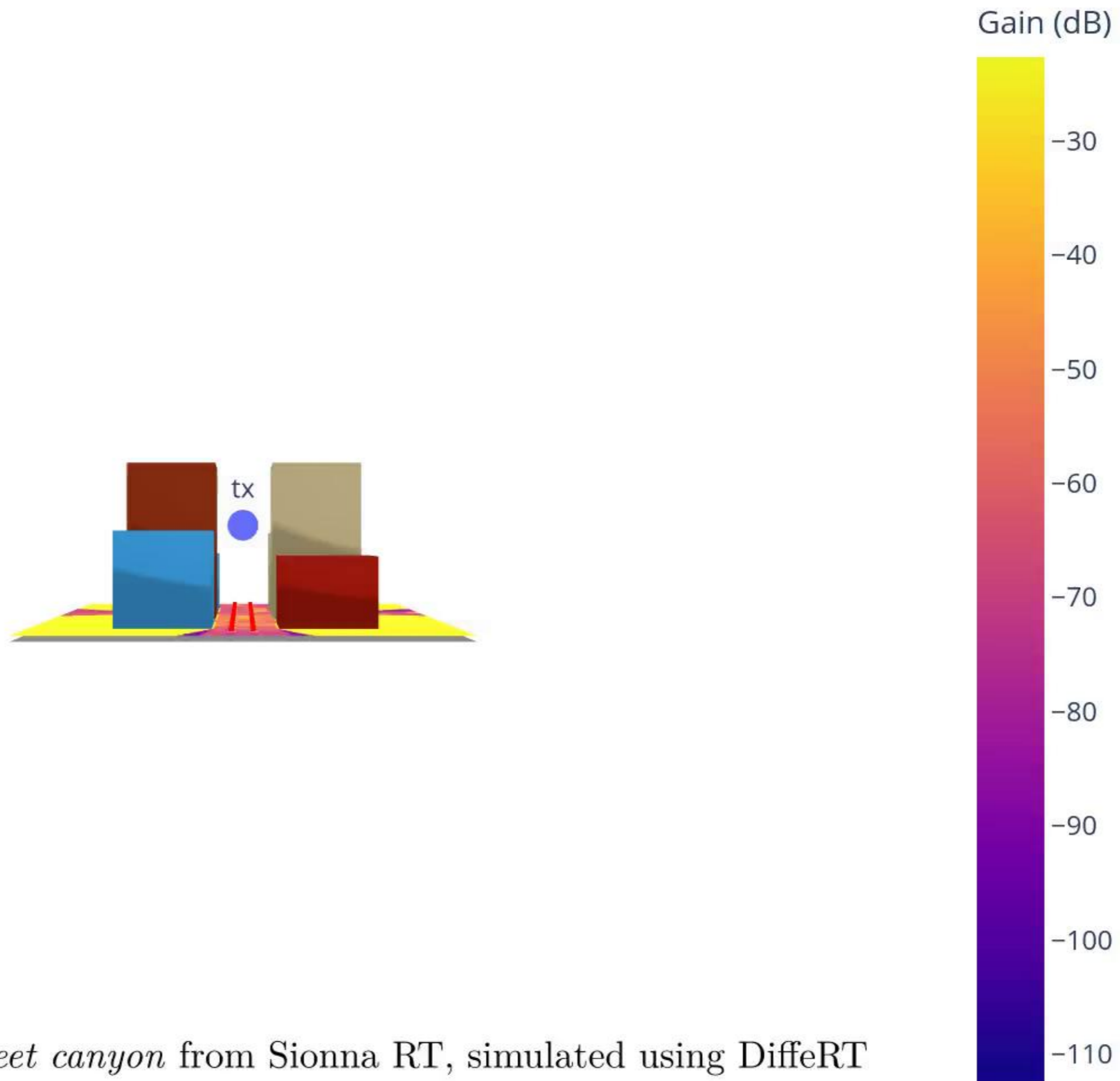


# Comparing Differentiable and Dynamic Ray Tracing: Introducing the Multipath Lifetime Map

J rome Eertmans - April 1<sup>st</sup>, EuCAP 2025, Stockholm

