



SIGGRAPH THINK
BEYOND
2020 S2020.SIGGRAPH.ORG

THE DESIGN AND EVOLUTION OF THE UBERBAKE LIGHT BAKING SYSTEM

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Michał Iwanicki², Wojciech Jarosz¹

¹



DARTMOUTH
VISUAL COMPUTING LAB

²





Evolve a **static light baking system** to
support **dynamic lights and geometry**

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- Which **design decision** made the process easier?

Evolve a **static light baking system** to support **dynamic lights and geometry**

- What major **changes** did we have to make?
- Which **design decision** made the process easier?
- How did our **constraints** guide us to good solutions?

What is this talk **not** about?

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- No **one specific** new technique or technical contribution

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*Peter-Pike is doing a session in
Advances in Real-time Rendering*

Light Baking Preliminaries

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Light Baking Preliminaries

Final Lighting

Light Baking Preliminaries

Final Lighting

Precomputed
Lighting

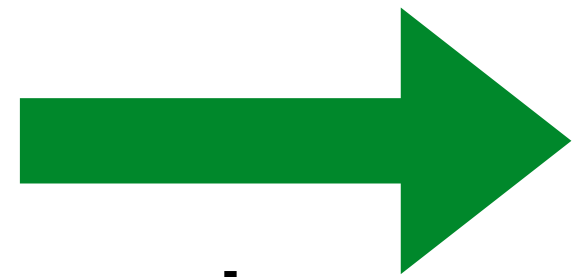
+

Run-time Light
Model

A basic system overview

A basic system overview

Level



Editor

A basic system overview

Bake Time

Level

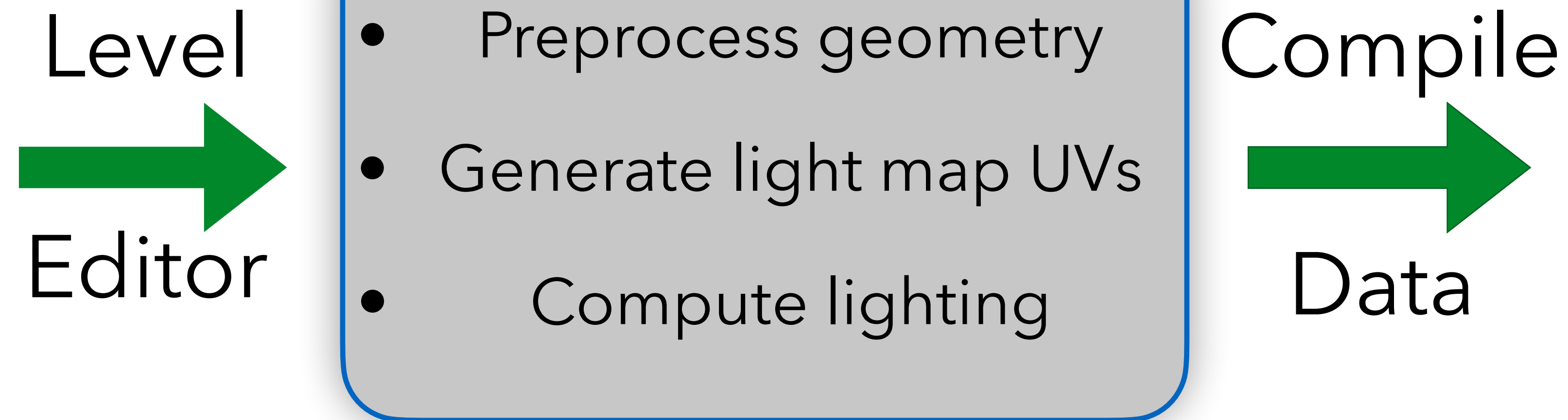


Editor

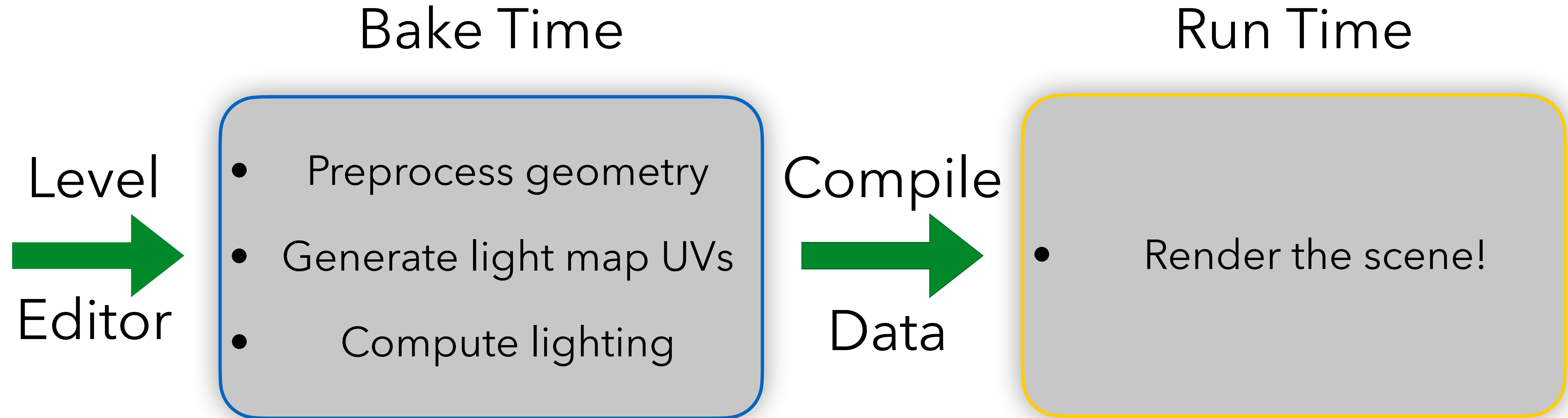
- Preprocess geometry
- Generate light map UVs
- Compute lighting

A basic system overview

Bake Time



A basic system overview



Light Baking Preliminaries

Light Baking Preliminaries

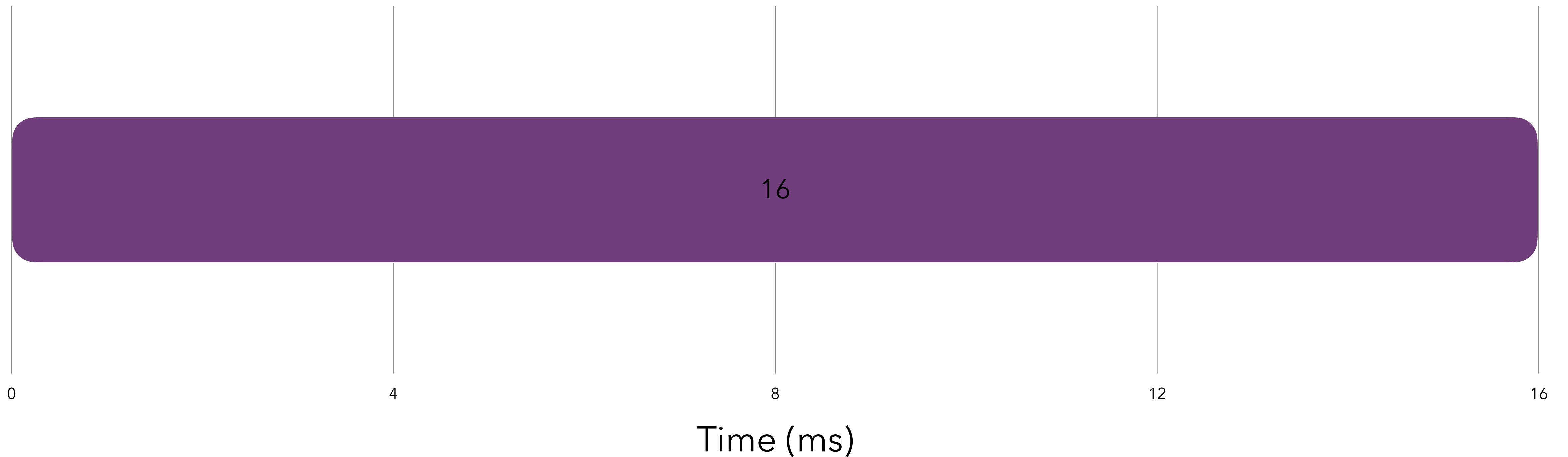
- **Why** do we bake lighting?

It's a matter of time

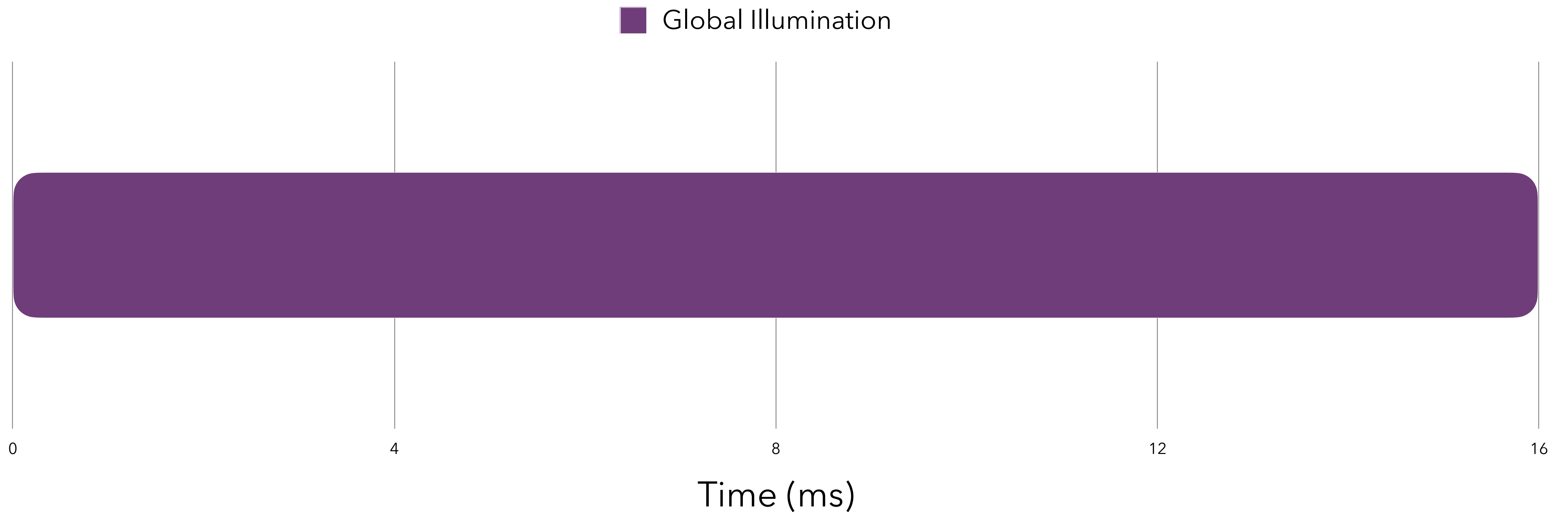
It's a matter of time

60 Frames per Second

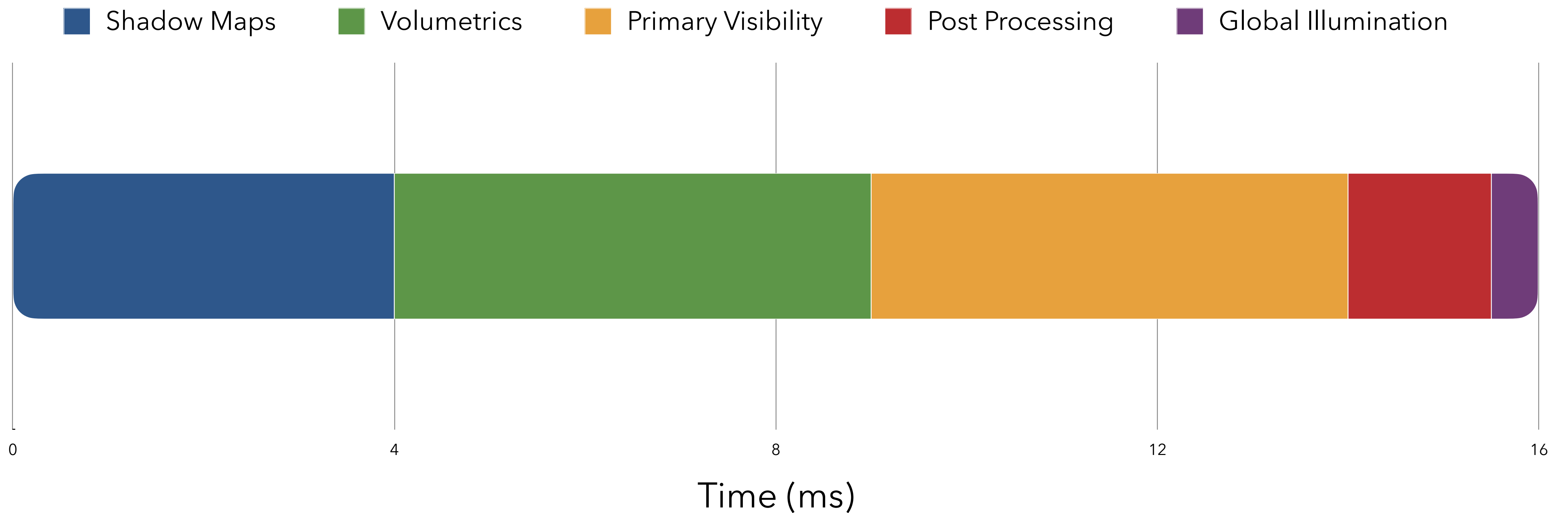
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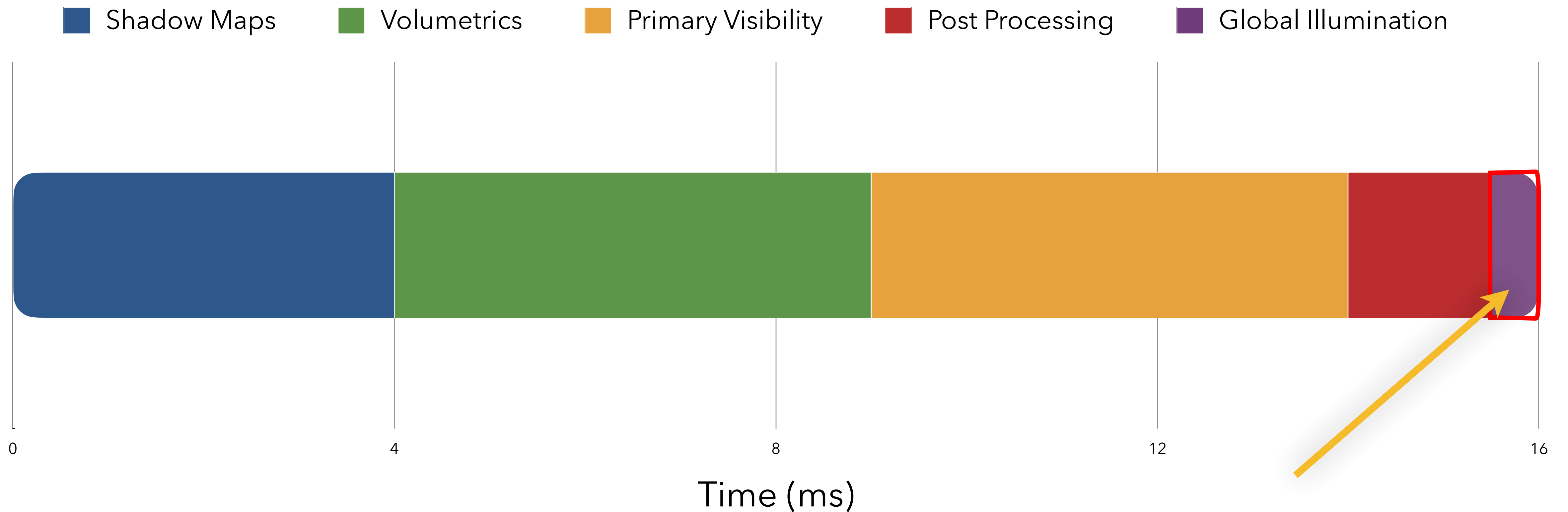
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It's a matter of time



Light Baking Preliminaries

- **Why** do we bake lighting?

Light Baking Preliminaries

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- **What** part of the lighting do we include?







All indirect lighting is baked



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Light Baking Preliminaries

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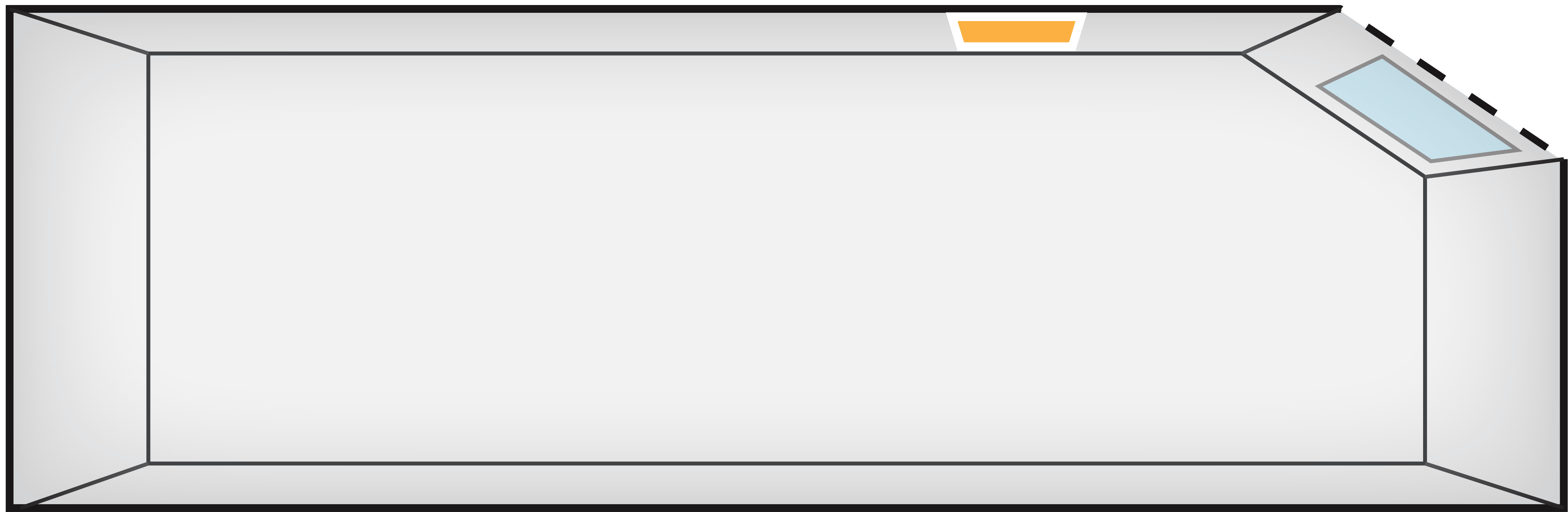
Light Baking Preliminaries

- **Why** do we bake lighting?
- **What** part of the lighting do we include?
- **How** do we do this efficiently?

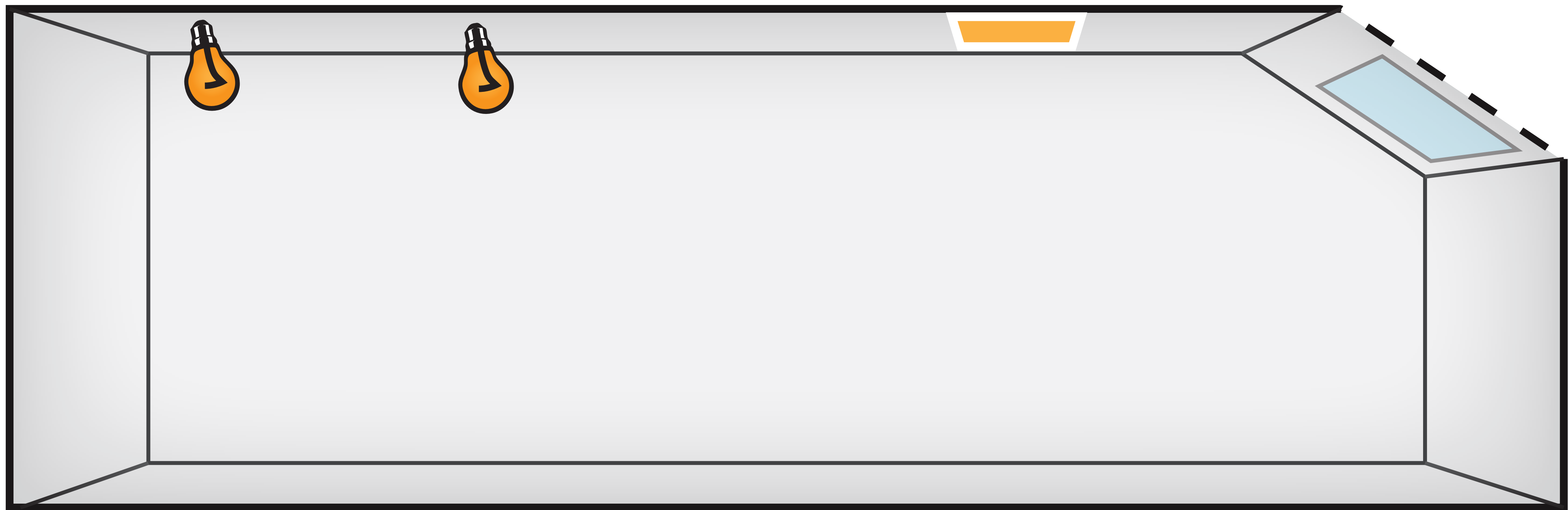


Baking via series expansion

Baking via series expansion



Baking via series expansion



Baking via series expansion

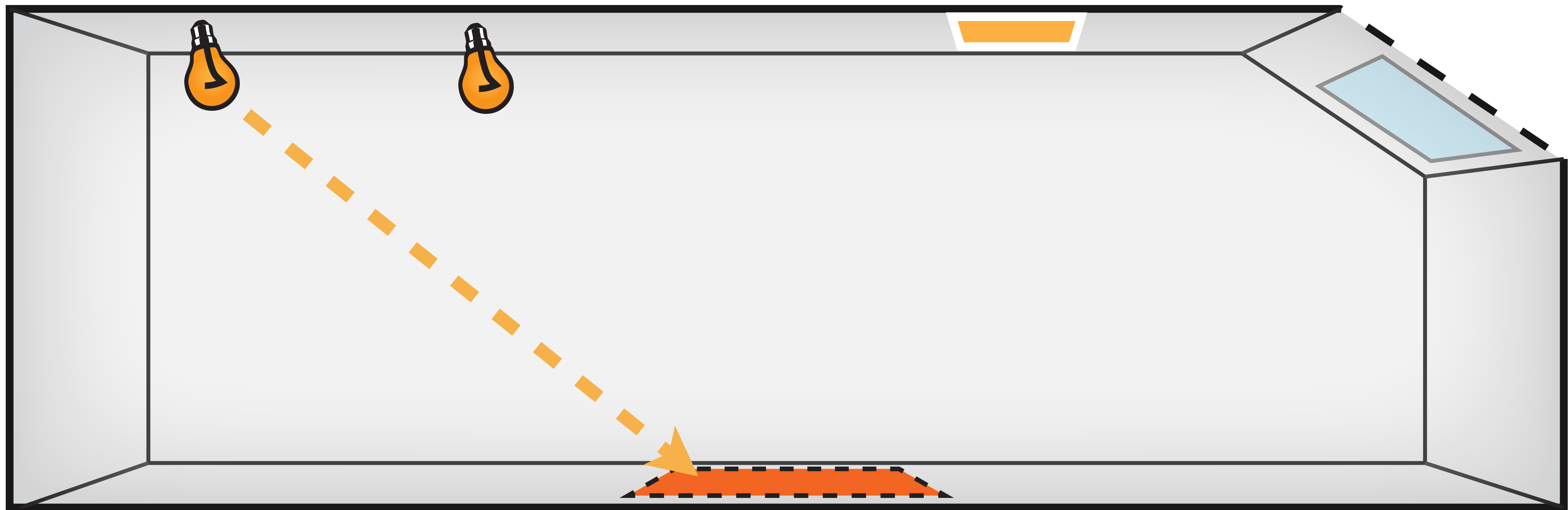


Baking via series expansion



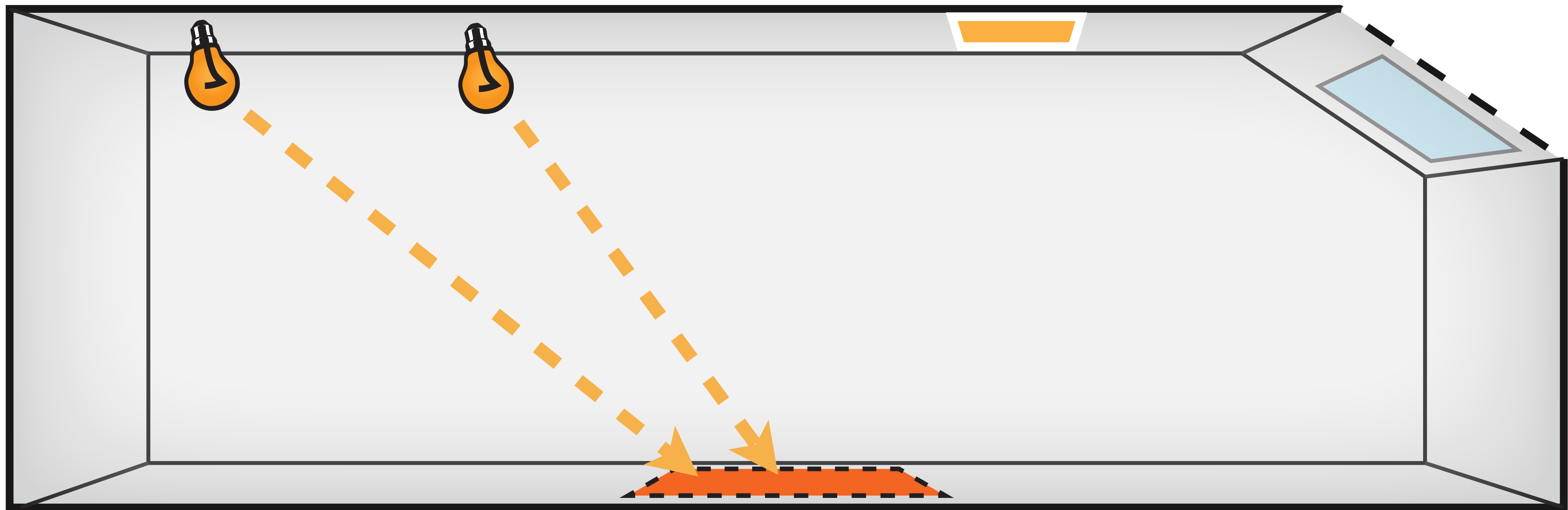
1. Inject Direct Lighting

Baking via series expansion



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Baking via series expansion

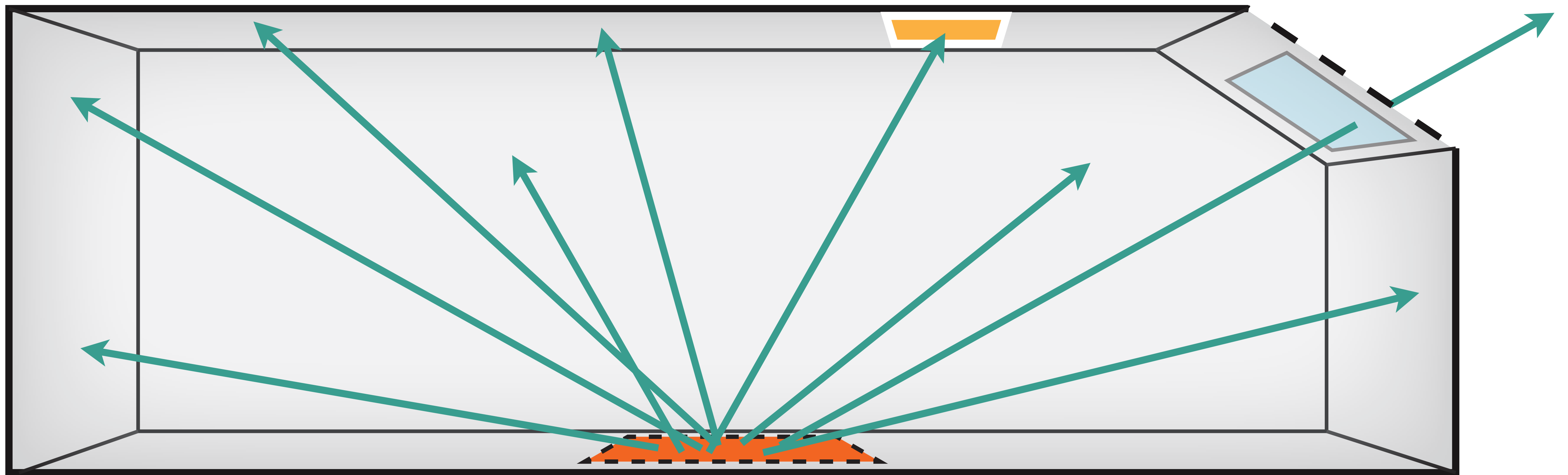


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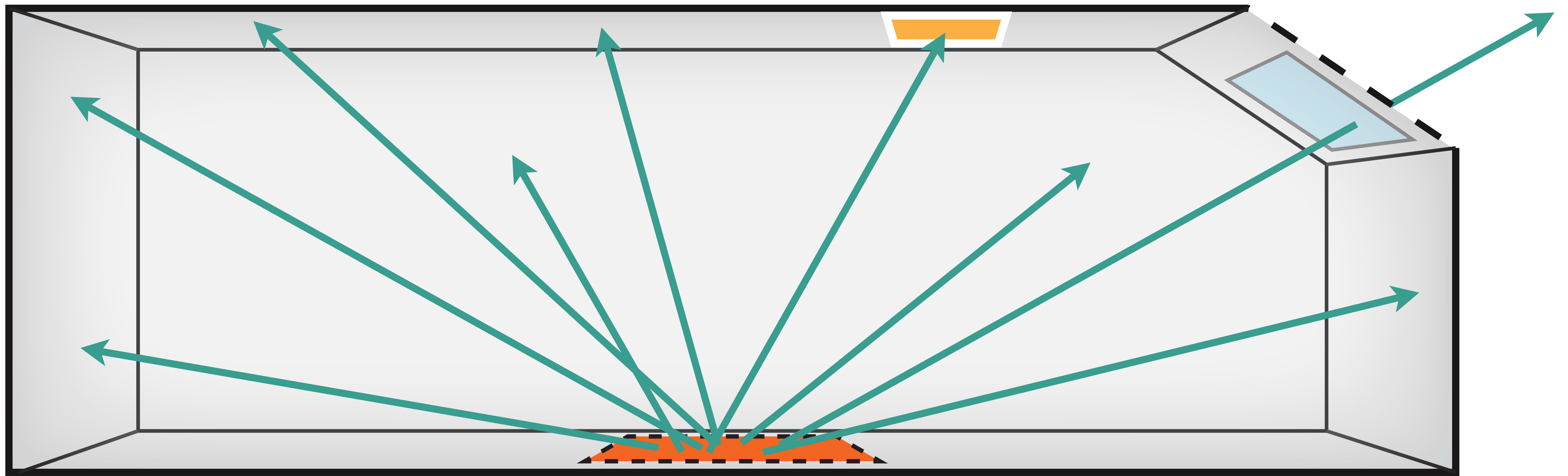
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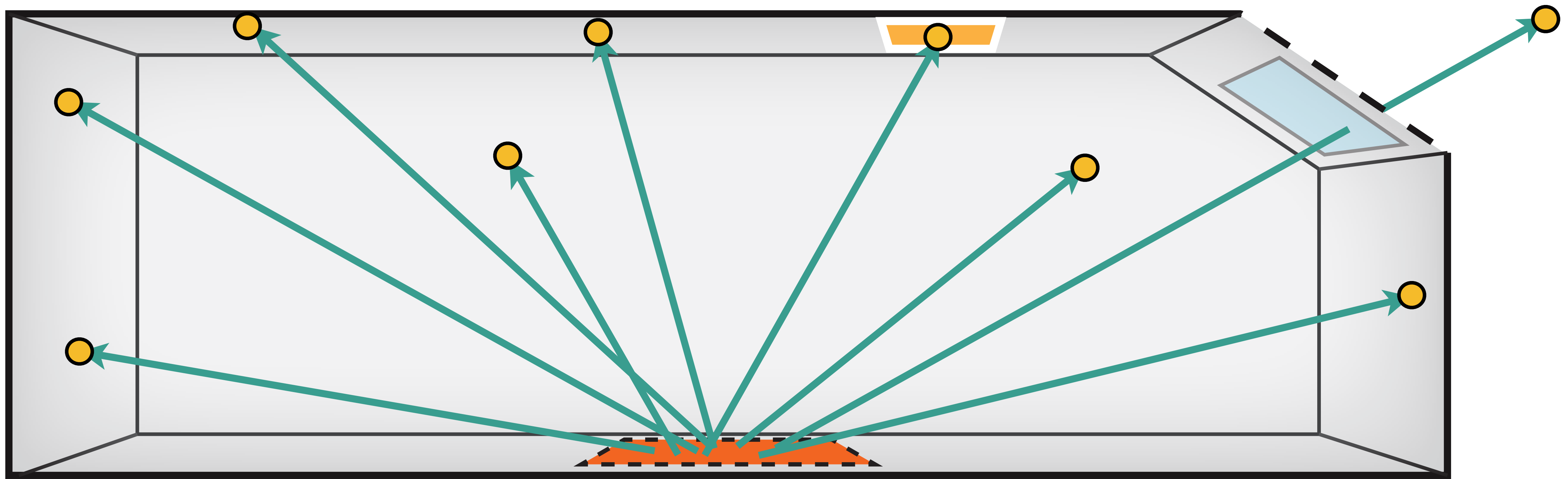


Baking via series expansion



2. Gather Indirect

Baking via series expansion



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Baking via series expansion



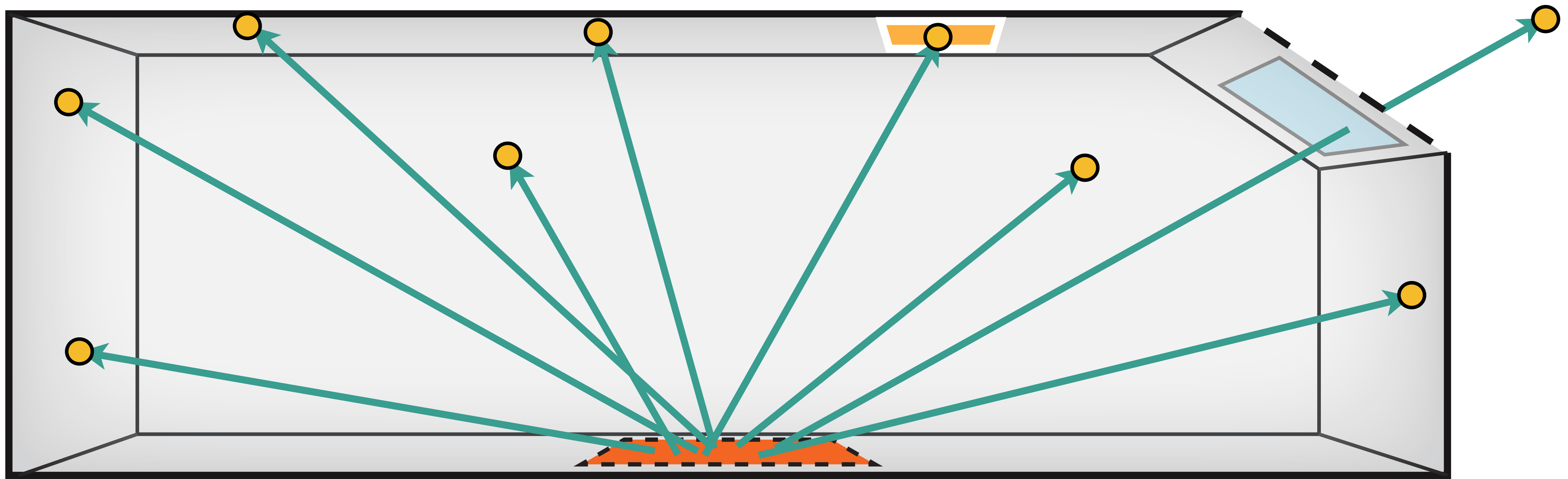
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Baking via series expansion



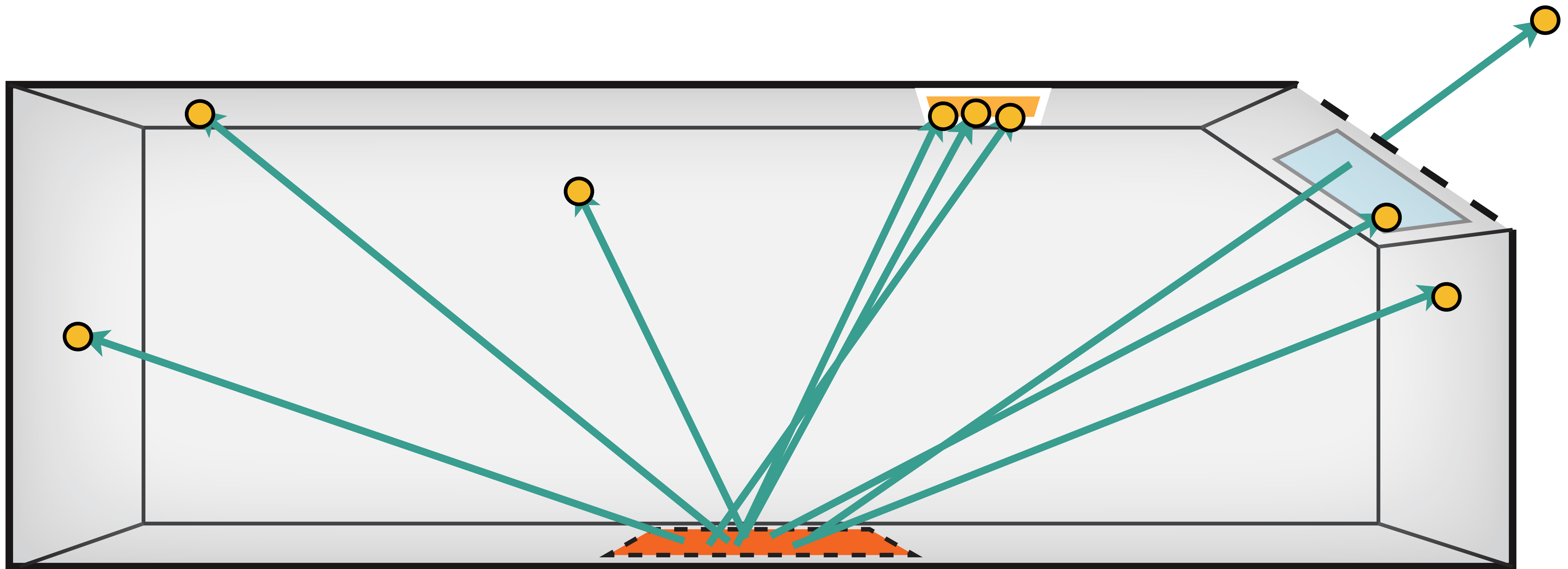
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Baking via series expansion



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Baking via series expansion



2. Gather Indirect with Path Guiding

[Silvennoinen and Sloan 2019]

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- **How** do we do this efficiently?



Light Baking Preliminaries

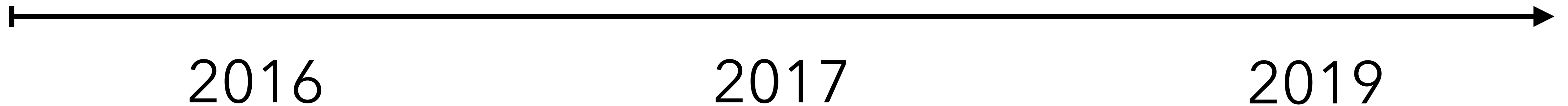
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Evolving UBERBAKE

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Evolving UBERBAKE

Static Lighting
and Geometry

2016

2017

2019

Evolving UBERBAKE

Static Lighting
and Geometry



2016

2017

2019

Evolving UBERBAKE

Static Lighting
and Geometry

Dynamic
Lighting

2016

2017

2019

Evolving UBERBAKE

Static Lighting
and Geometry

Dynamic
Lighting

Limited Dynamic
Geometry

2016

2017

2019

In Game Lighting



In Game Lighting





28
360



2



2





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We have a set of hard constraints...

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C1: Near-zero **runtime overhead**

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C2: No additional **constraints on geometry**

We have a set of hard constraints...

C1: Near-zero **runtime overhead**

C2: No additional **constraints on geometry**

C3: No major revisions to **engine and tools code**

... and guiding goals

... and guiding goals

G1: Minimize **artist iteration time**

... and guiding goals

G1: Minimize **artist iteration time**

G2: Minimal **content creation overhead**

... and guiding goals

G1: Minimize **artist iteration time**

G2: Minimal **content creation overhead**

G3: Maximize **implementation orthogonality**

Making things more dynamic

Precomputed Lighting

(static lighting and geometry)



Baked Lighting in Games

[Barré-Brisebois 2017; Chen 2008; Gunier 2020; Iwanicki and Sloan 2017; Neubelt and Pettineo 2015; O'Donnell 2018; ...]

Precomputed Light Transport

(dynamic lighting, static geometry)



Precomputed Visibility

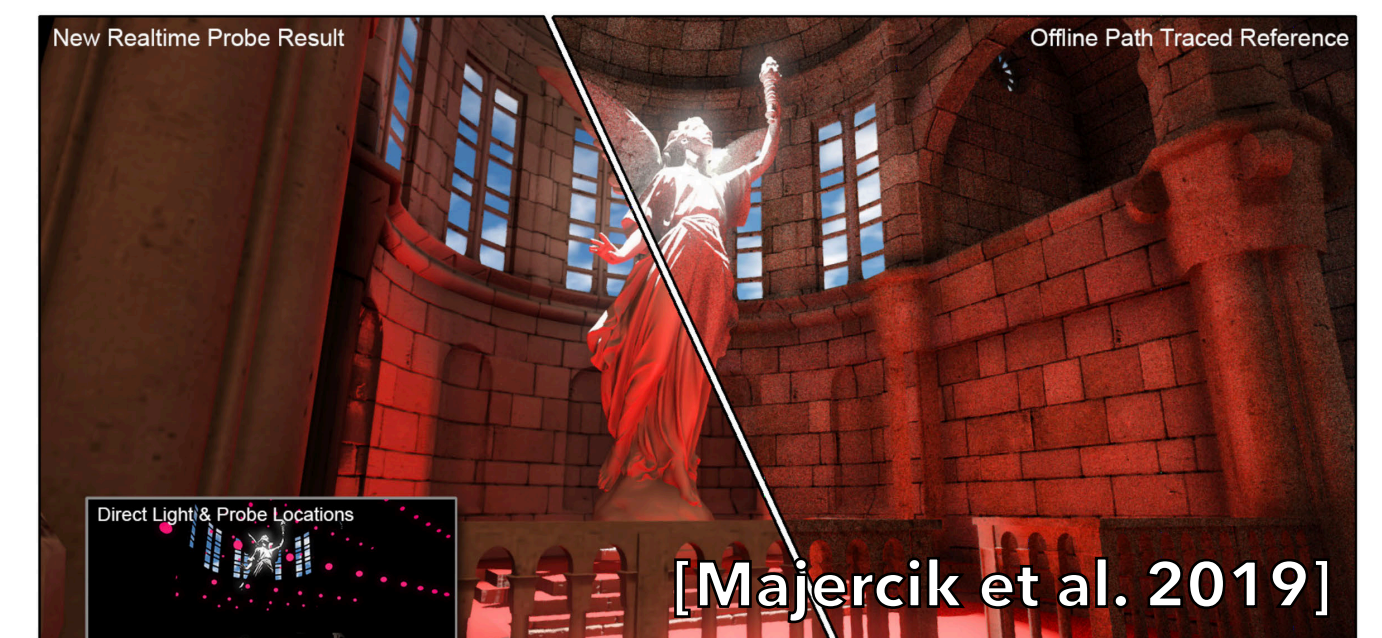
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(dynamic lighting and geometry)



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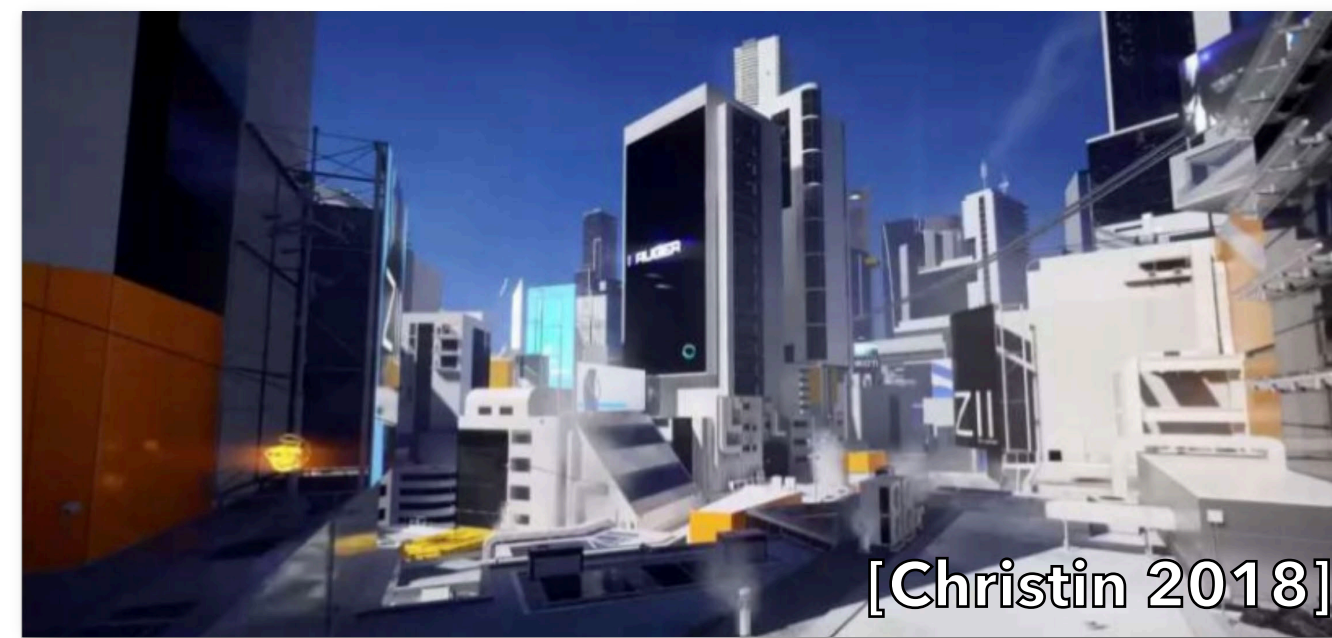
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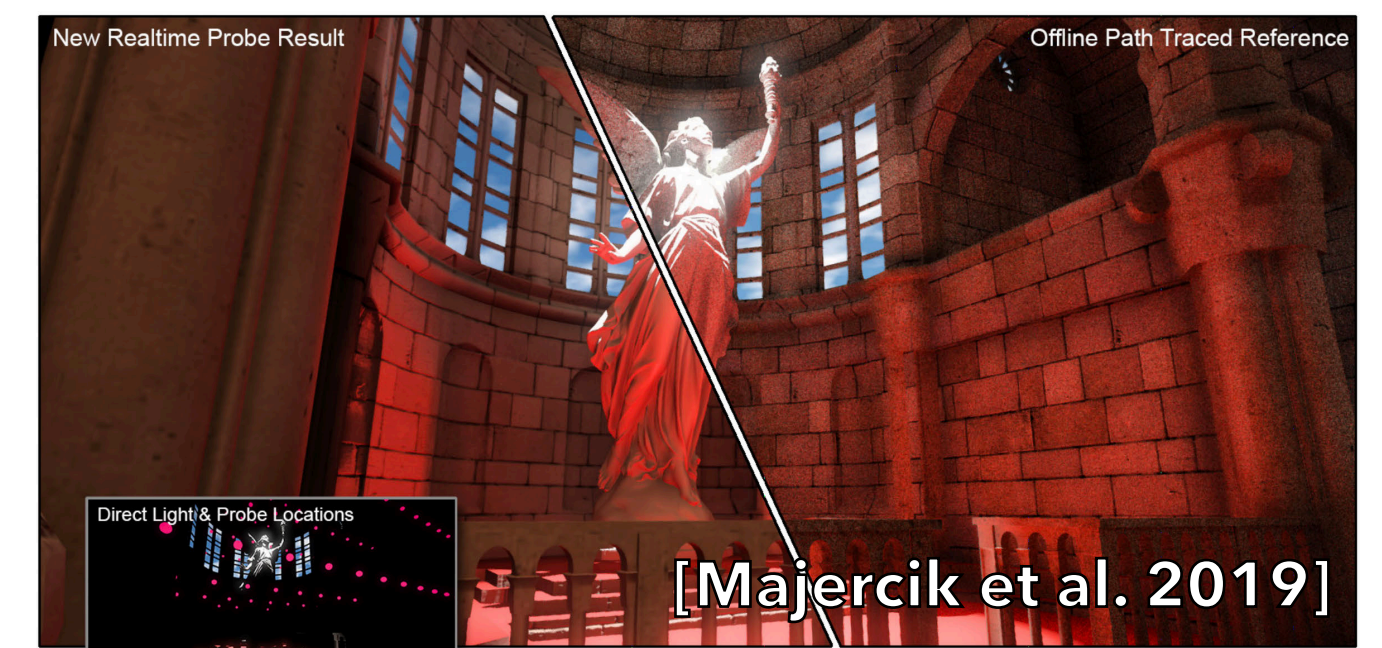
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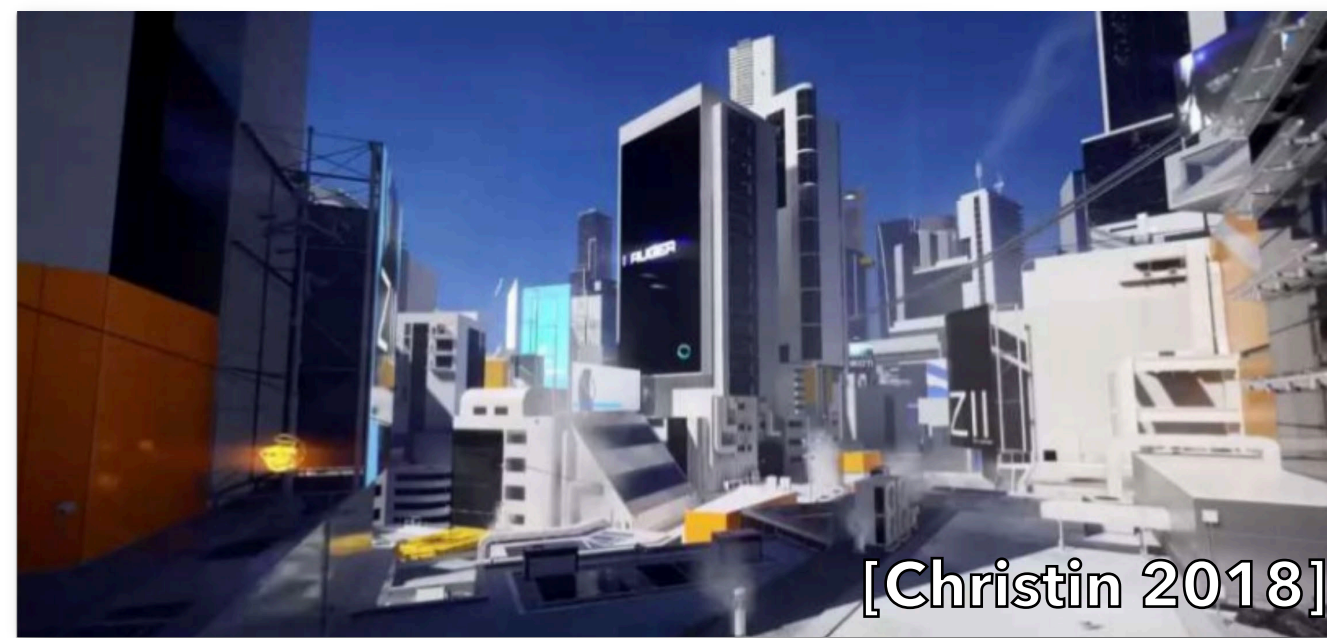


