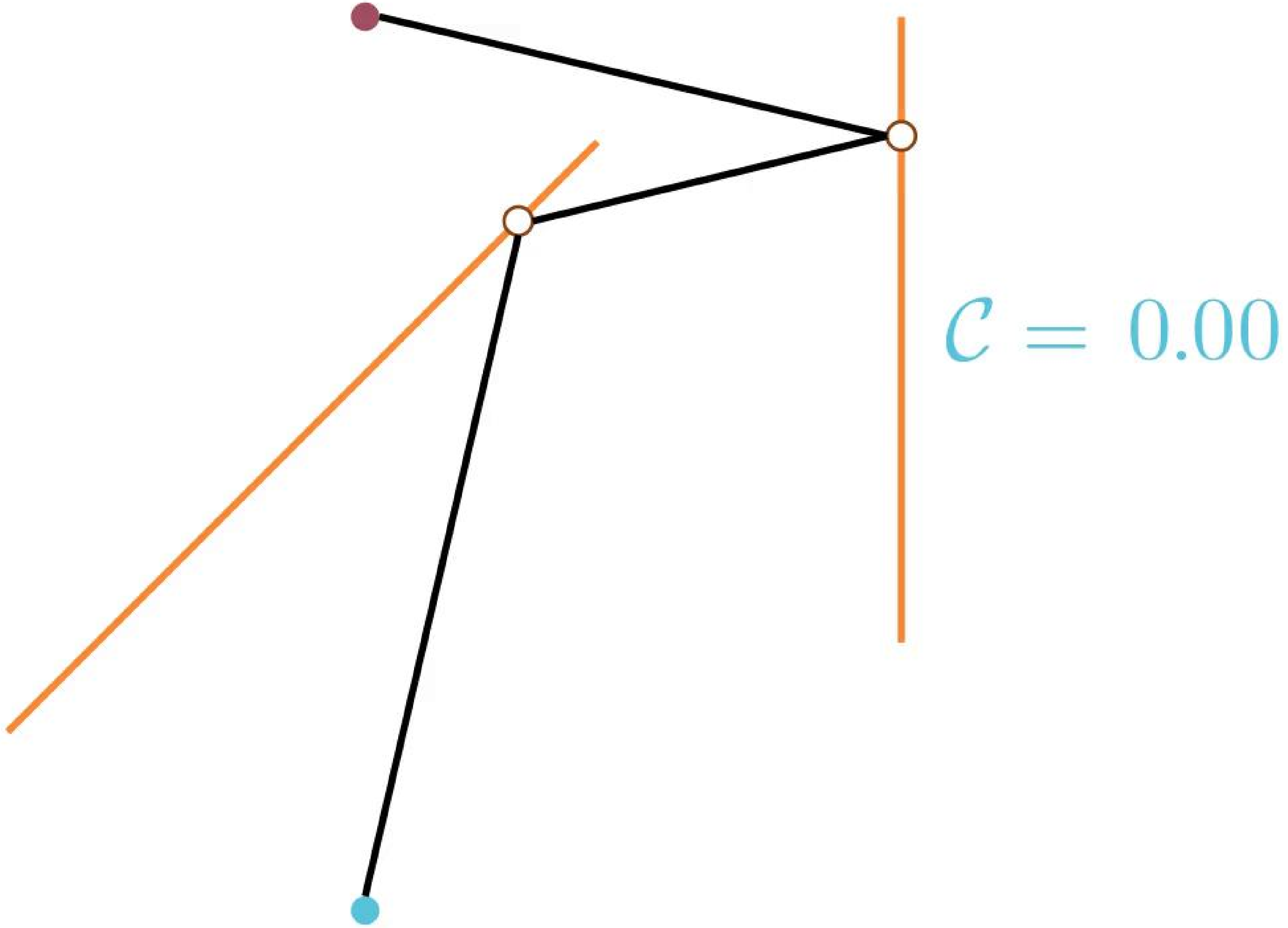


What if we had a metasurface?