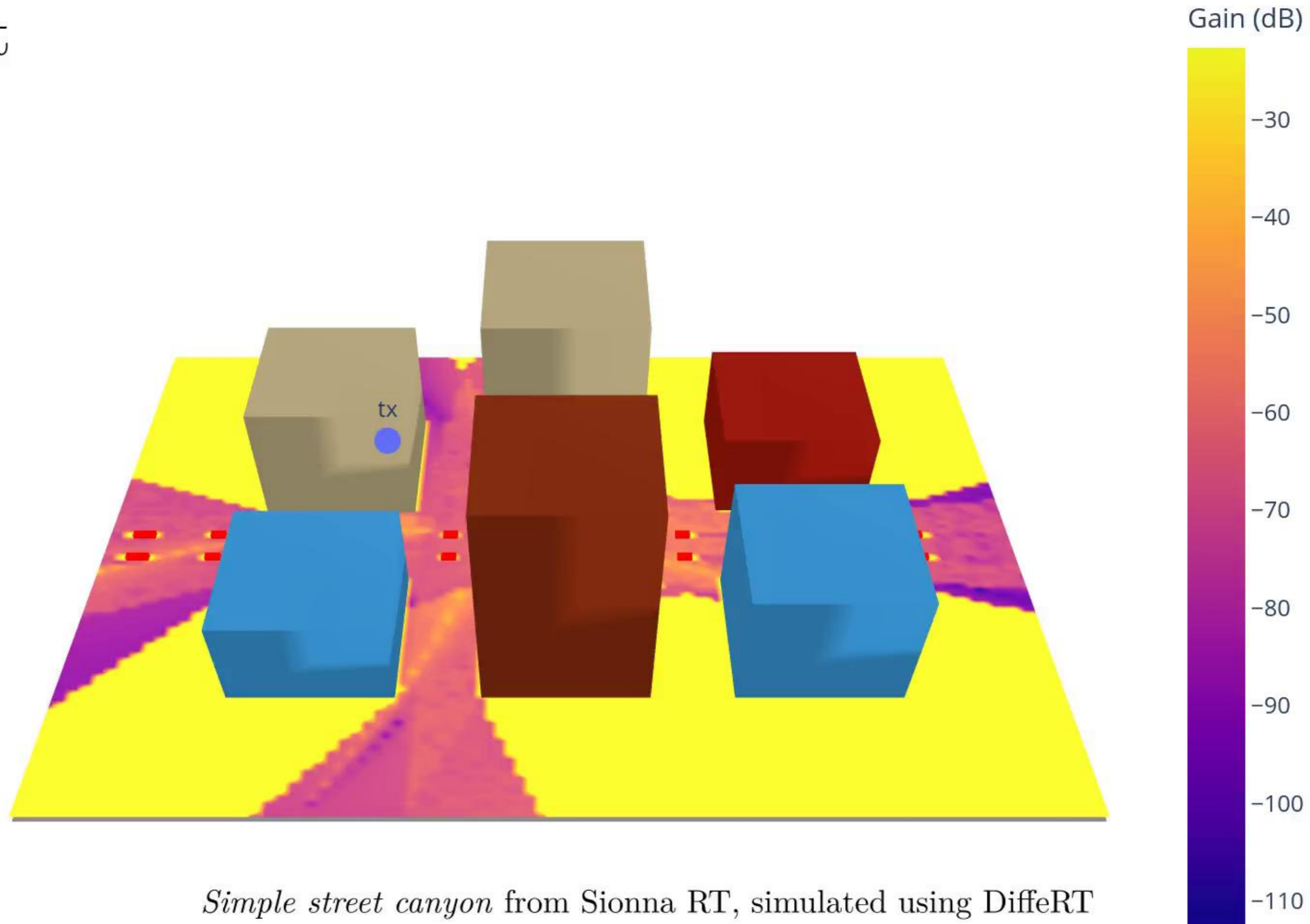
Authors: J rome Eertmans, Enrico Maria Vitucci, Vittorio Degli-Esposti,  
Laurent Jacques, Claude Oestges