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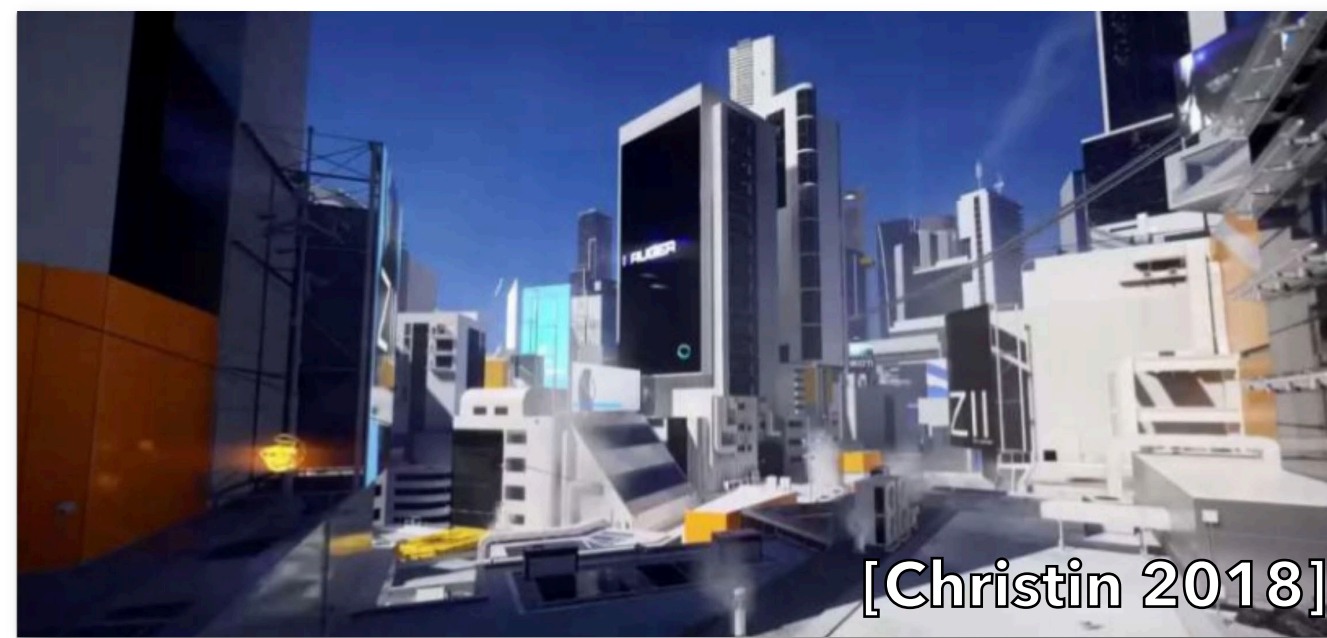
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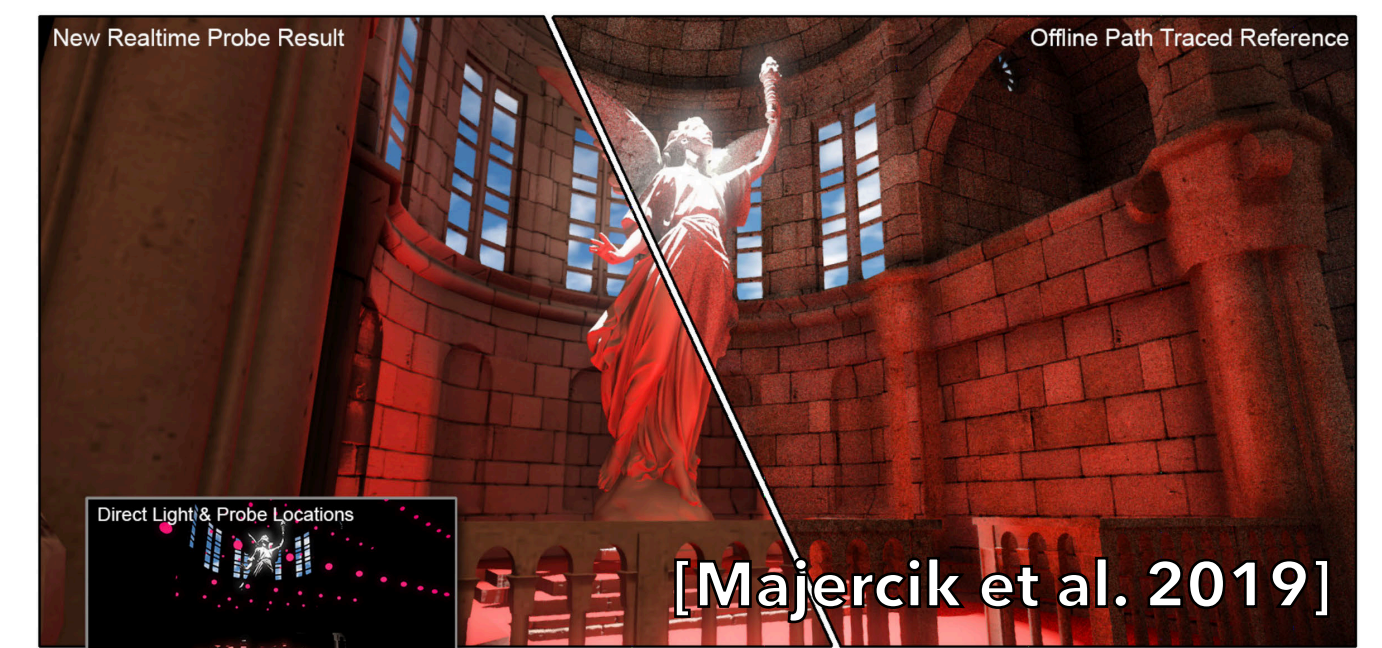
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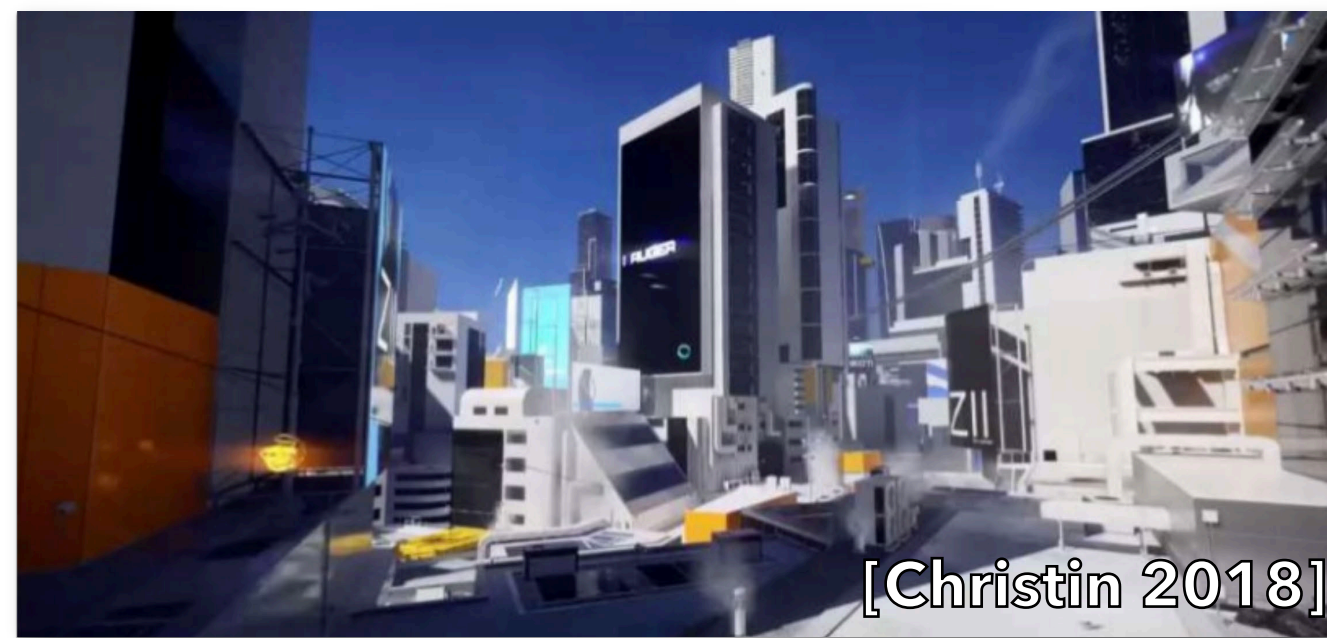


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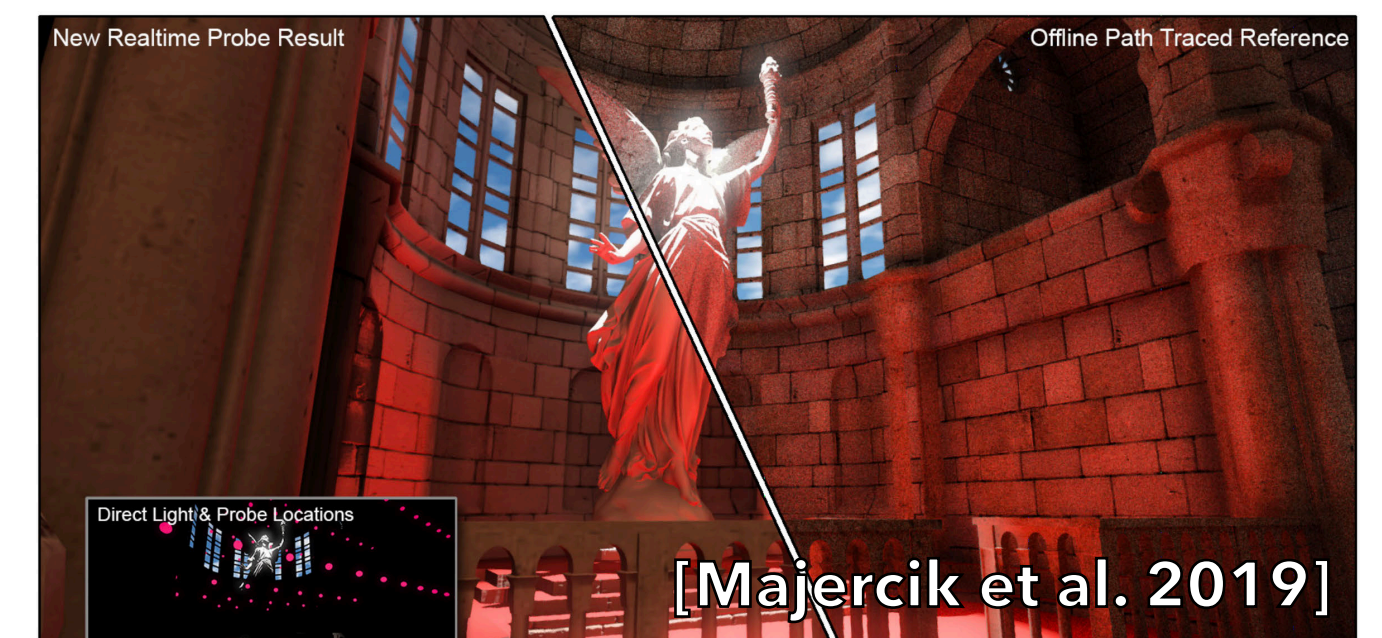
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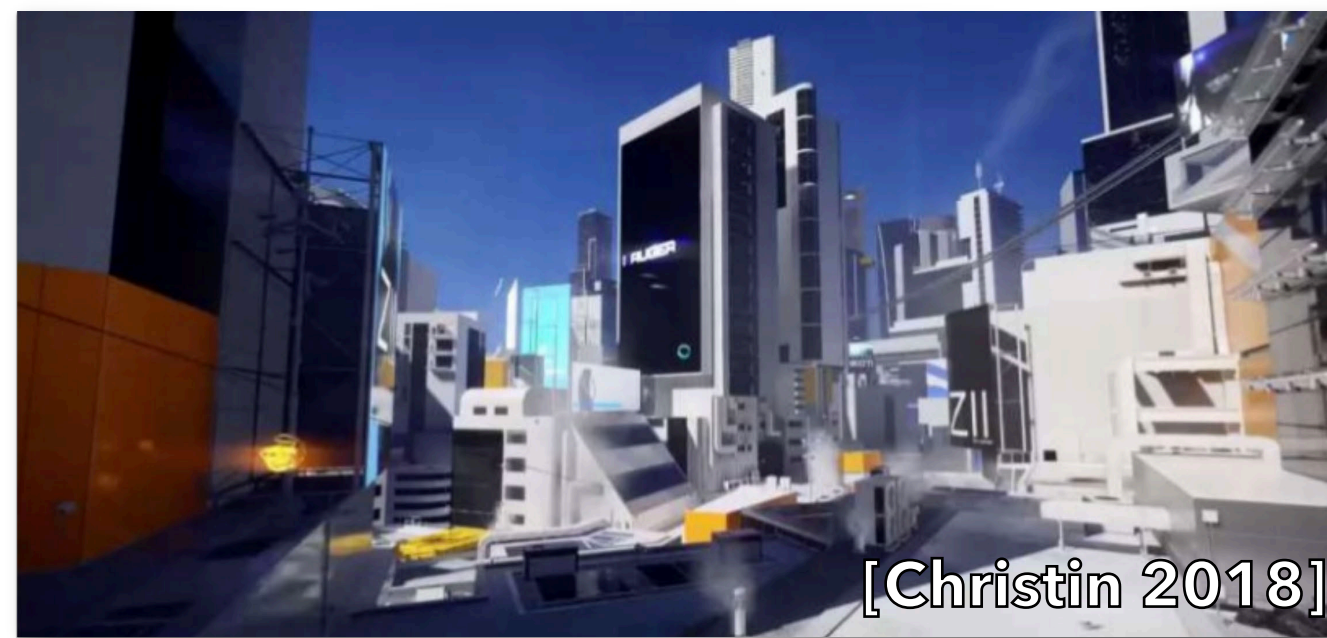
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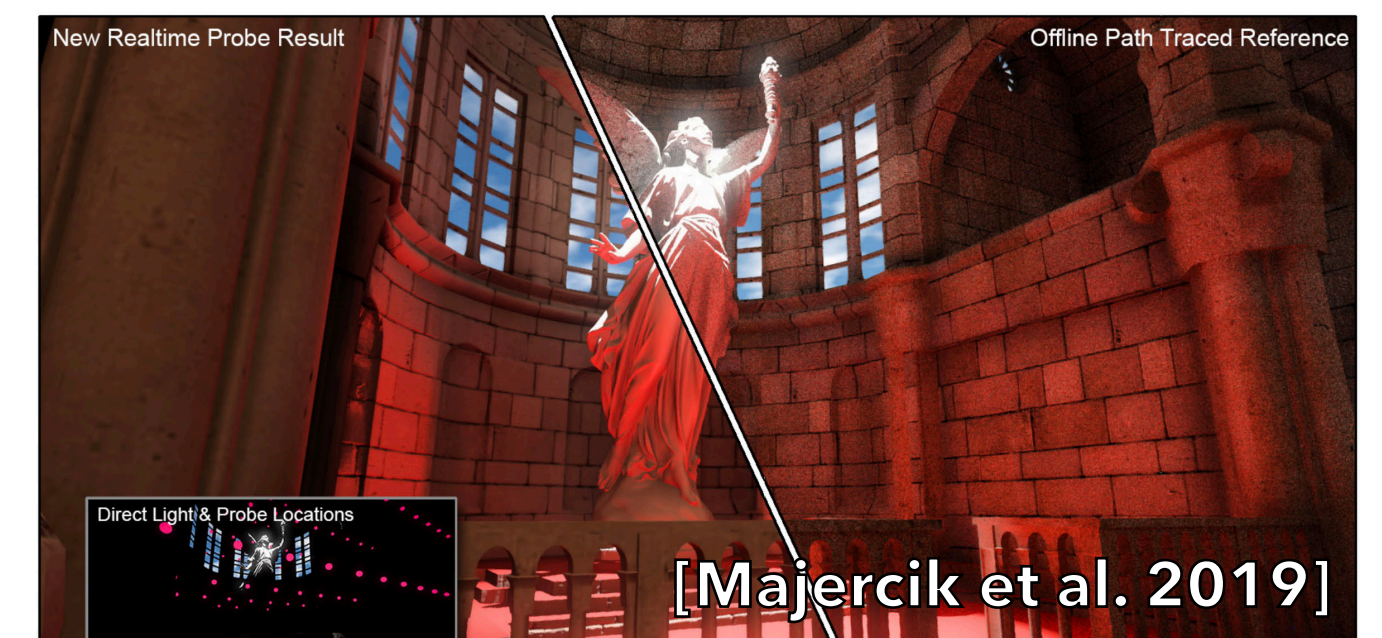
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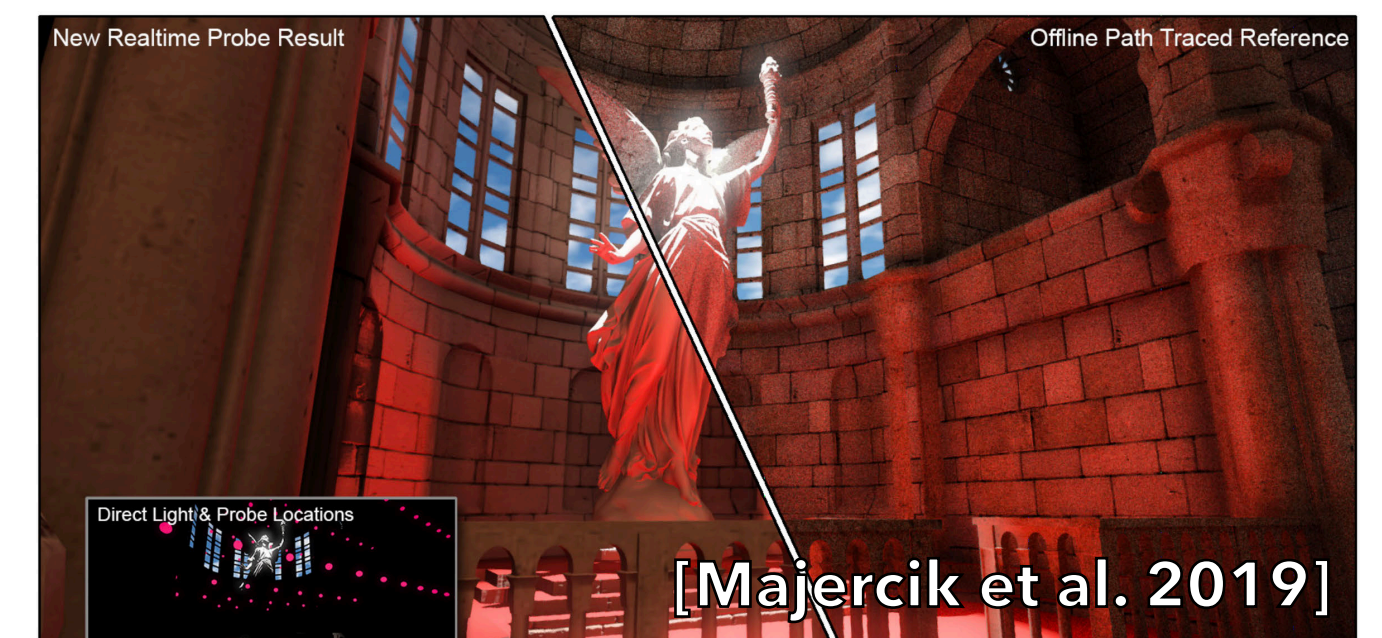
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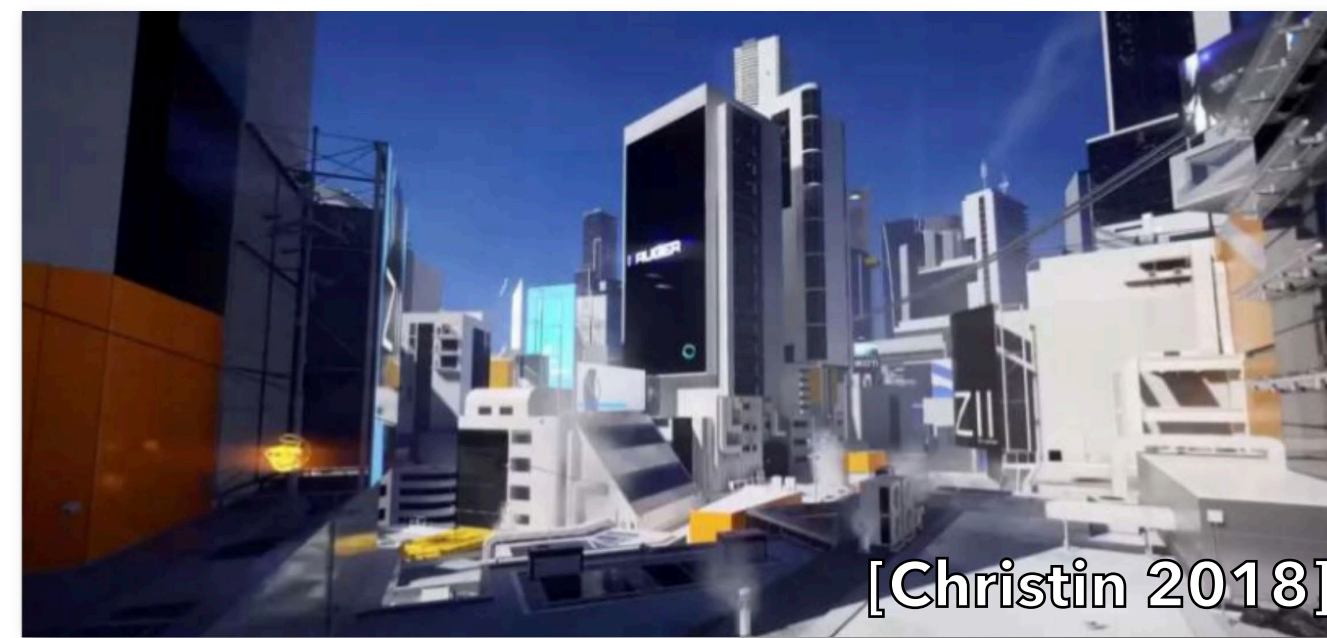
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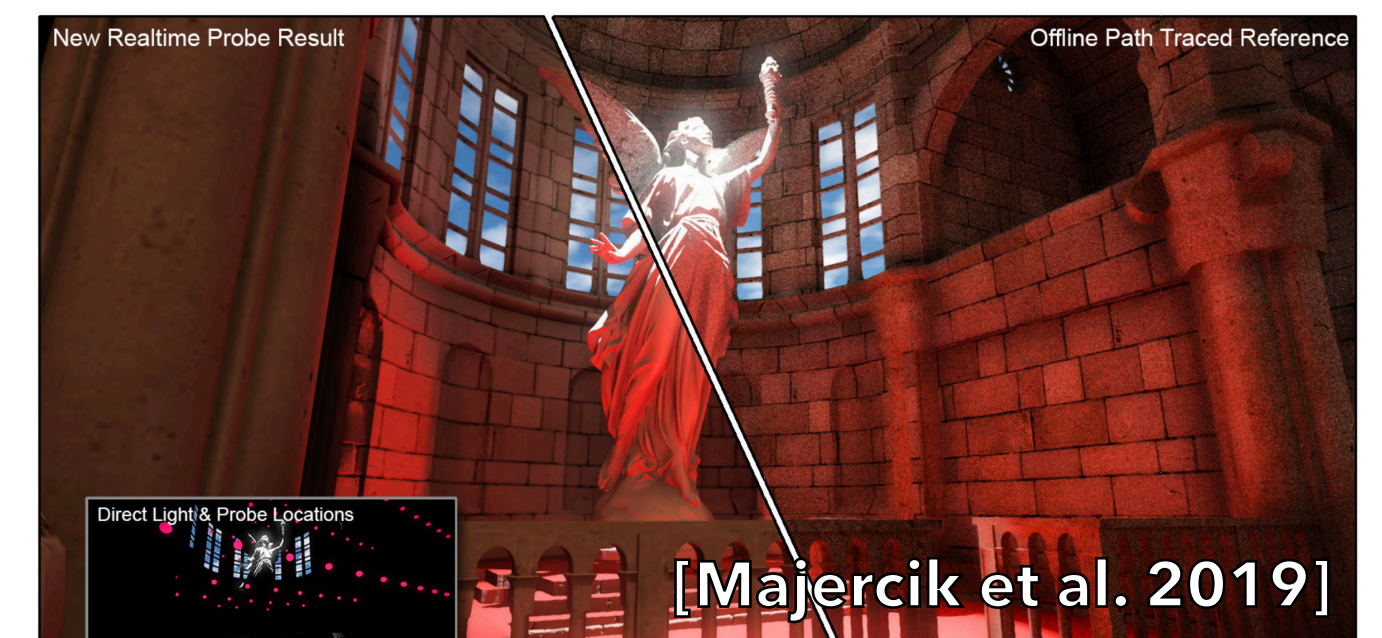
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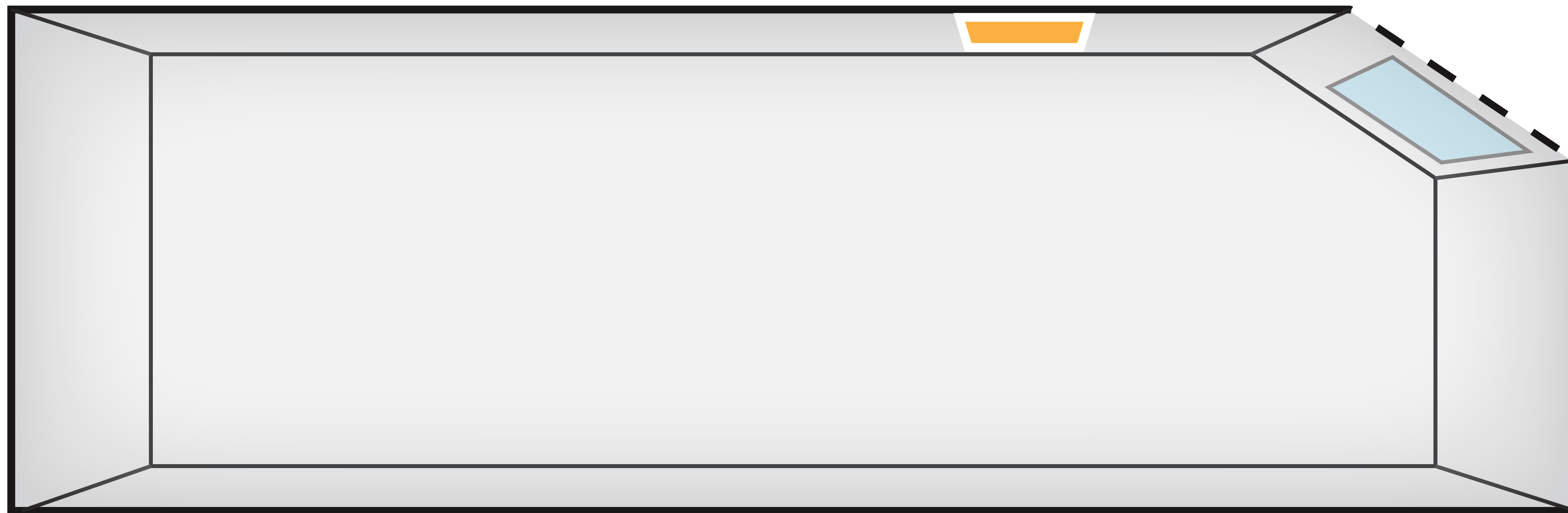
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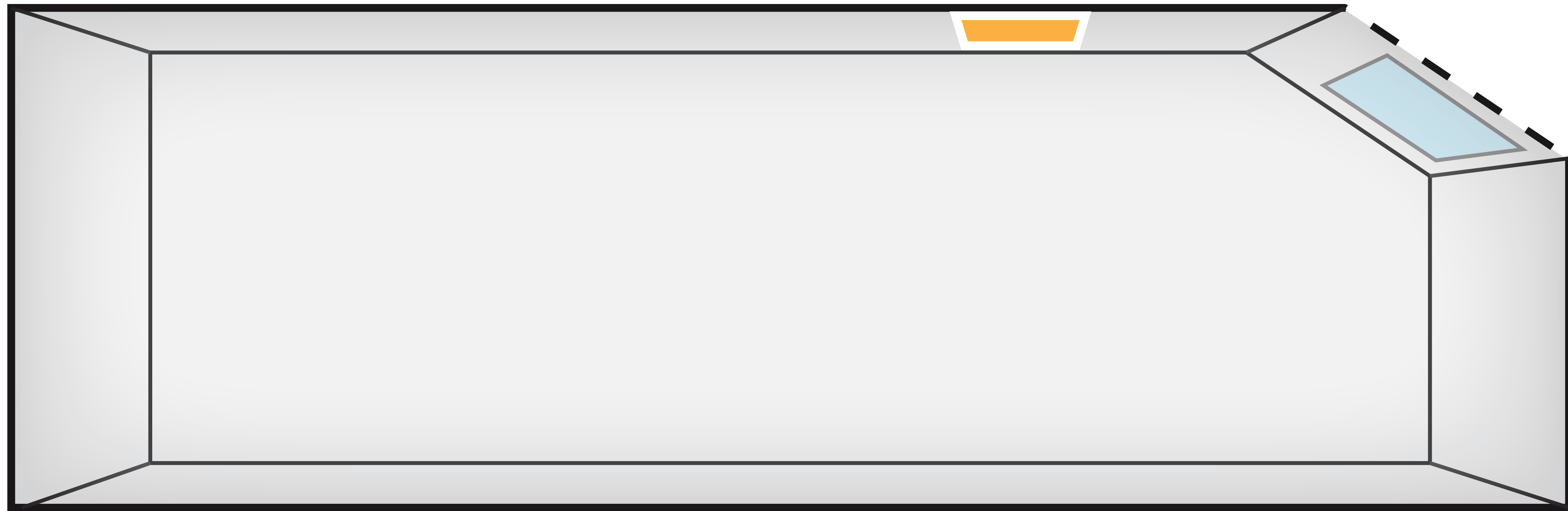
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Dynamic Lights in the Bake

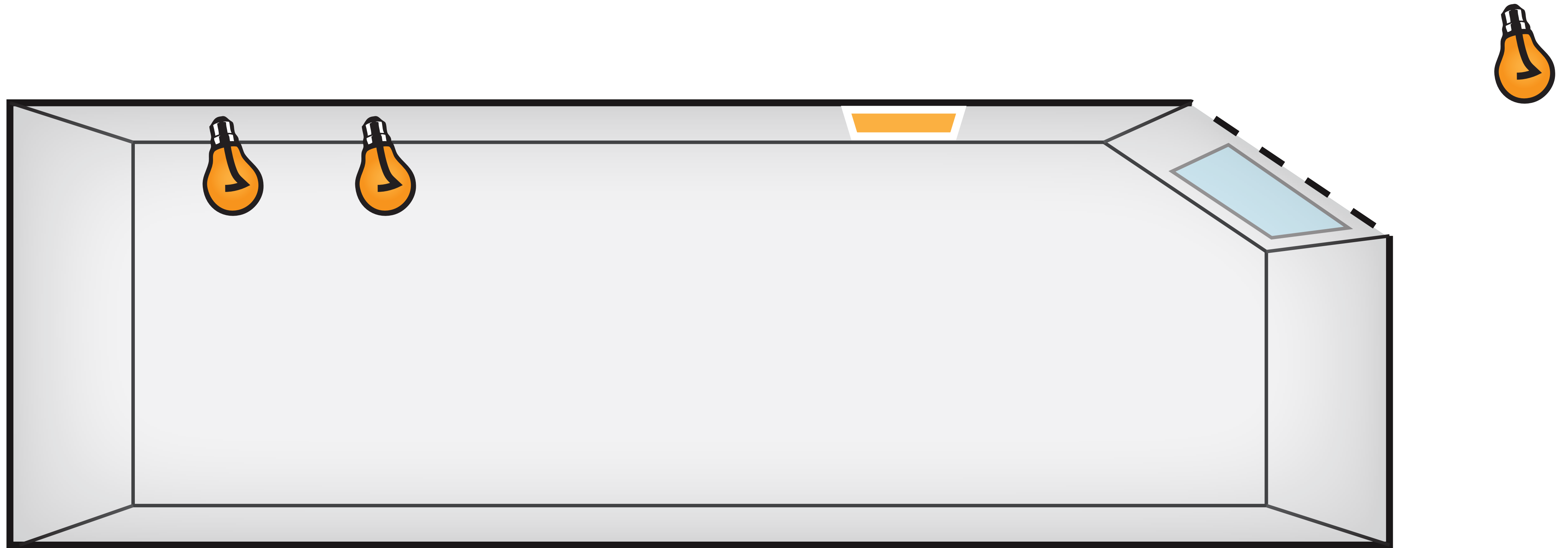
Supporting dynamic lights



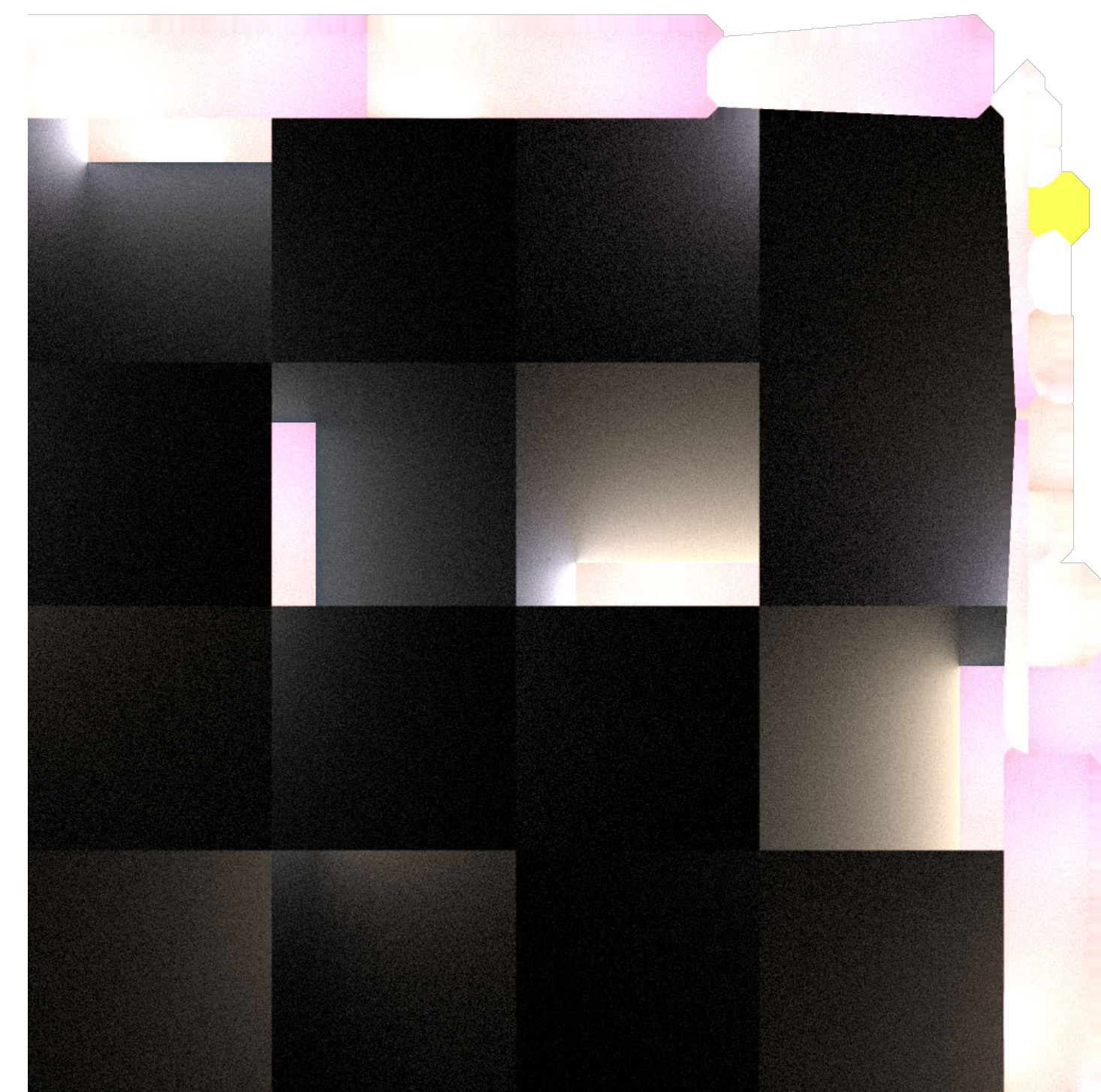
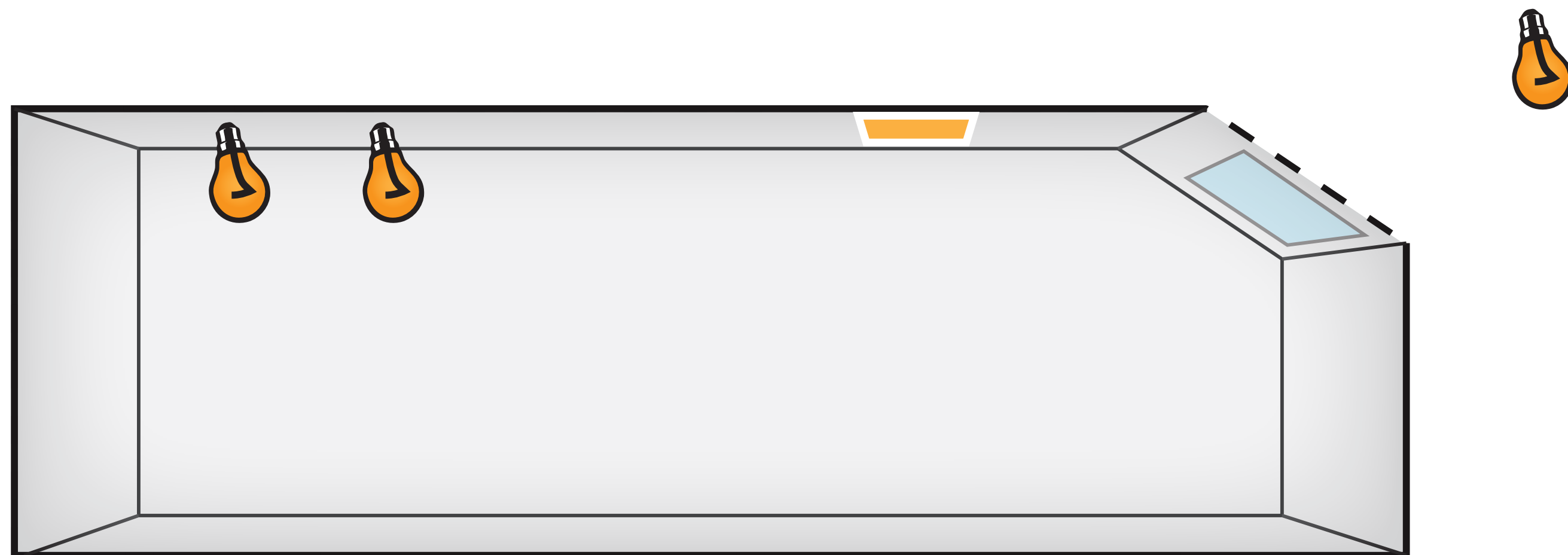
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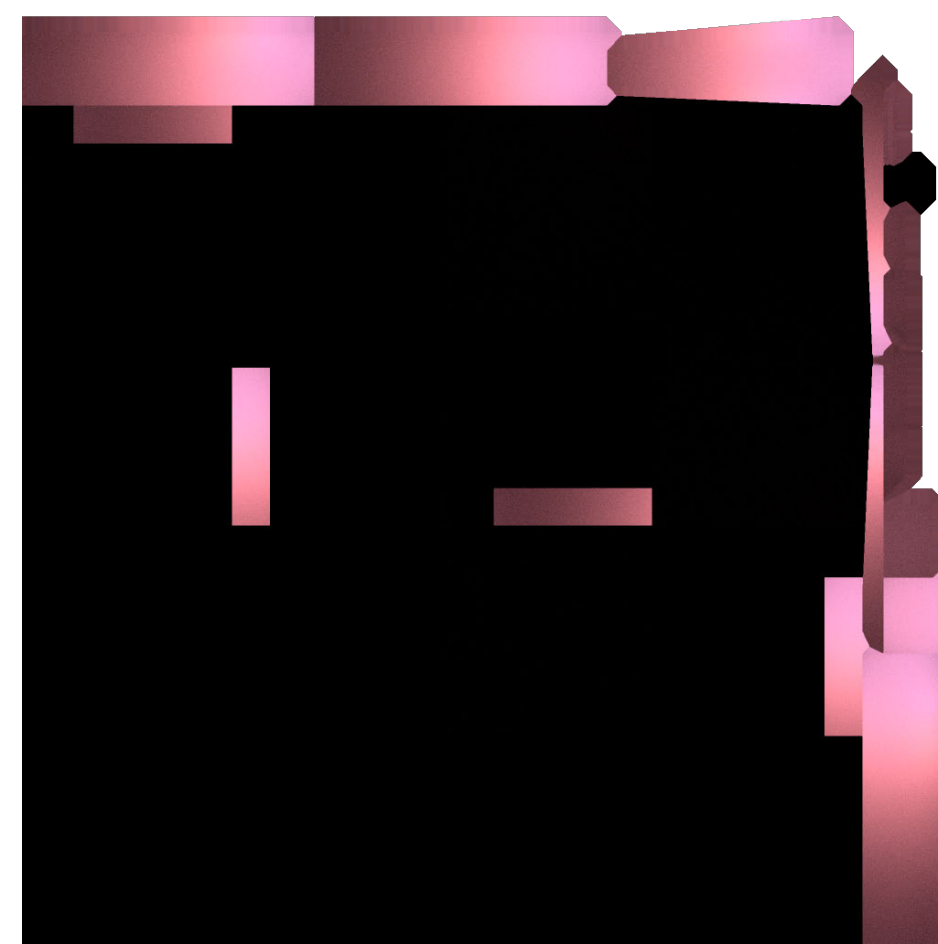
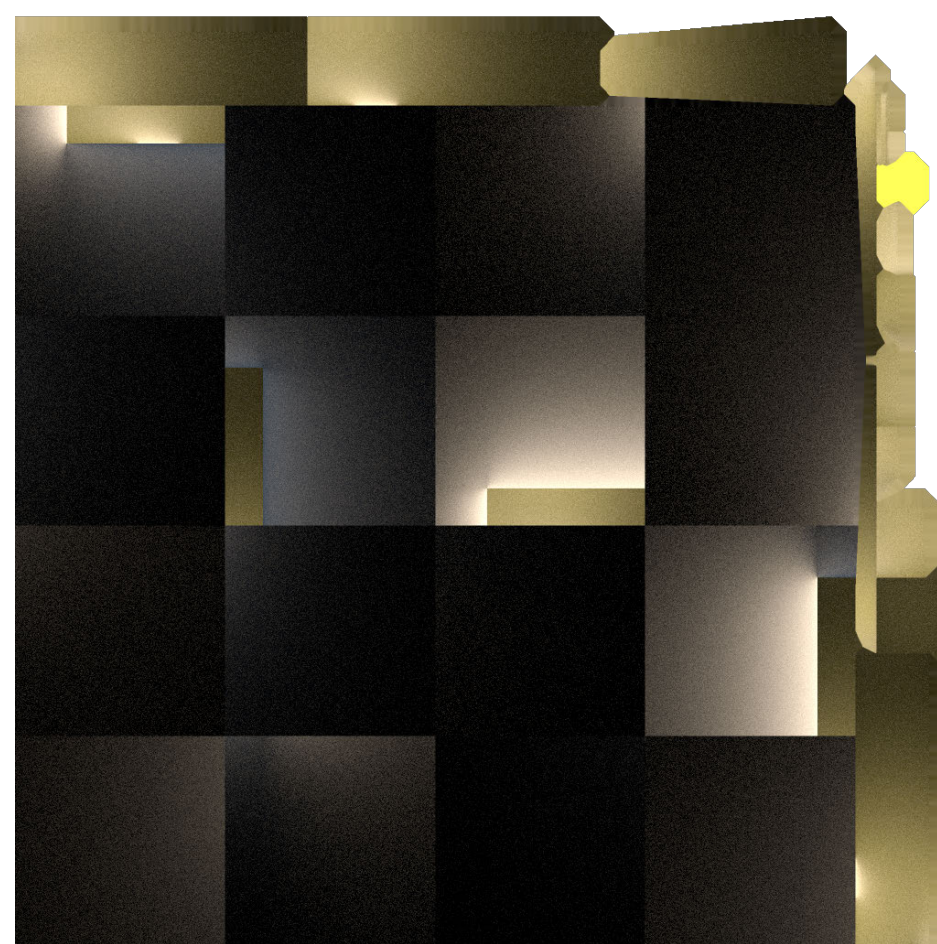
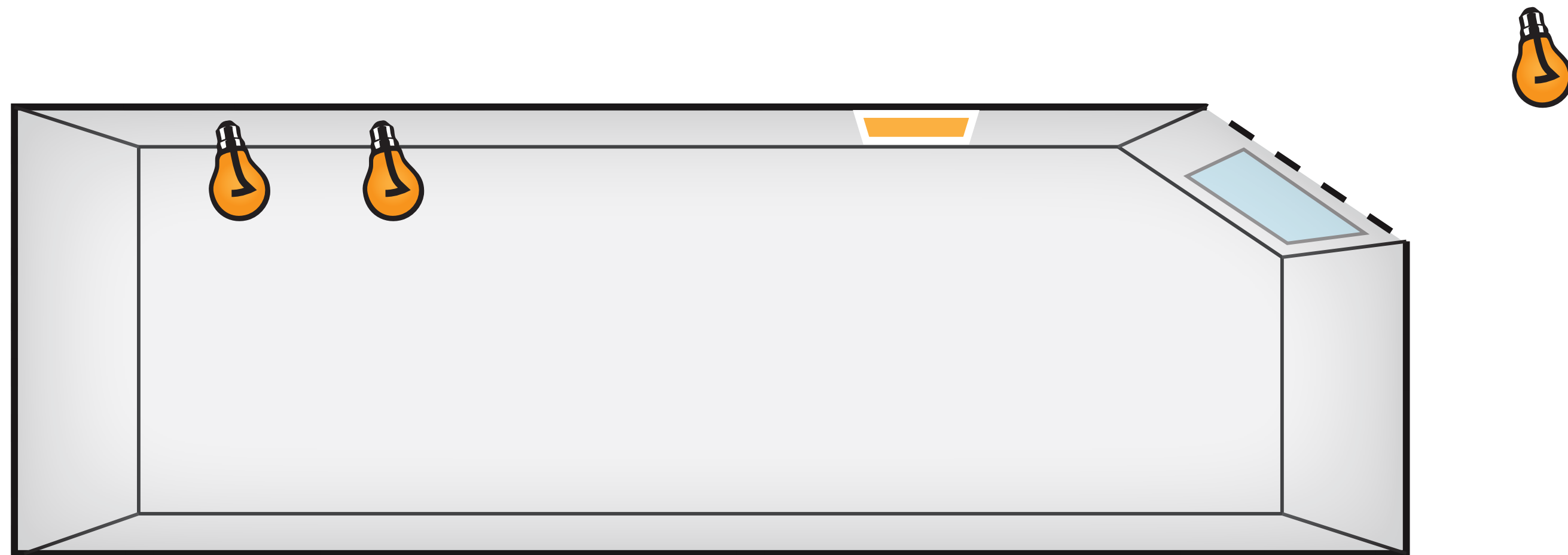


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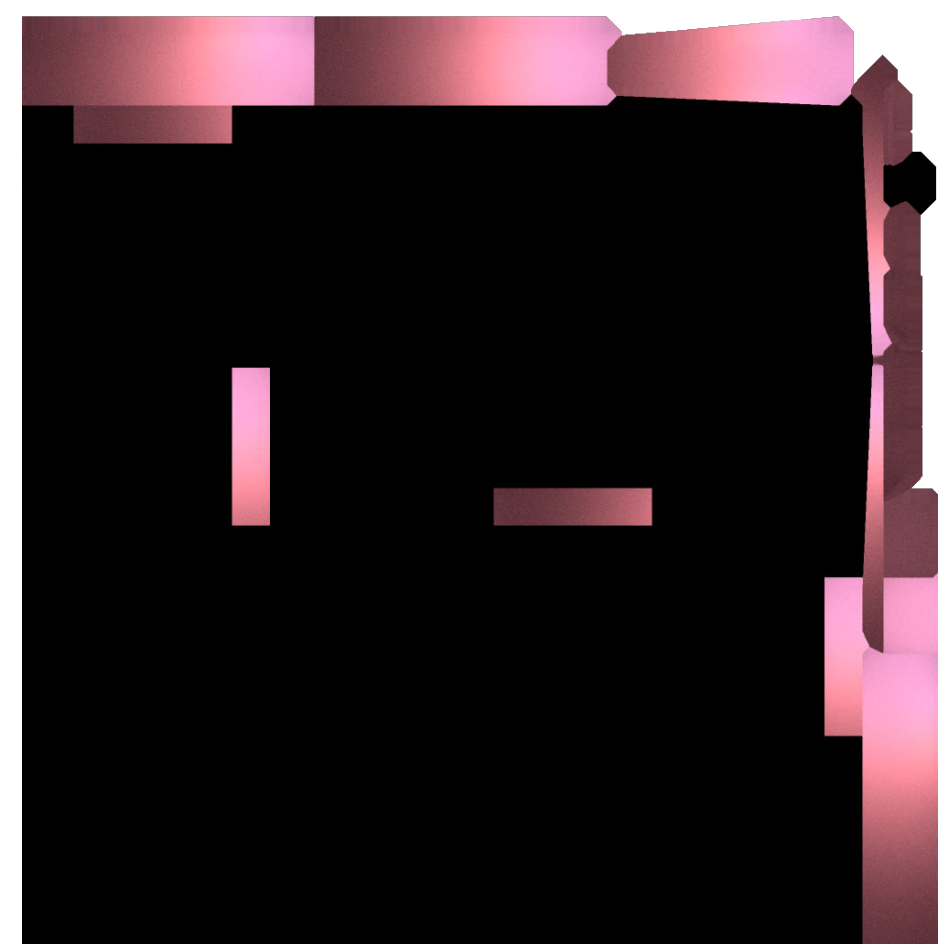
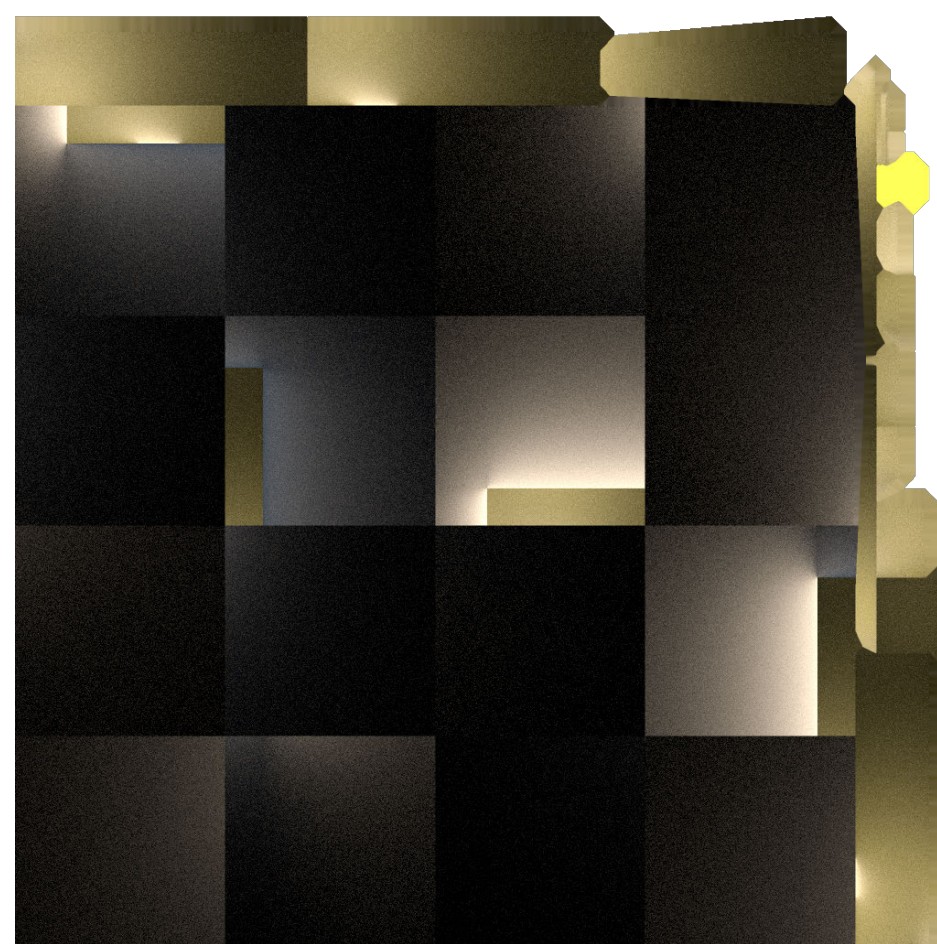
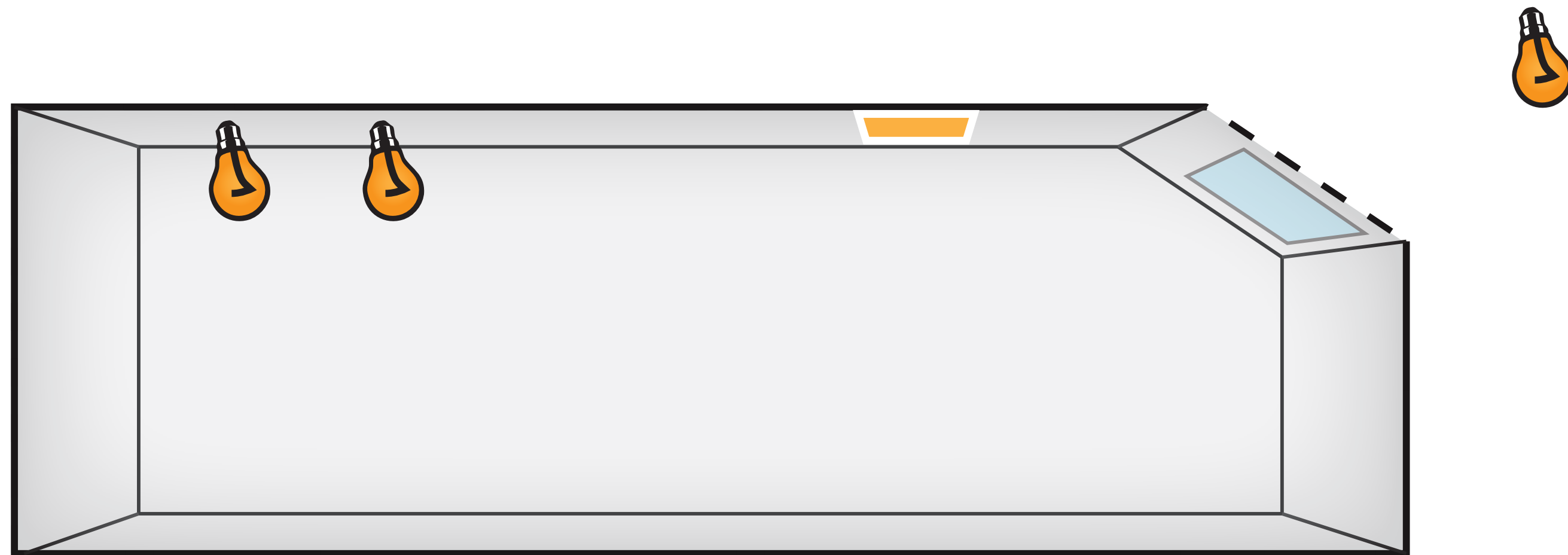