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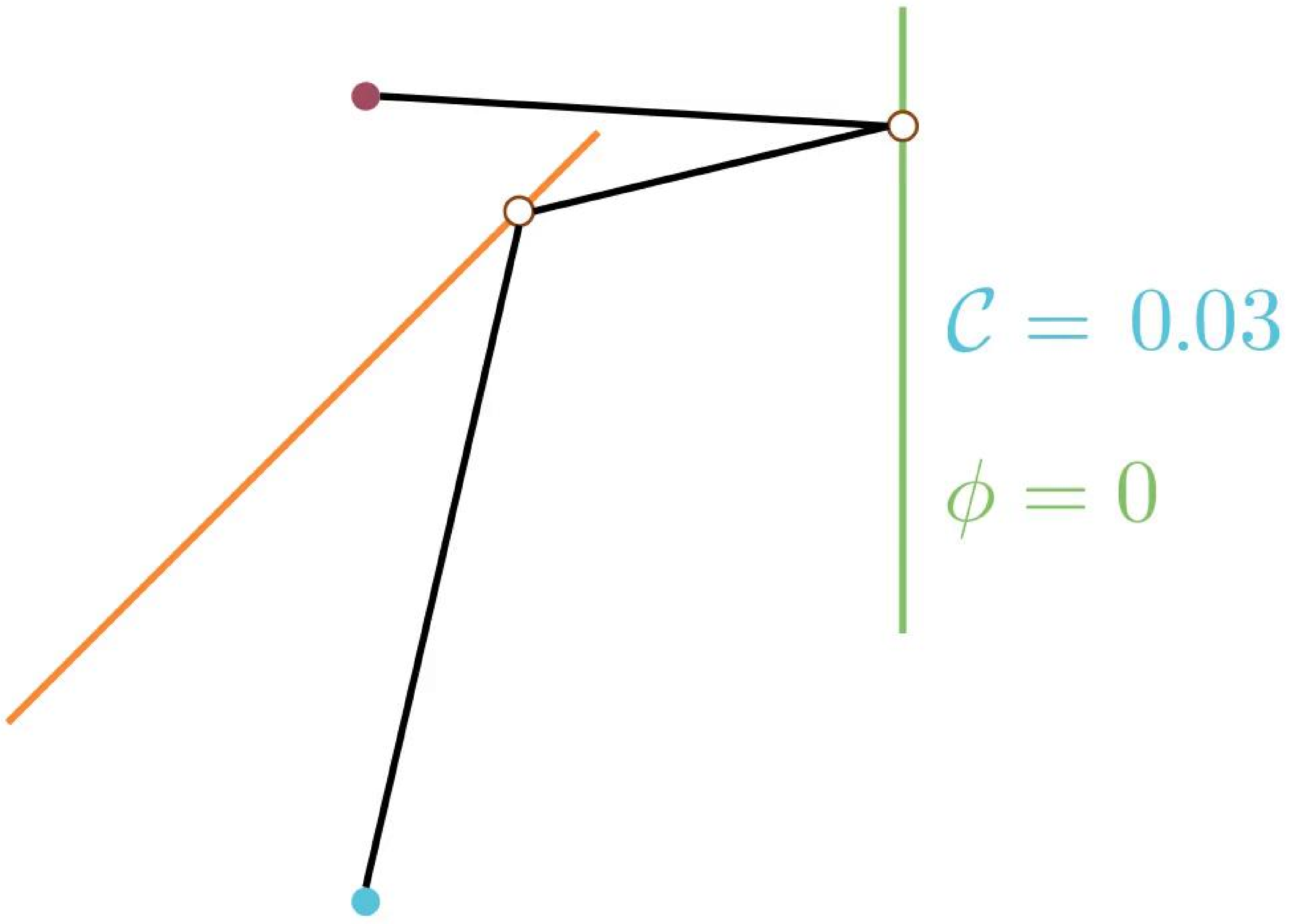