Baked Lighting

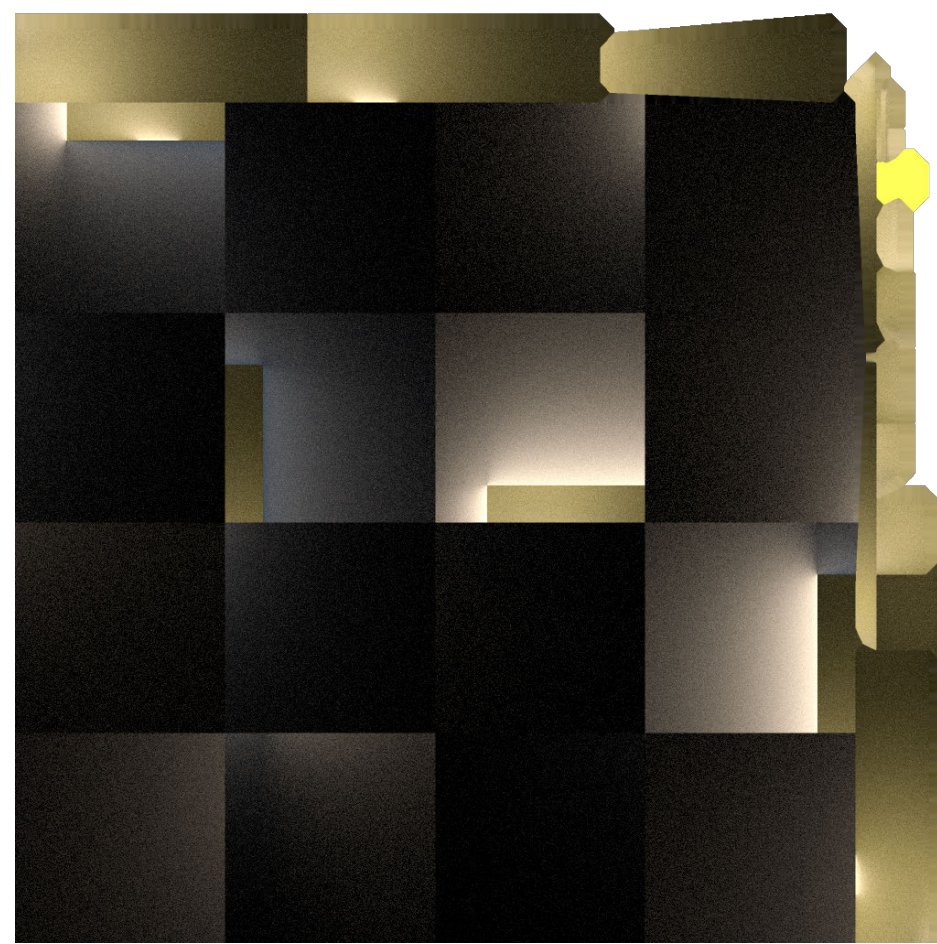
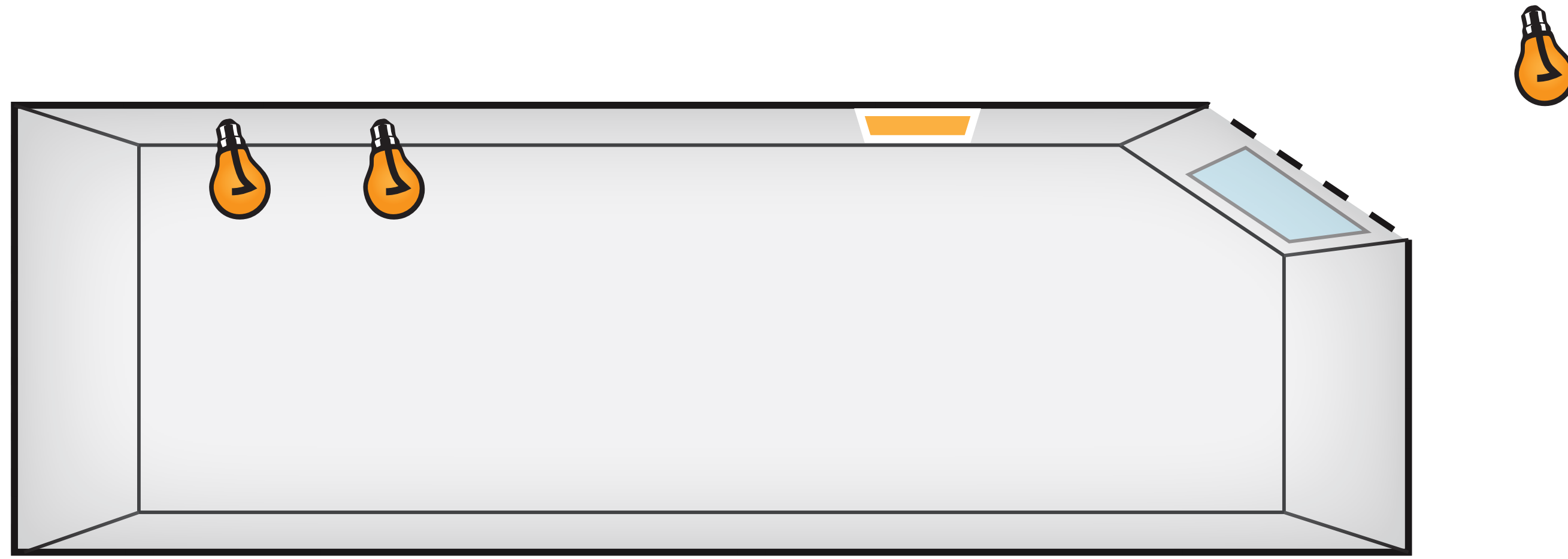
Dynamic Light Sets (DLS)



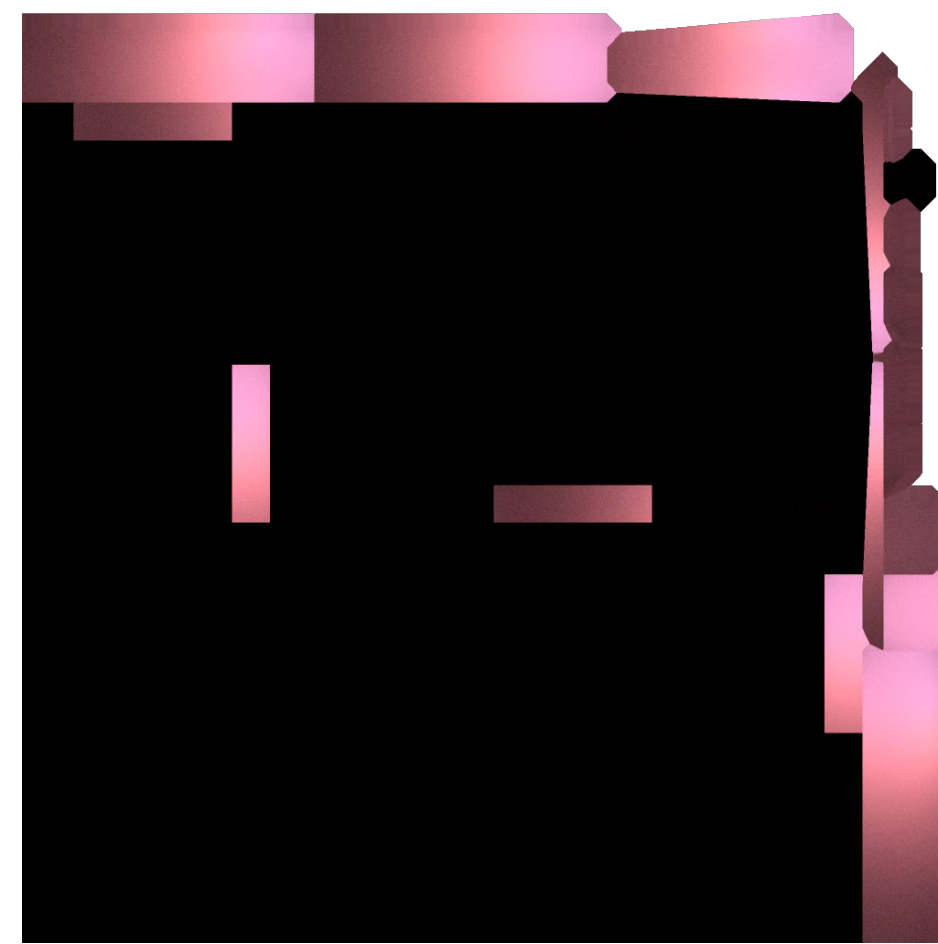
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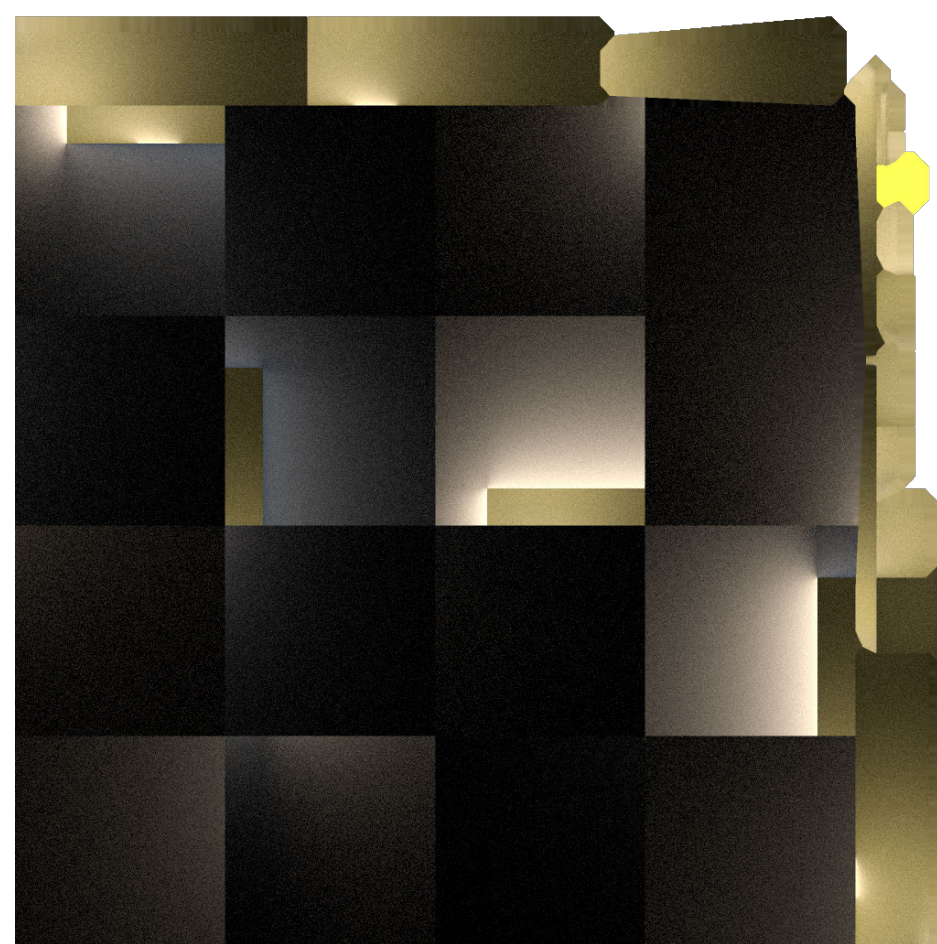
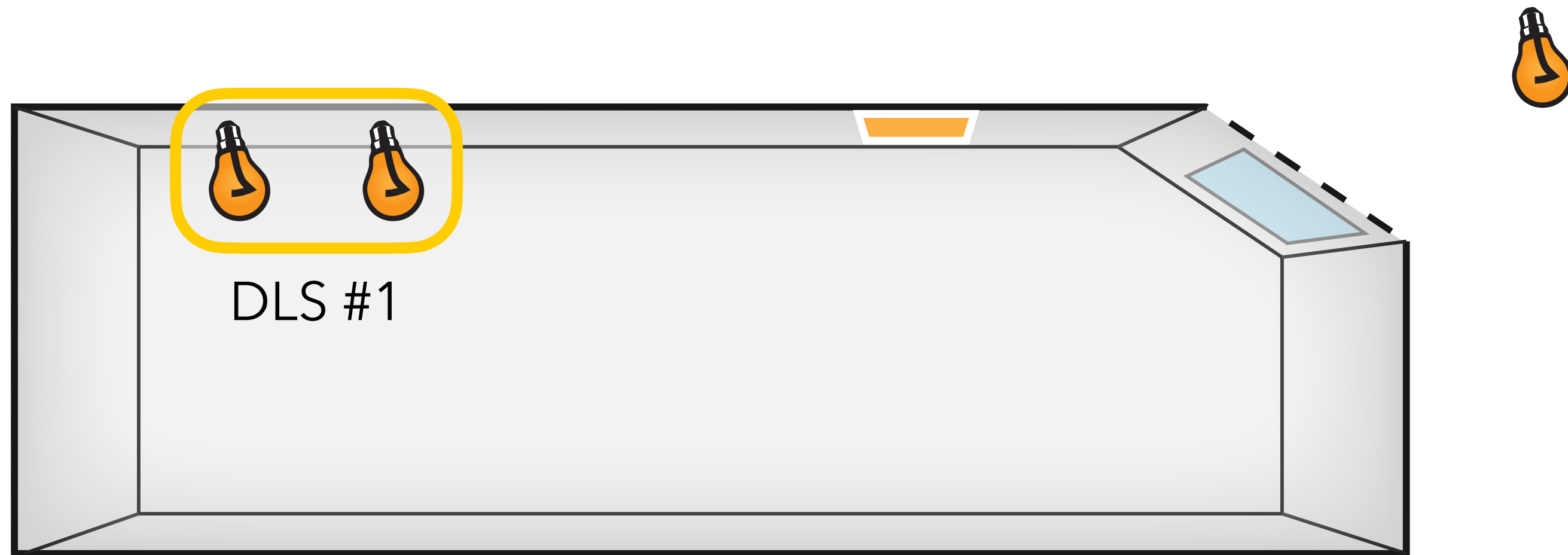
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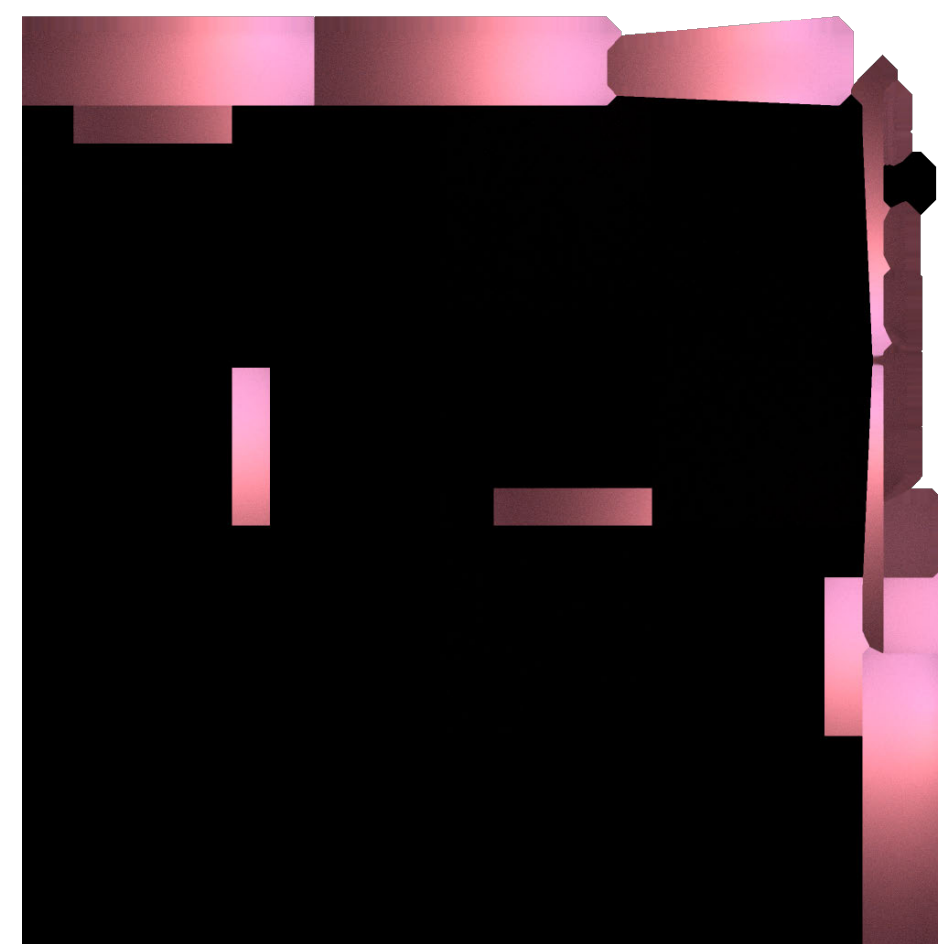
Base Bake



Dynamic Light Sets (DLS)



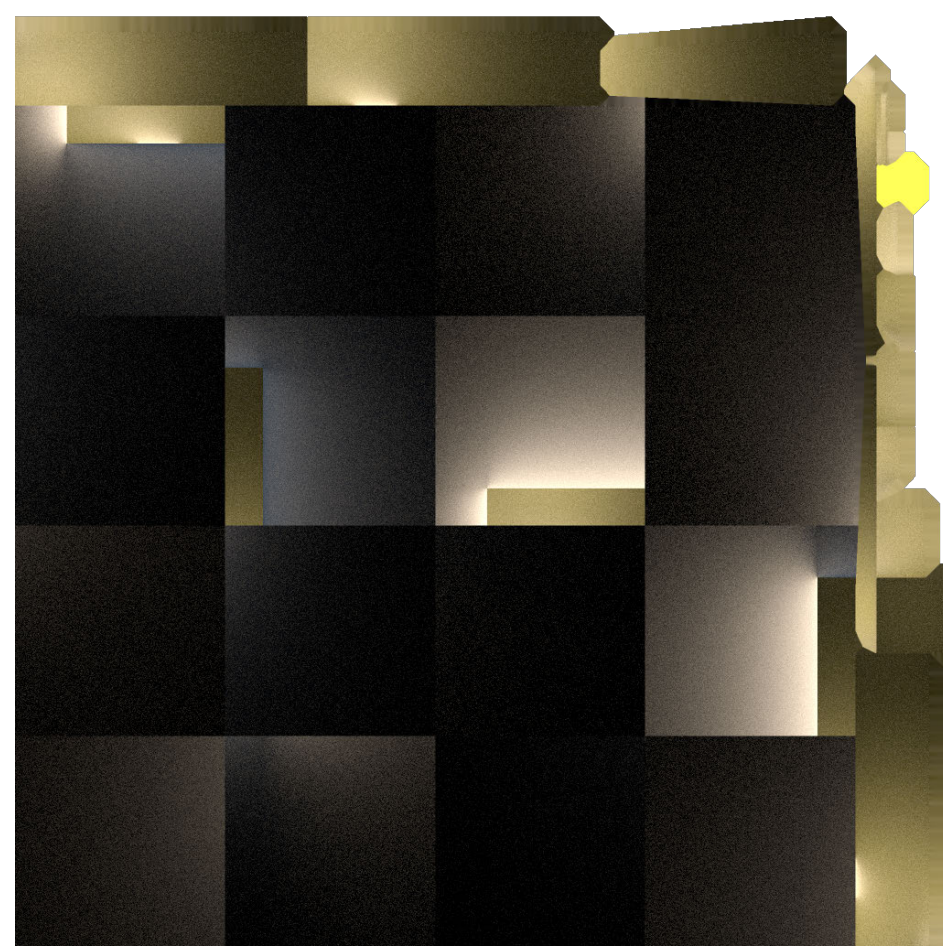
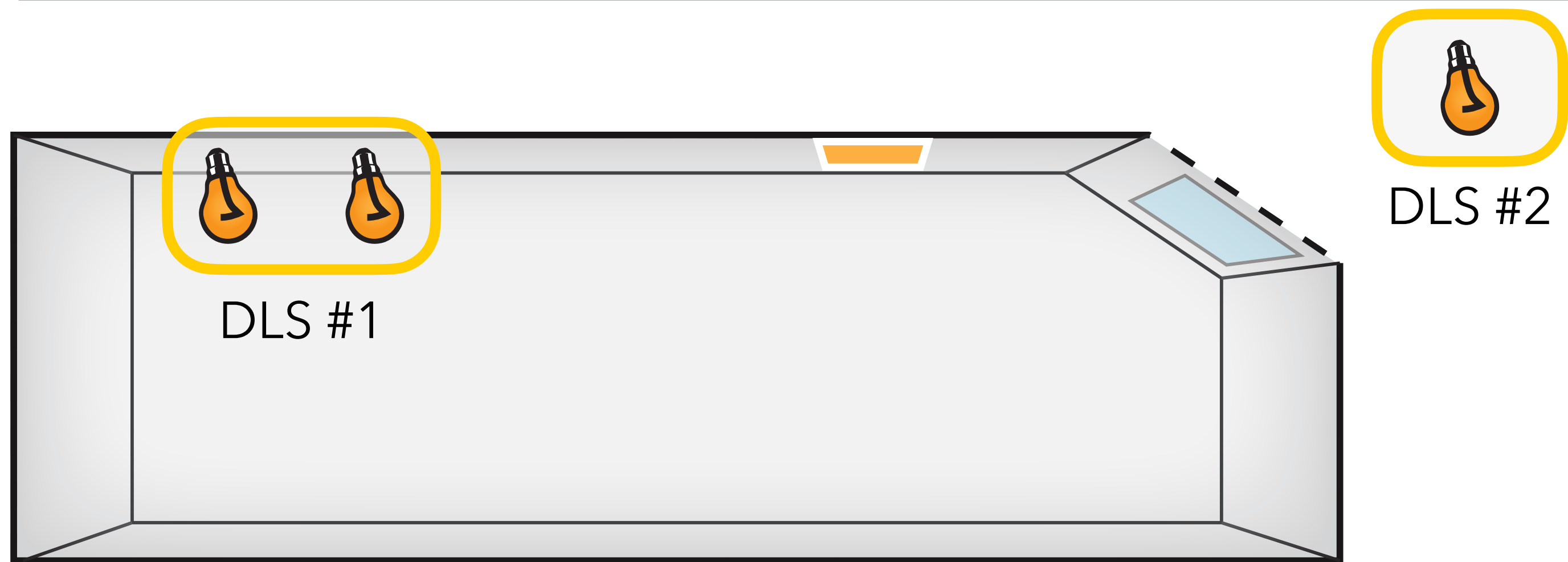
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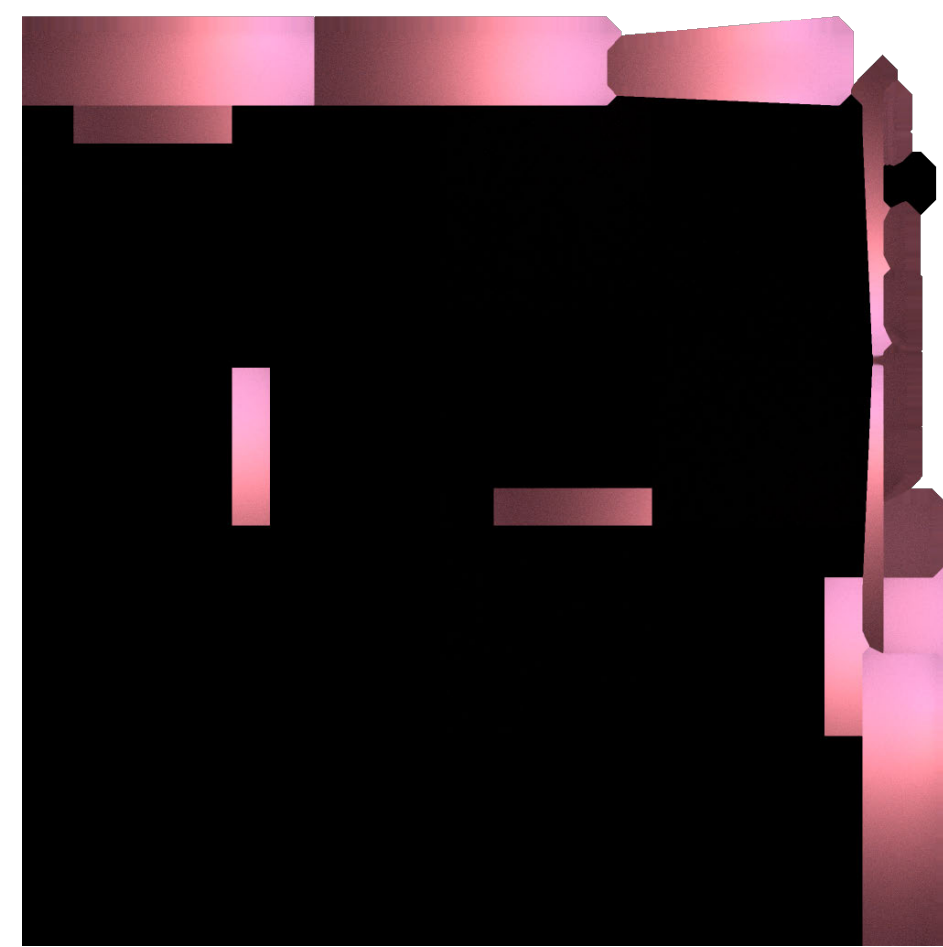
DLS #1



Dynamic Light Sets (DLS)



Base Bake



DLS #1

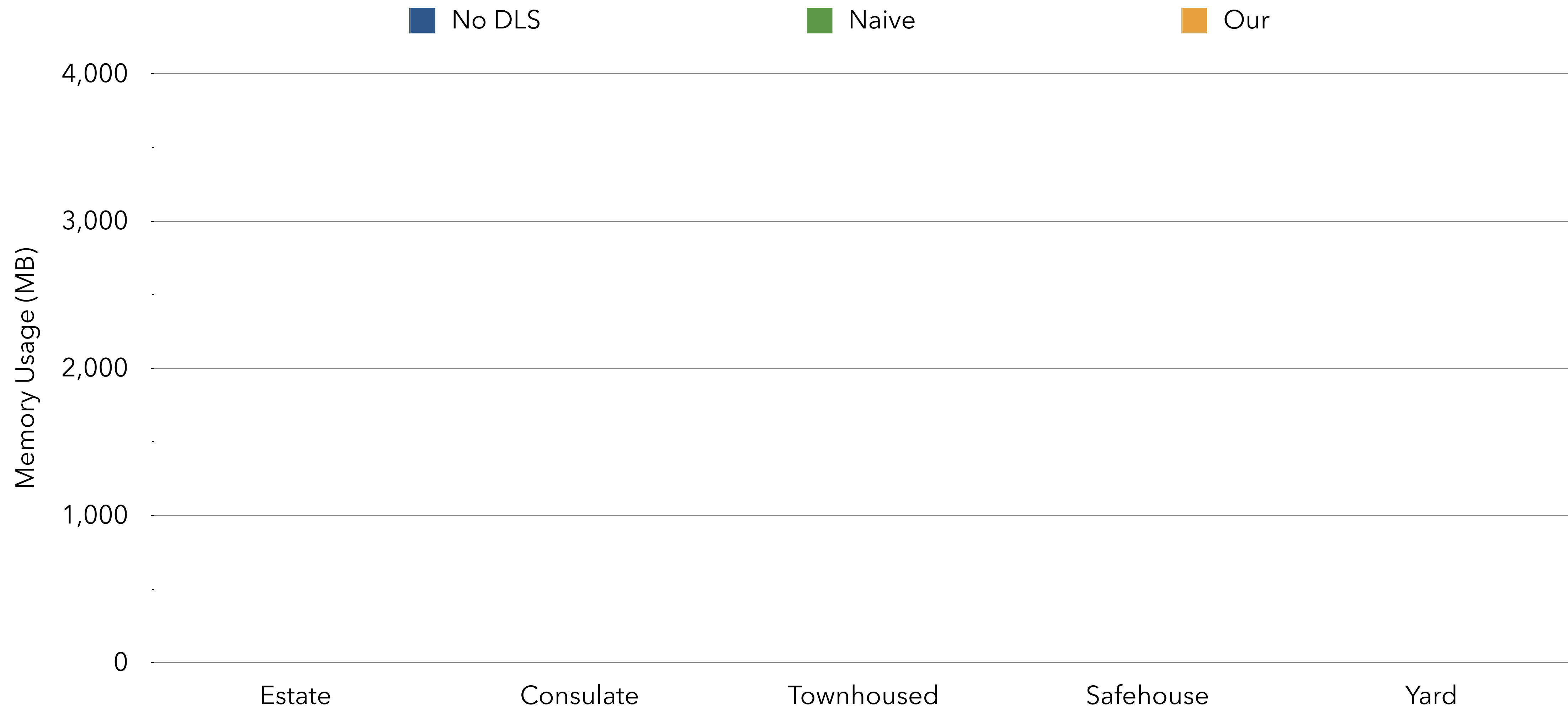


DLS #2

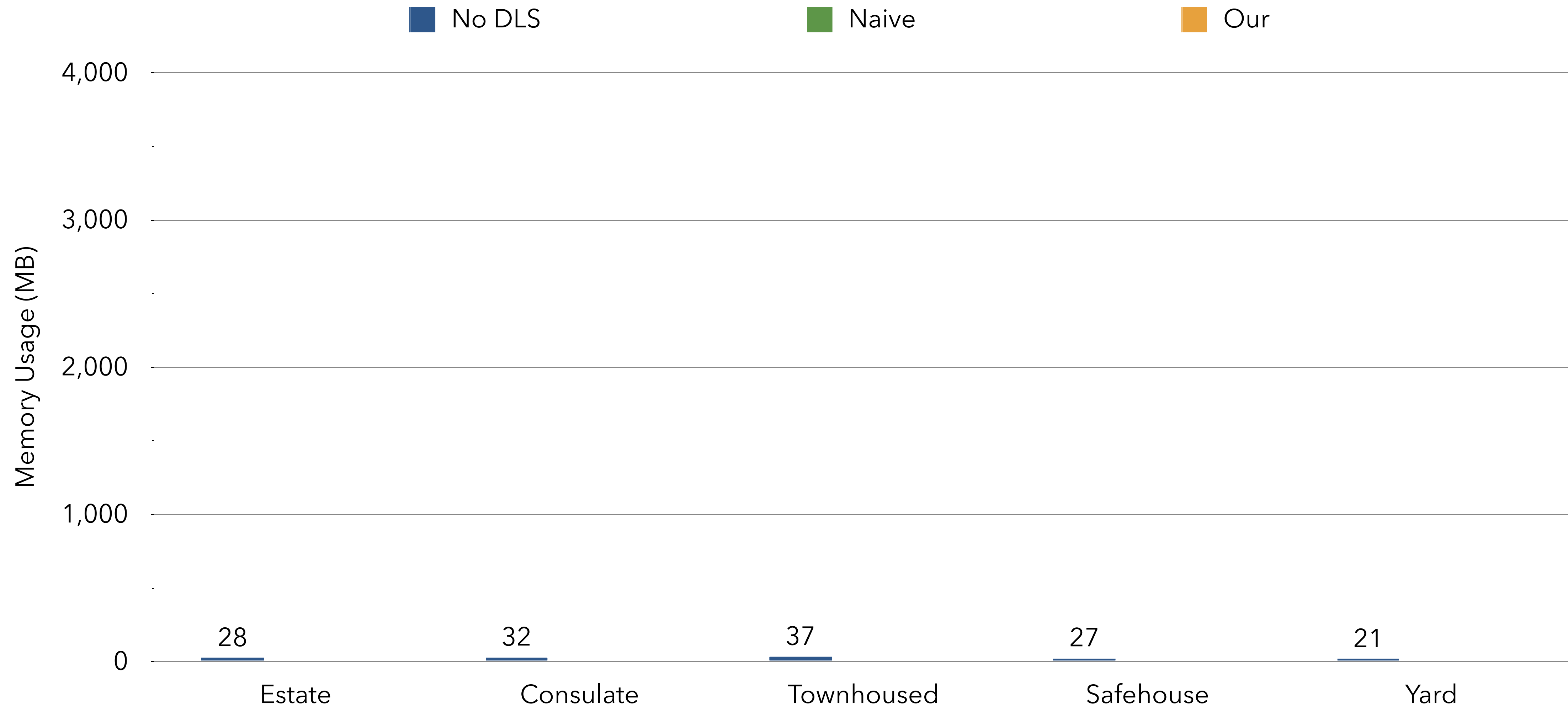


Large memory requirements

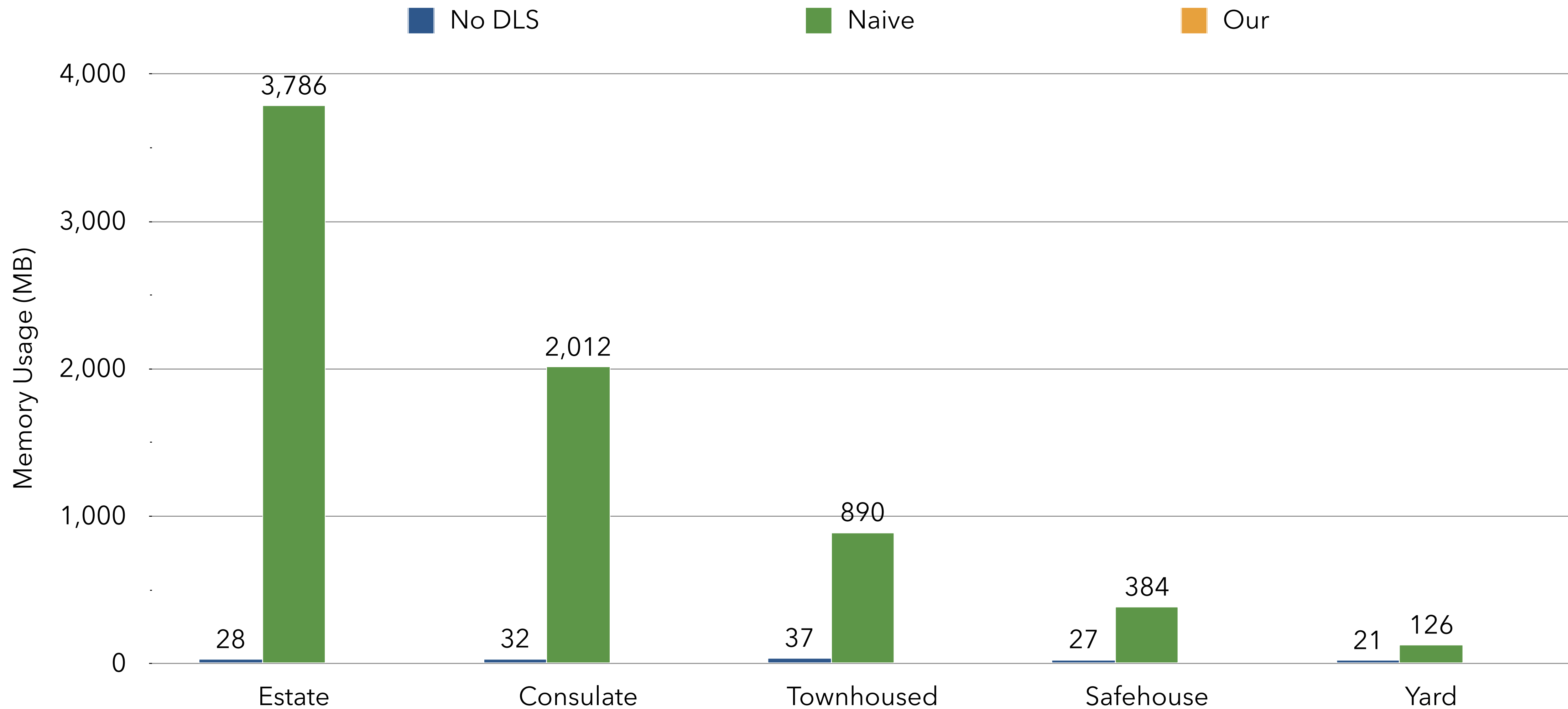
Large memory requirements



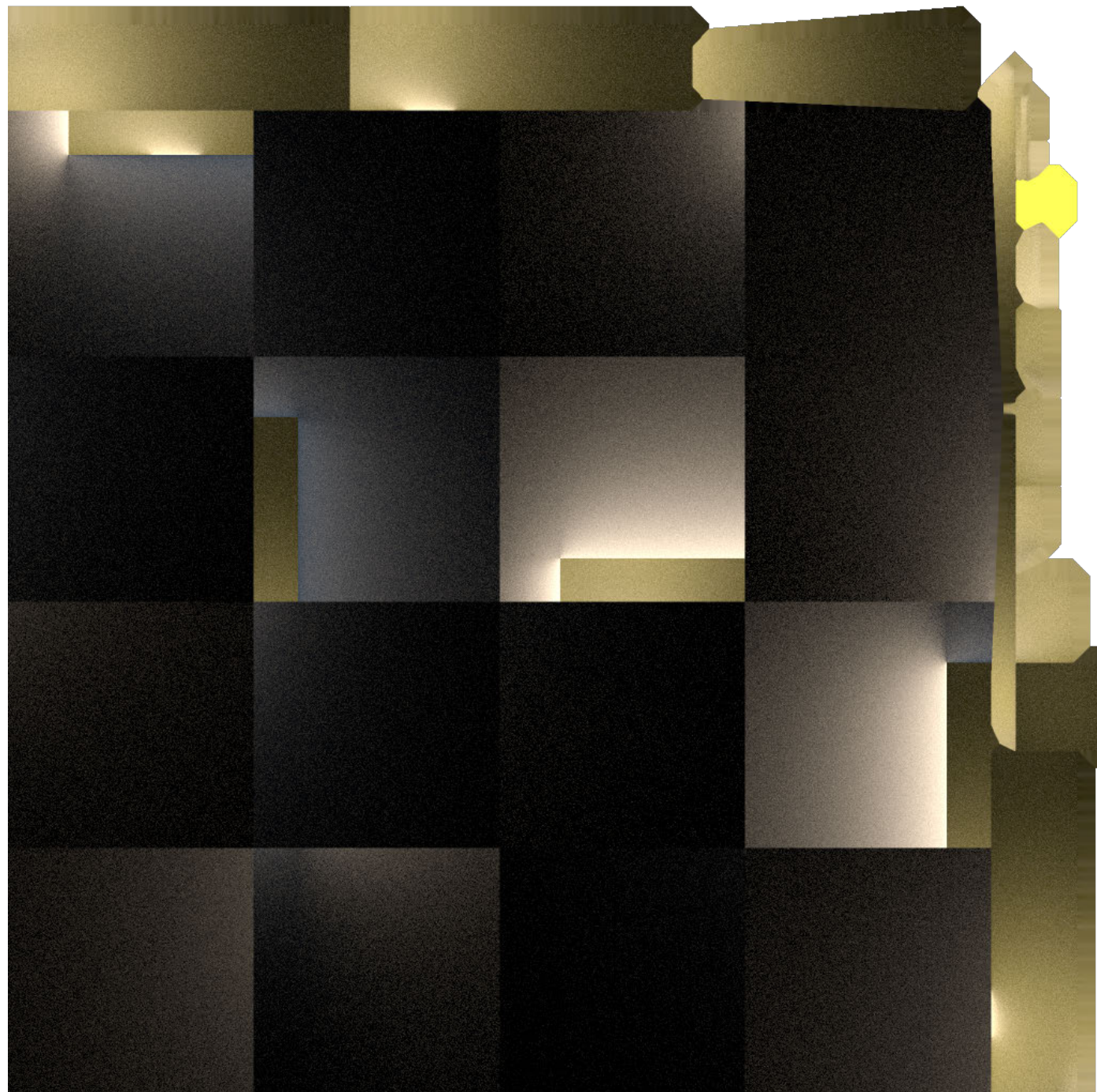
Large memory requirements



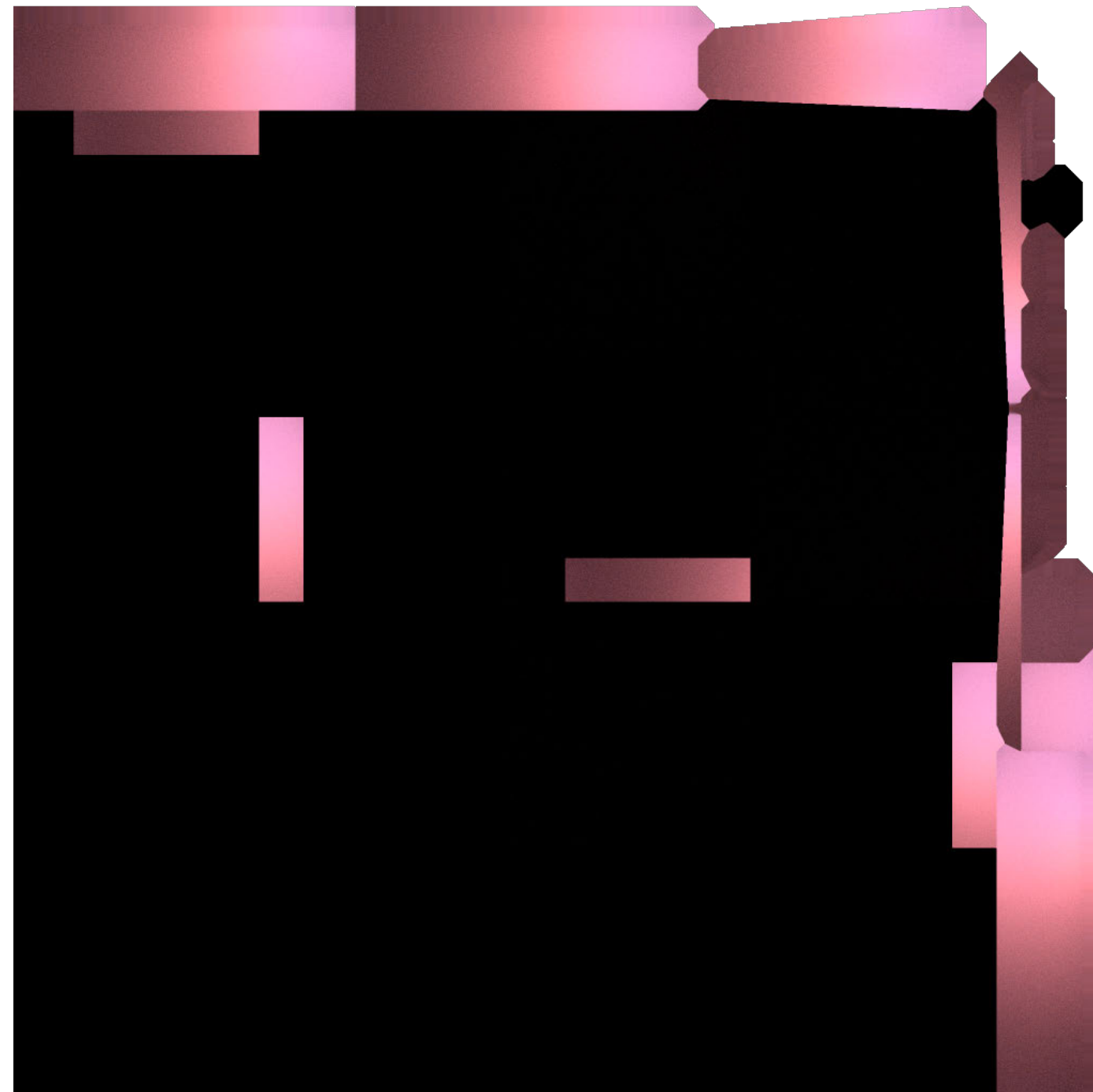
Large memory requirements



Sparse light maps for dynamic light sets



Base Bake

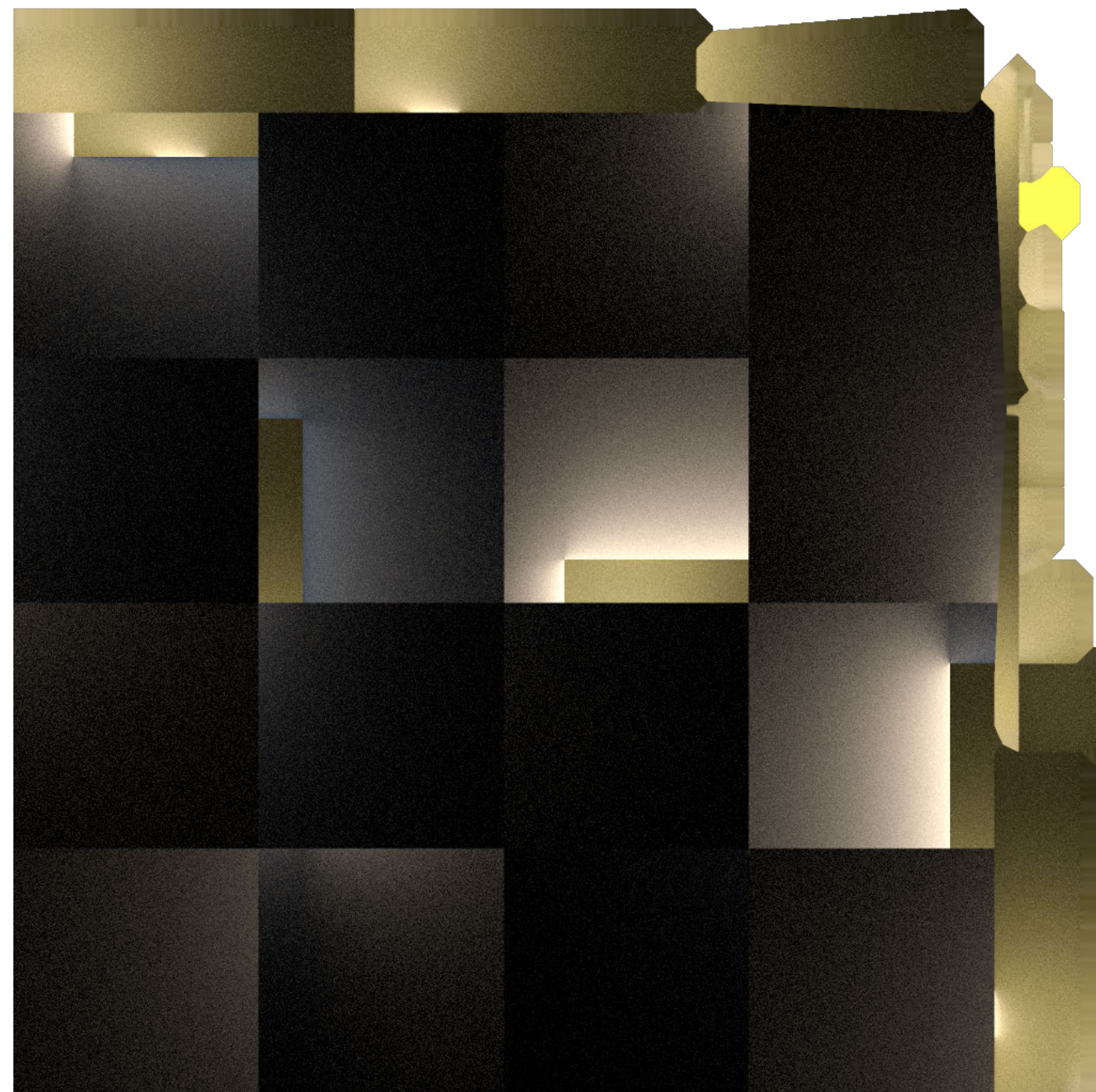


DLS #1

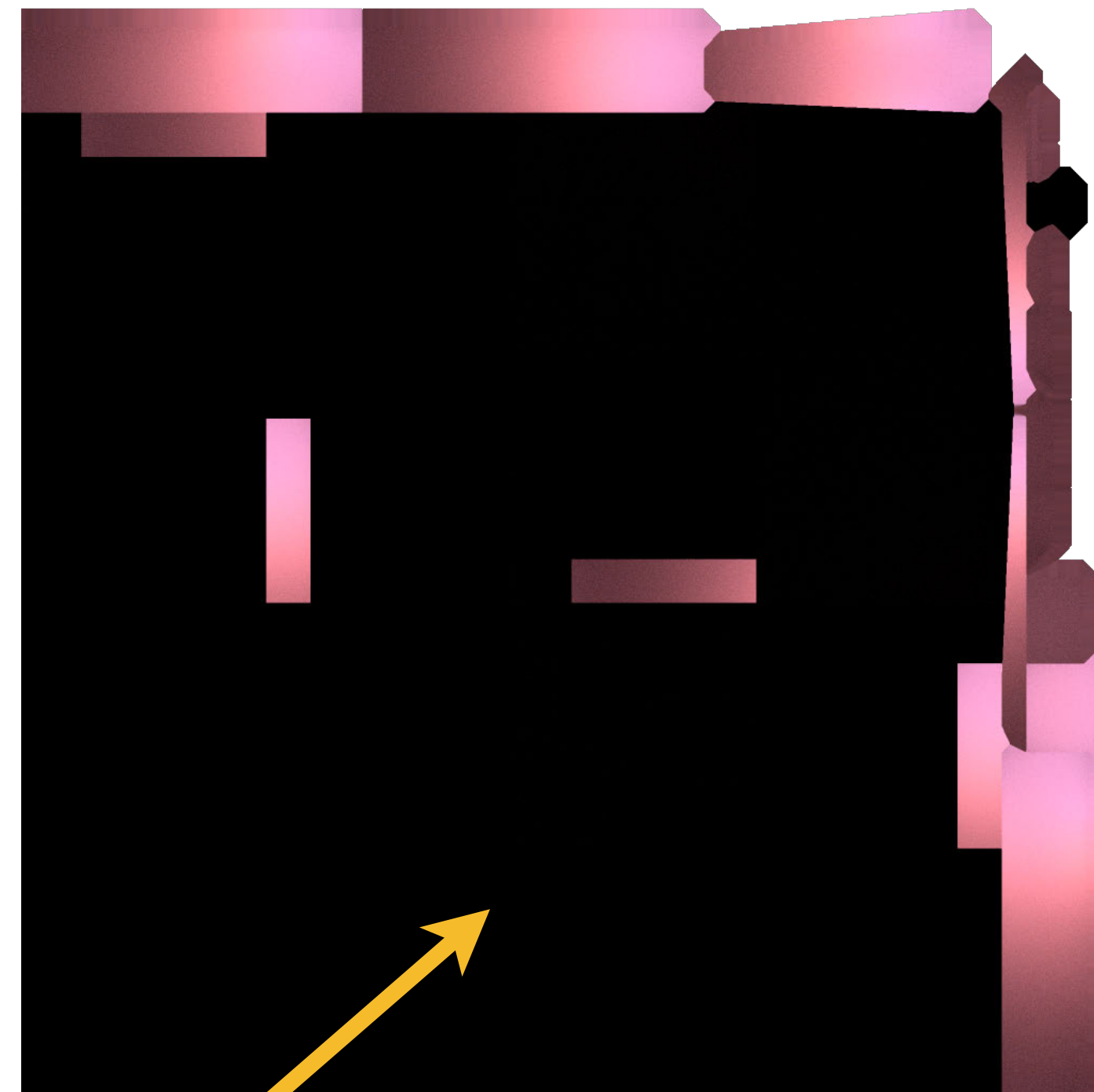


DLS #2

Sparse light maps for dynamic light sets



Base Bake

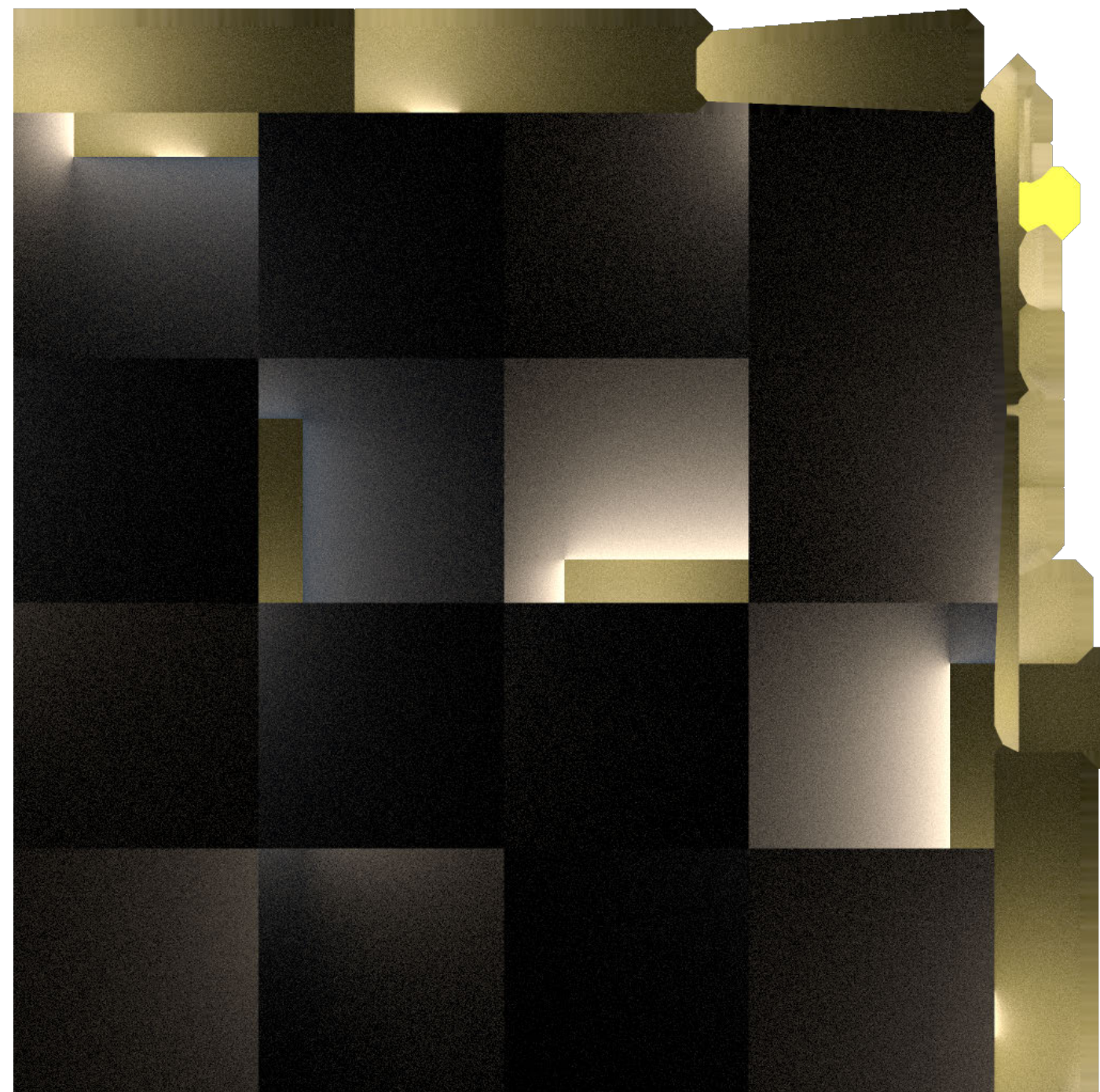


DLS #1

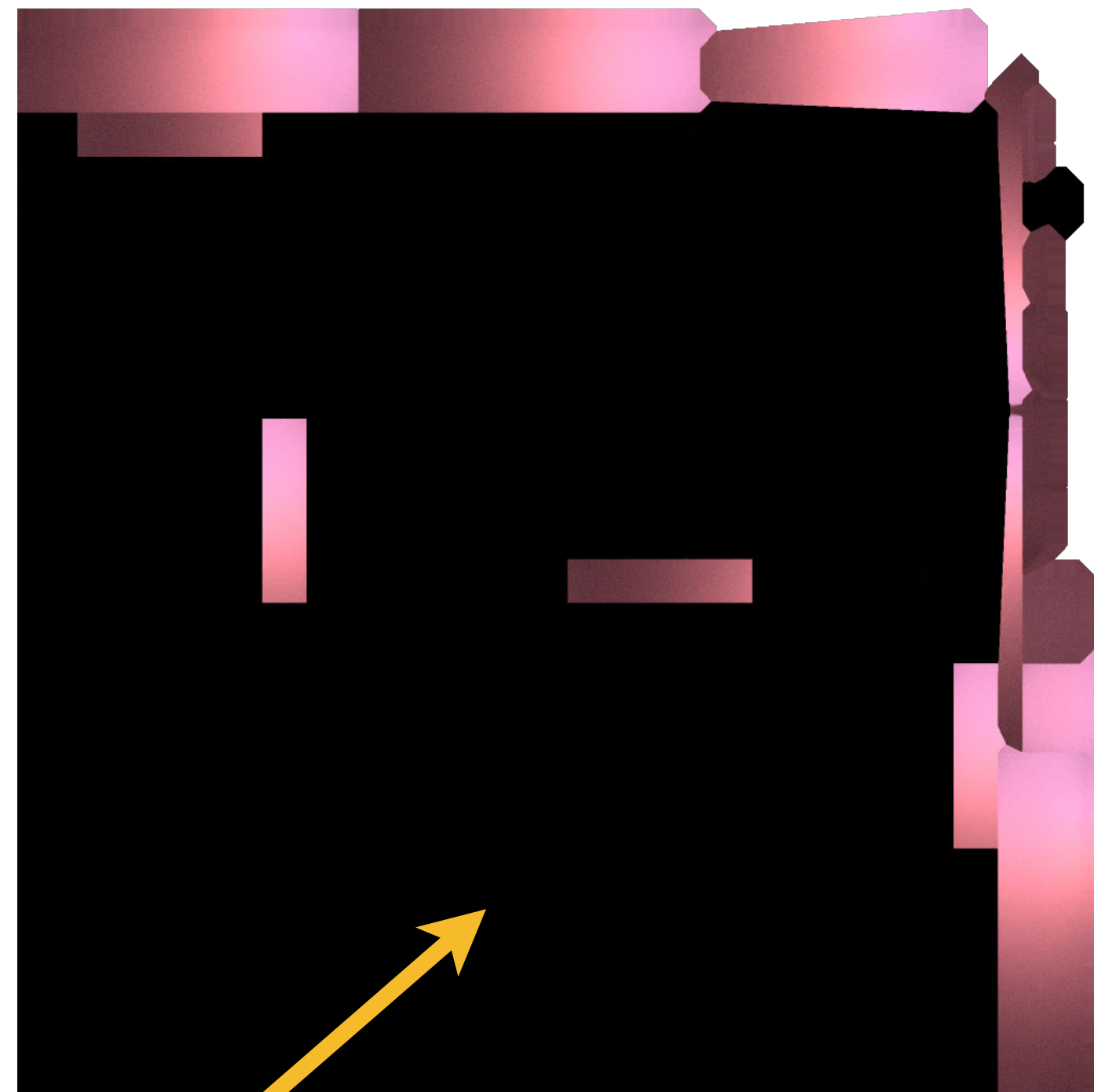


DLS #2

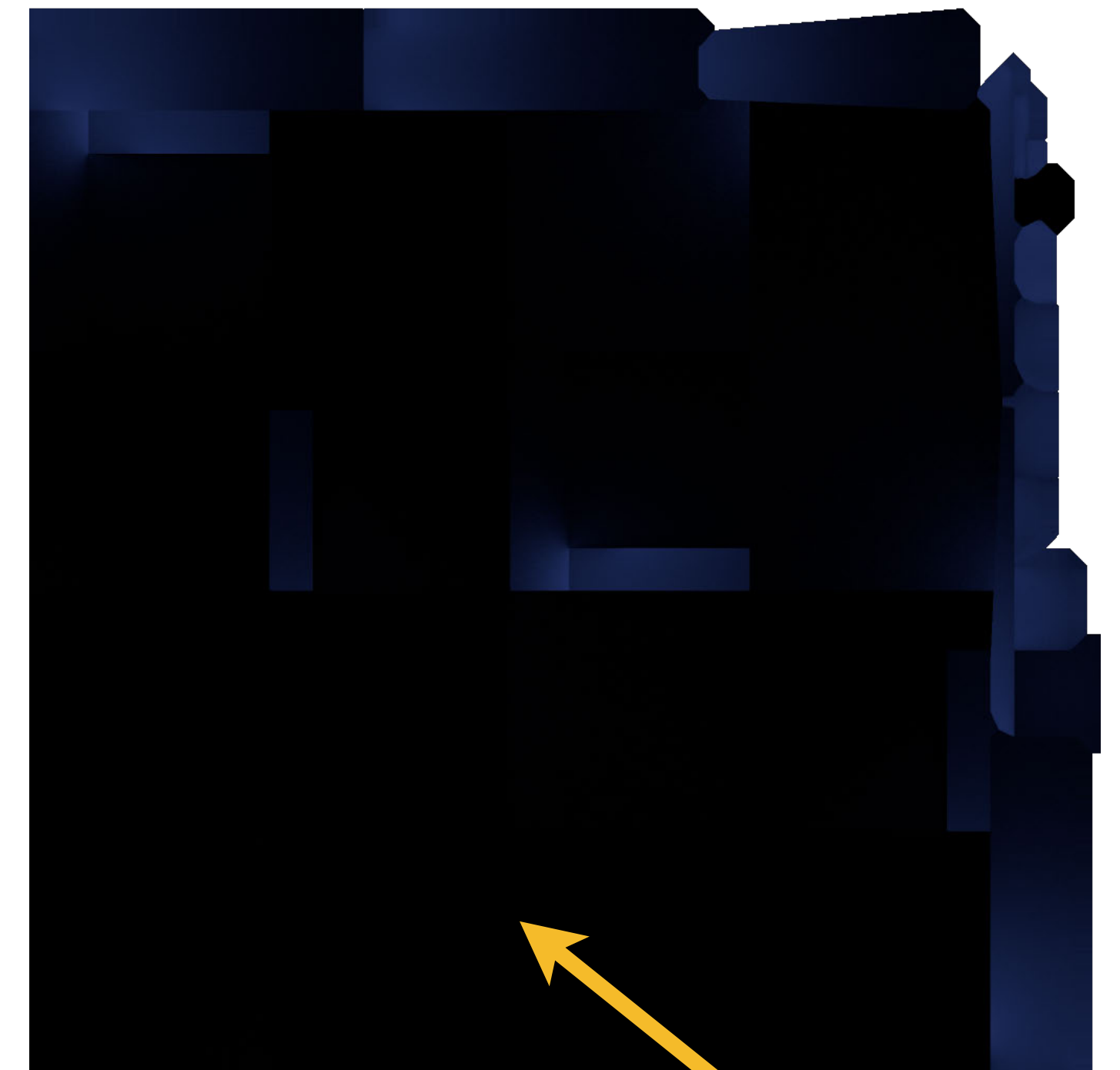
Sparse light maps for dynamic light sets



Base Bake

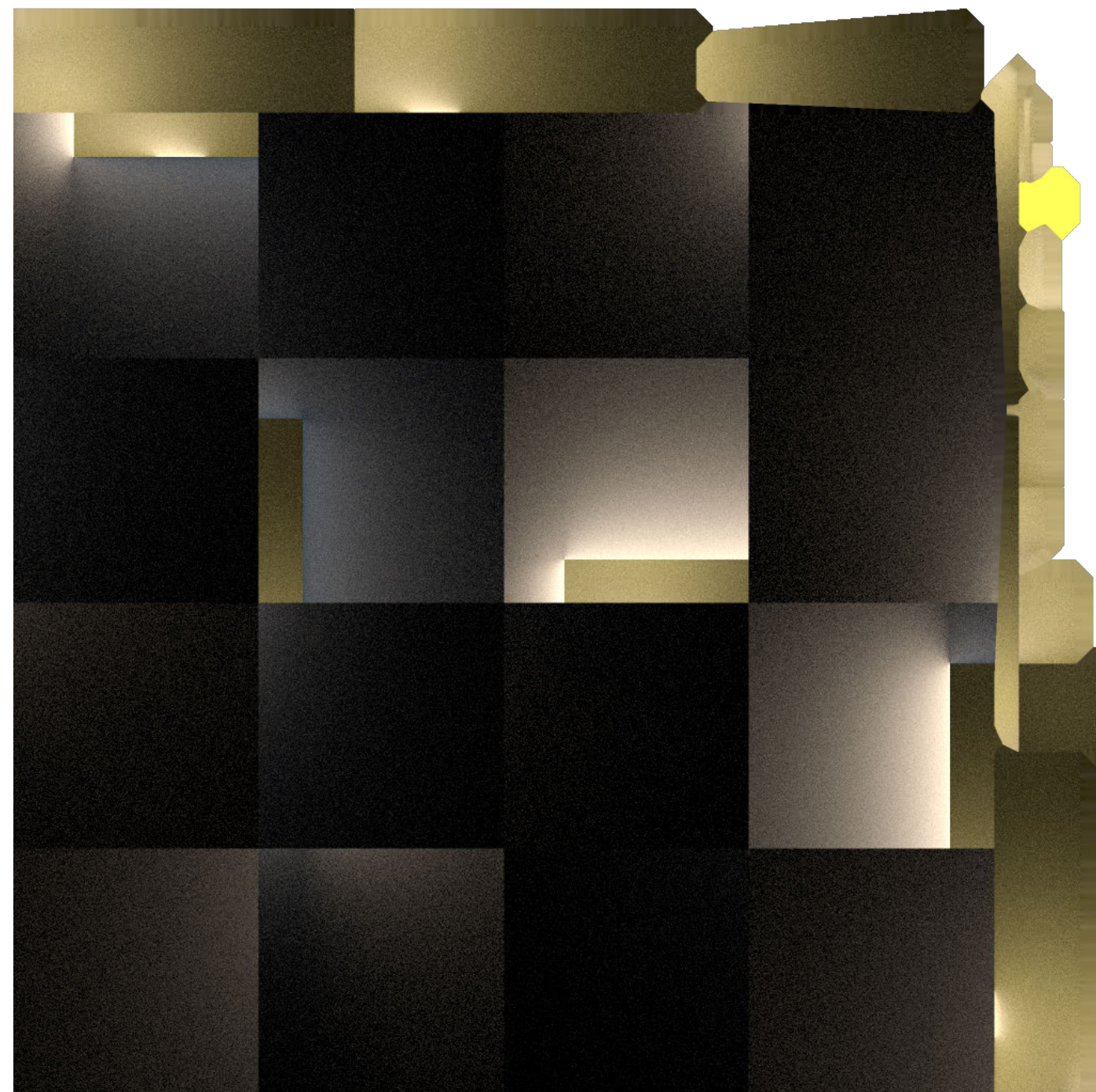


DLS #1



DLS #2

Sparse light maps for dynamic light sets



Base Bake

Texel ID	Value
0	Red
2	Pink
41	Dark Red
53	Red
56	Red
75	Pink
94	Dark Red
124	Red

⋮

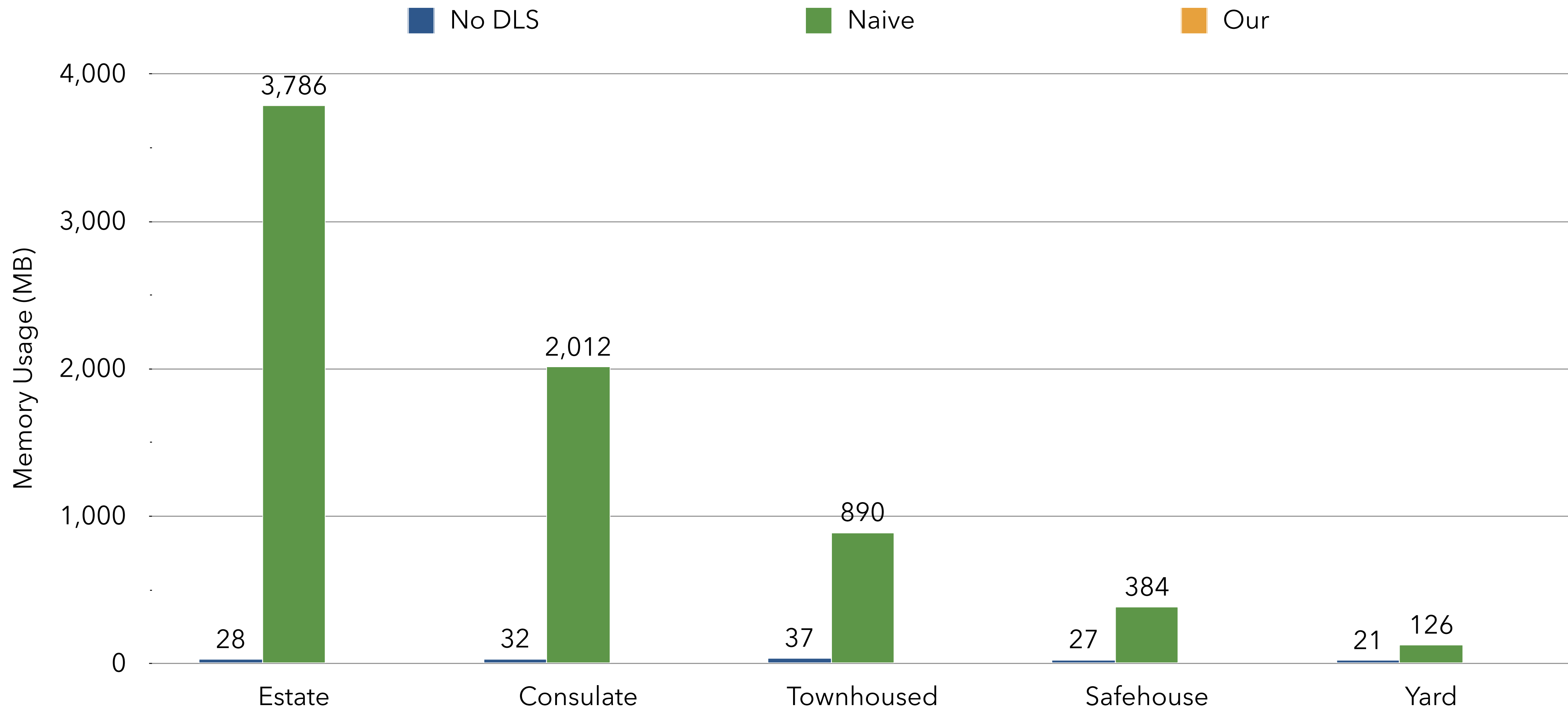
DLS #1

Texel ID	Value
32	Dark Blue
54	Dark Blue
64	Dark Blue
65	Dark Blue
73	Dark Blue
77	Black
81	Dark Blue
109	Blue

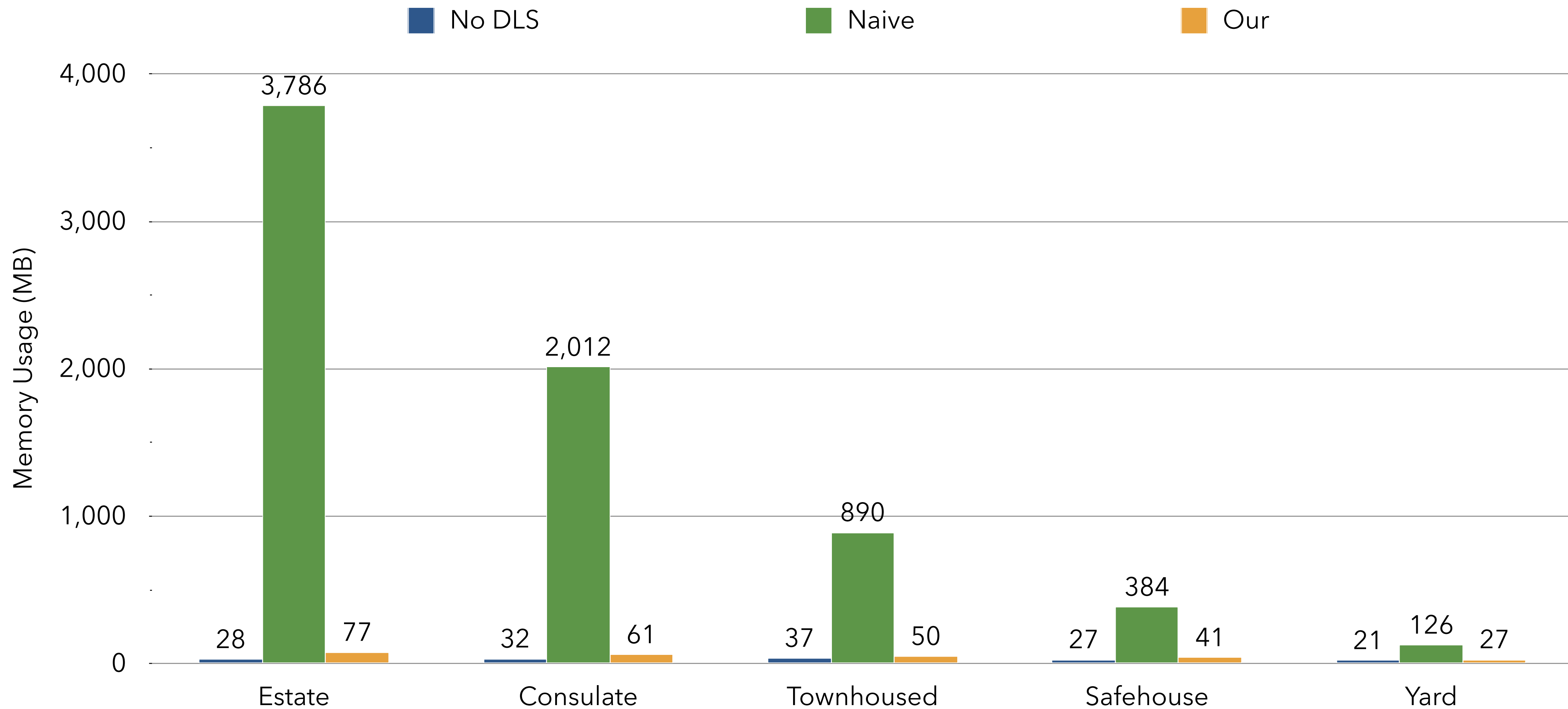
⋮

DLS #2

Reducing memory usage

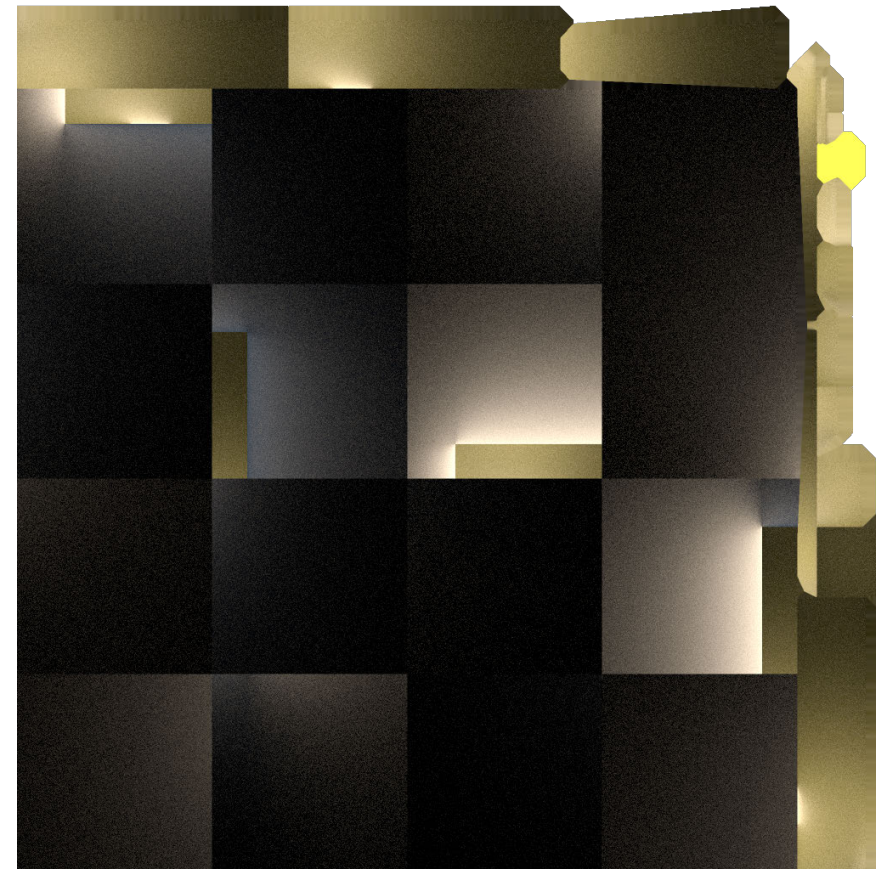


Reducing memory usage



Run-time combination of dynamic light sets

Base
Bake



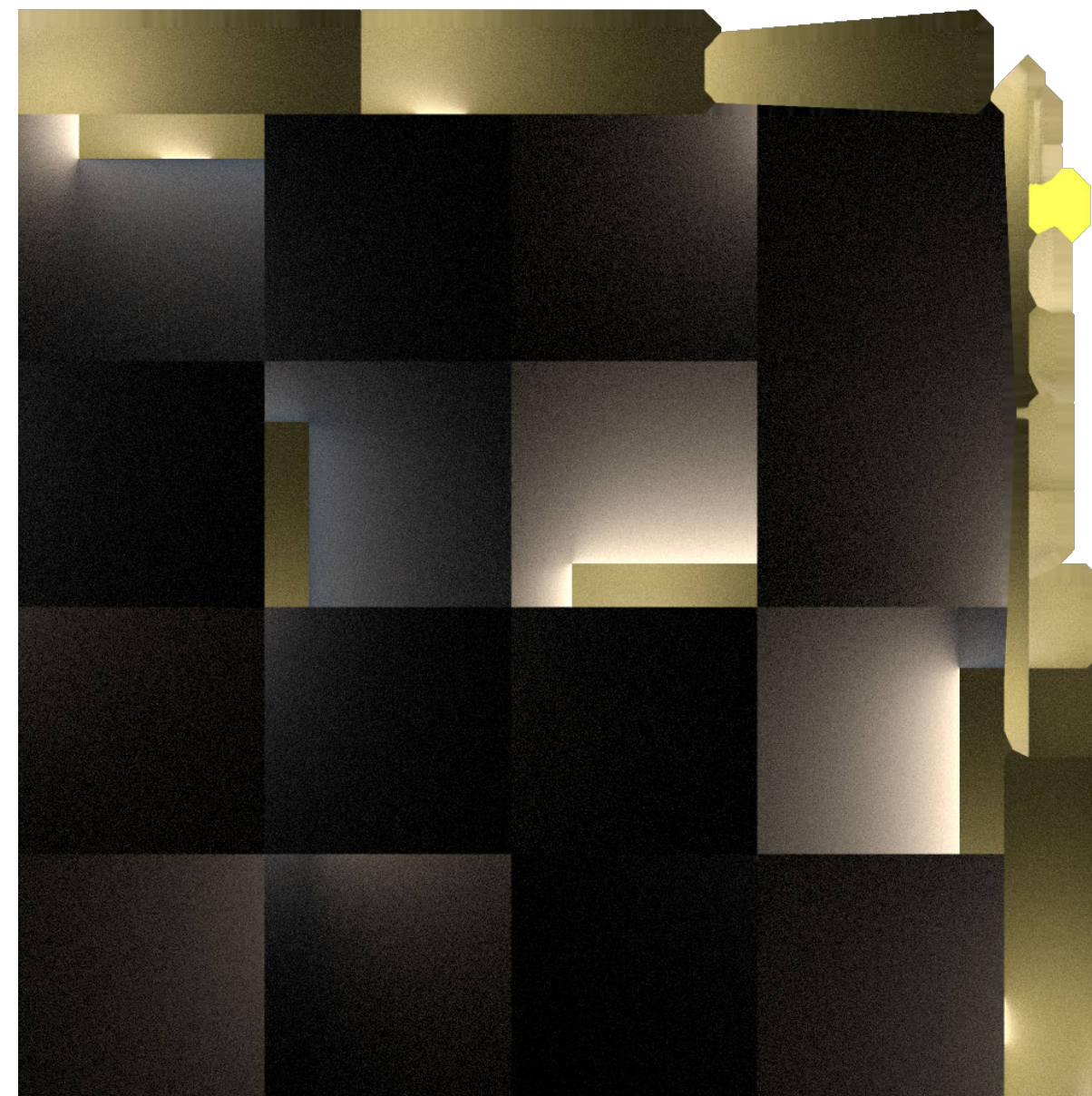
DLS #1

Tex	Val
0	Red
2	Pink
41	Dark Red
53	Red
56	Red
75	Pink
94	Dark Red
124	Red
⋮	

DLS #2

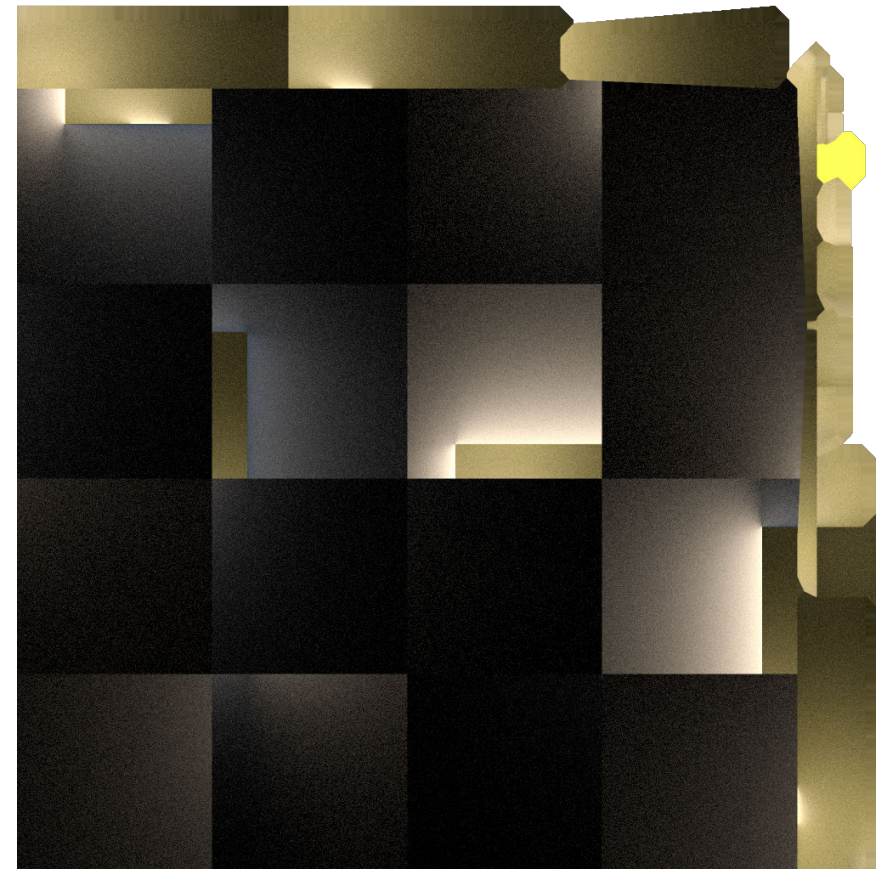
Tex	Val
32	Dark Blue
54	Dark Blue
64	Dark Blue
65	Dark Blue
73	Dark Blue
77	Black
81	Dark Blue
109	Blue
⋮	

Final



Run-time combination of dynamic light sets

Base
Bake



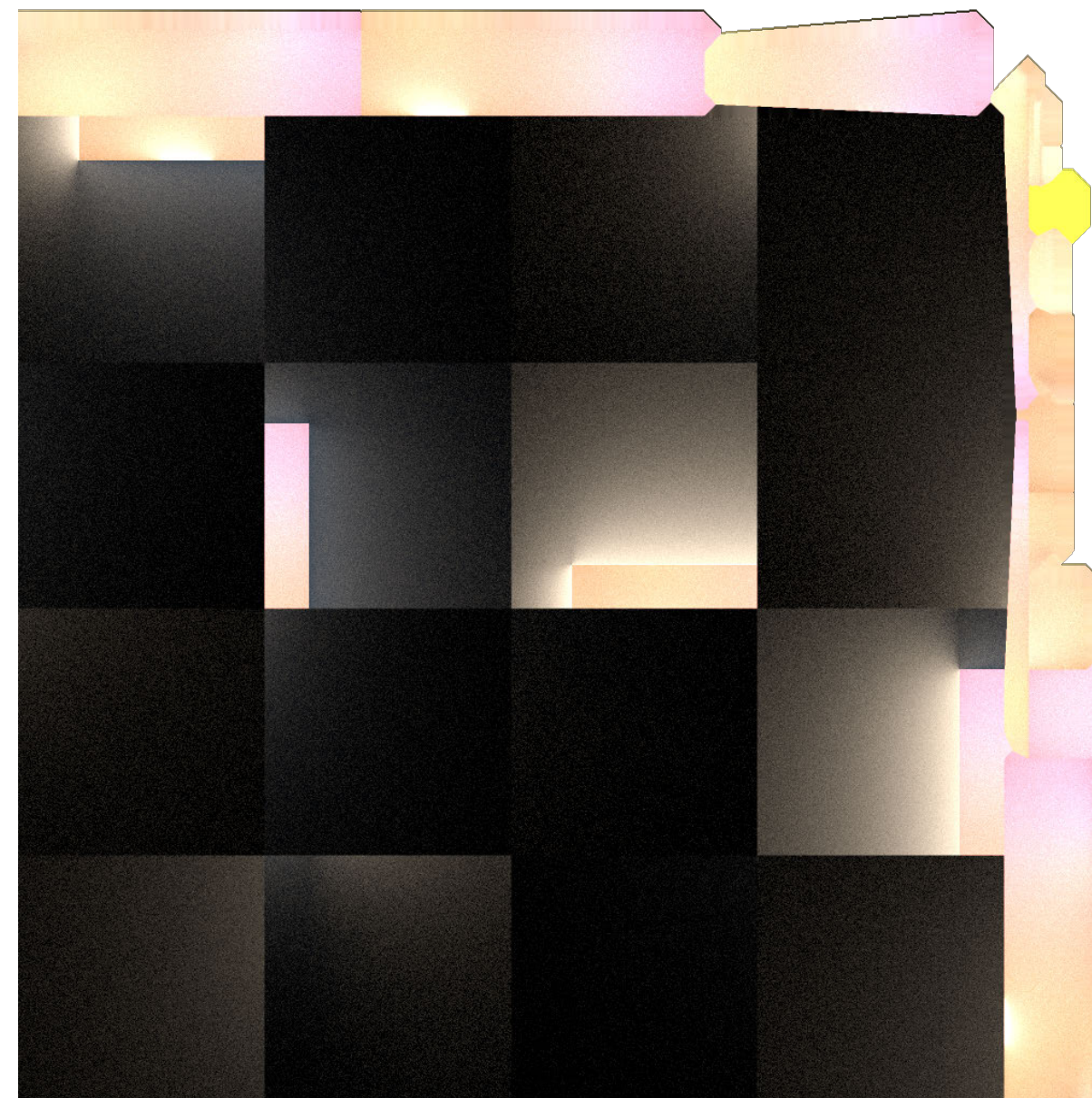
DLS #1

Tex	Val
0	Red
2	Pink
41	Dark Red
53	Red
56	Red
75	Pink
94	Dark Red
124	Red
⋮	

DLS #2

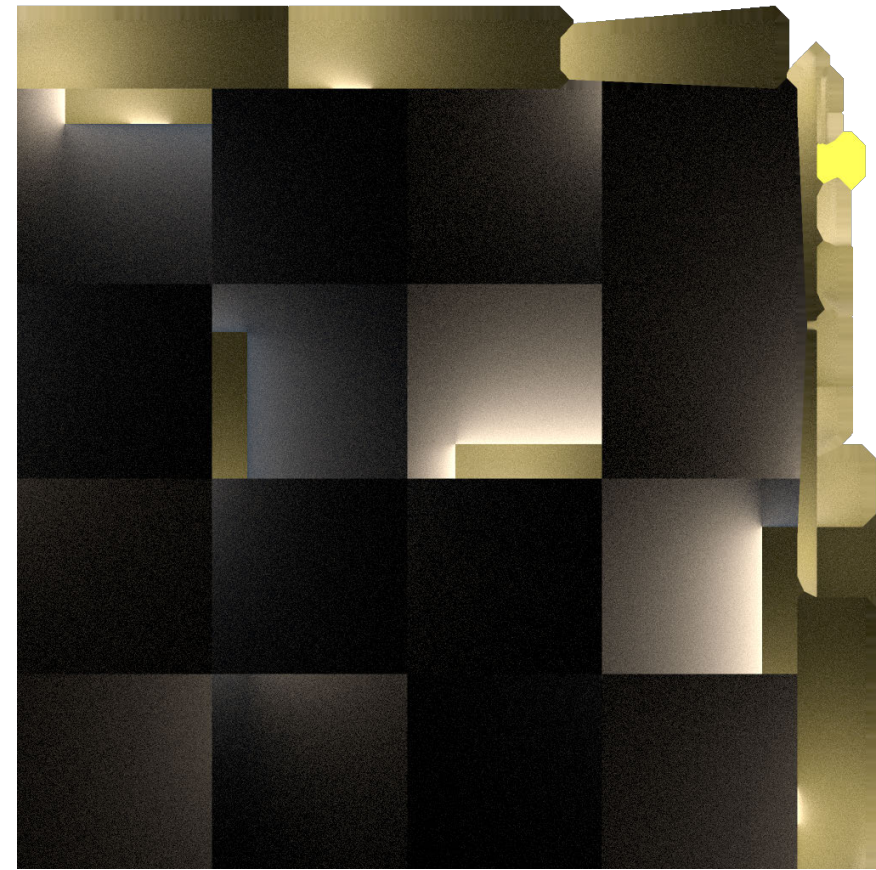
Tex	Val
32	Dark Blue
54	Dark Blue
64	Dark Blue
65	Dark Blue
73	Dark Blue
77	Black
81	Dark Blue
109	Blue
⋮	

Final



Run-time combination of dynamic light sets

Base
Bake



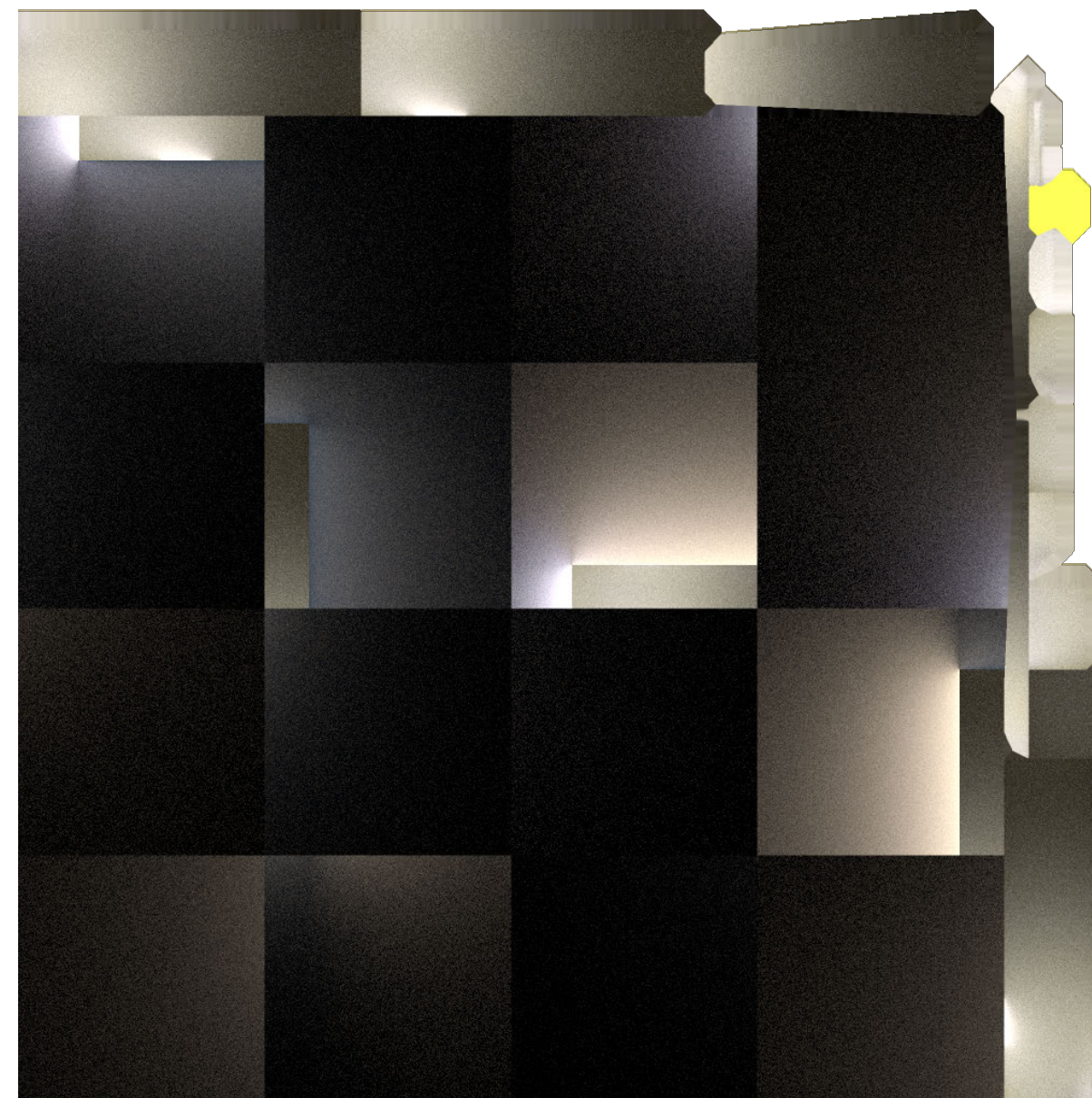
DLS #1

Tex	Val
0	Red
2	Pink
41	Dark Red
53	Red
56	Red
75	Pink
94	Dark Red
124	Red
⋮	

DLS #2

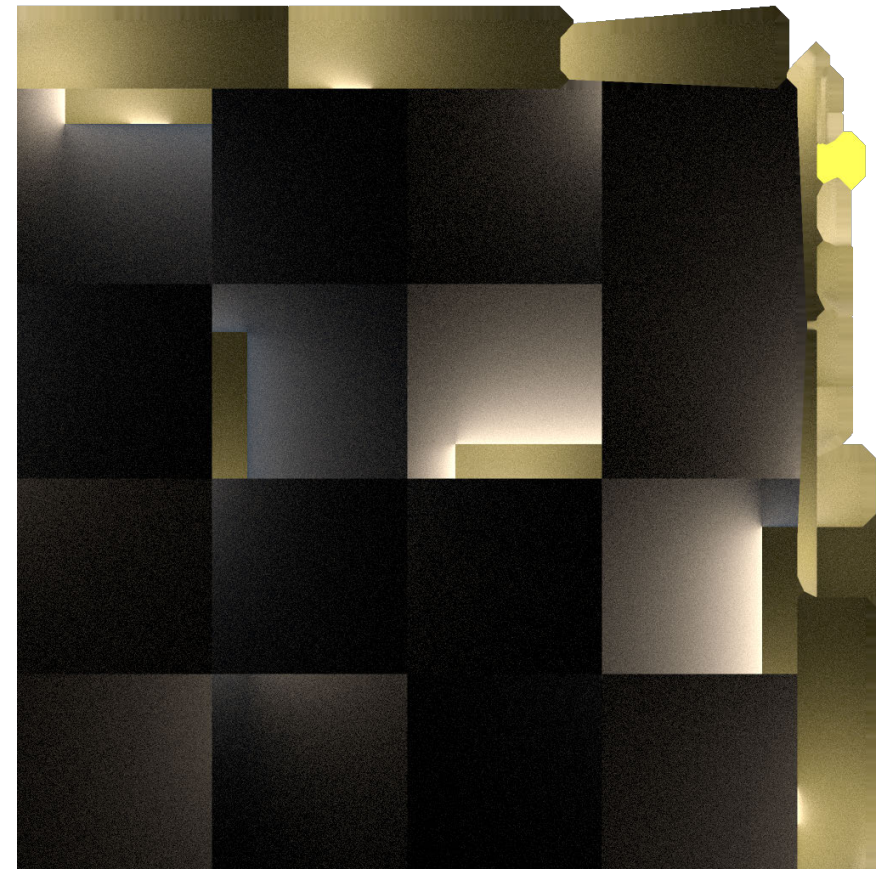
Tex	Val
32	Dark Blue
54	Dark Blue
64	Dark Blue
65	Dark Blue
73	Dark Blue
77	Black
81	Dark Blue
109	Blue
⋮	

Final



Run-time combination of dynamic light sets

Base
Bake



DLS #1

Tex	Val
0	Red
2	Pink
41	Dark Red
53	Red
56	Red
75	Pink
94	Dark Red
124	Red
⋮	

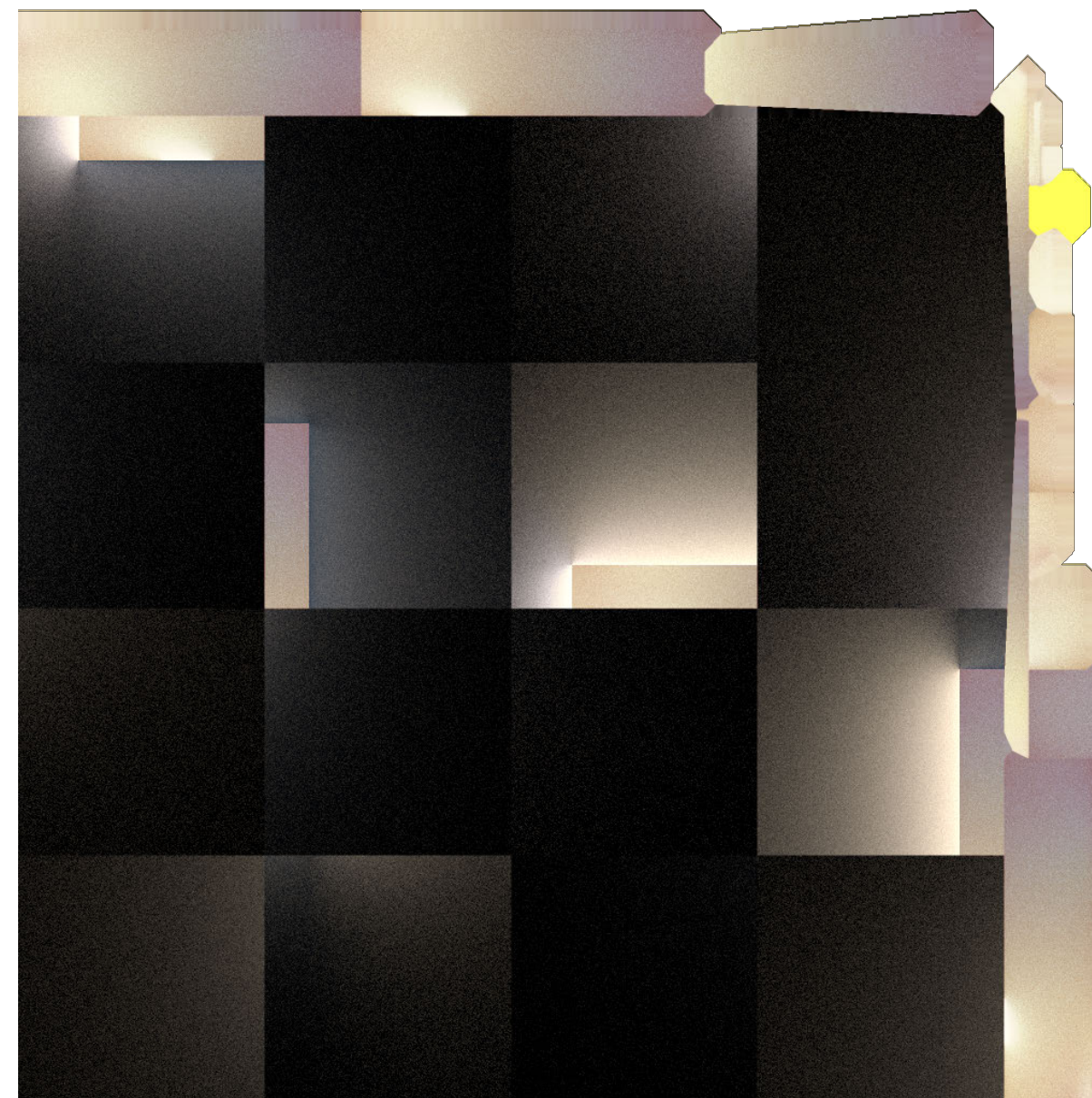


DLS #2

Tex	Val
32	Dark Blue
54	Dark Blue
64	Dark Blue
65	Dark Blue
73	Dark Blue
77	Black
81	Dark Blue
109	Blue
⋮	



Final



0/1

Checkpoint reached.



0/1

Checkpoint reached.