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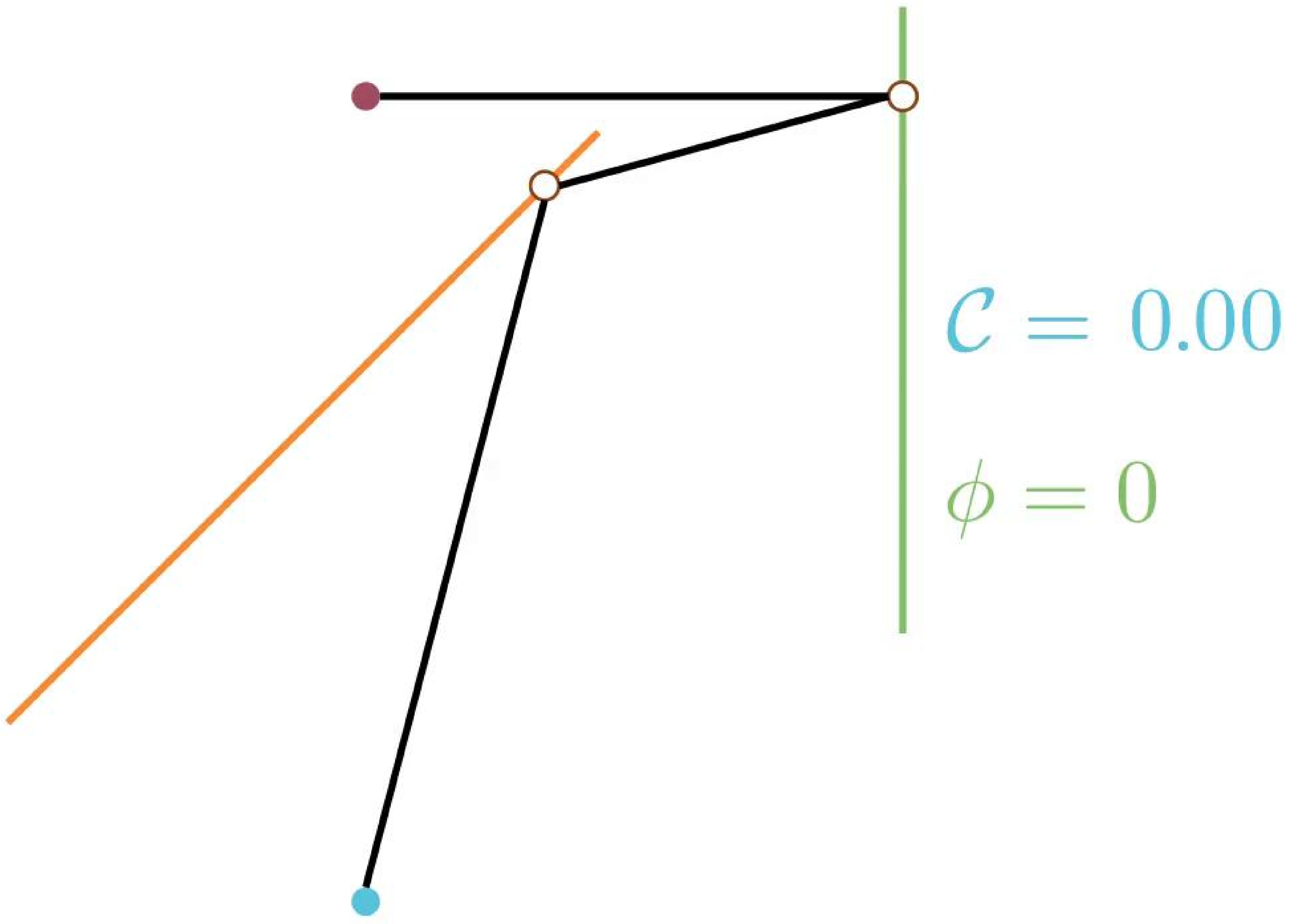