Evolving UBERBAKE

Static Lighting
and Geometry

Dynamic
Lighting

Limited Dynamic
Geometry

2016

2017

2019

Evolving UBERBAKE



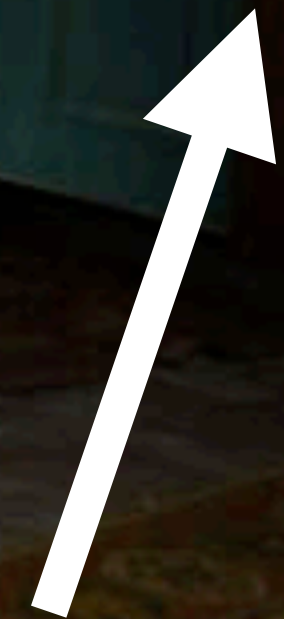


Dark Room



Dark Room

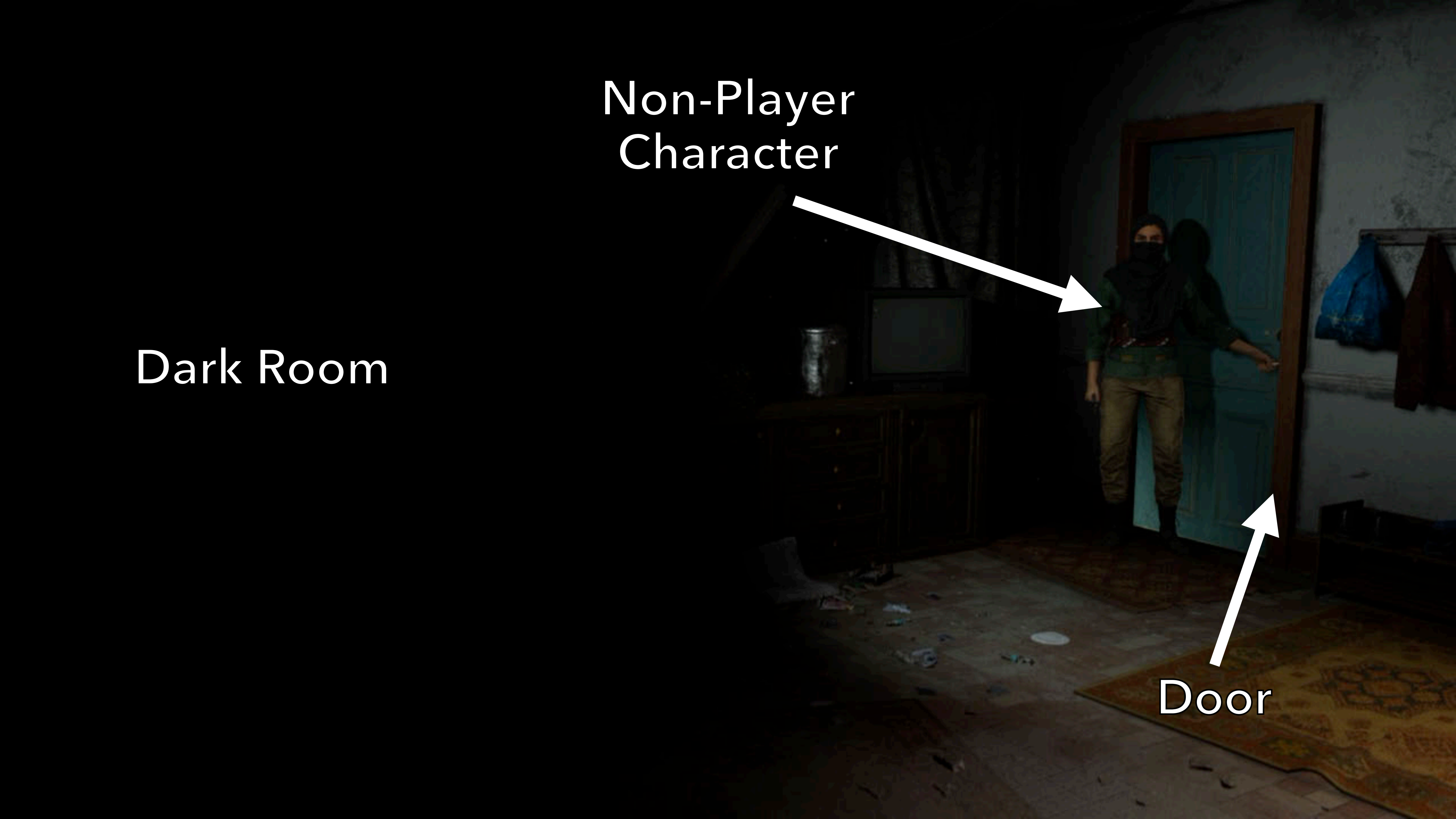
Door



Non-Player
Character

Dark Room

Door









Bright Sun

Still Dark Room



Bright Sun

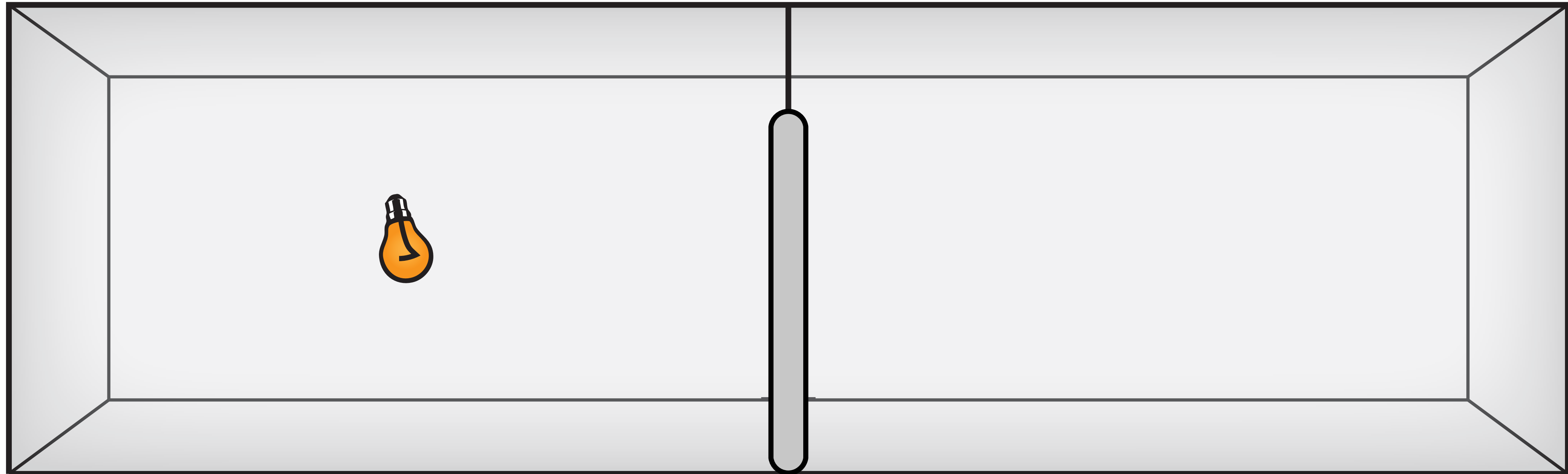


Lit up room!

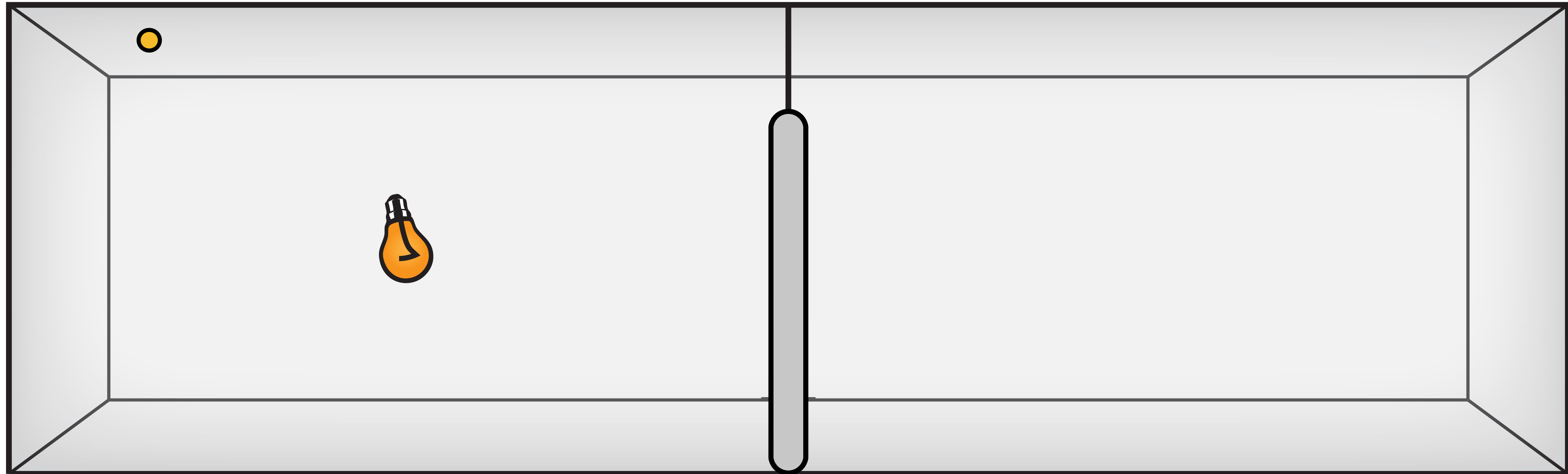


From dynamic lights to dynamic geometry

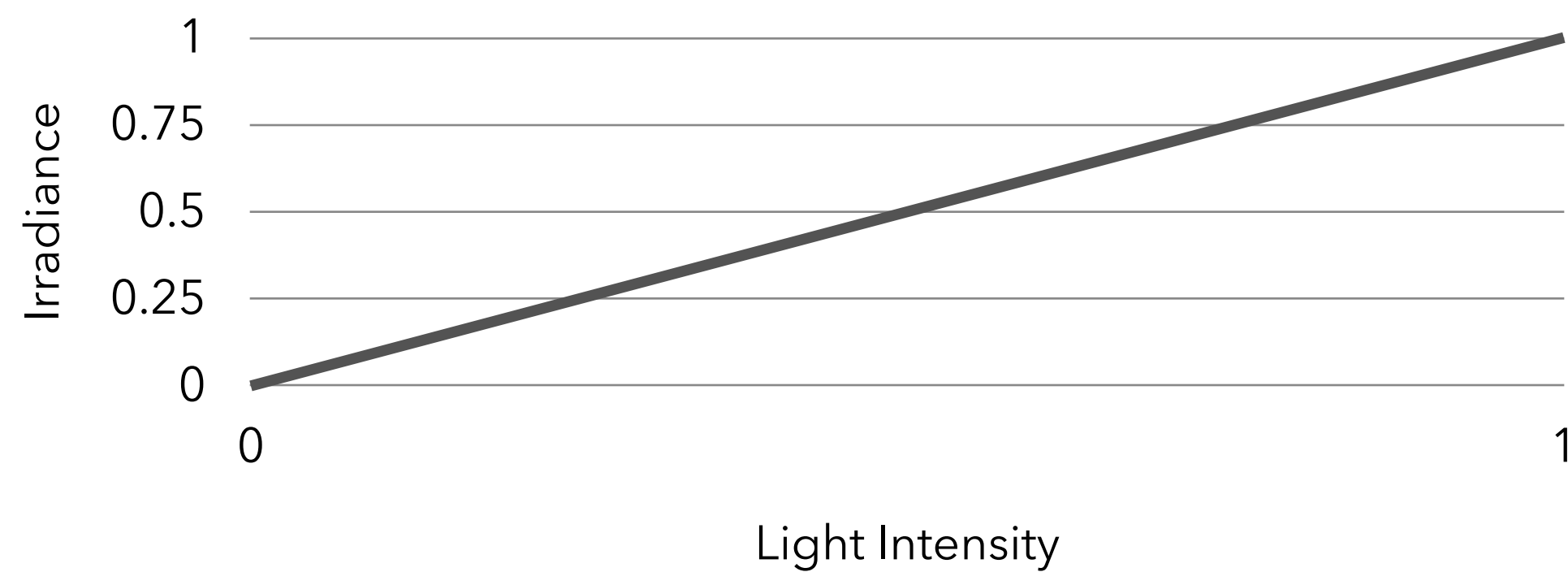
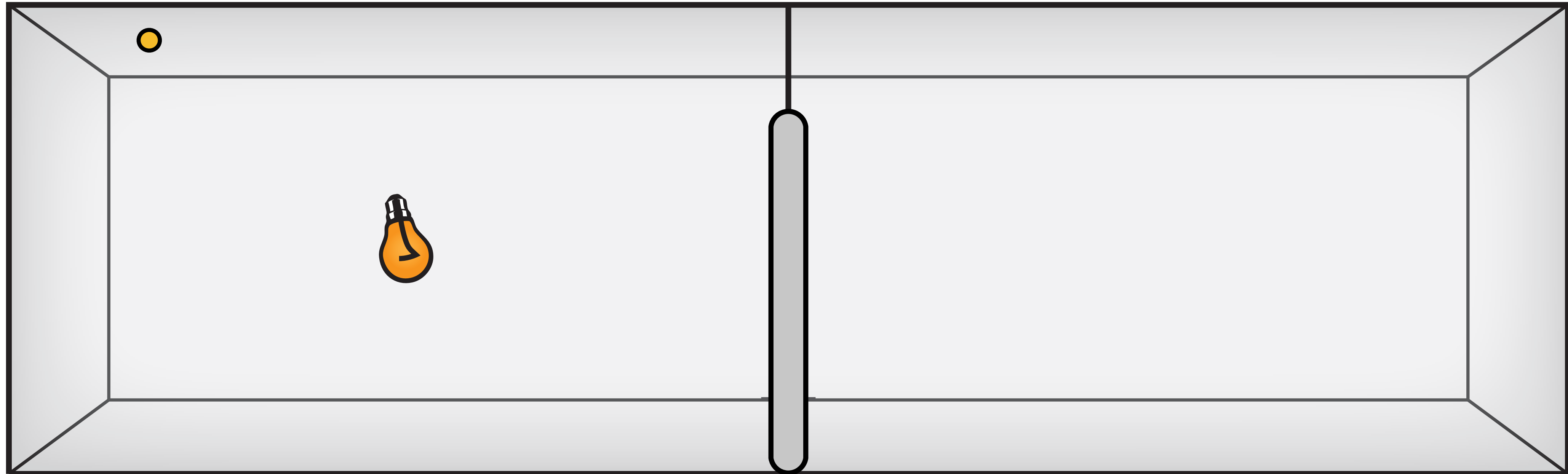
Geometry changes induce non-linear lighting effects



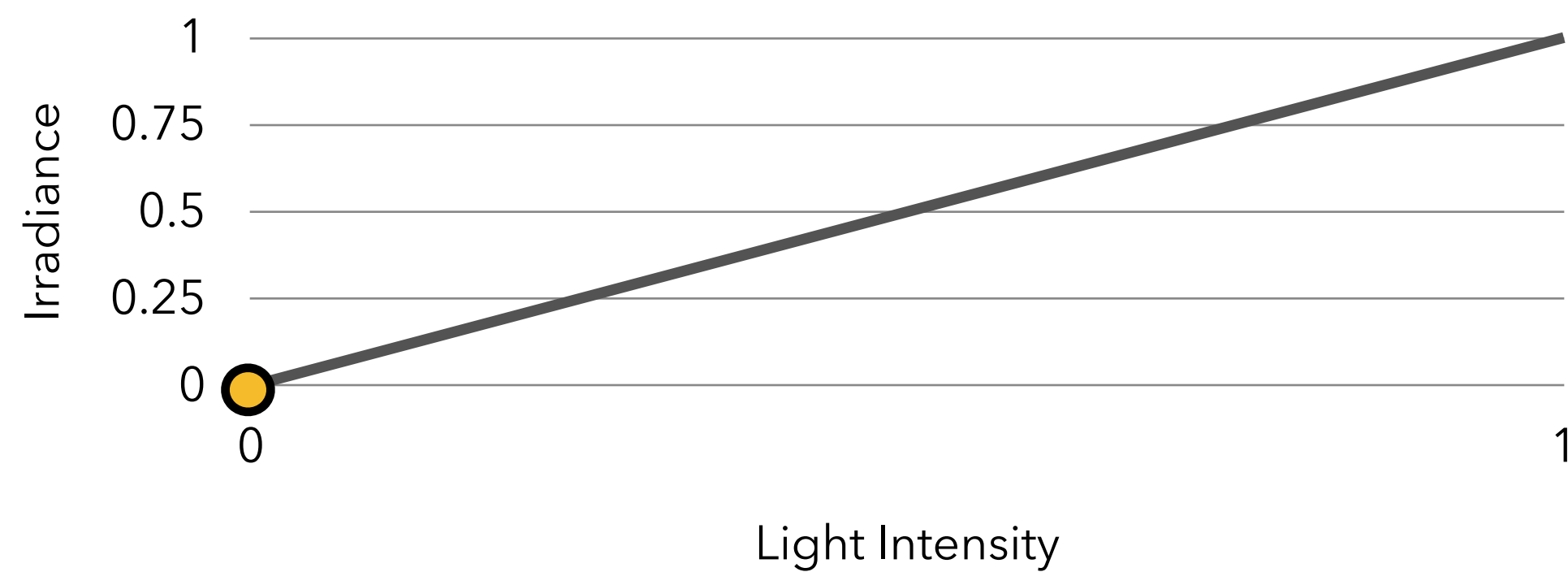
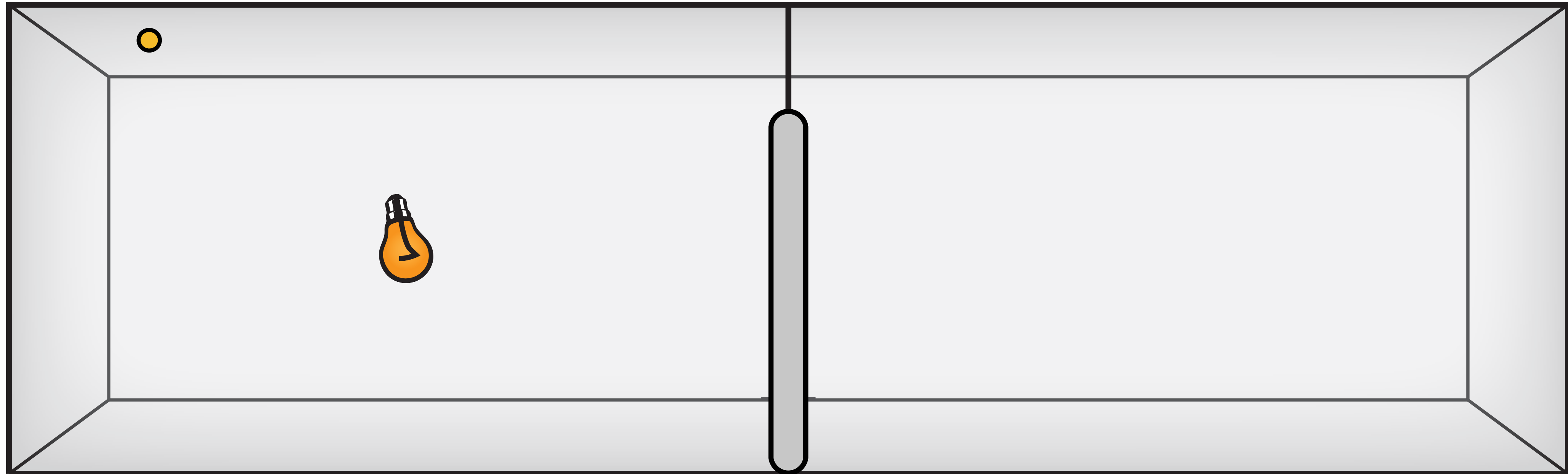
Geometry changes induce non-linear lighting effects



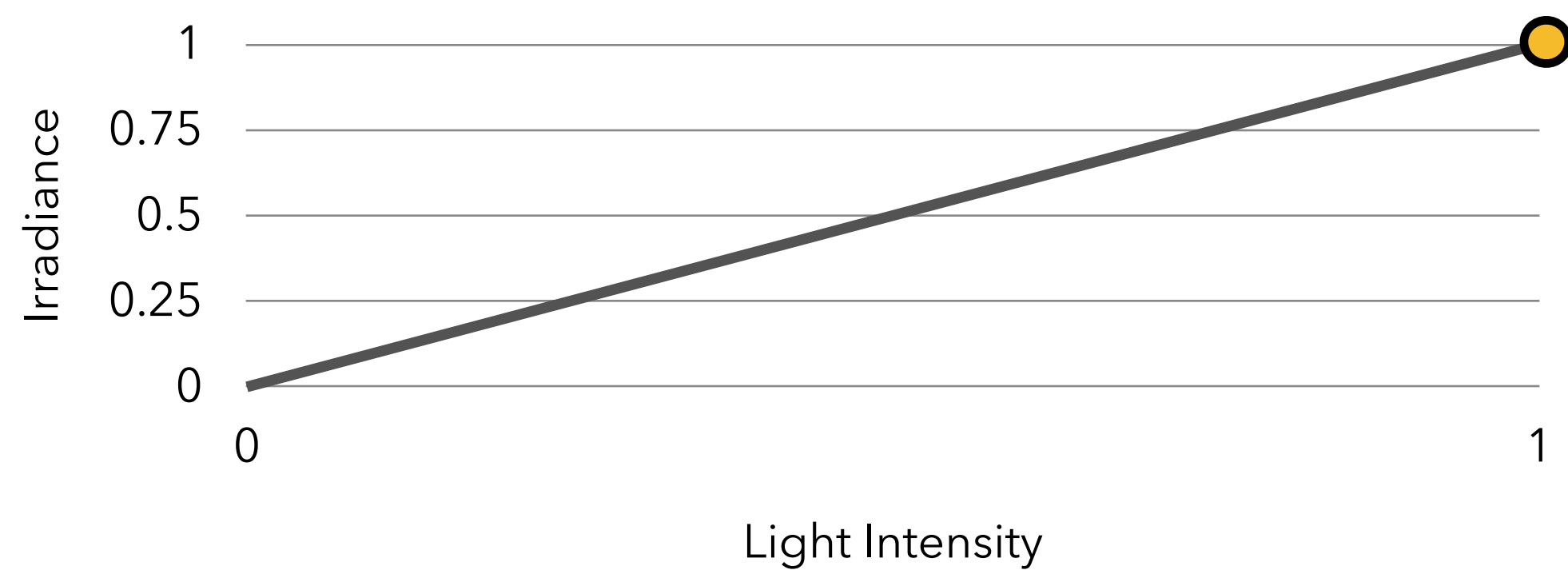
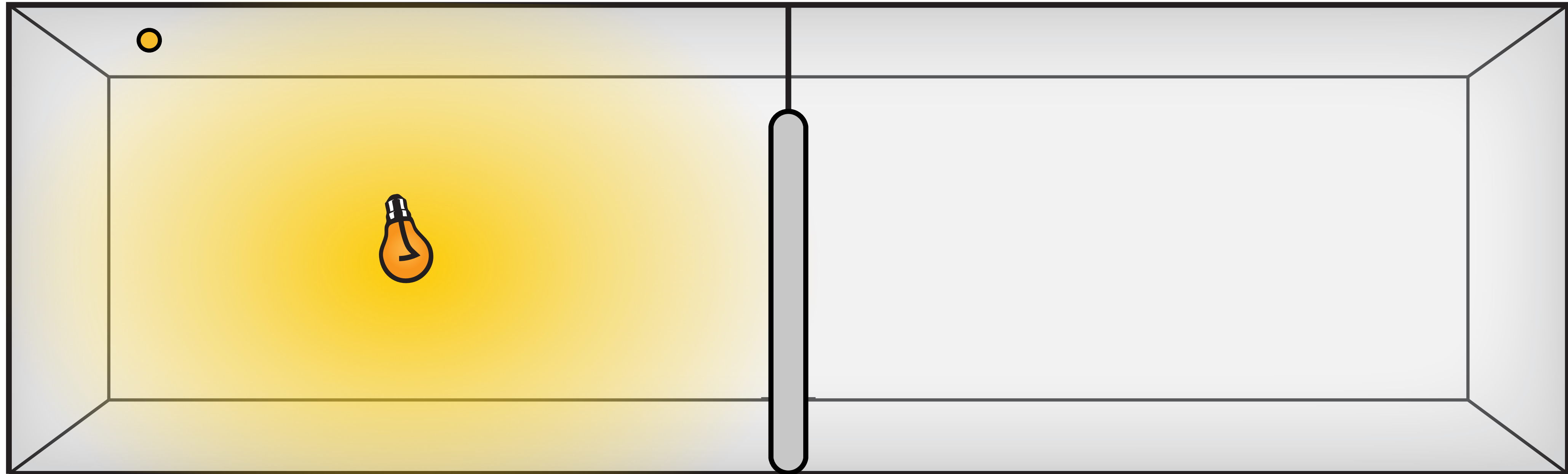
Geometry changes induce non-linear lighting effects



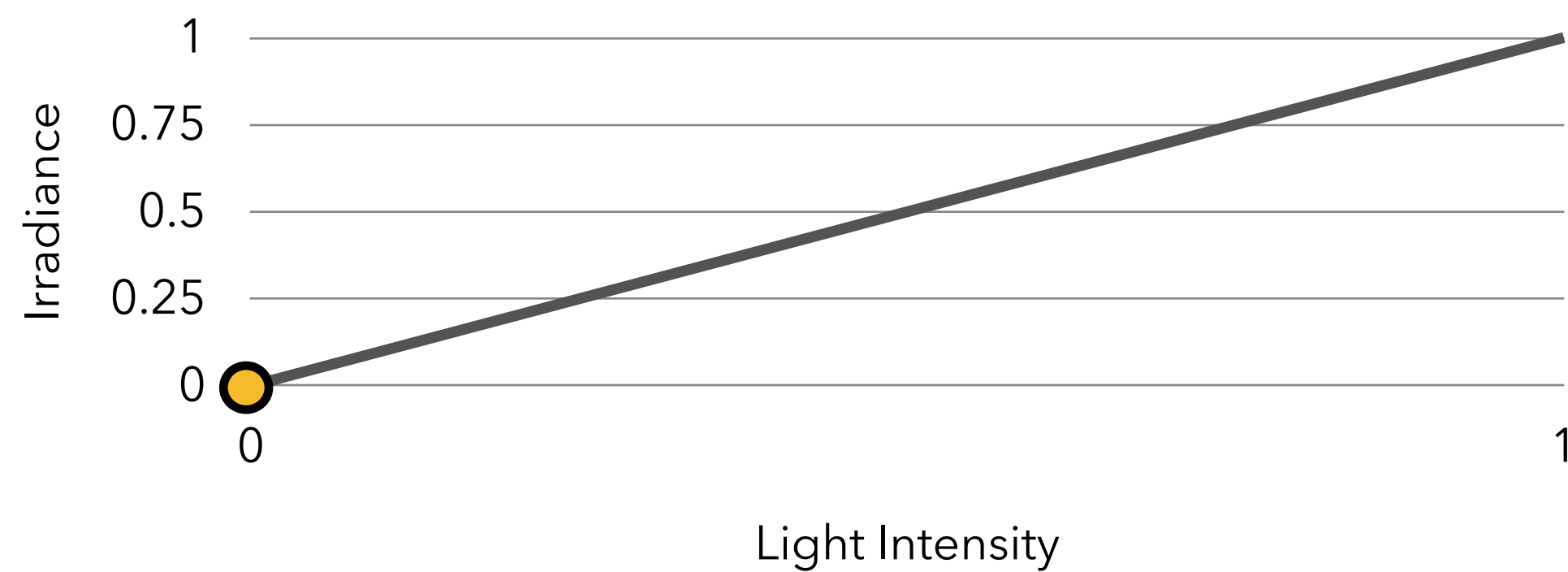
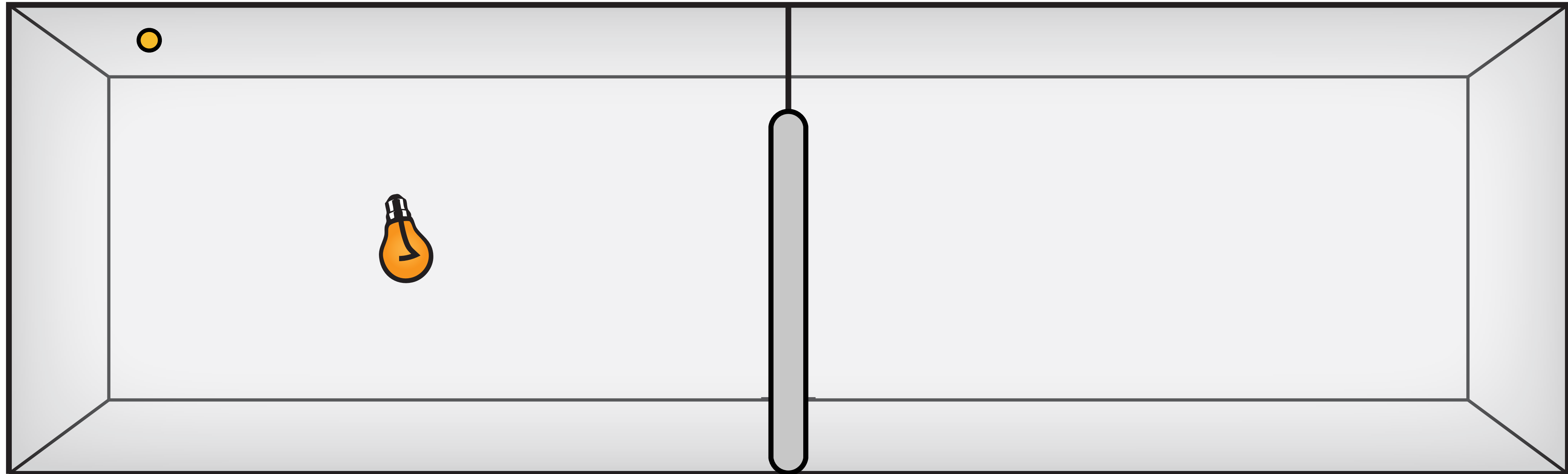
Geometry changes induce non-linear lighting effects



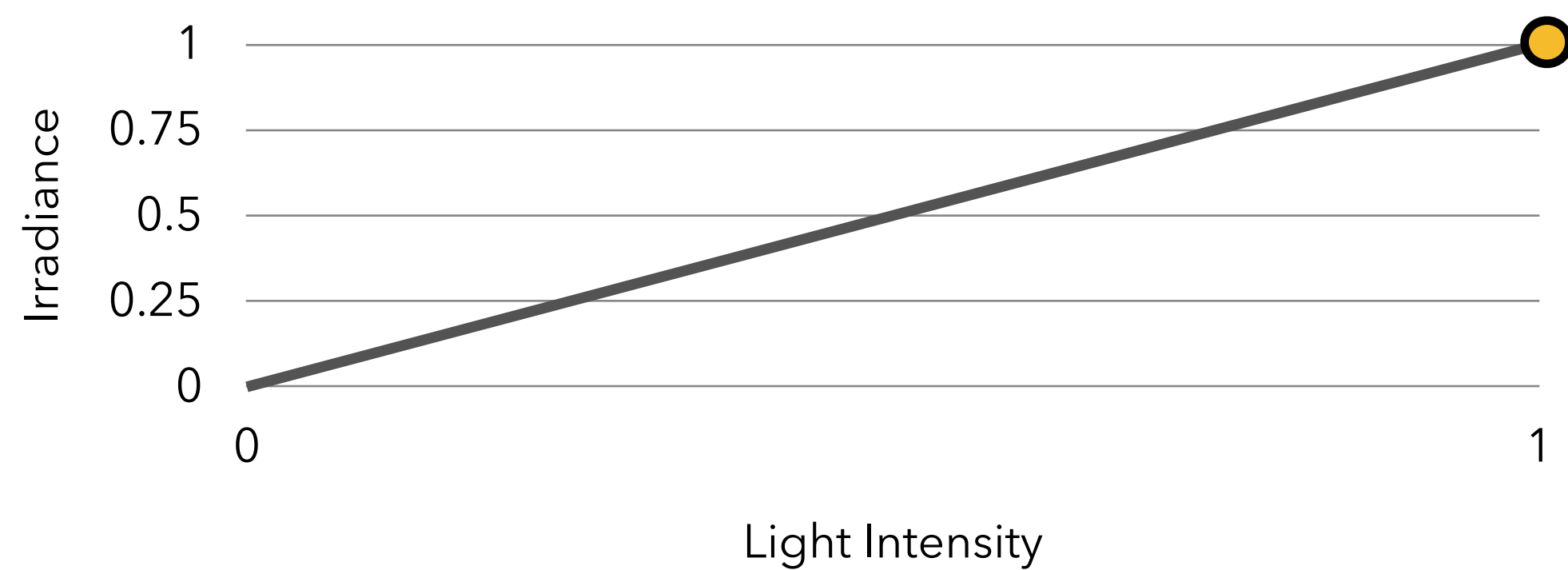
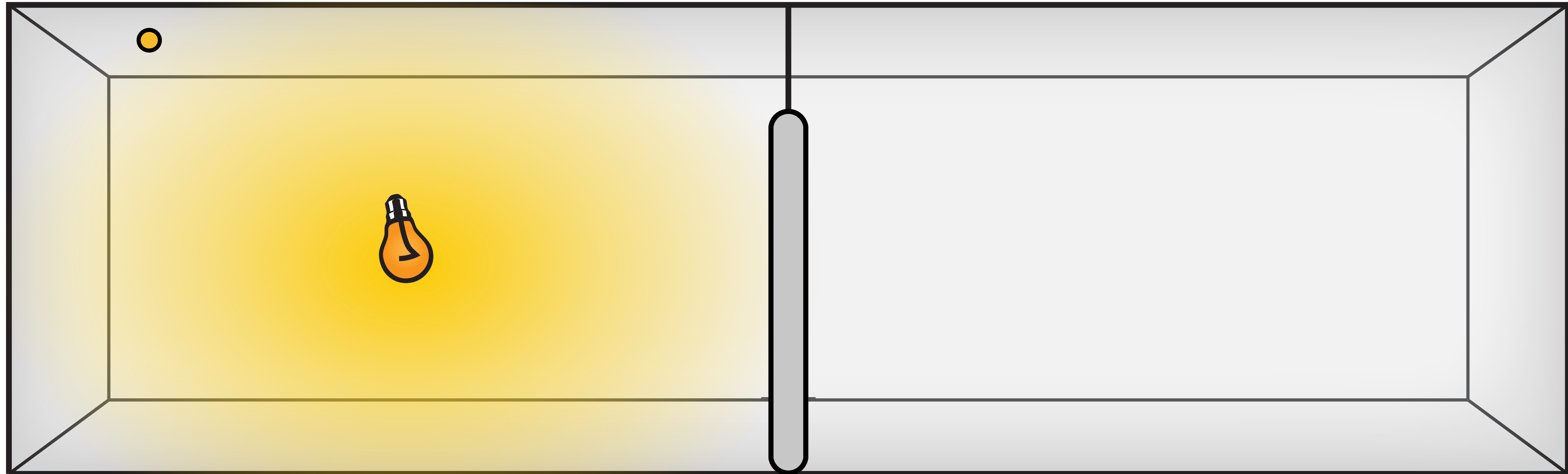
Geometry changes induce non-linear lighting effects



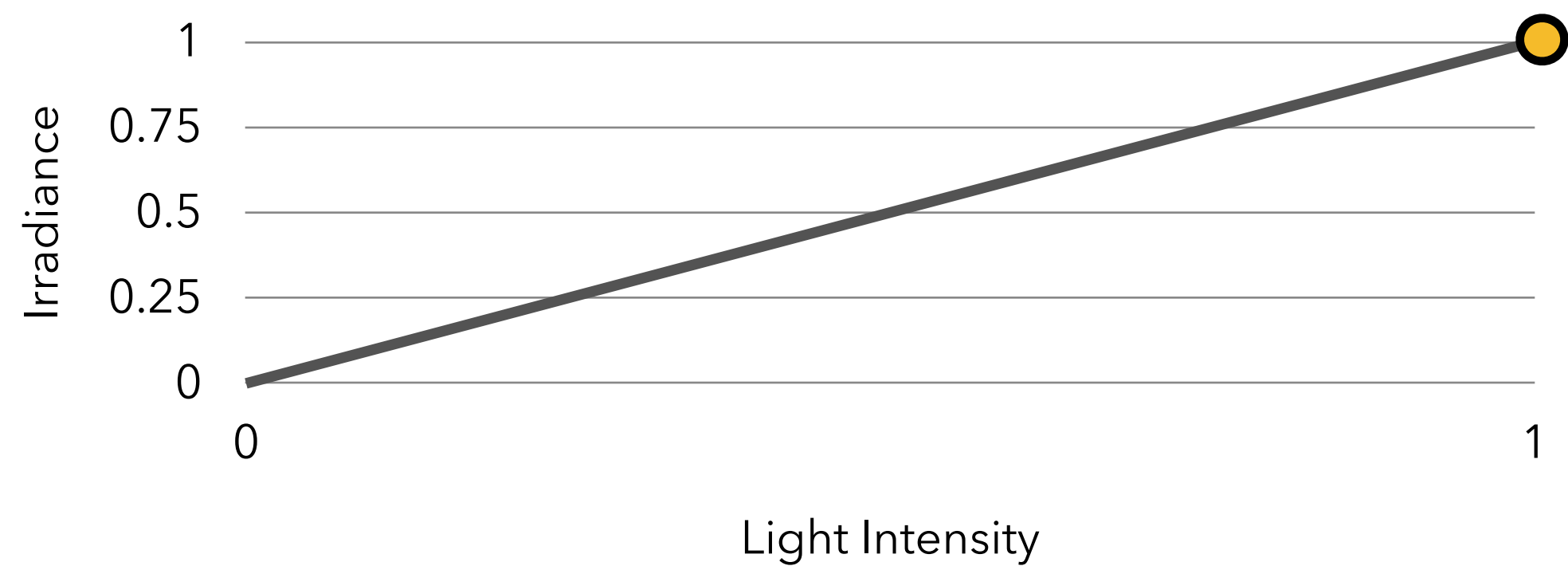
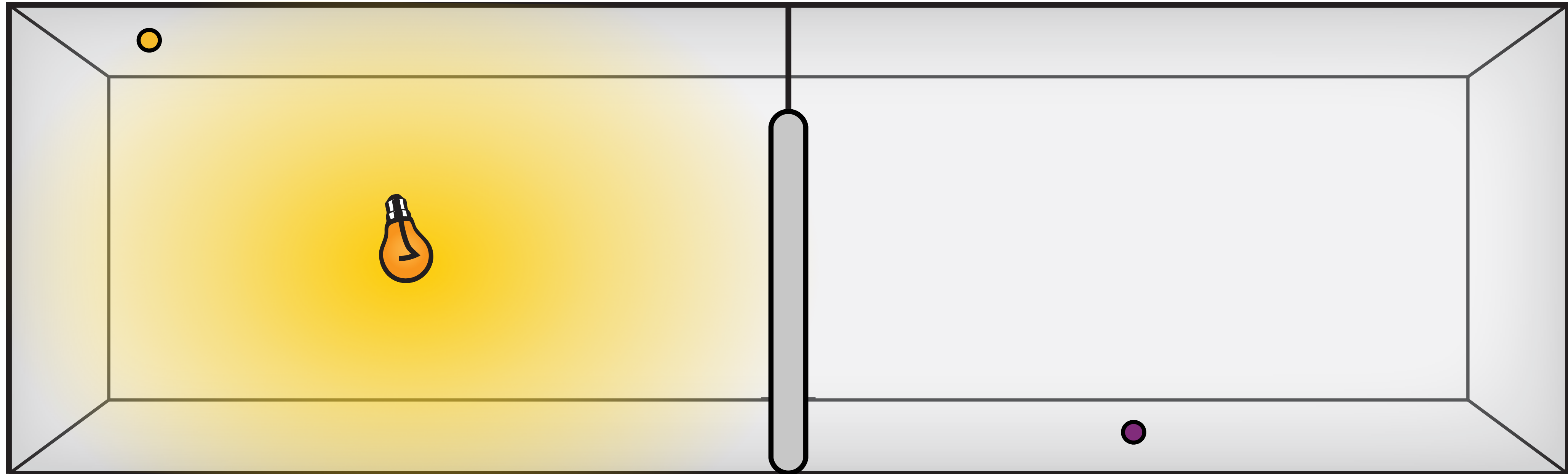
Geometry changes induce non-linear lighting effects



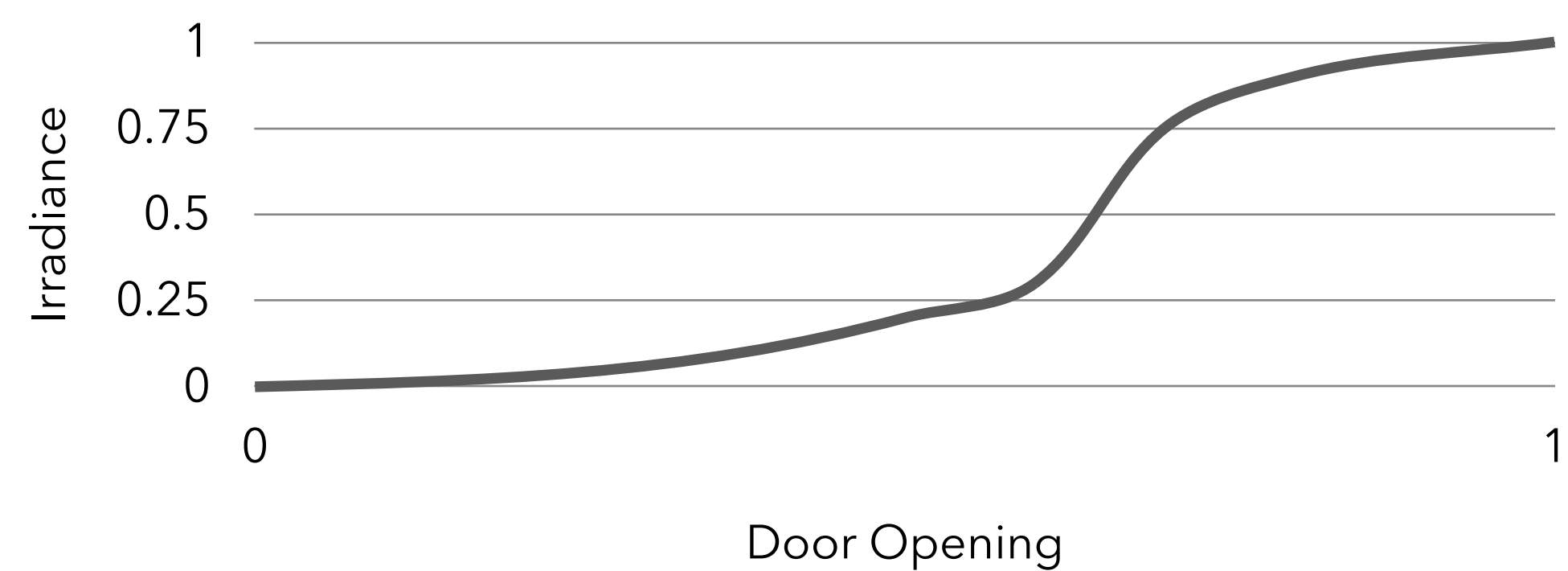
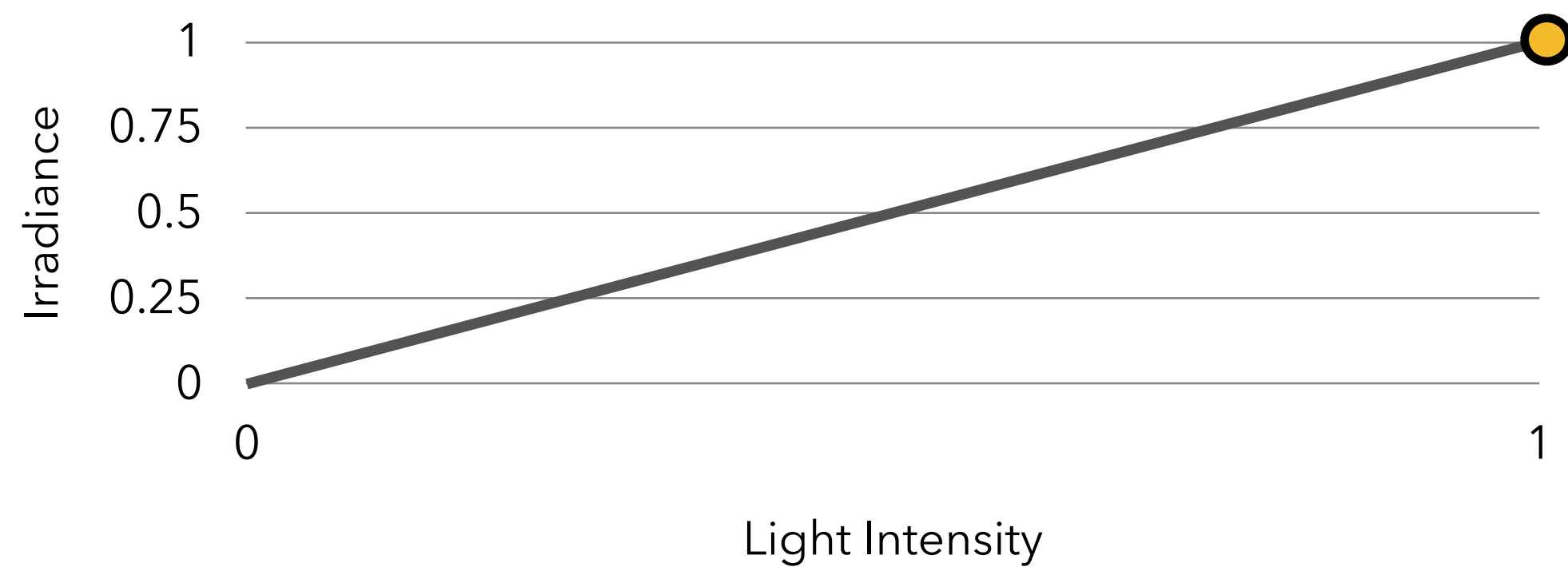
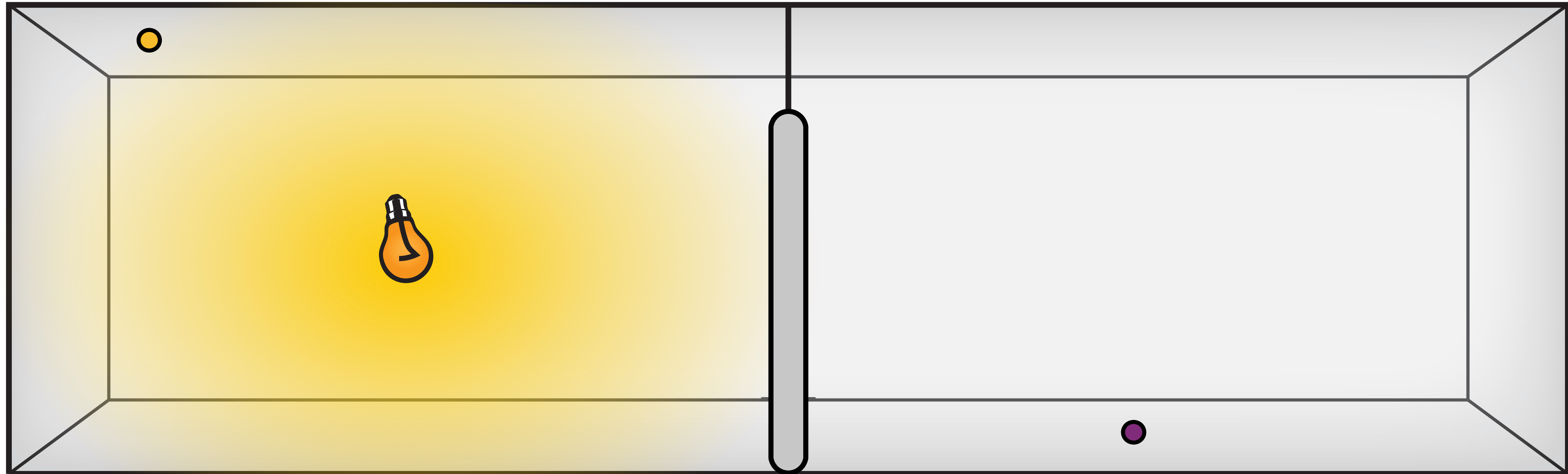
Geometry changes induce non-linear lighting effects



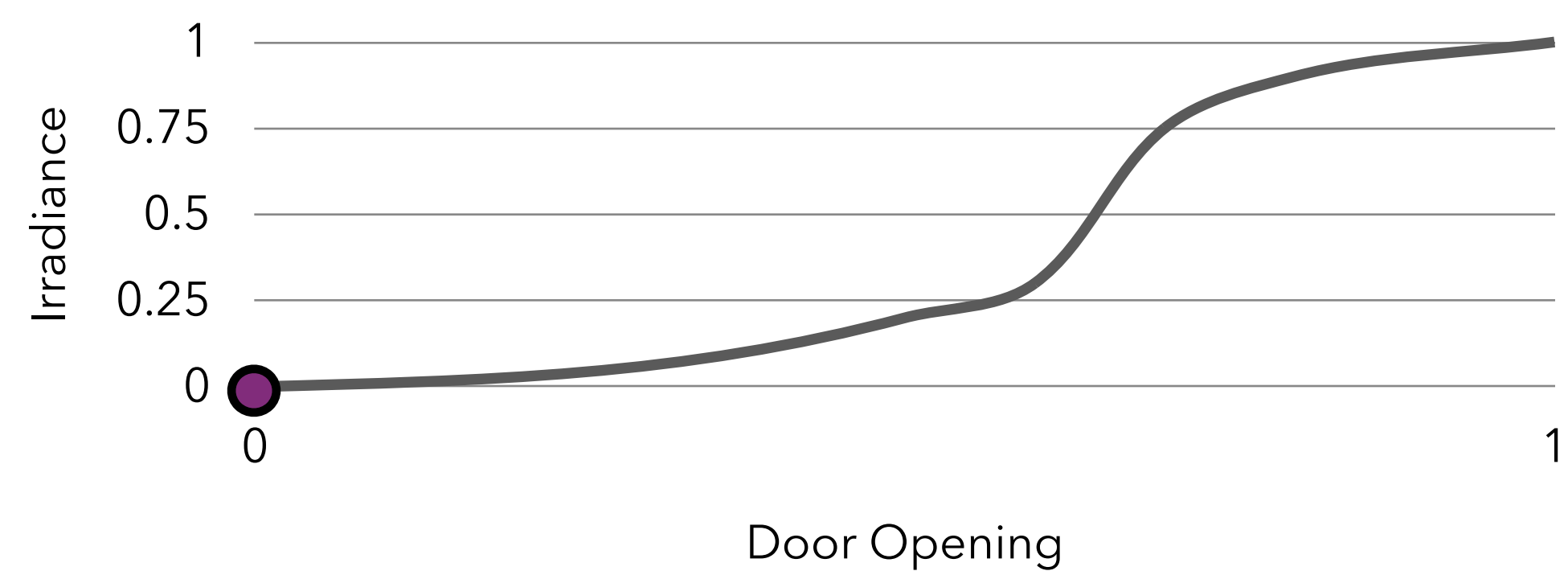
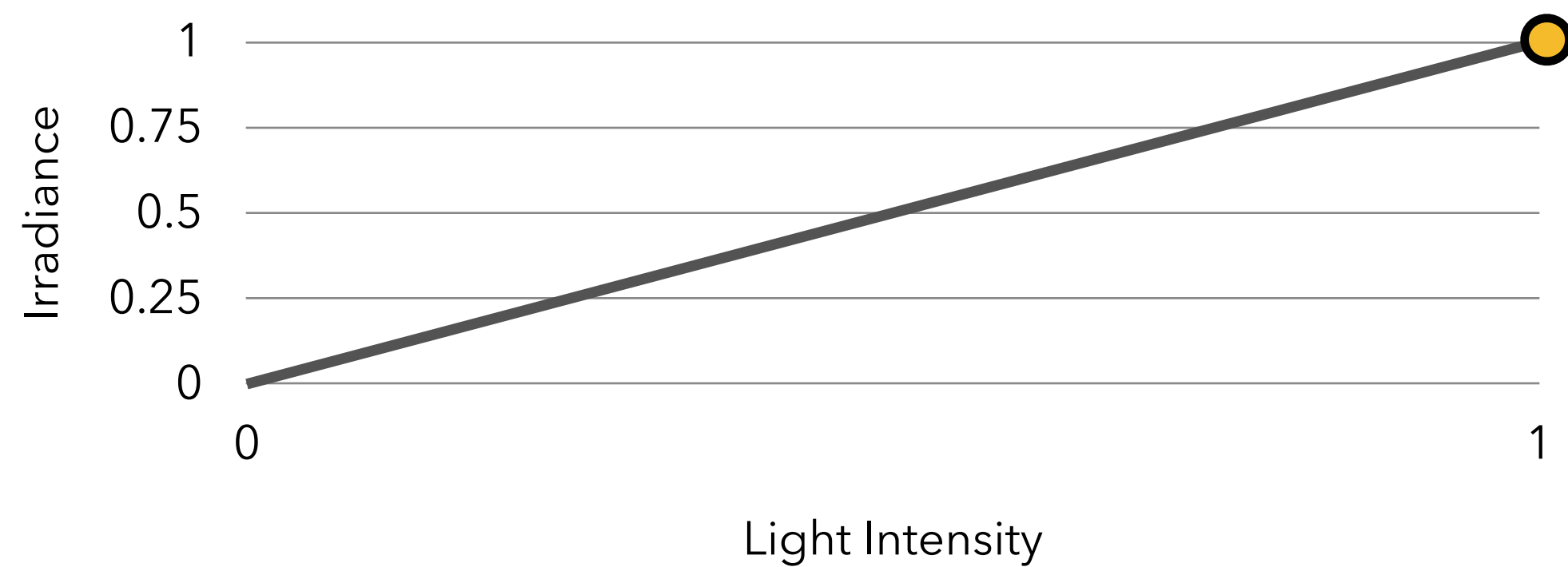
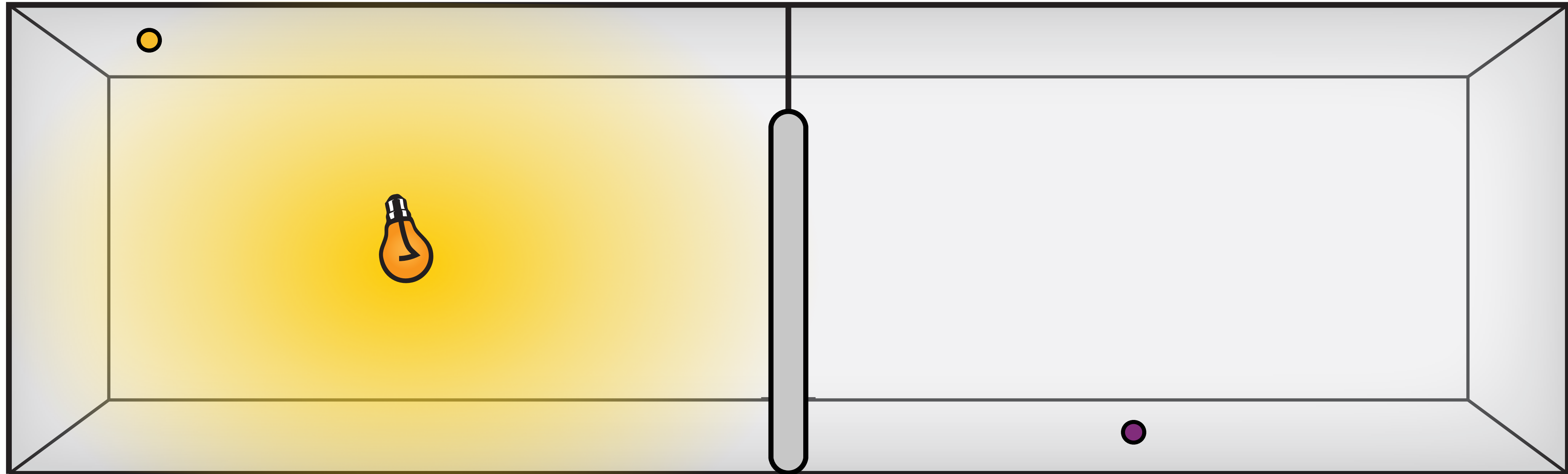
Geometry changes induce non-linear lighting effects



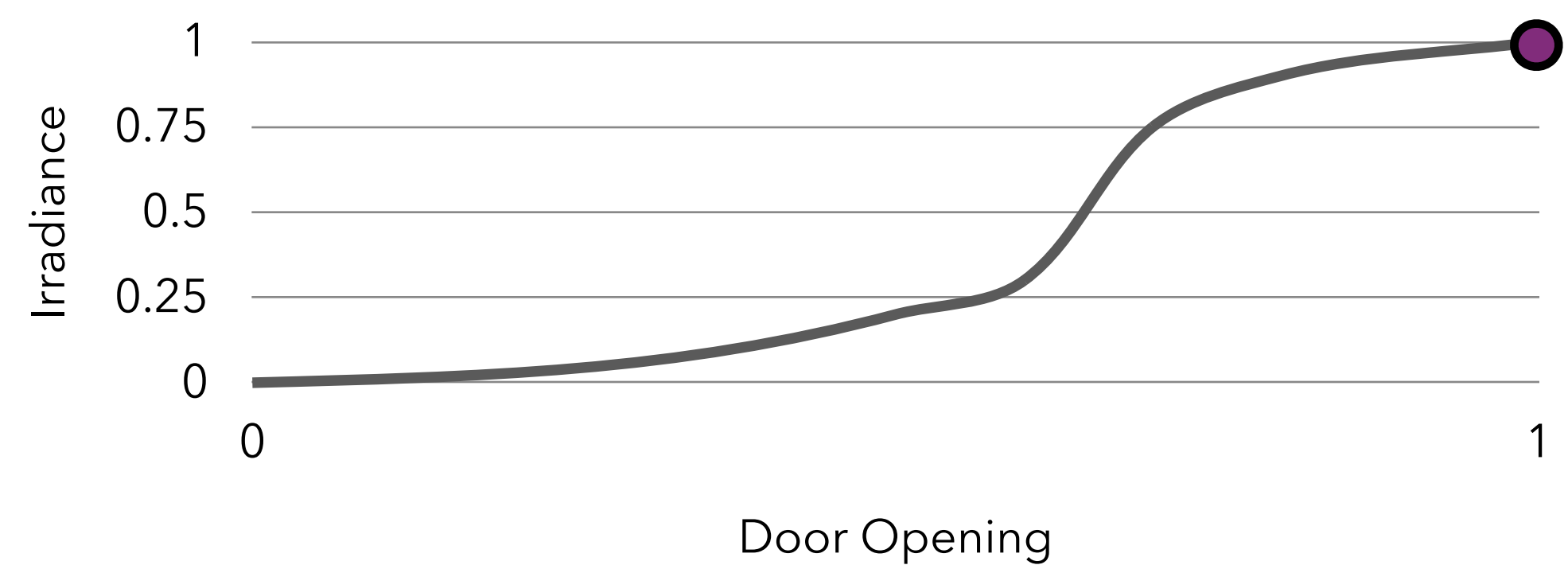
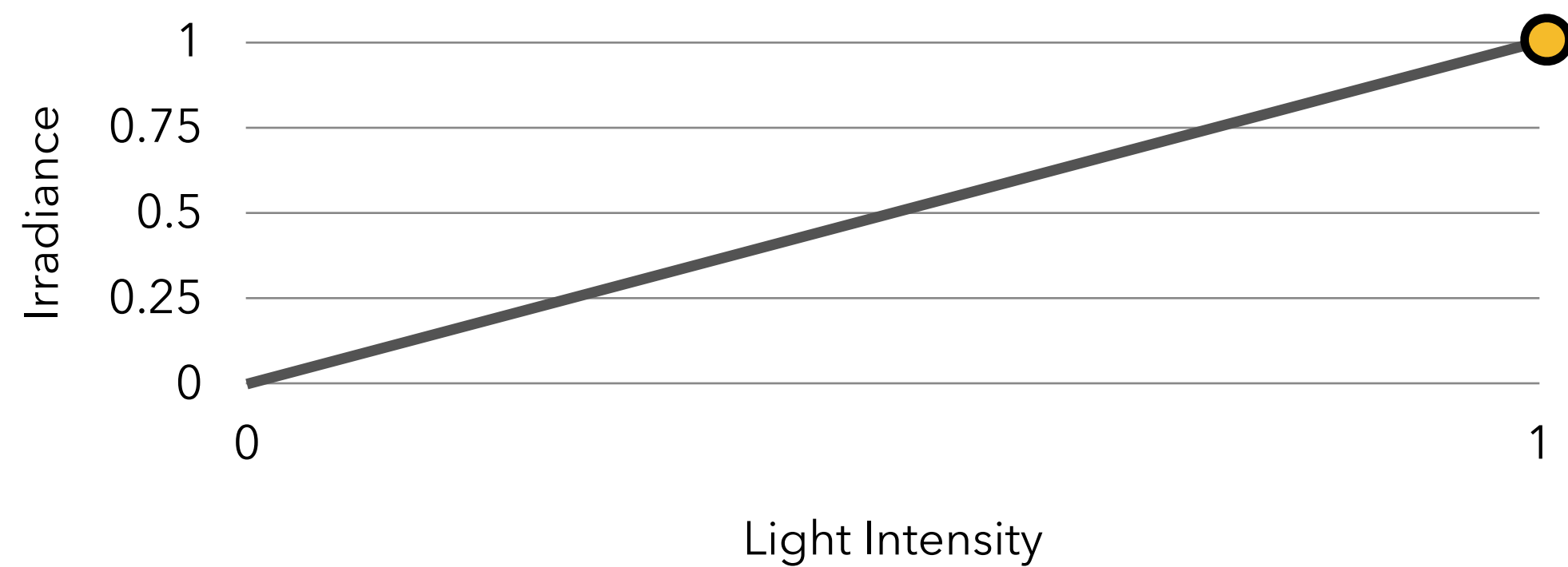
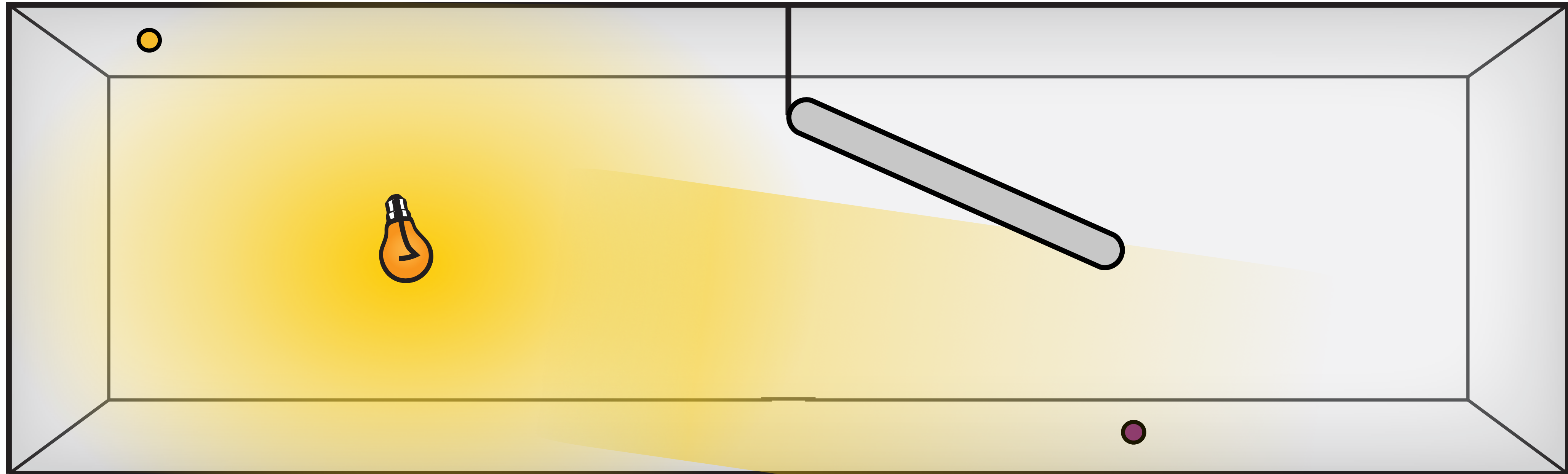
Geometry changes induce non-linear lighting effects



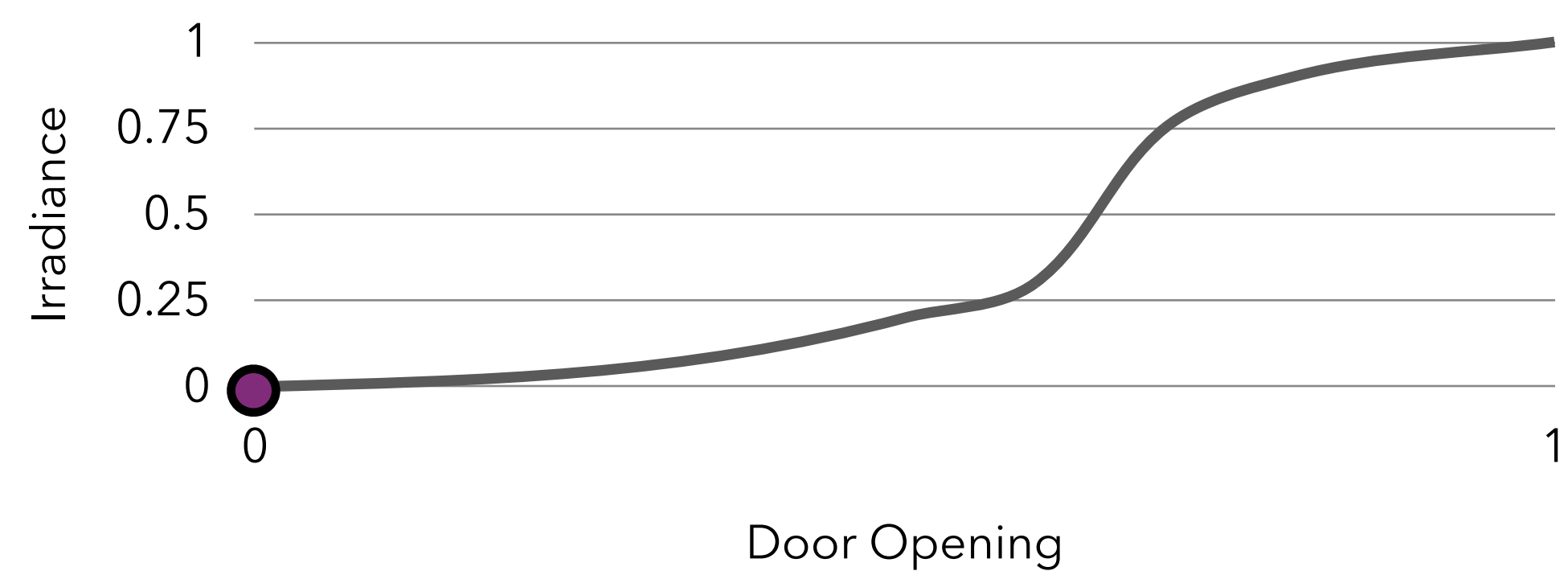
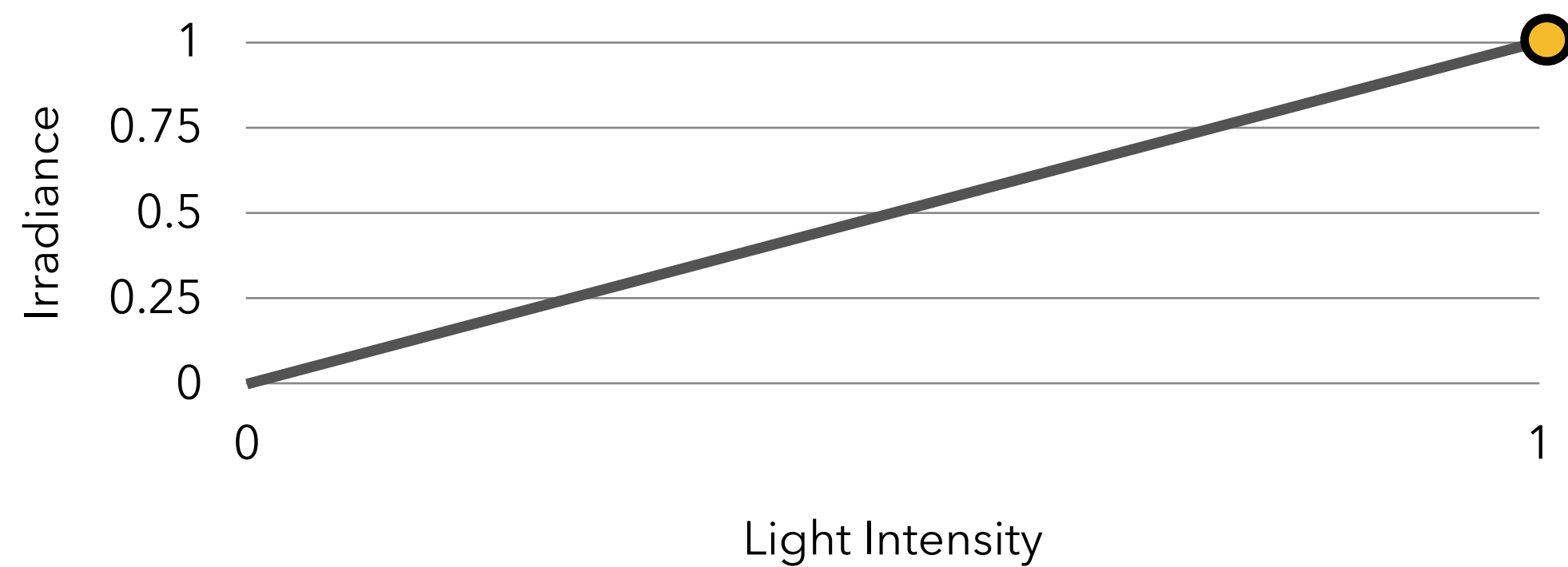
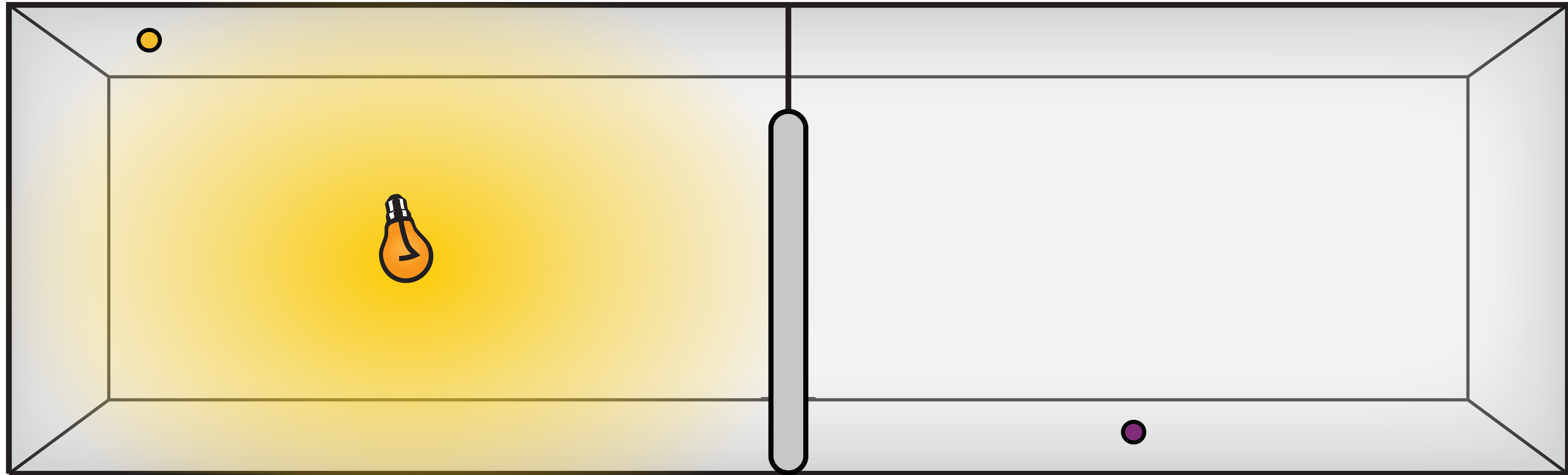
Geometry changes induce non-linear lighting effects



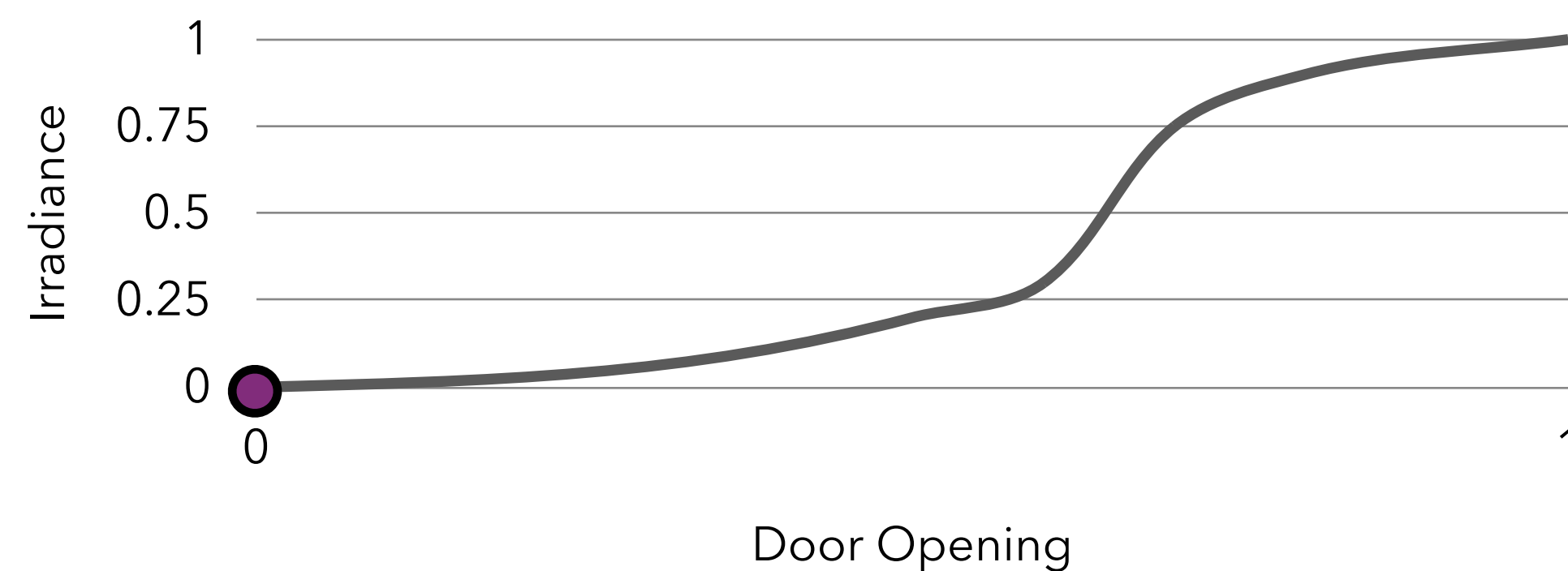
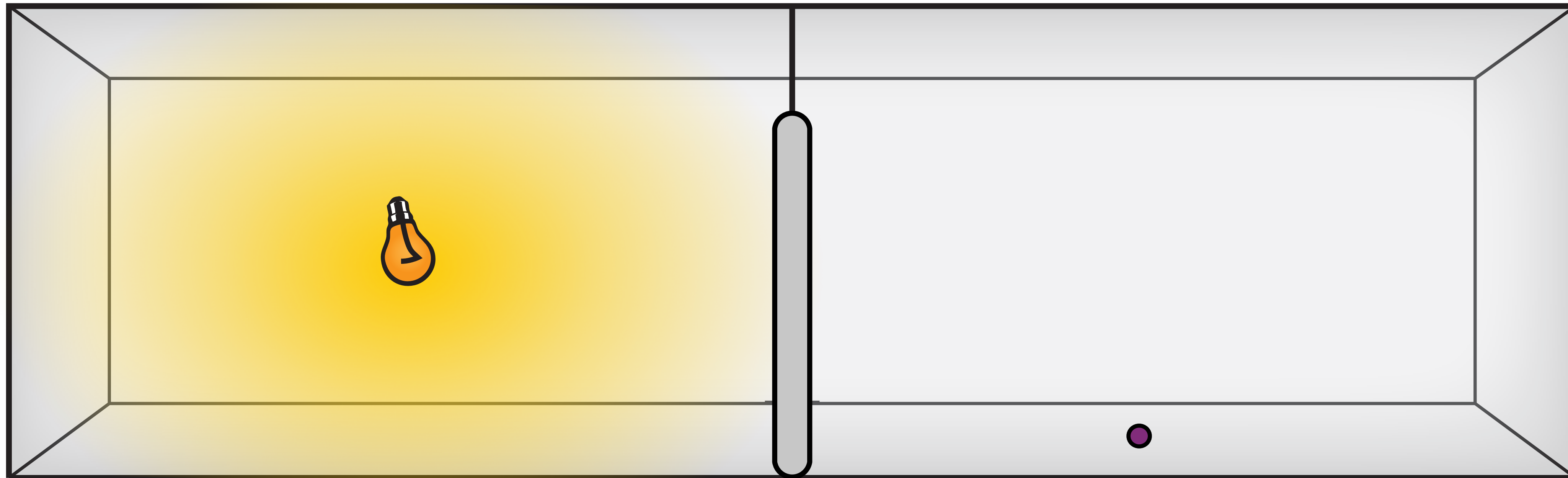
Geometry changes induce non-linear lighting effects



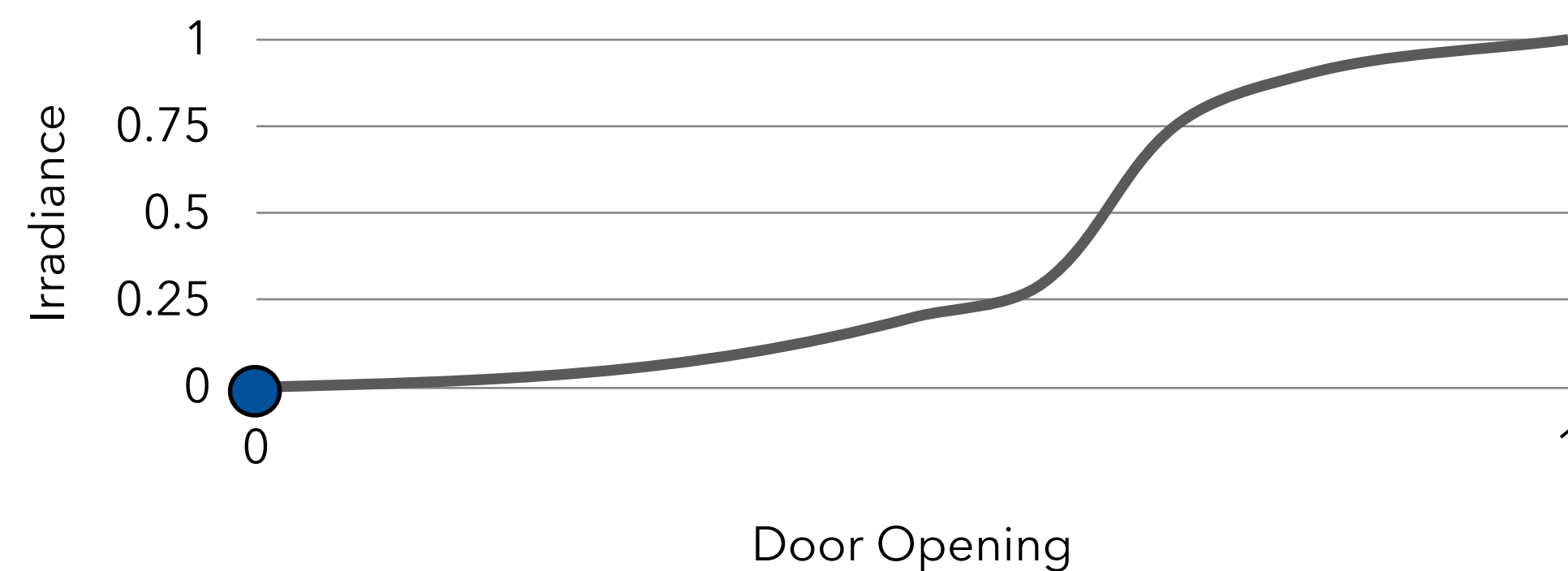
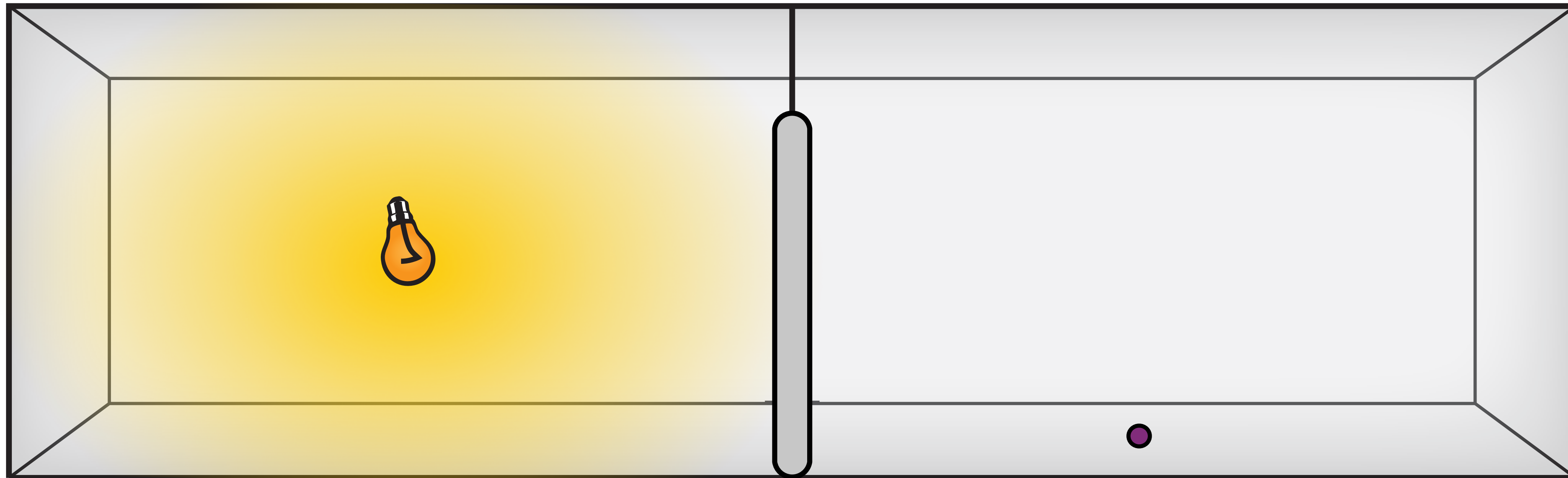
Geometry changes induce non-linear lighting effects



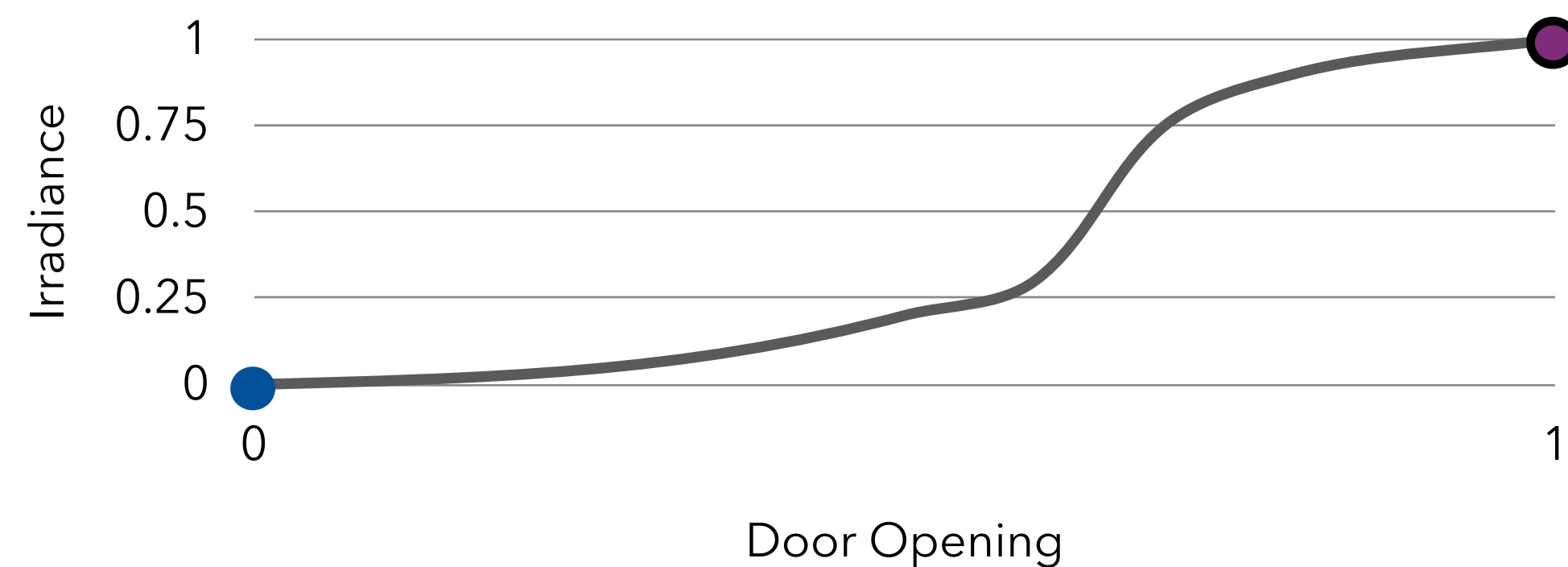
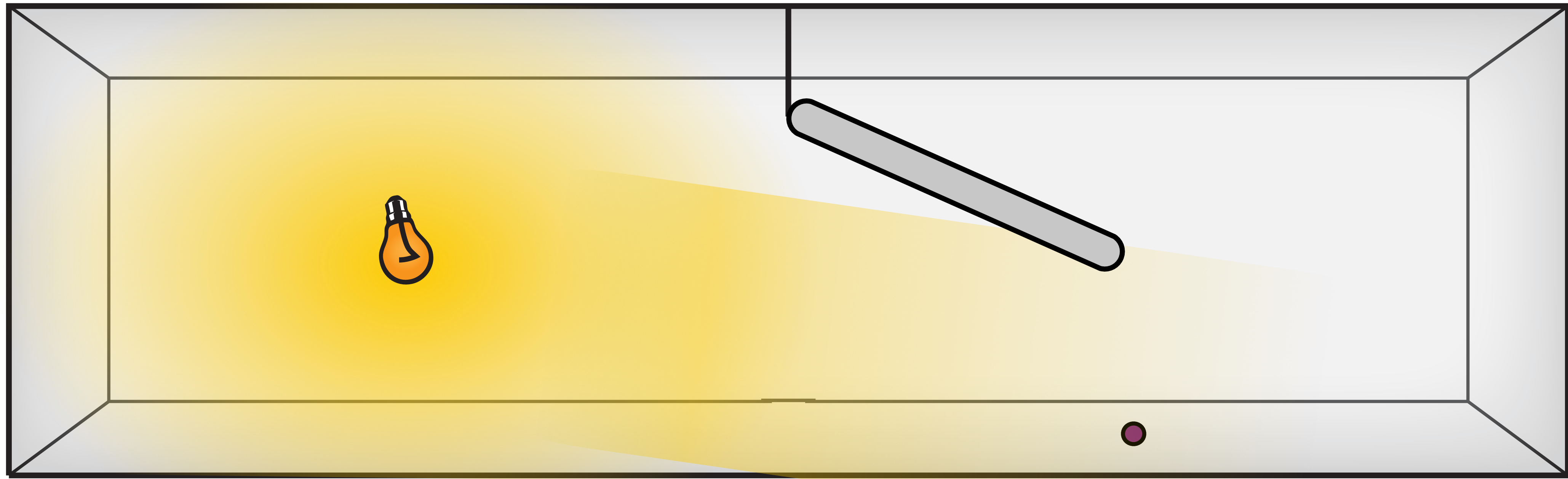
Linearizing door lighting



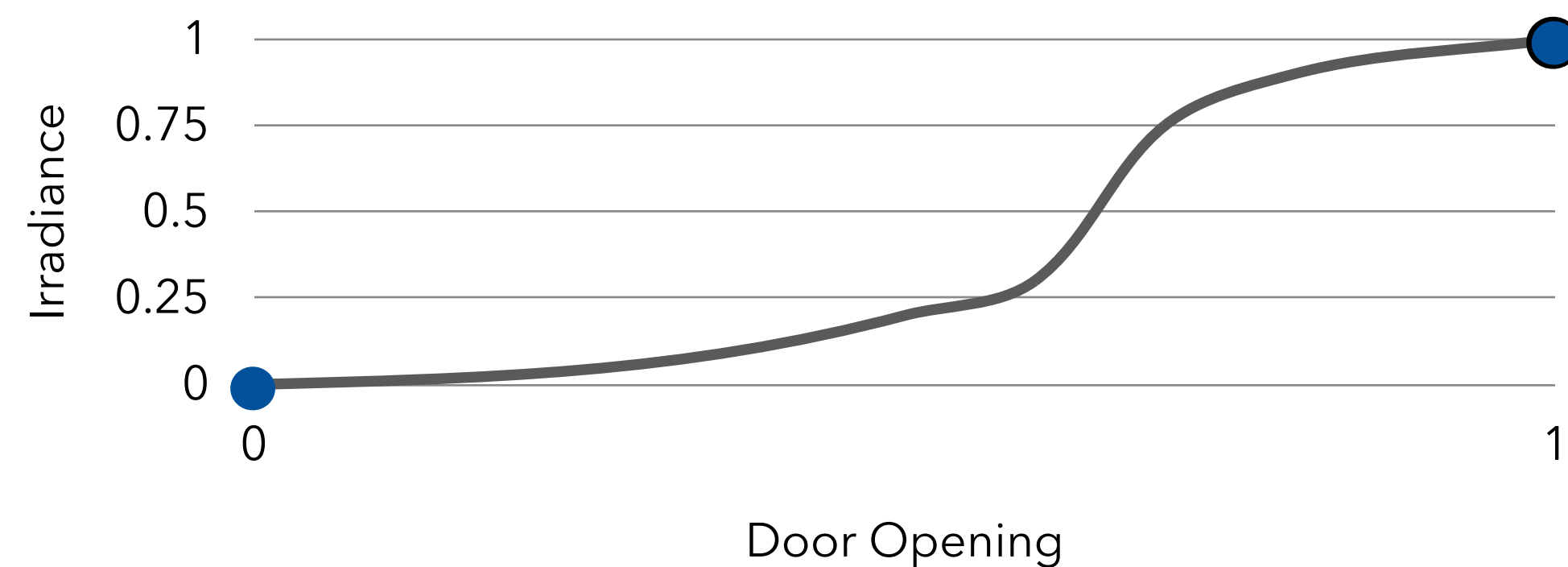
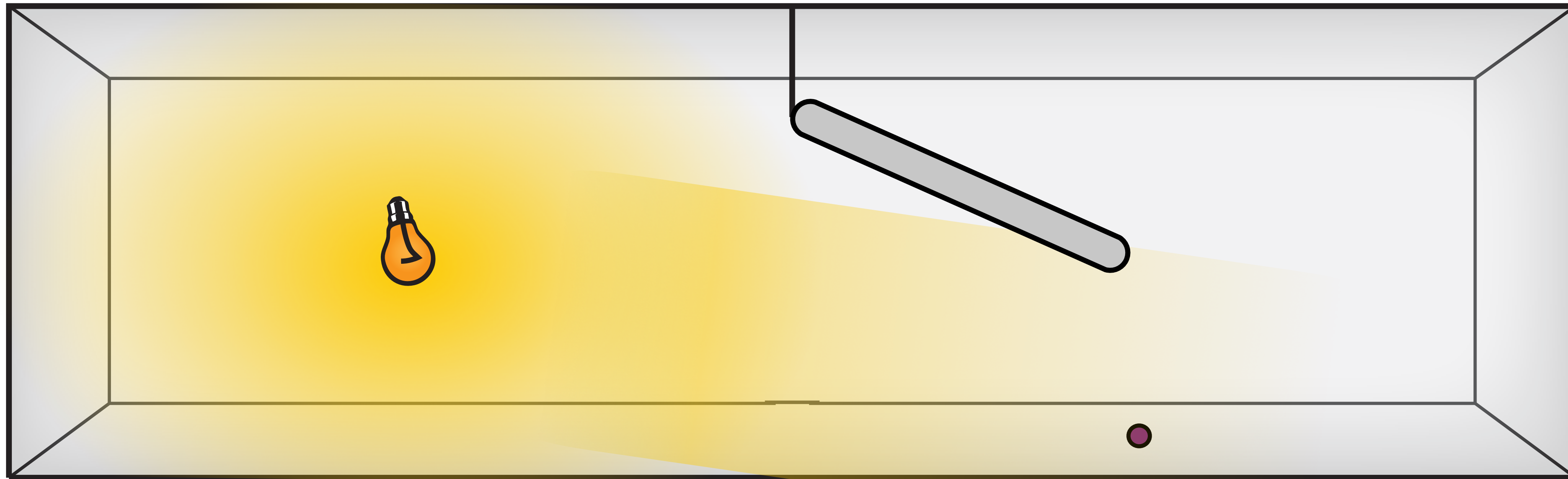
Linearizing door lighting



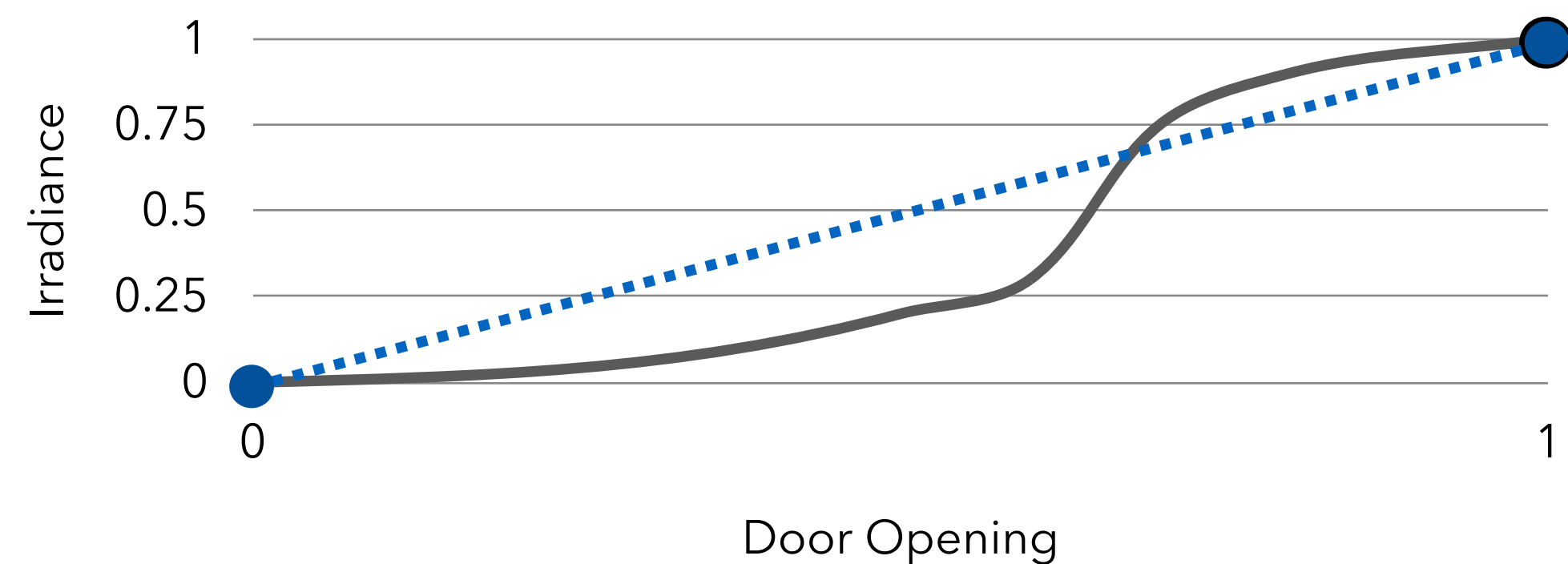
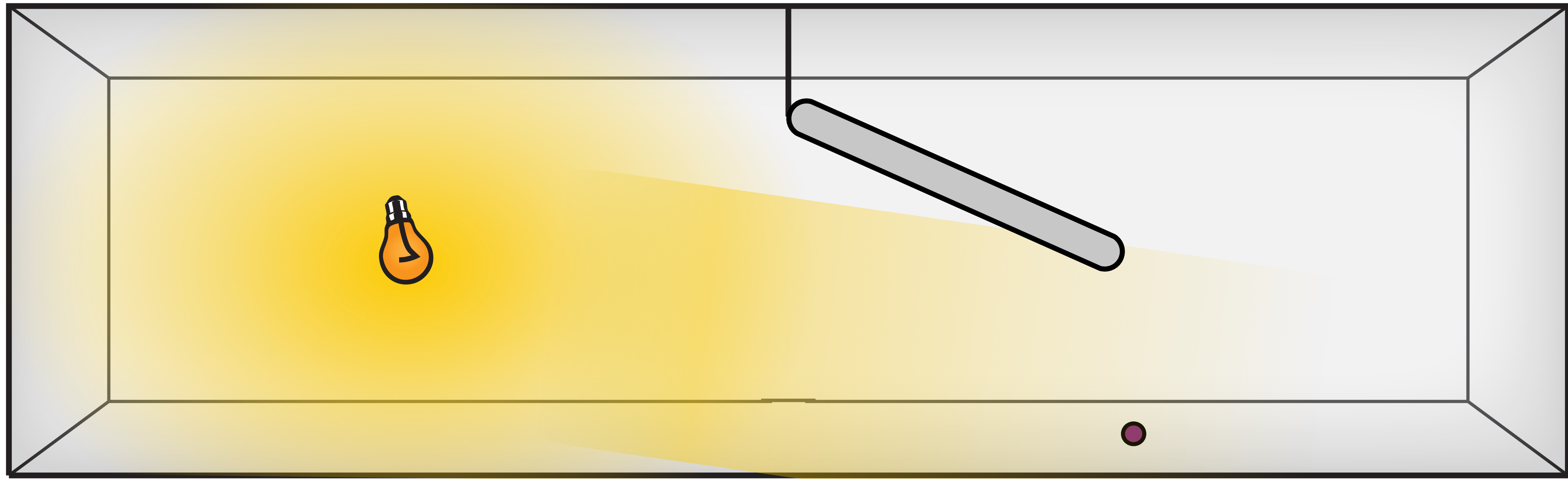
Linearizing door lighting



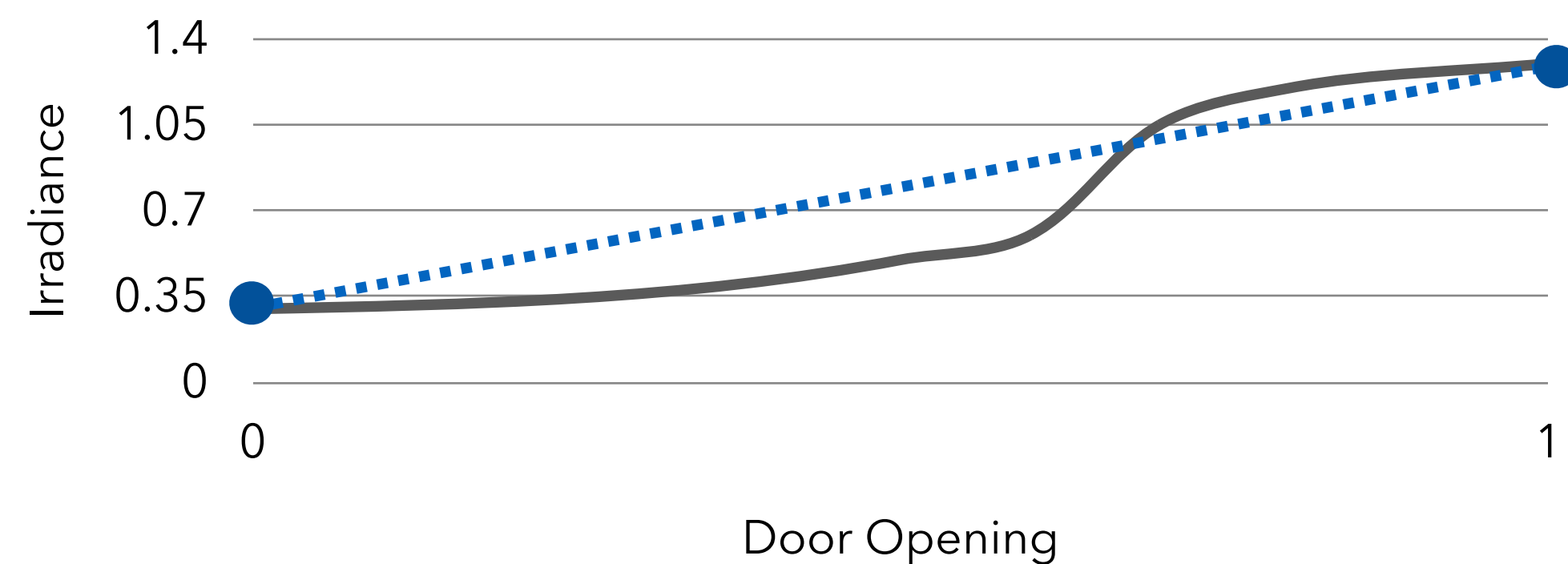
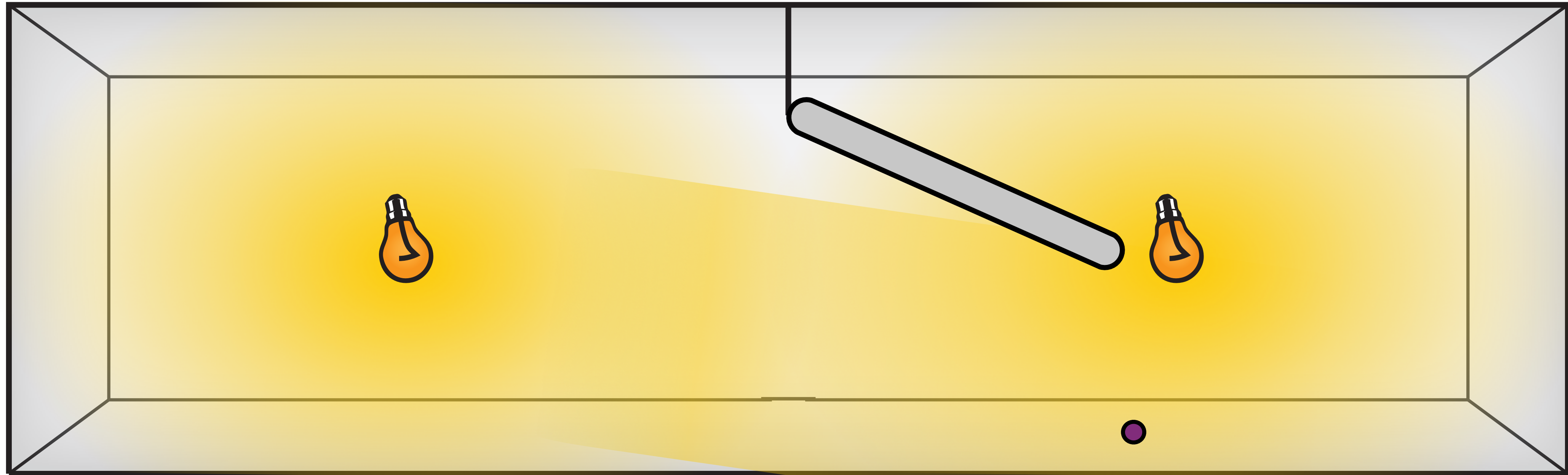
Linearizing door lighting