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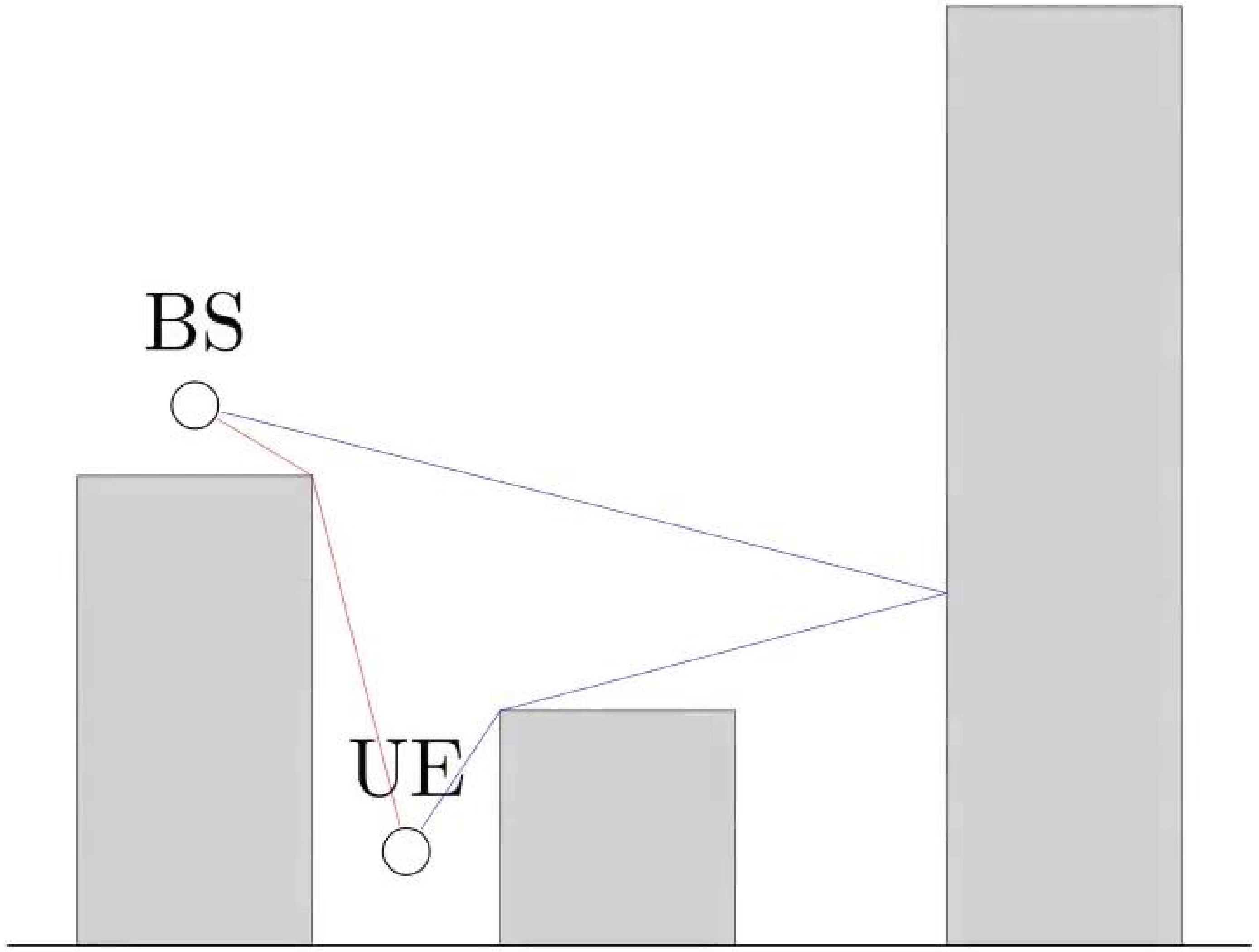