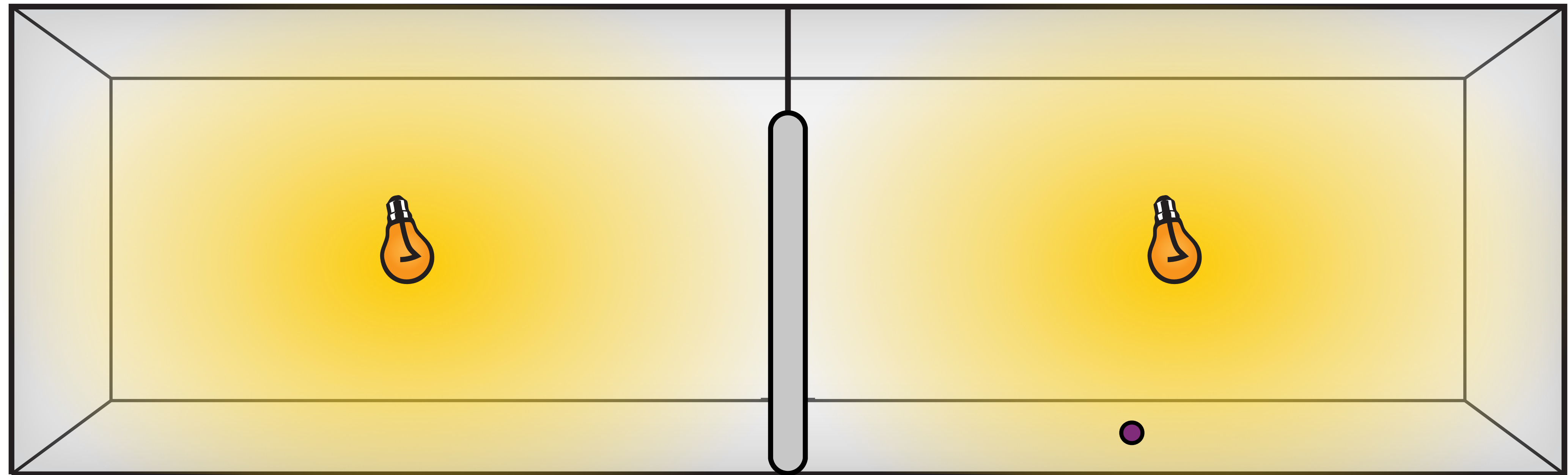
Linearizing door lighting



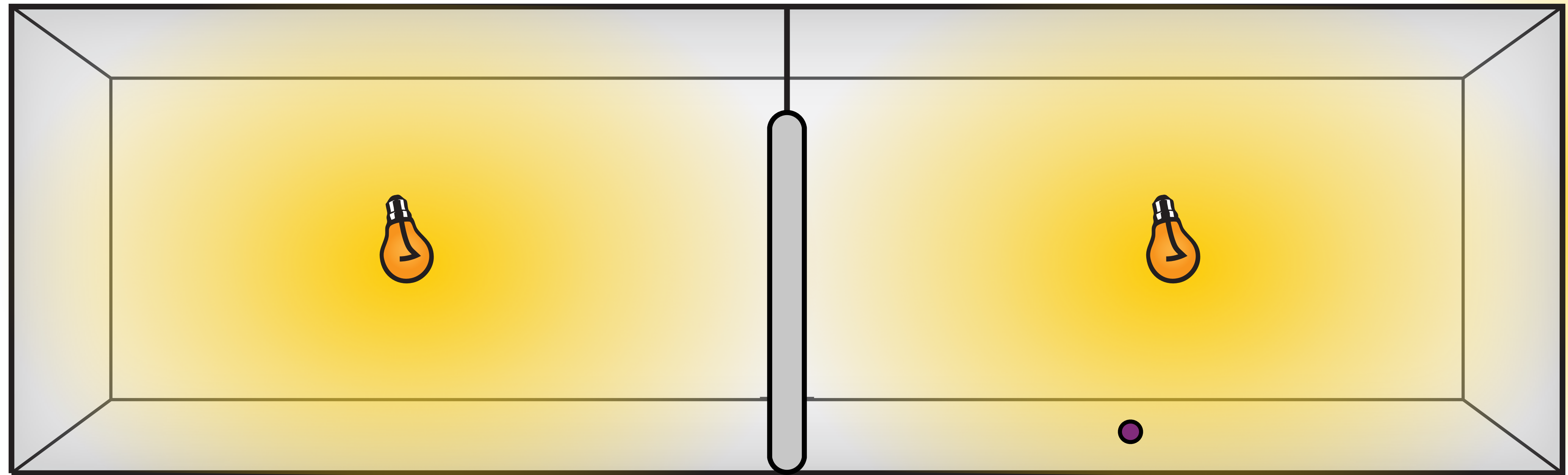
Linearizing door lighting



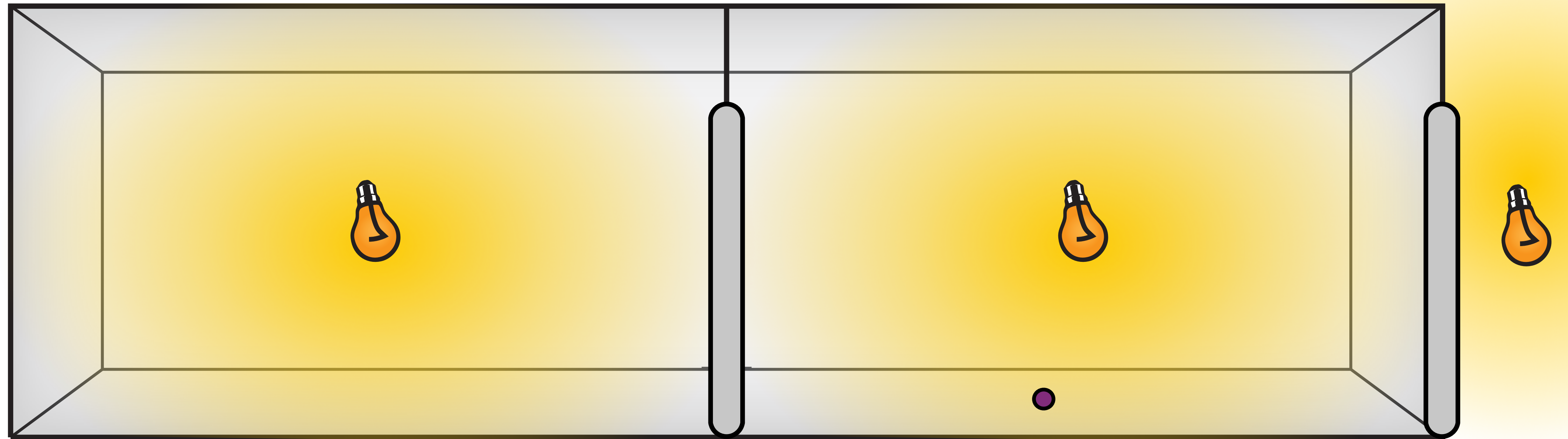
Avoiding a combinatorial explosion



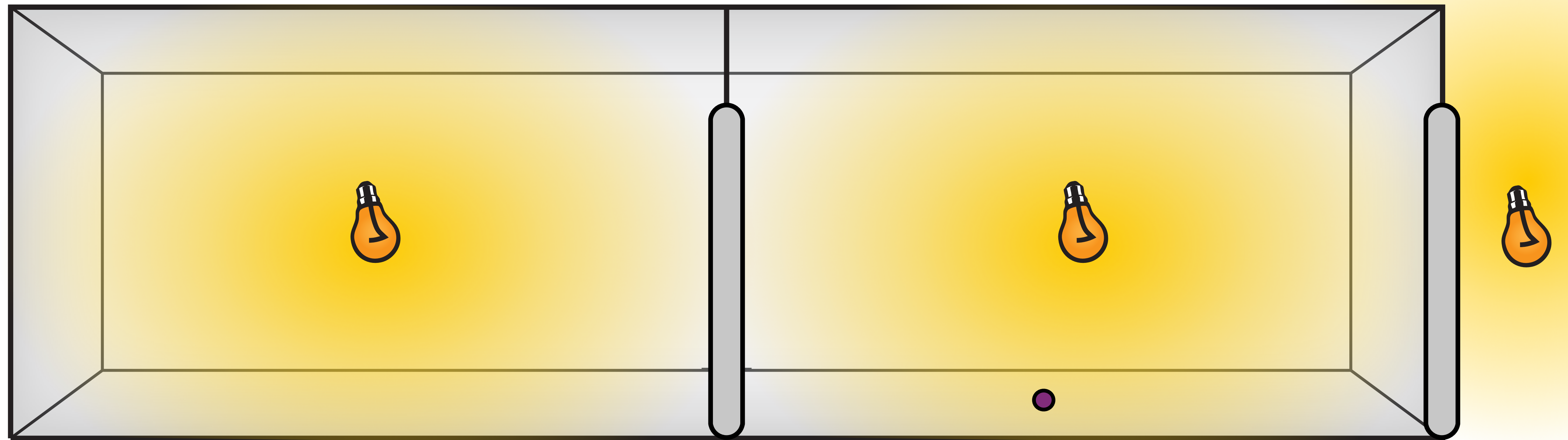
Avoiding a combinatorial explosion



Avoiding a combinatorial explosion

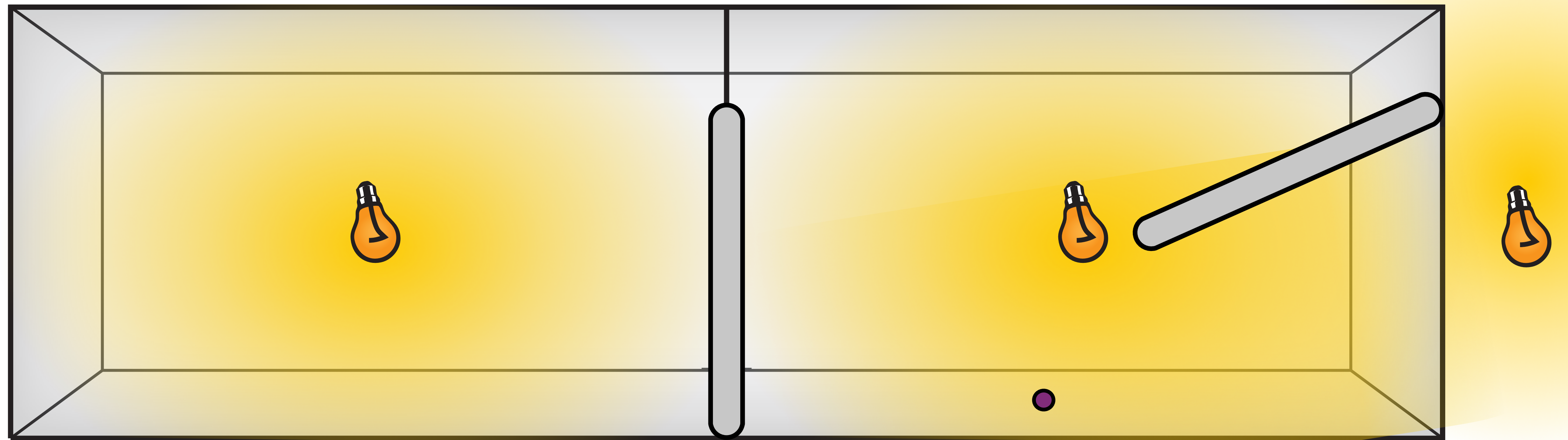


Avoiding a combinatorial explosion



Closed/Closed

Avoiding a combinatorial explosion

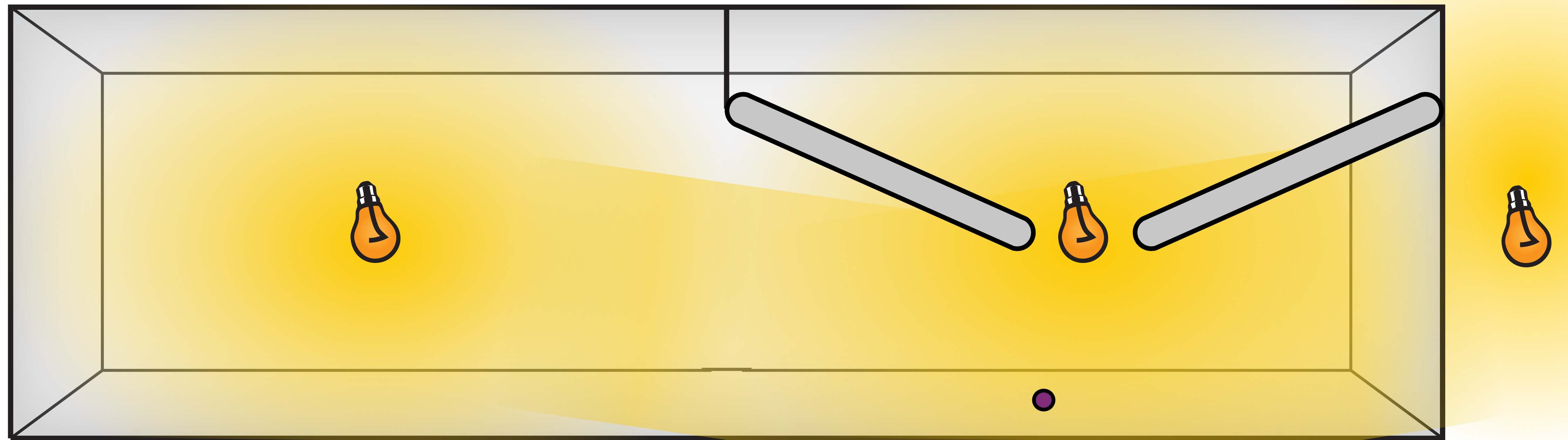


Closed/Closed

Open/Closed

Closed/Open

Avoiding a combinatorial explosion



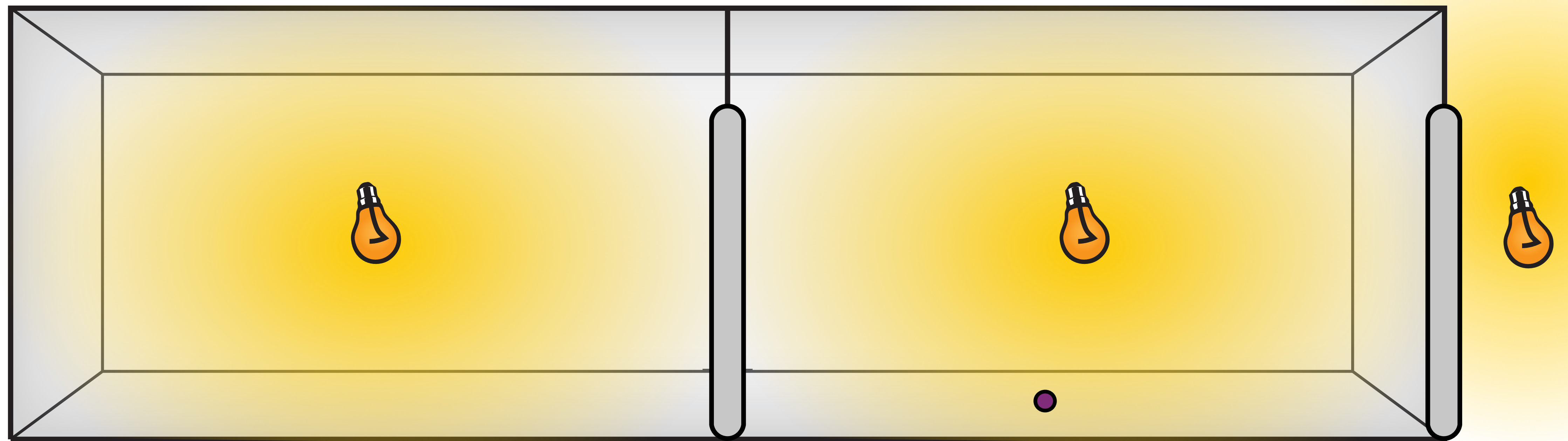
Closed/Closed

Open/Closed

Closed/Open

Open/Open

Avoiding a combinatorial explosion



A *

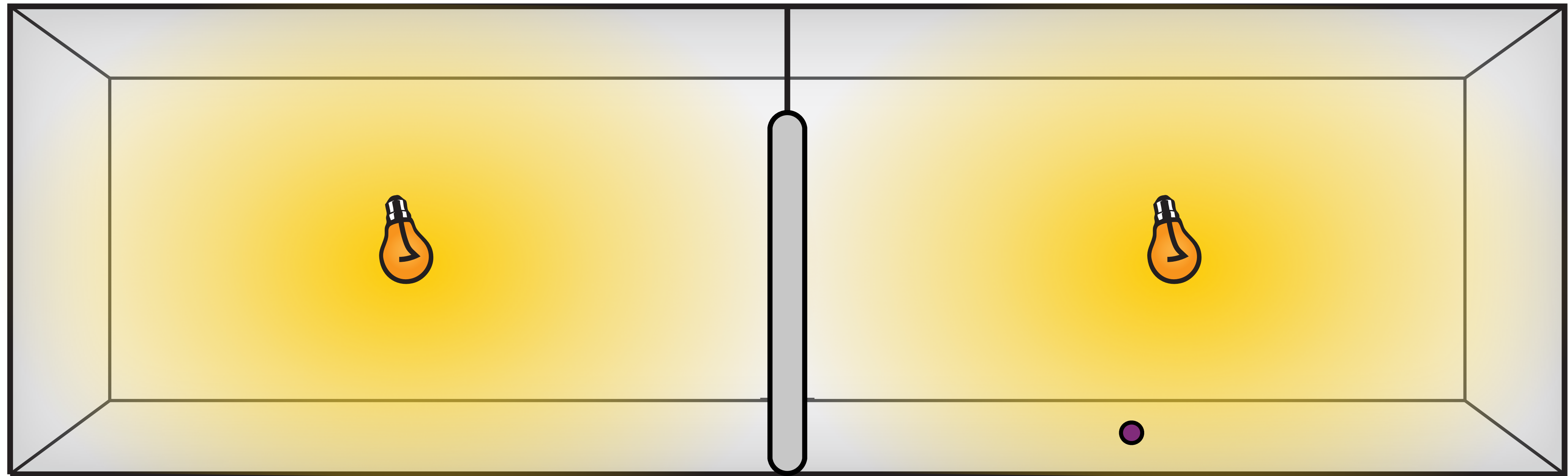
#1 Open

+

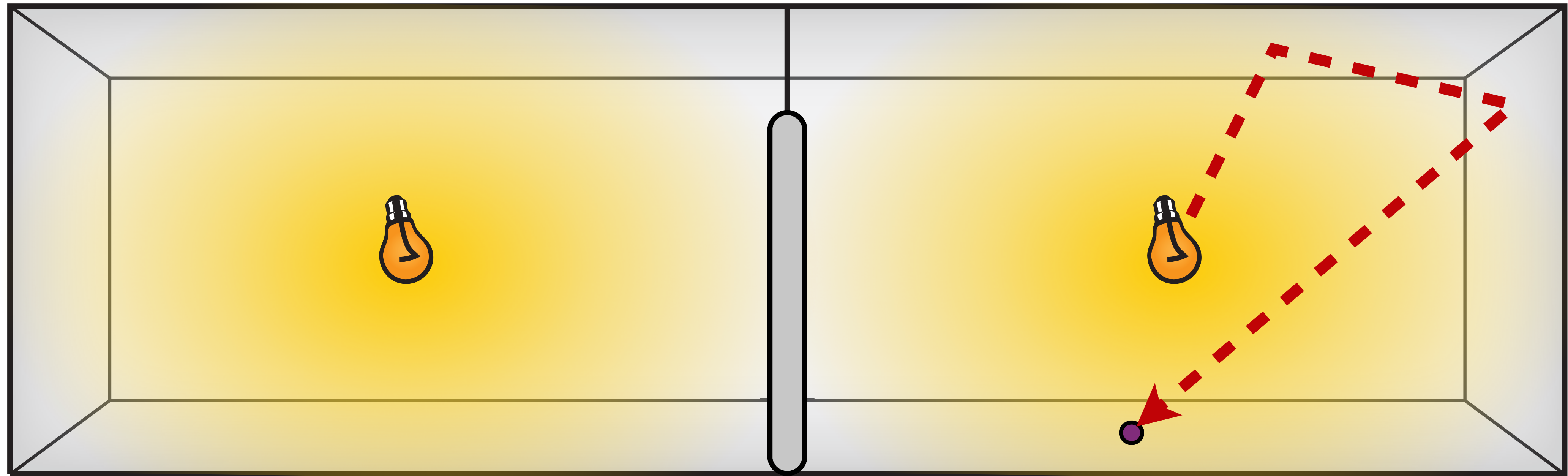
B *

#2 Open

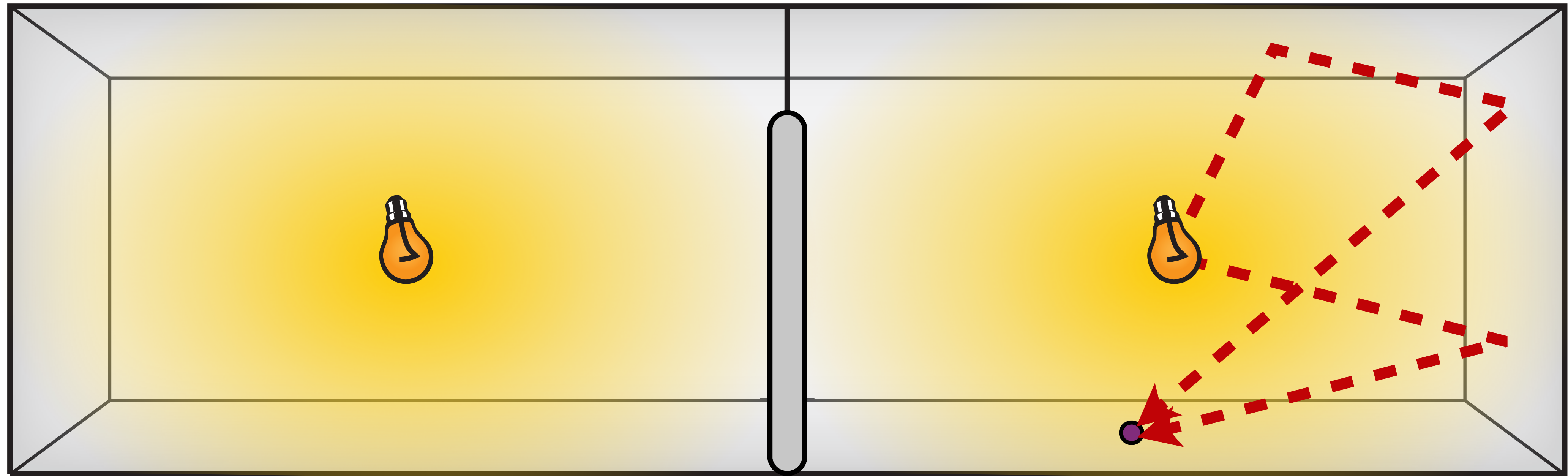
Splitting path space during the bake



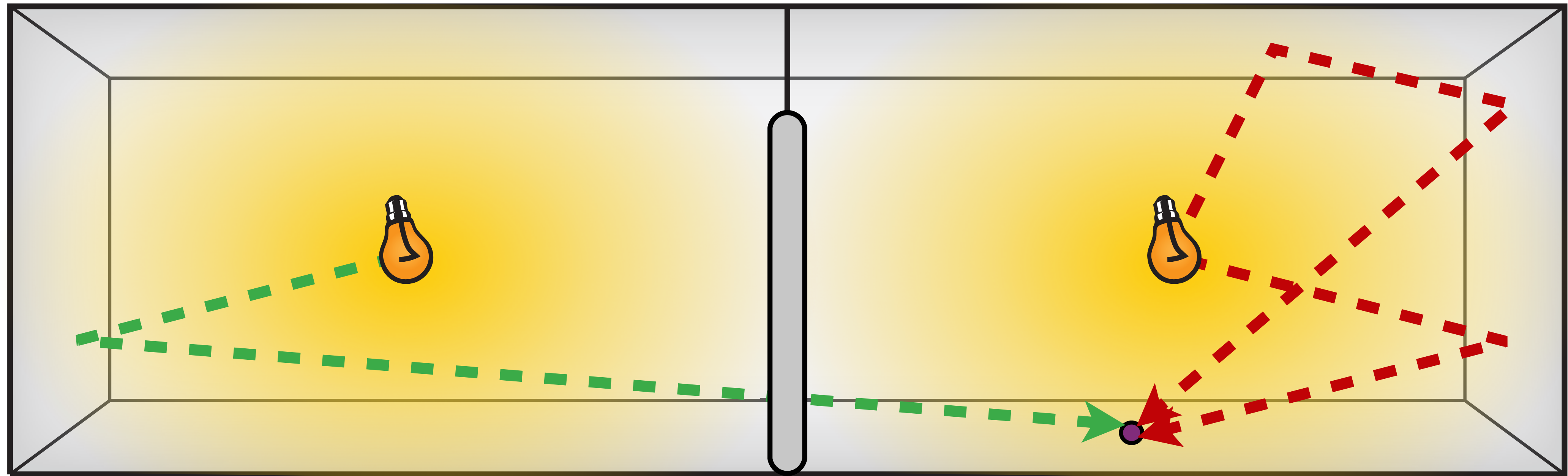
Splitting path space during the bake



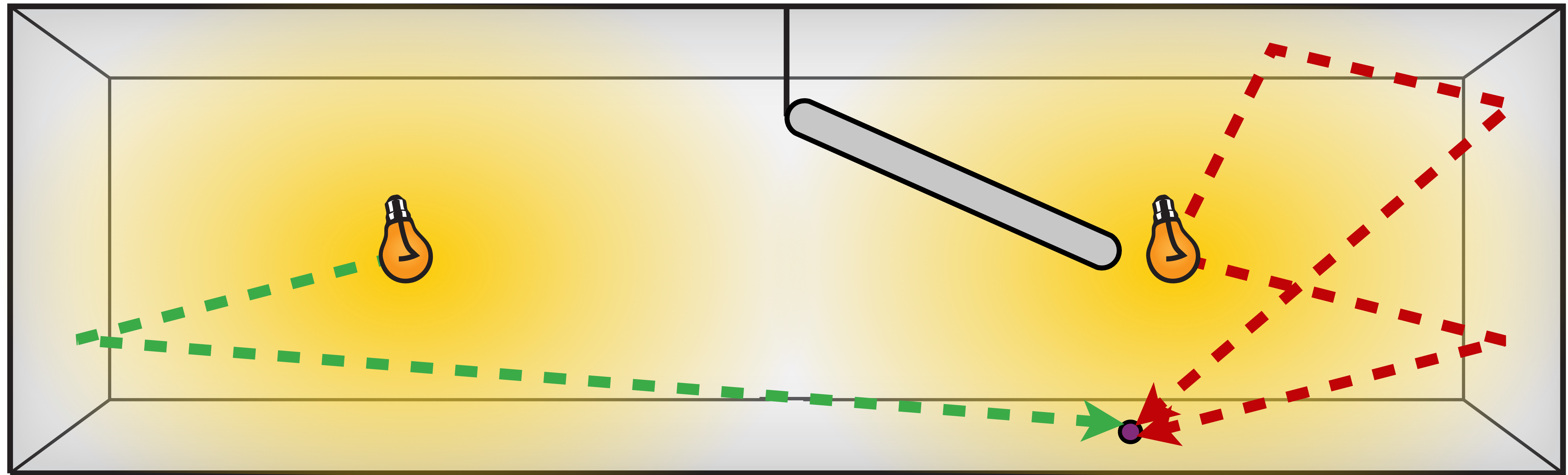
Splitting path space during the bake



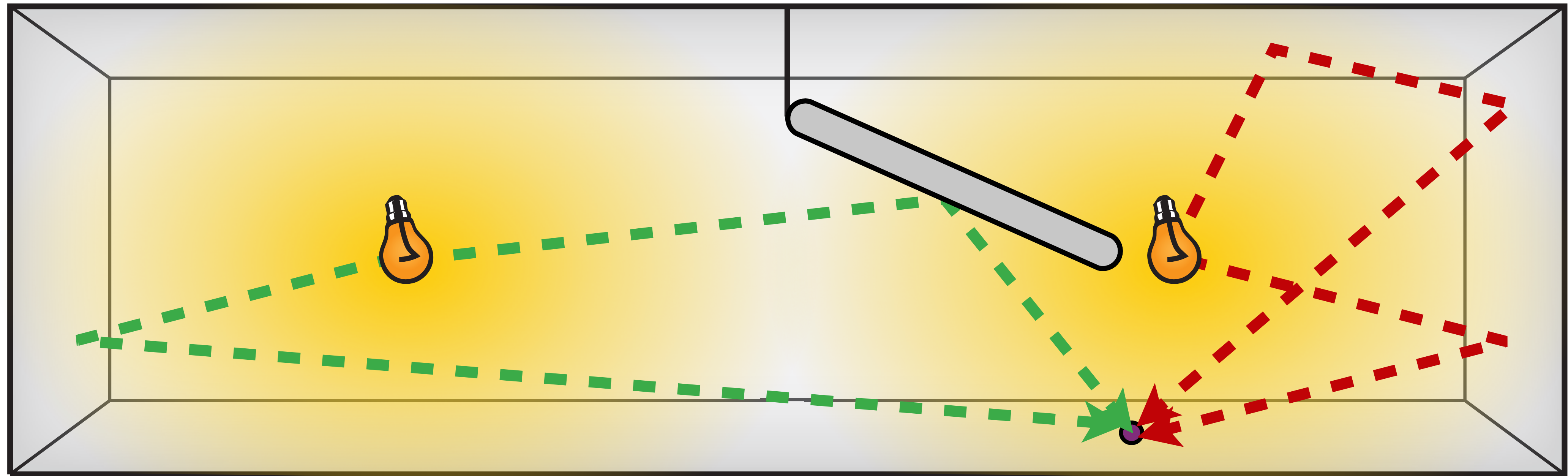
Splitting path space during the bake



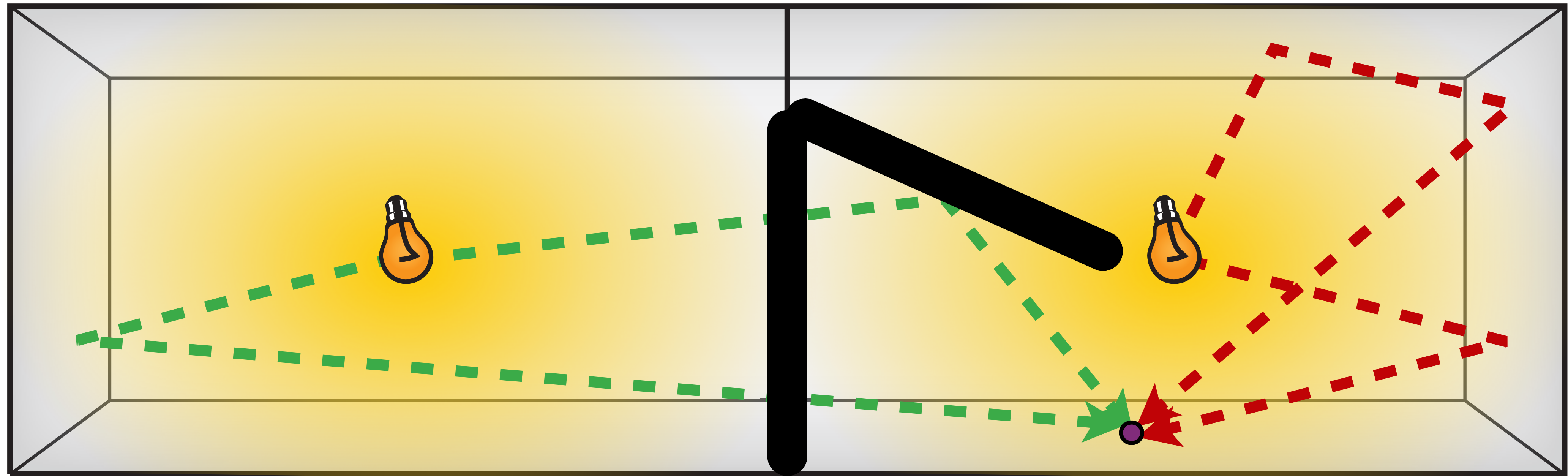
Splitting path space during the bake



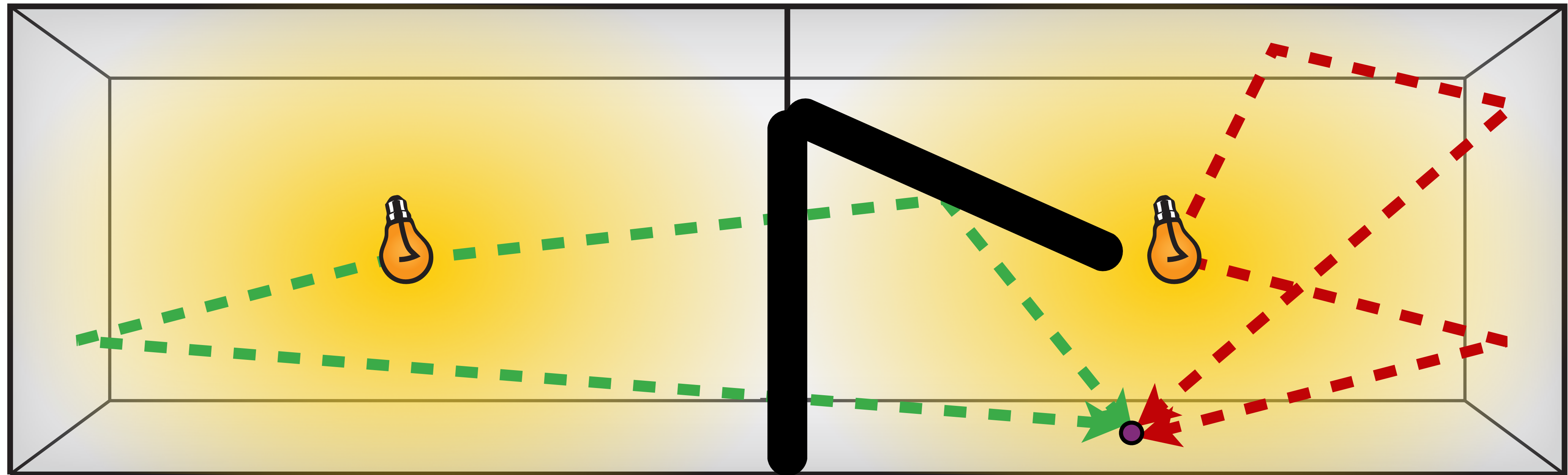
Splitting path space during the bake



Splitting path space during the bake

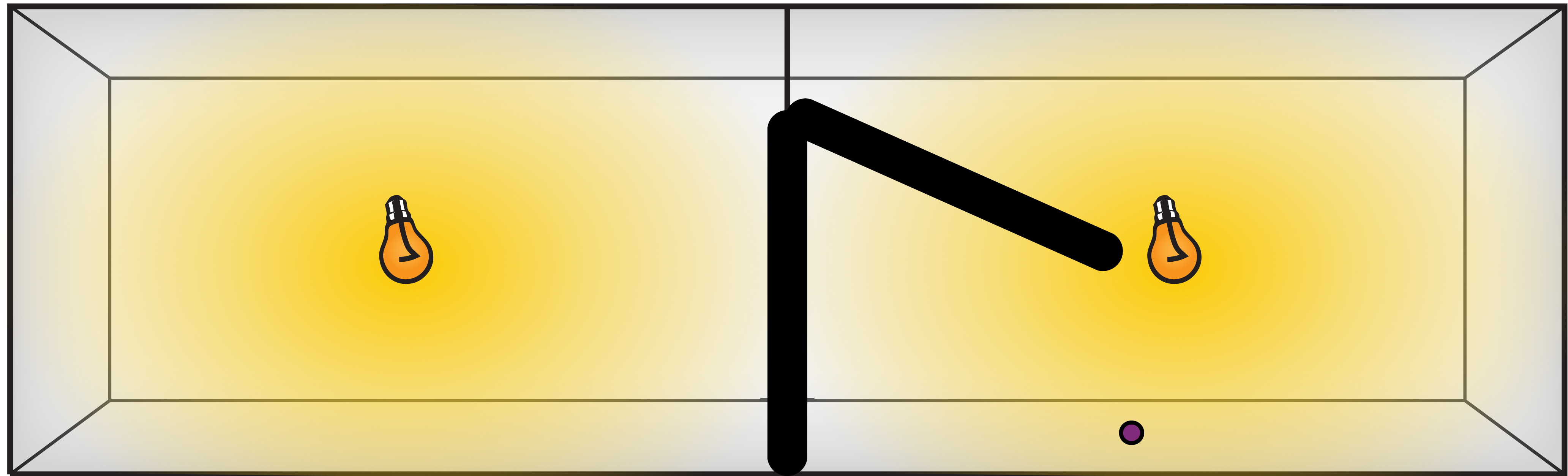


Splitting path space during the bake



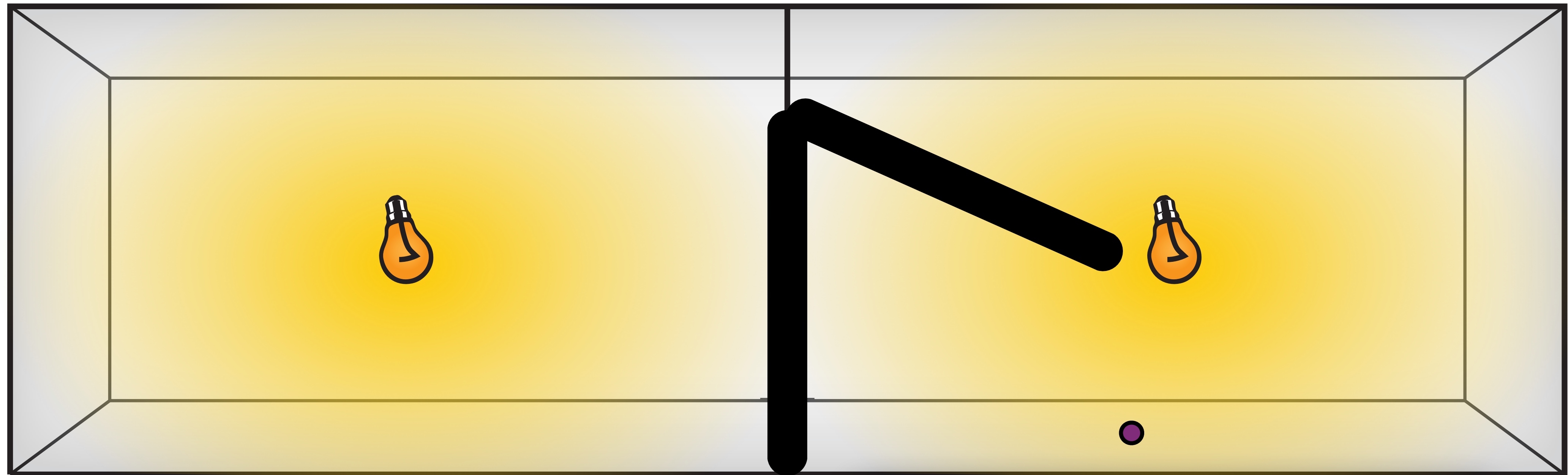
Base Bake

Splitting path space during the bake



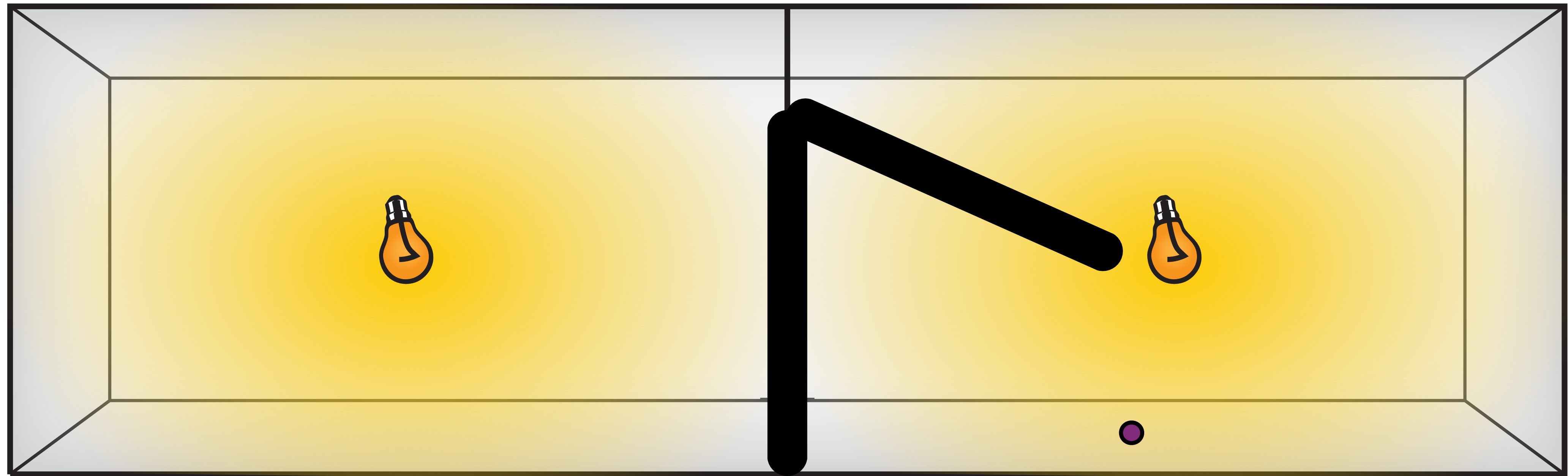
Base Bake

Splitting path space during the bake



Base Bake

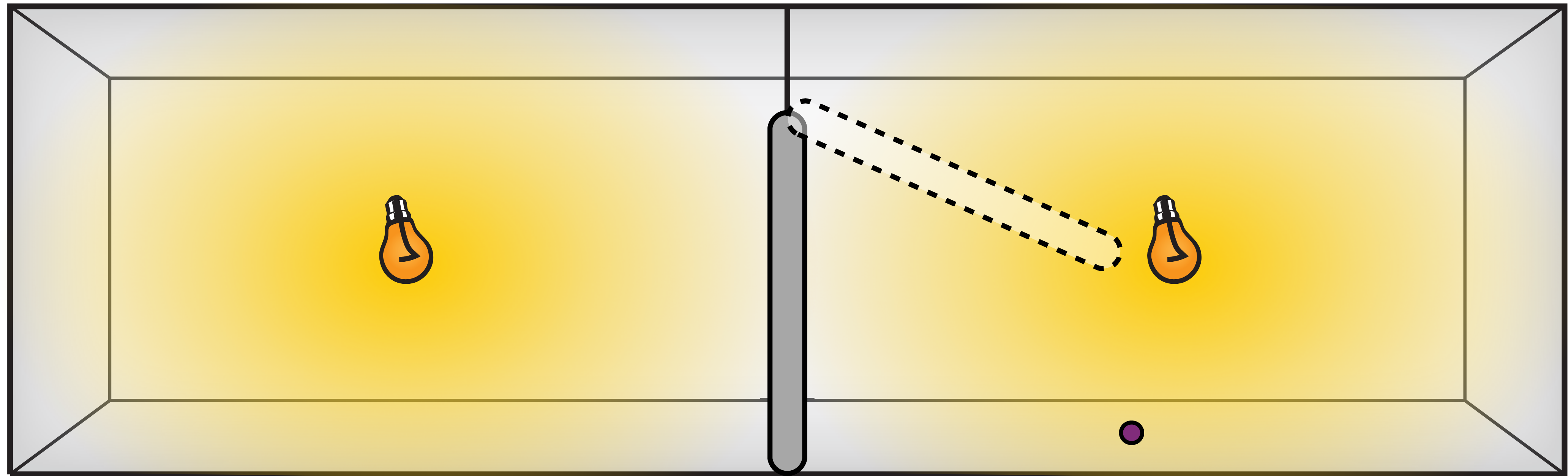
Splitting path space during the bake



State #1

State #2

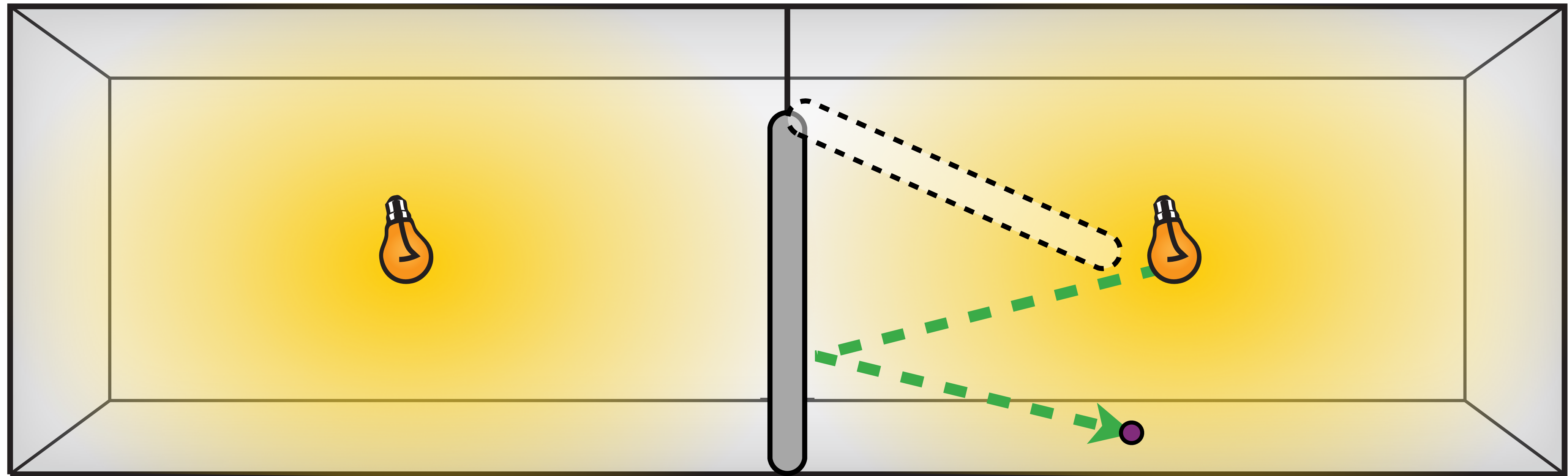
Splitting path space during the bake



State #1

State #2

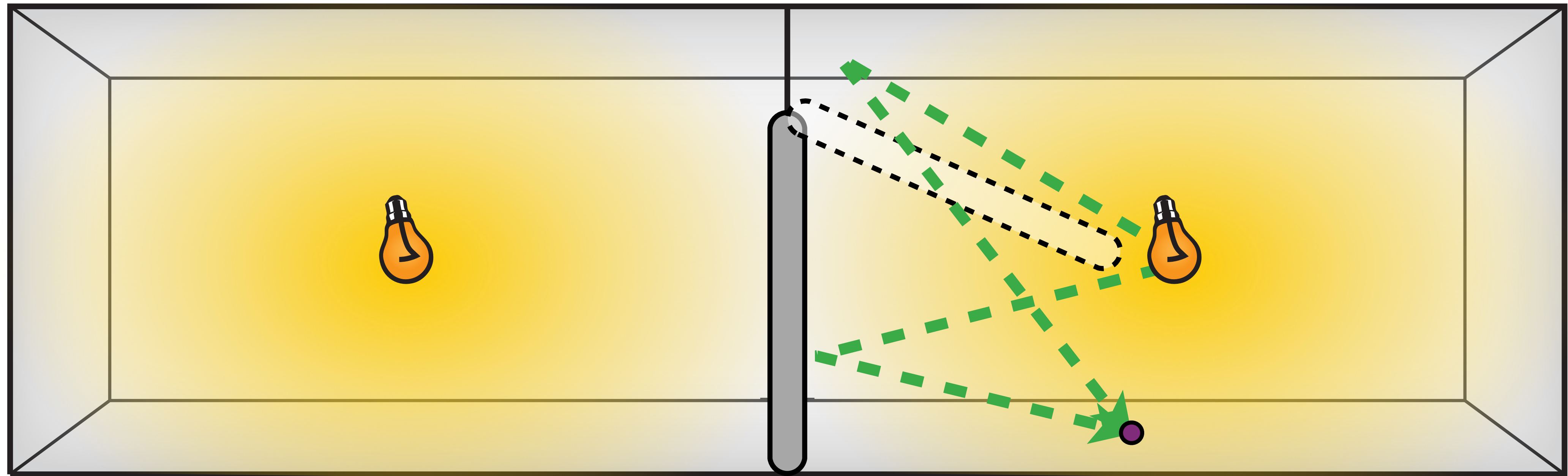
Splitting path space during the bake



State #1

State #2

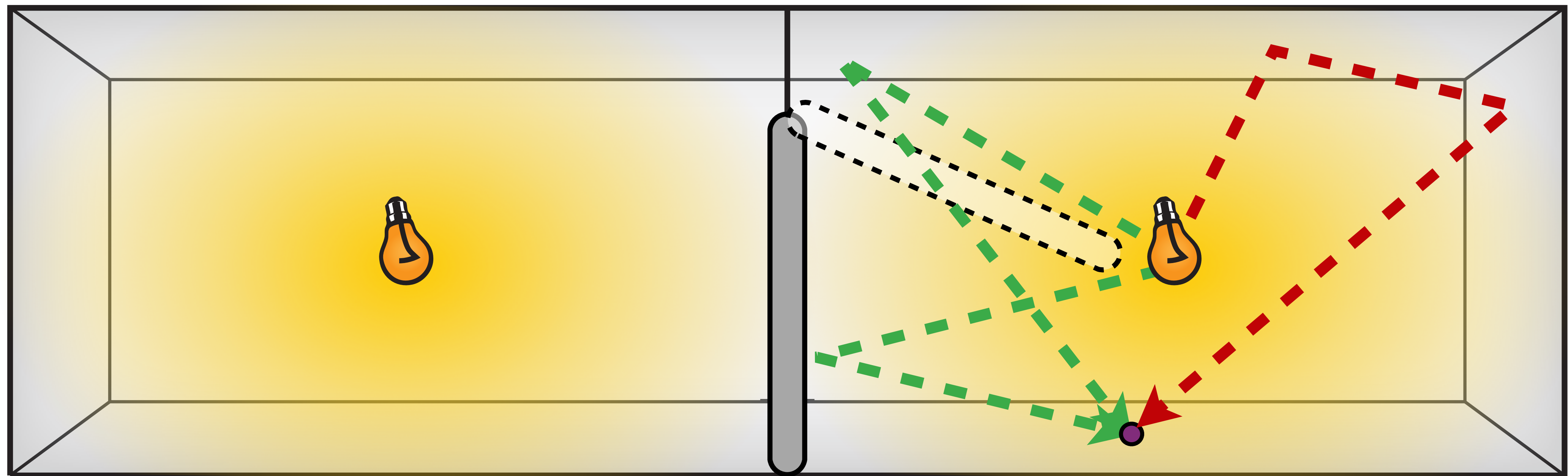
Splitting path space during the bake



State #1

State #2

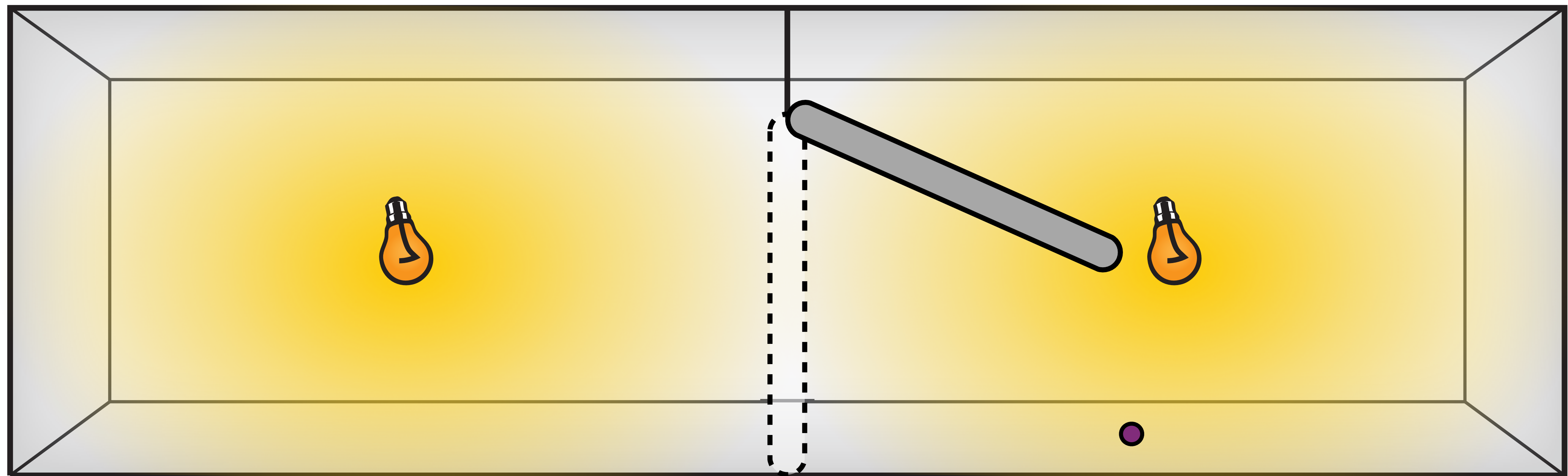
Splitting path space during the bake



State #1

State #2

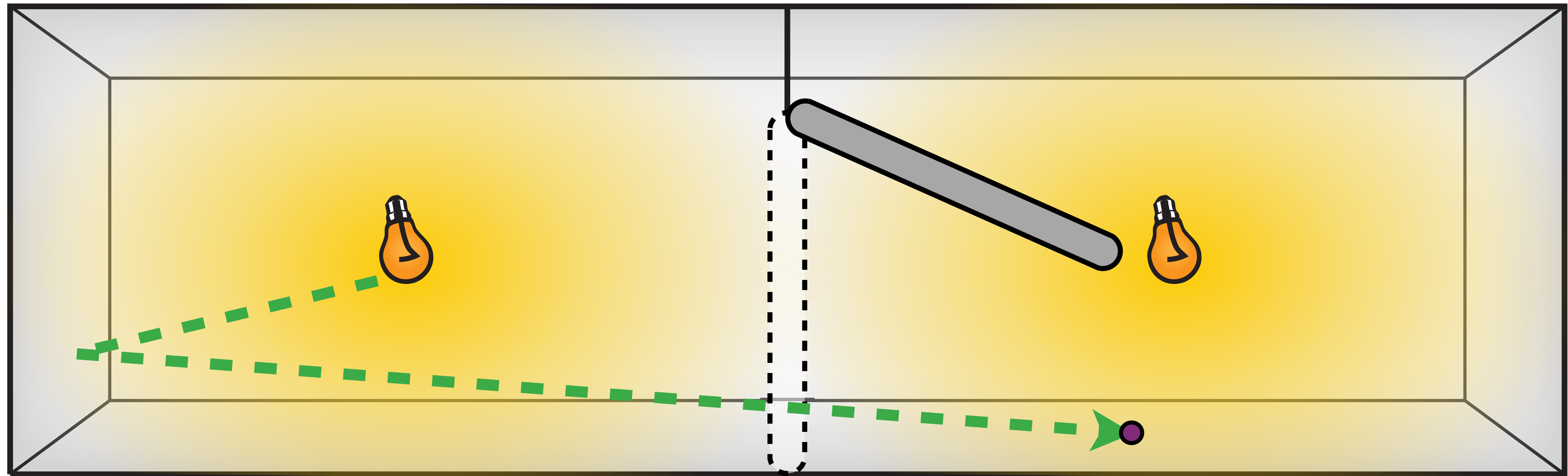
Splitting path space during the bake



State #1

State #2

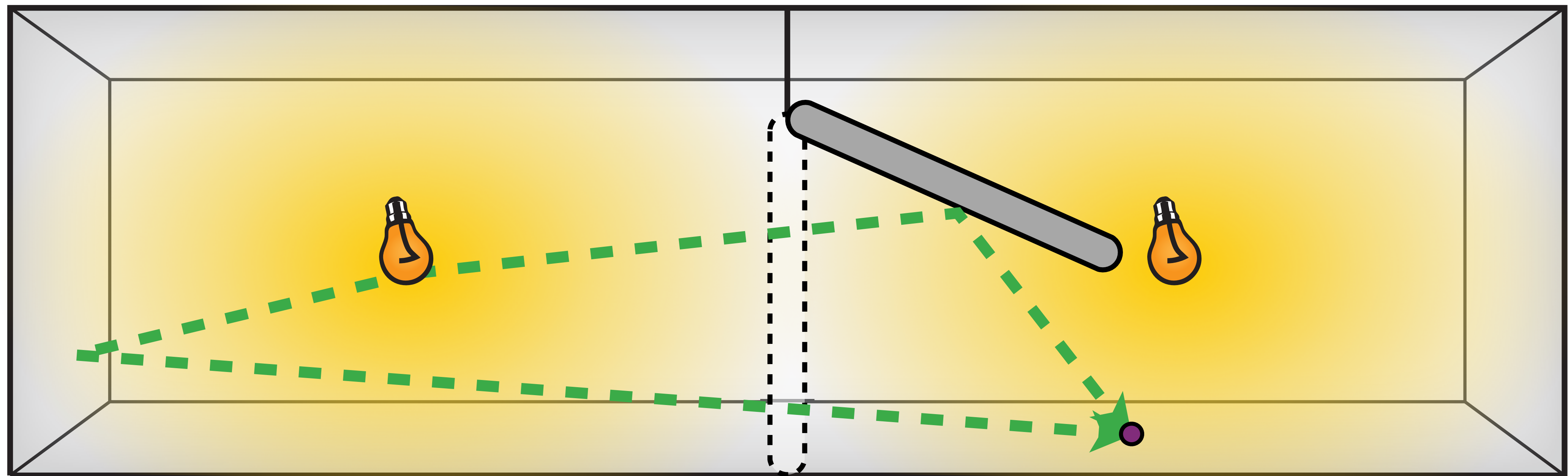
Splitting path space during the bake



State #1

State #2

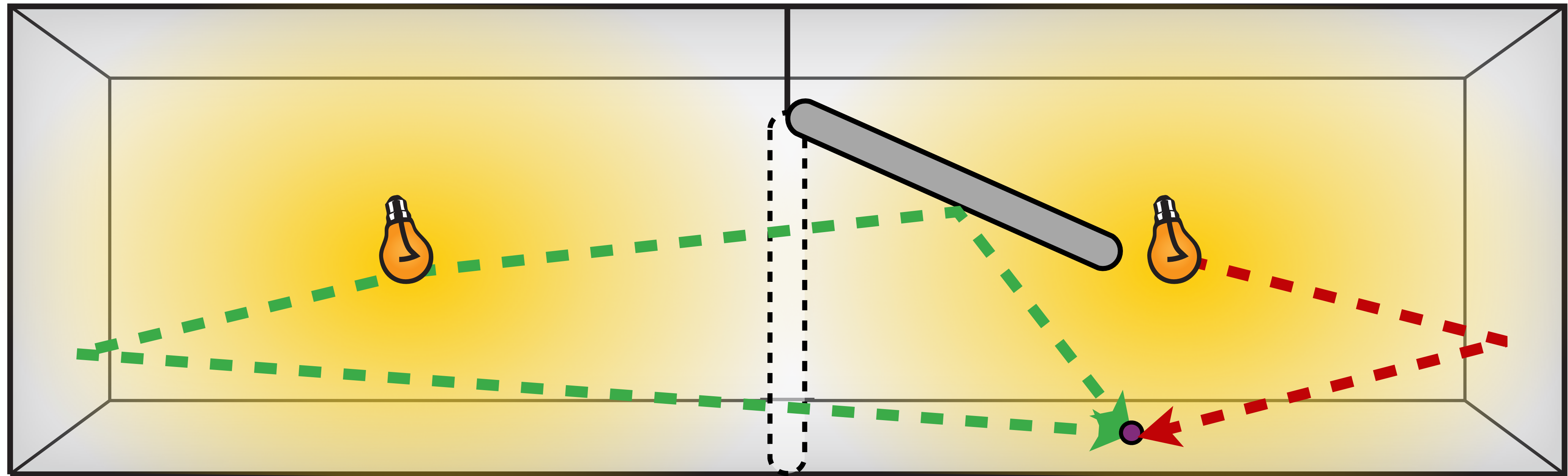