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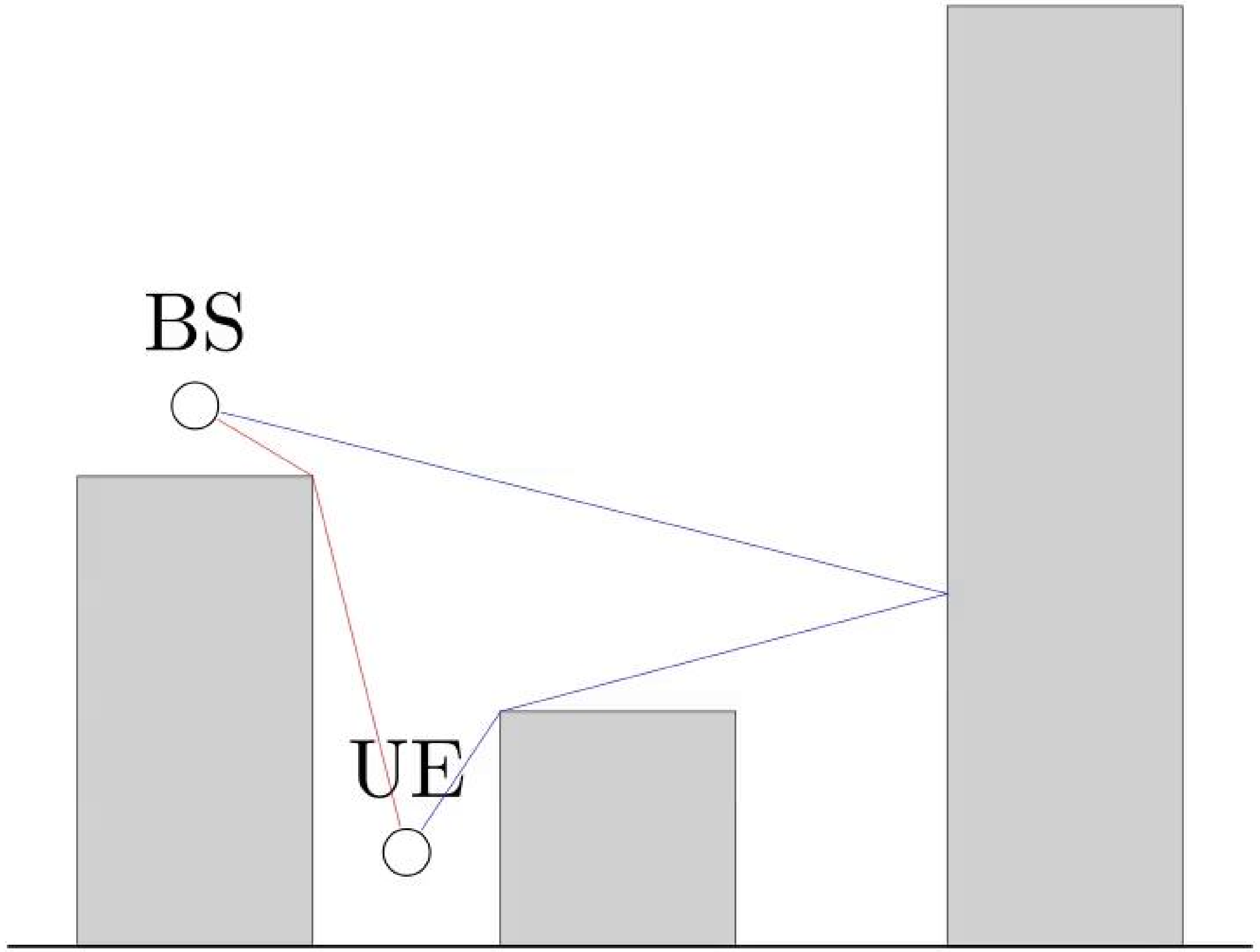

Number of interactions	1	2			3						
Interactions list	D	RD	DR	DD	RRD	RDR	RDD	DRR	DRD	DDR	DDD
E/E_{LOS} (dB)	**-32**	-236	-242	**-44**	-231	-246	**-69**	-212	**-72**	-81	**-60**

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Pros

- Any geometry (but requires more info.)
- Any # of reflect., diff., and refract.
- Allows for multiple solutions
- Optimizer can be chosen

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- Any geometry (but requires more info.)
- Any # of reflect., diff., and refract.
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Cons

- In general, problem is not convex
- Slower - $\mathcal{O}(k \cdot n)$

Future work:

- Compare with Ray Launching
- Discuss different solvers / minimizers

Thanks for listening!