Splitting path space during the bake



State #1

State #2

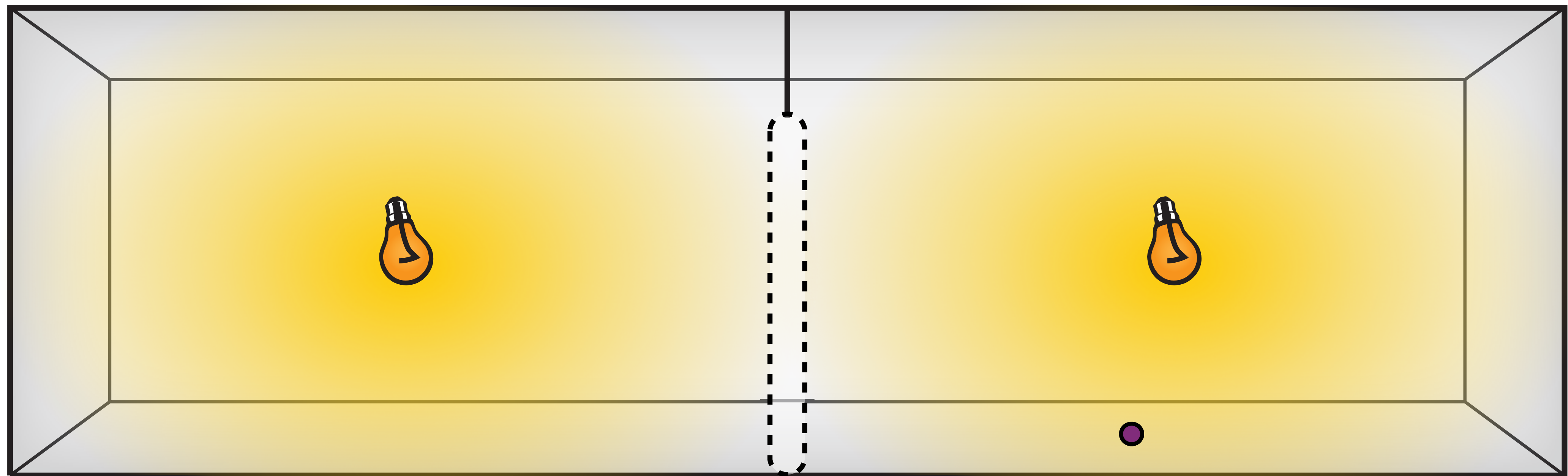
Splitting path space during the bake



State #1

State #2

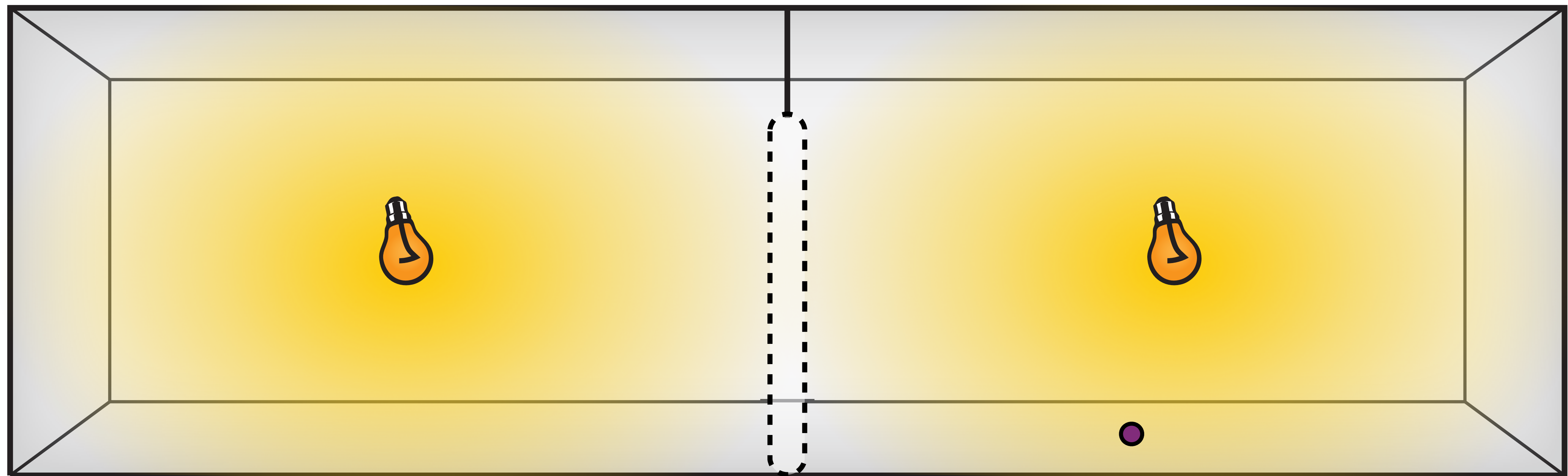
Further Simplifications



State #2

Further Simplifications

1. Disregard Bounce Light

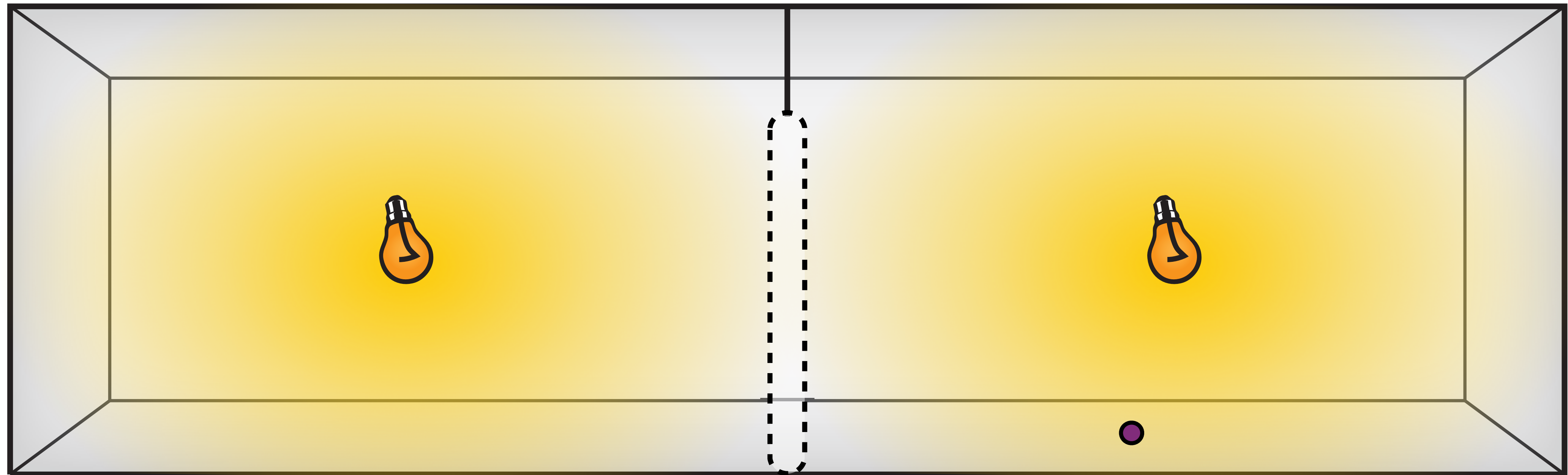


State #2

Further Simplifications

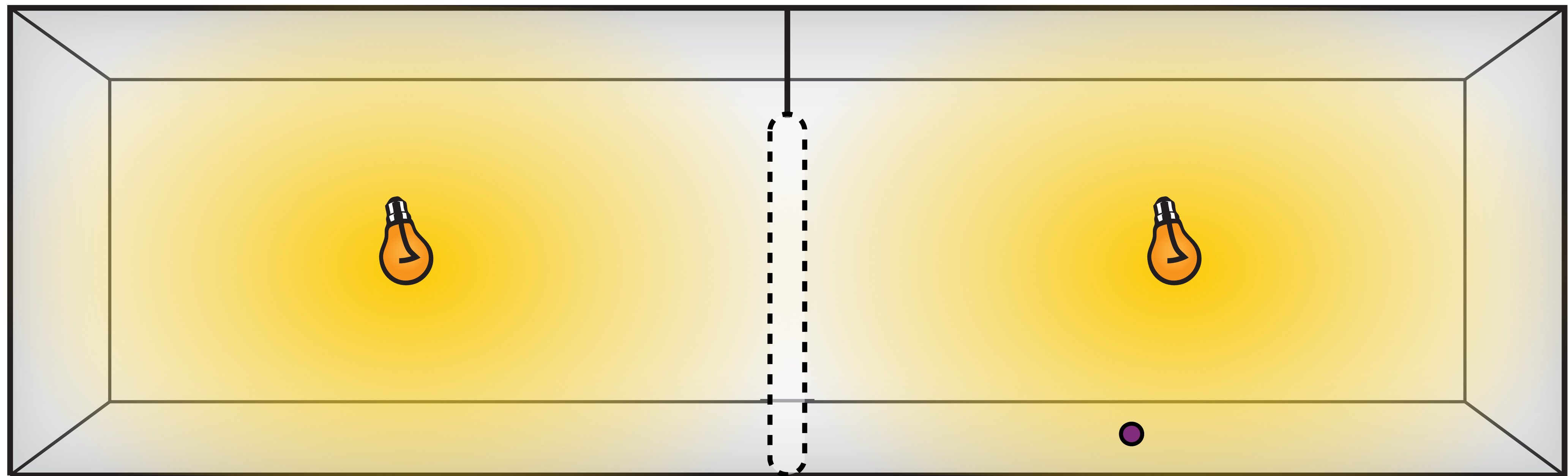
1. Disregard Bounce Light

2. Ignore the "Open Door" geometry



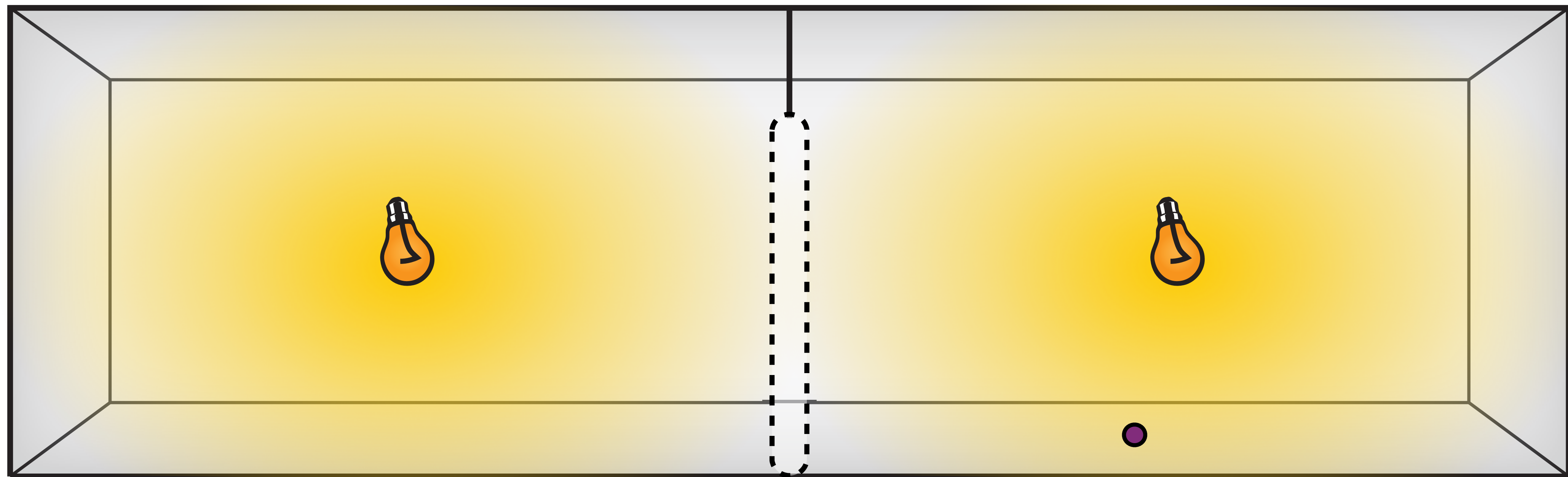
State #2

Further Simplifications



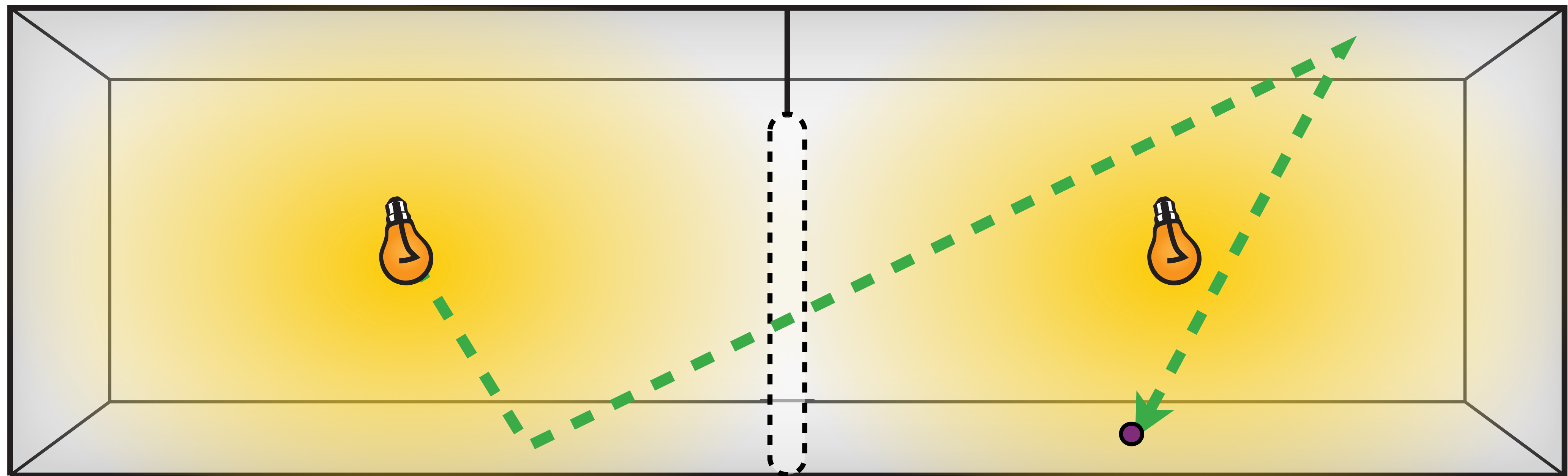
Door Open

Further Simplifications



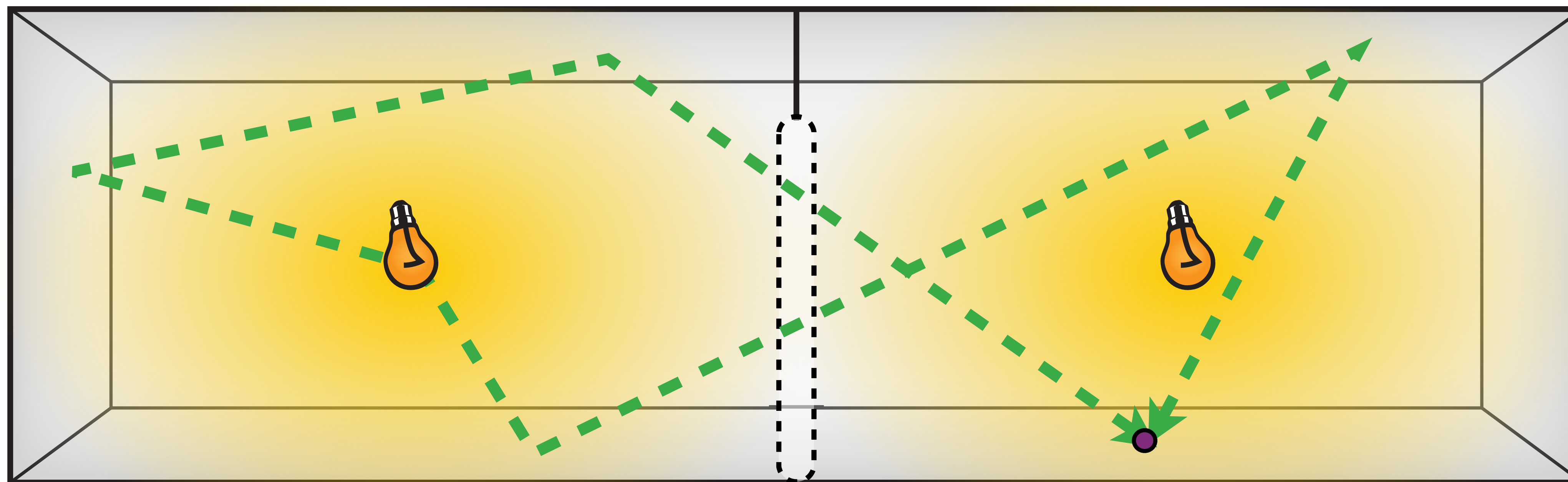
Door Open

Further Simplifications



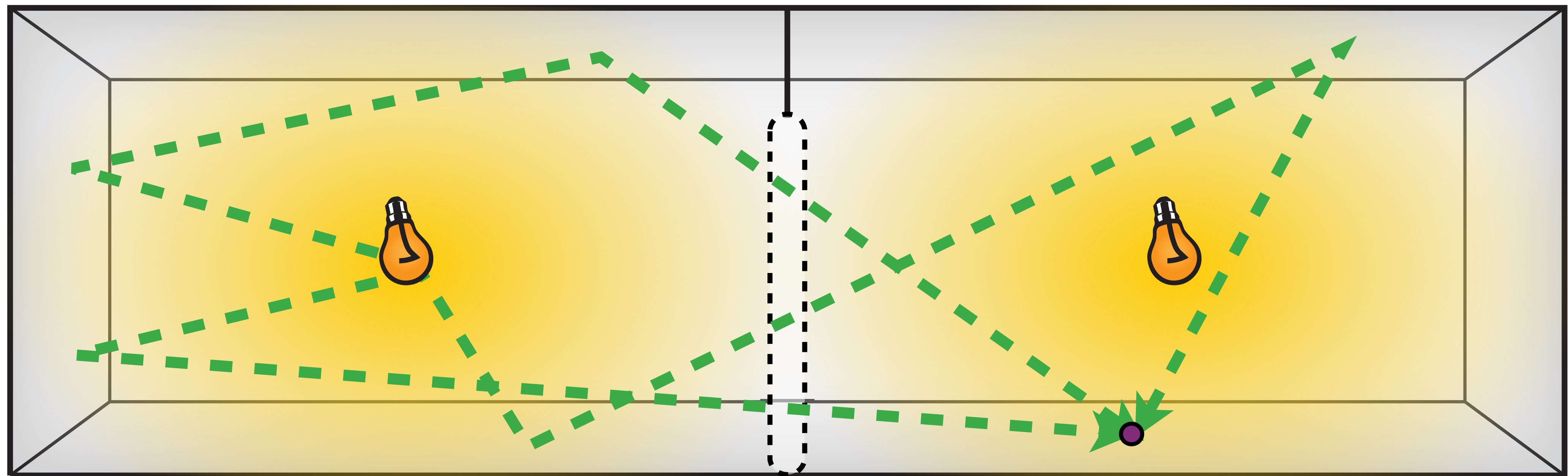
Door Open

Further Simplifications



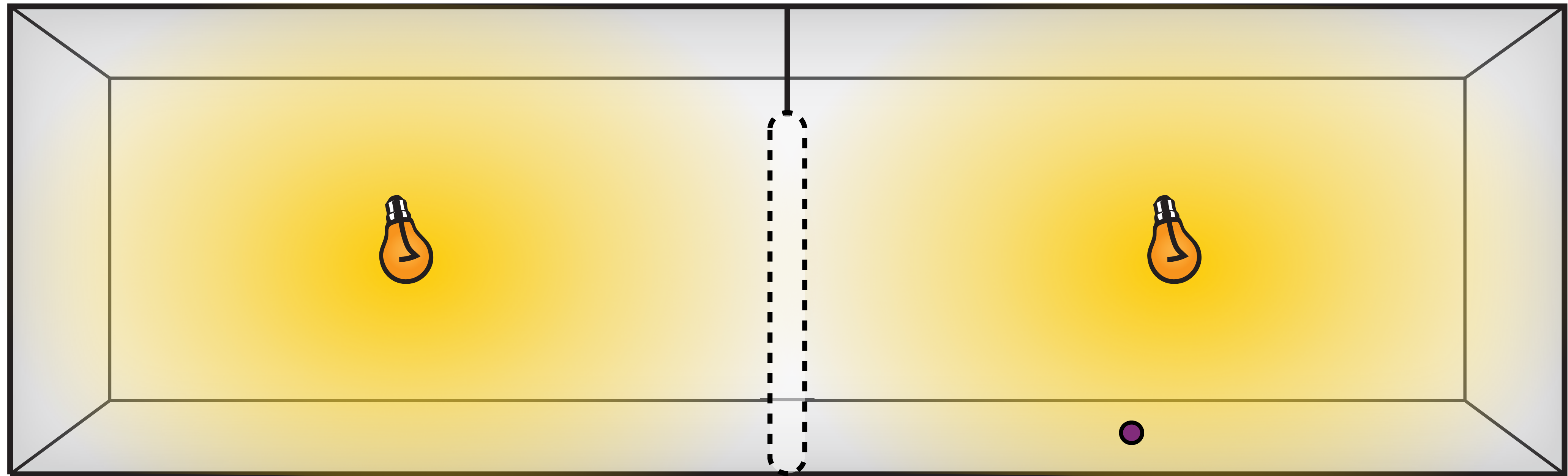
Door Open

Further Simplifications

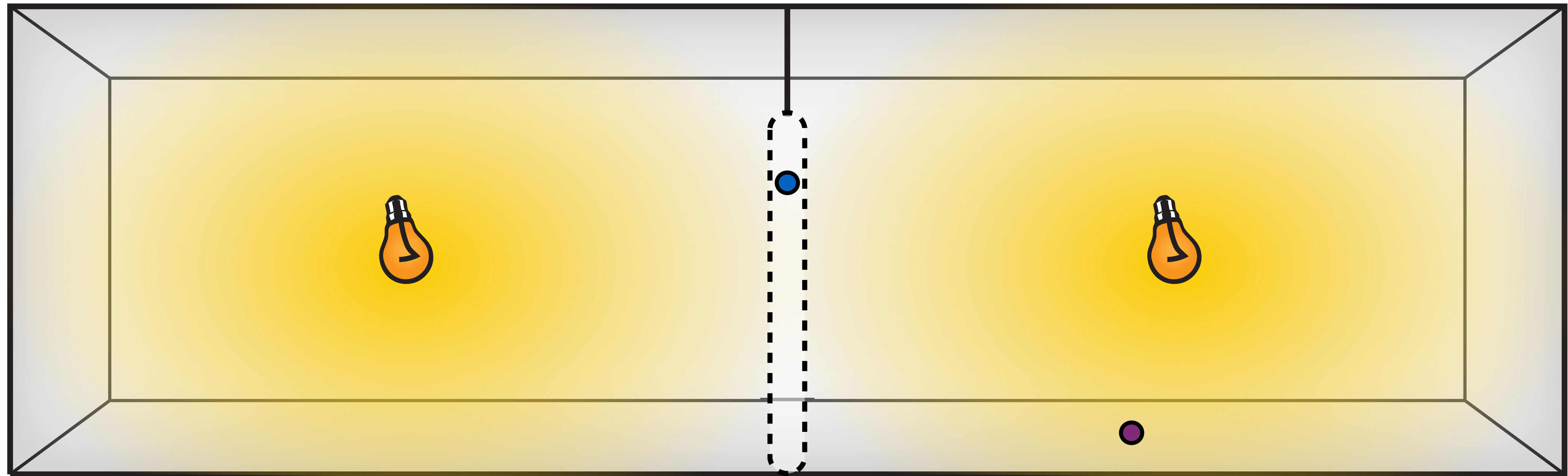


Door Open

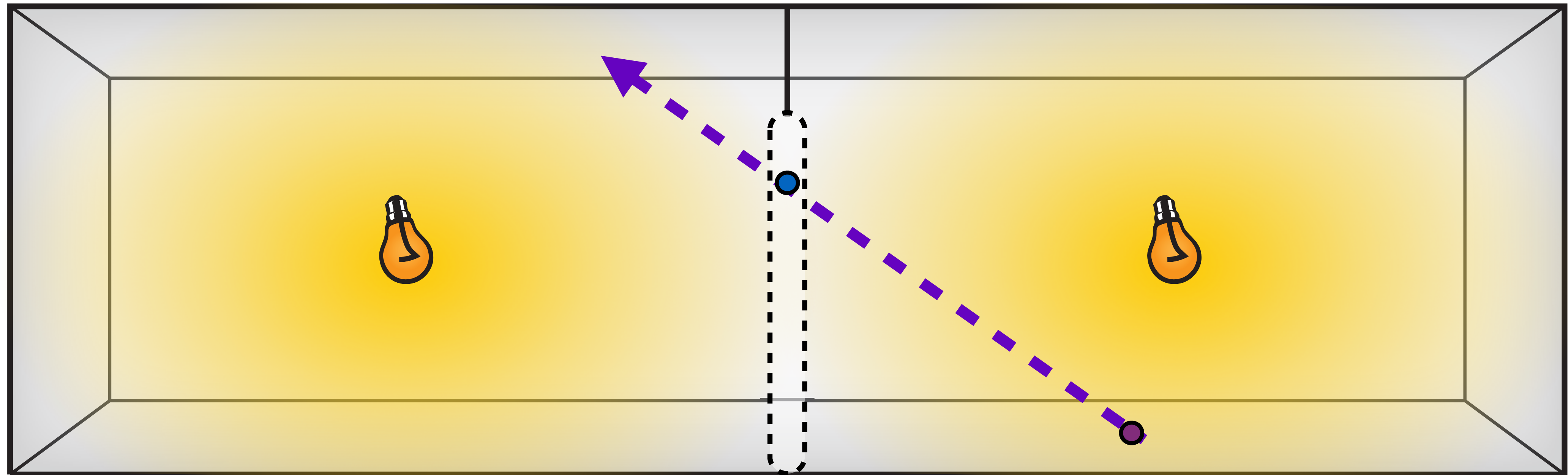
Efficient Sampling



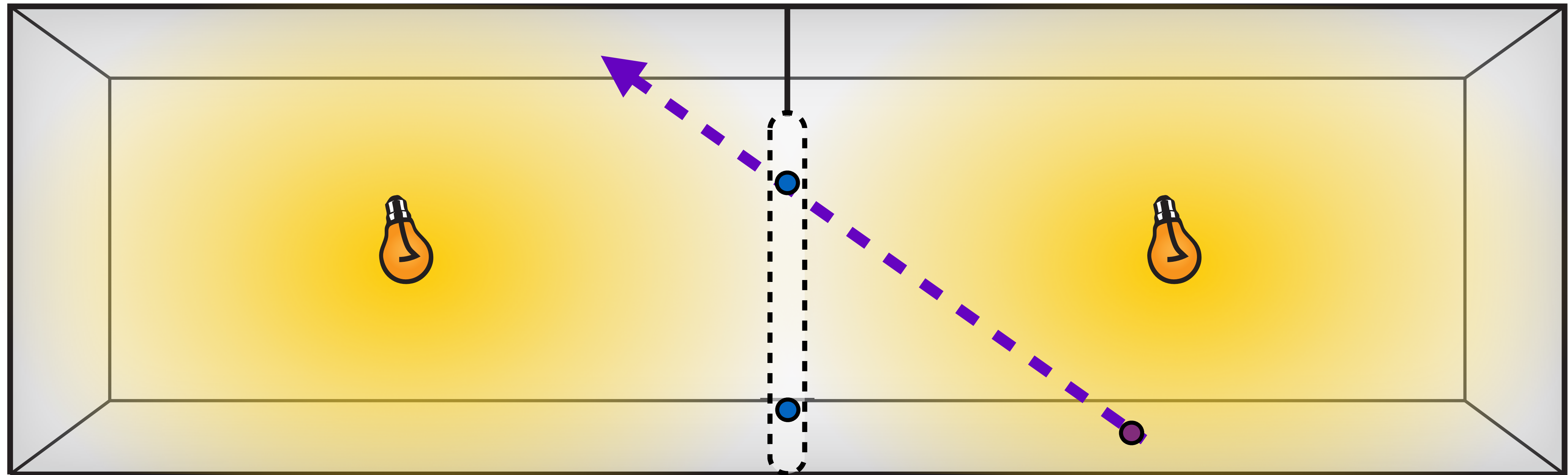
Efficient Sampling



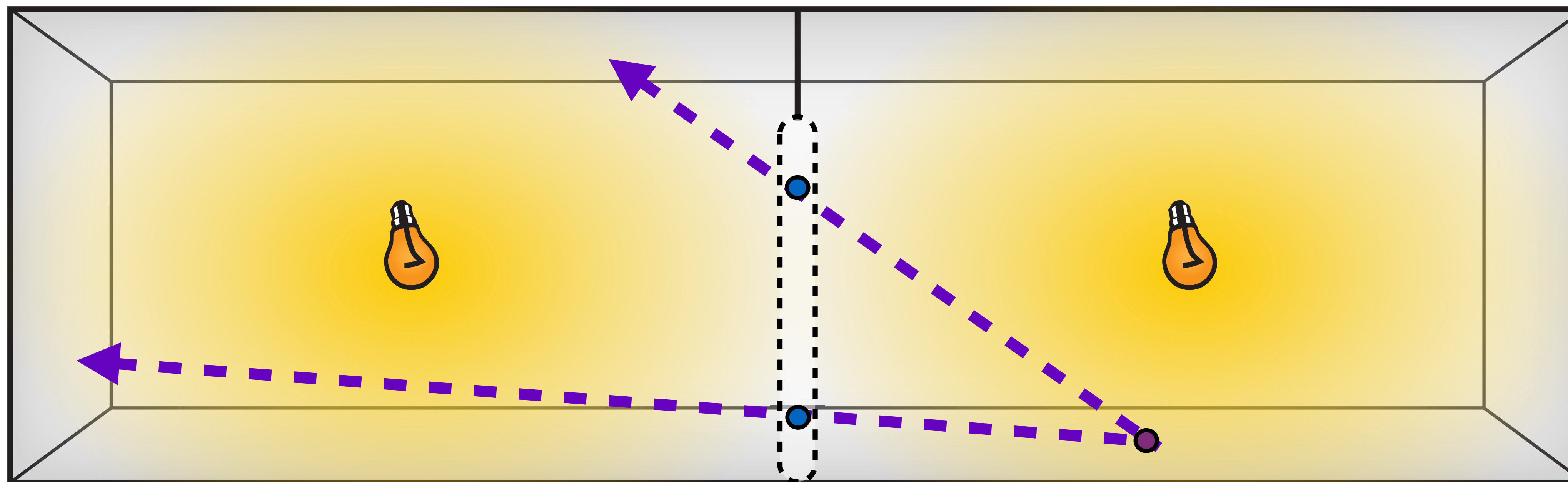
Efficient Sampling



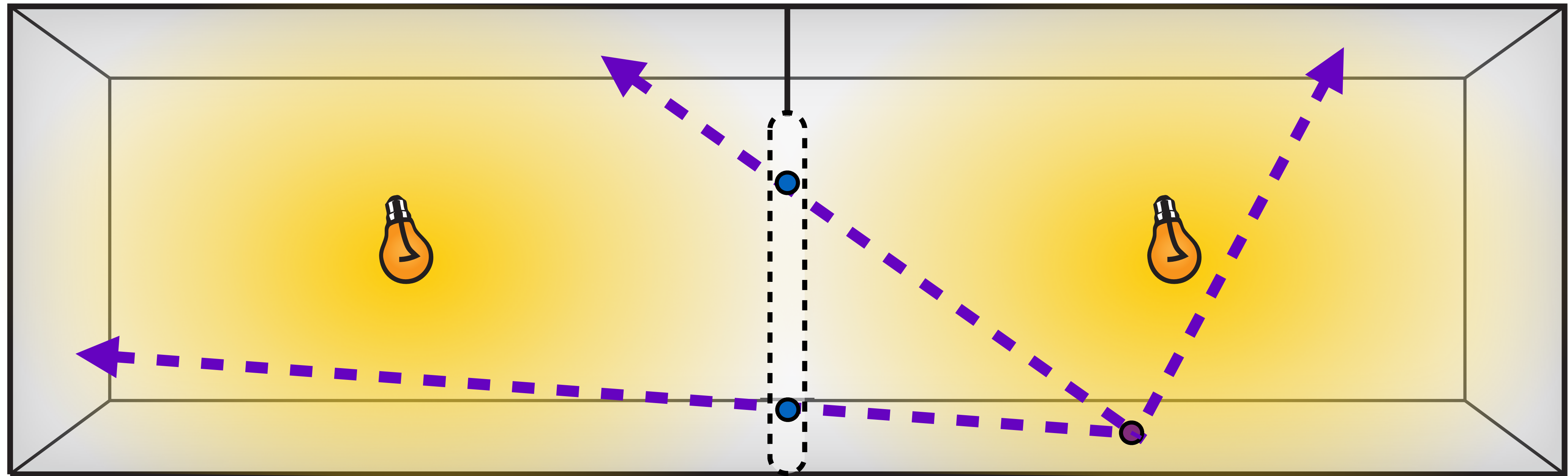
Efficient Sampling



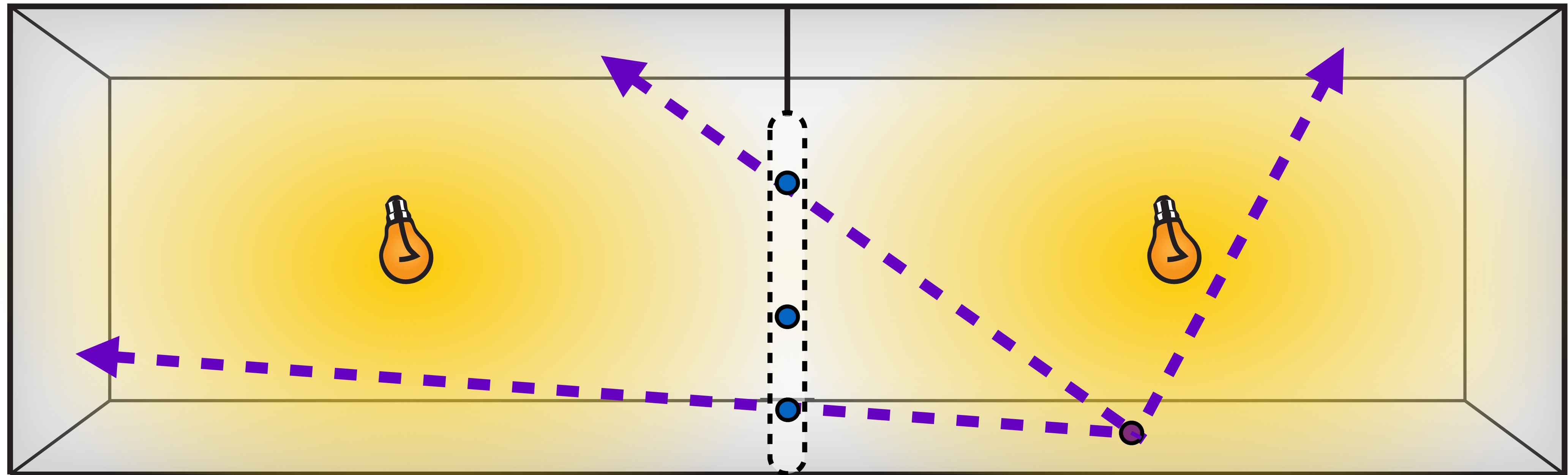
Efficient Sampling



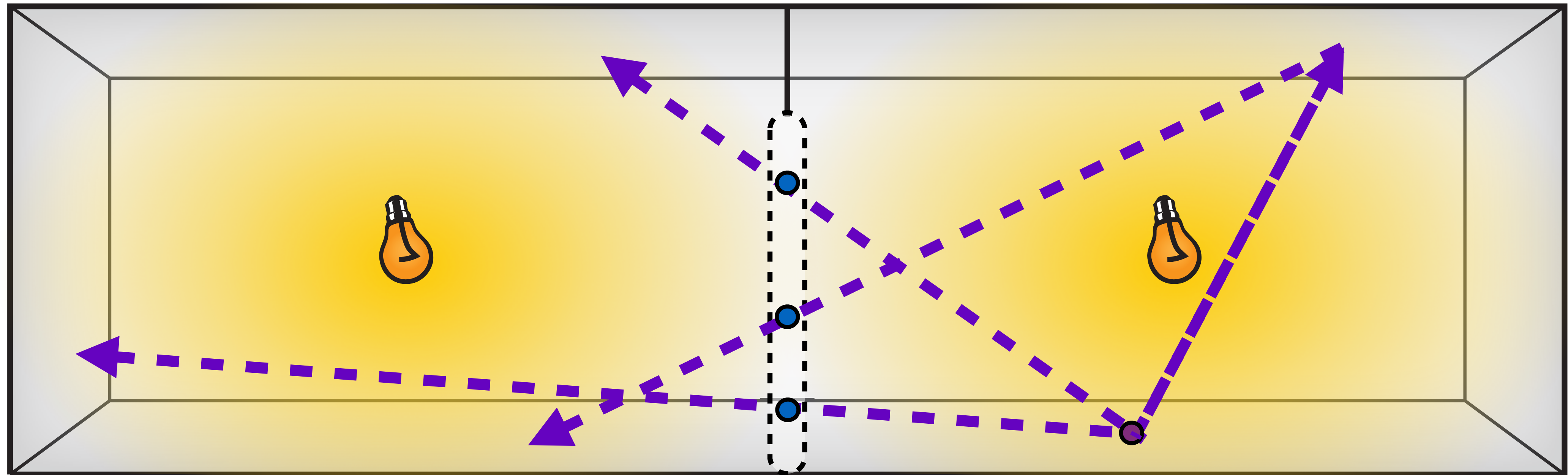
Efficient Sampling



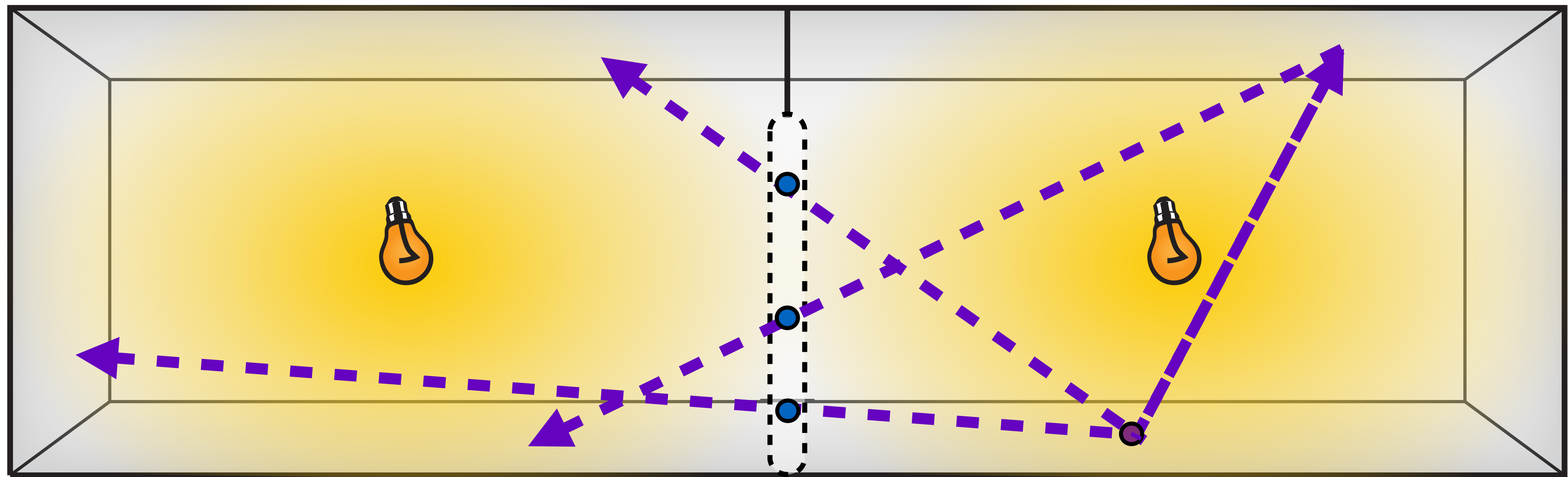
Efficient Sampling



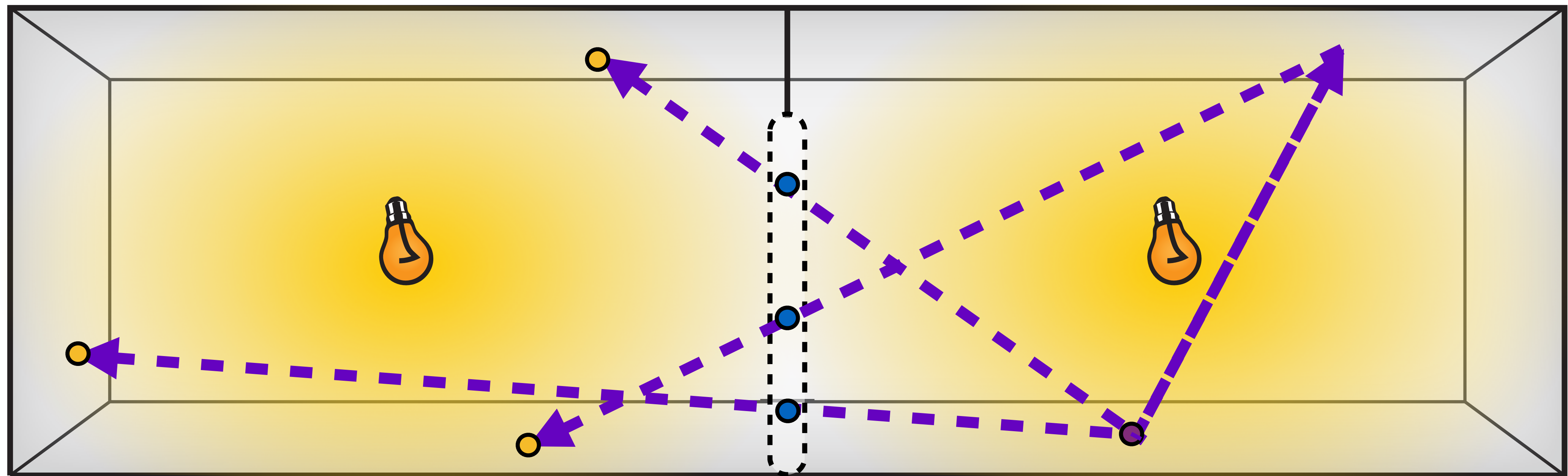
Efficient Sampling



Reusing Base Bake Information



Reusing Base Bake Information



Conclusion



Conclusion

Static Lighting
and Geometry

Dynamic
Lighting

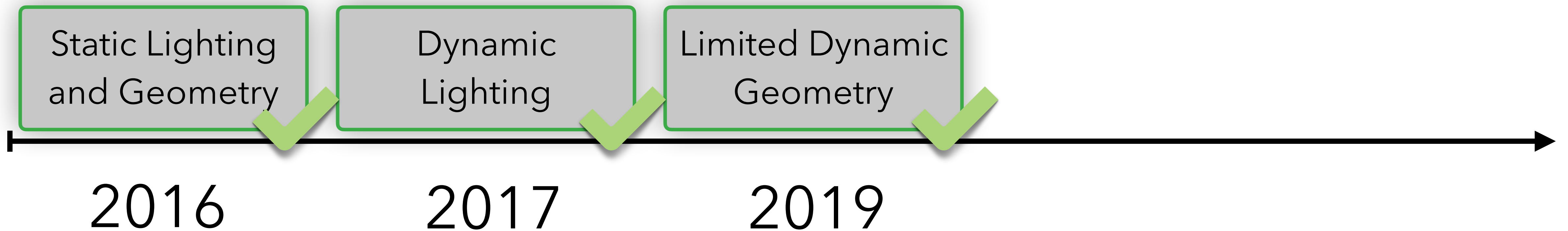
Limited Dynamic
Geometry

2016

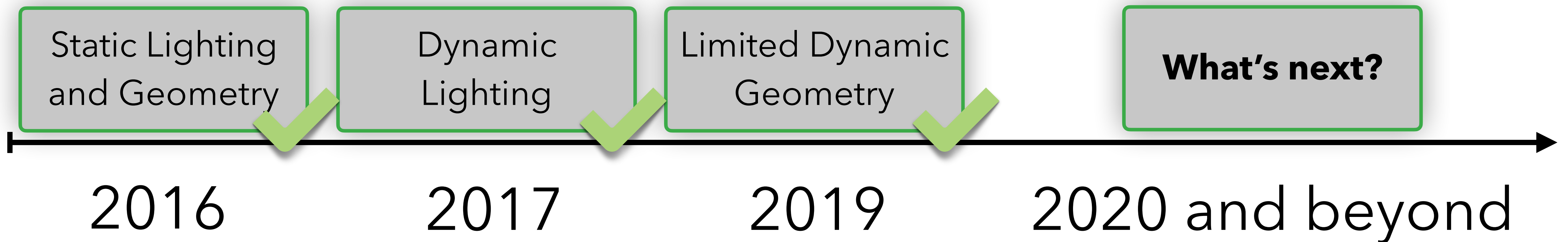
2017

2019

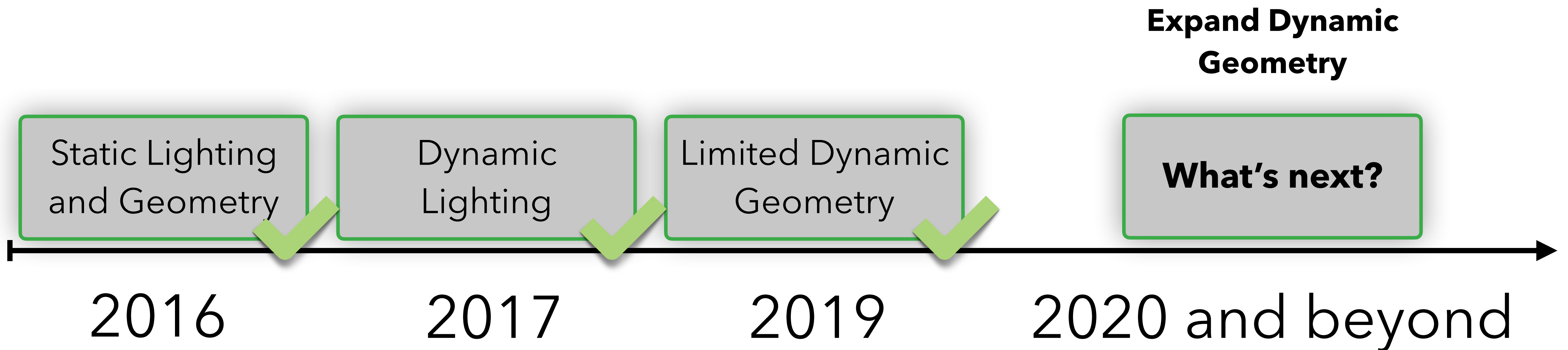
Conclusion



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Won't better hardware solve this?

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- We are orders of magnitude off!

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- Players are moving to mobile devices.

Won't better hardware solve this?

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- Players are moving to mobile devices.
- VR requires even higher frame rates.

Acknowledgements

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Thank you!

Please visit

dartgo.org/uberbake

for the full paper and
supplemental material

Scan Me!



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