# Context

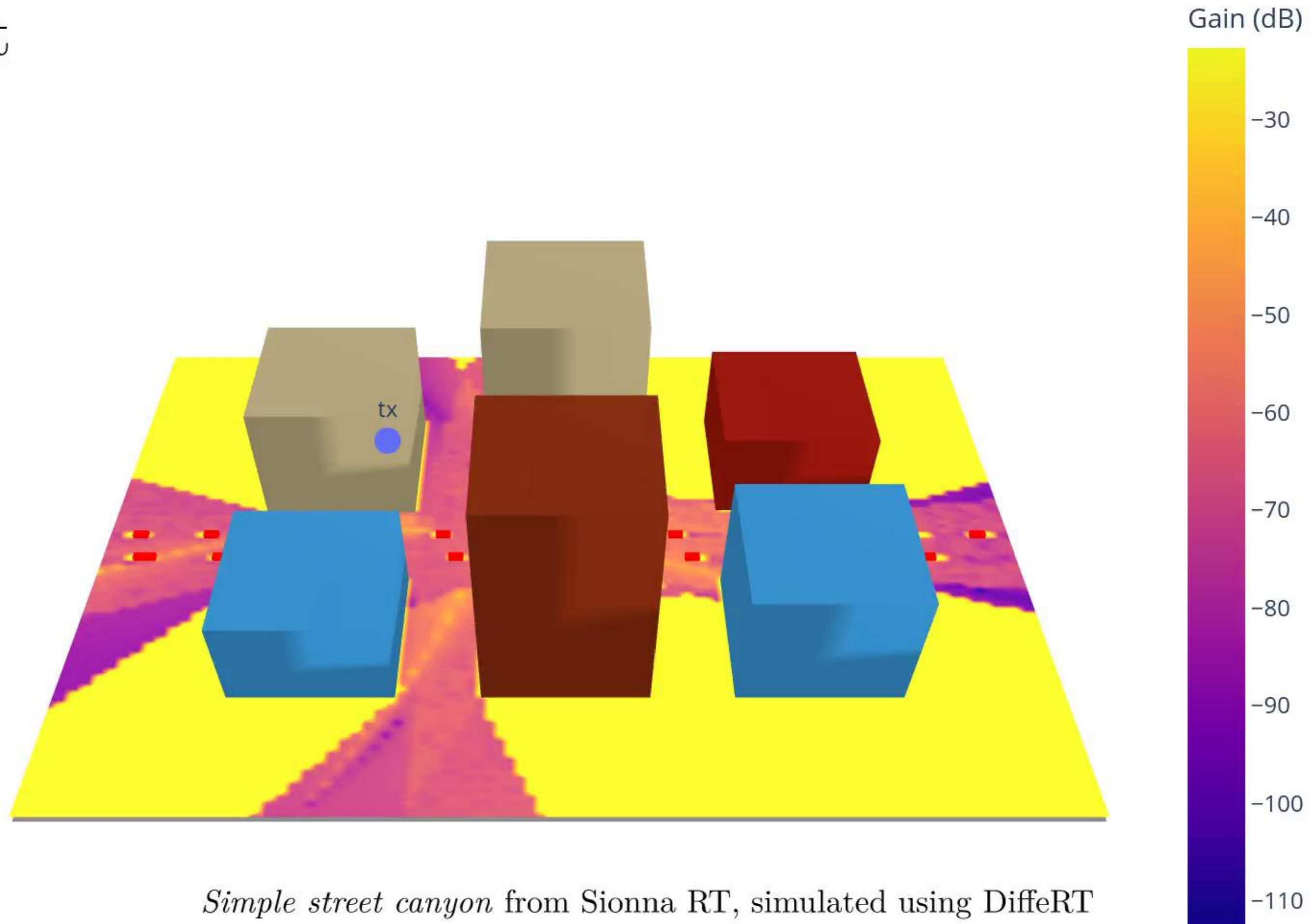


*Simple street canyon* from Sionna RT, simulated using DiffeRT

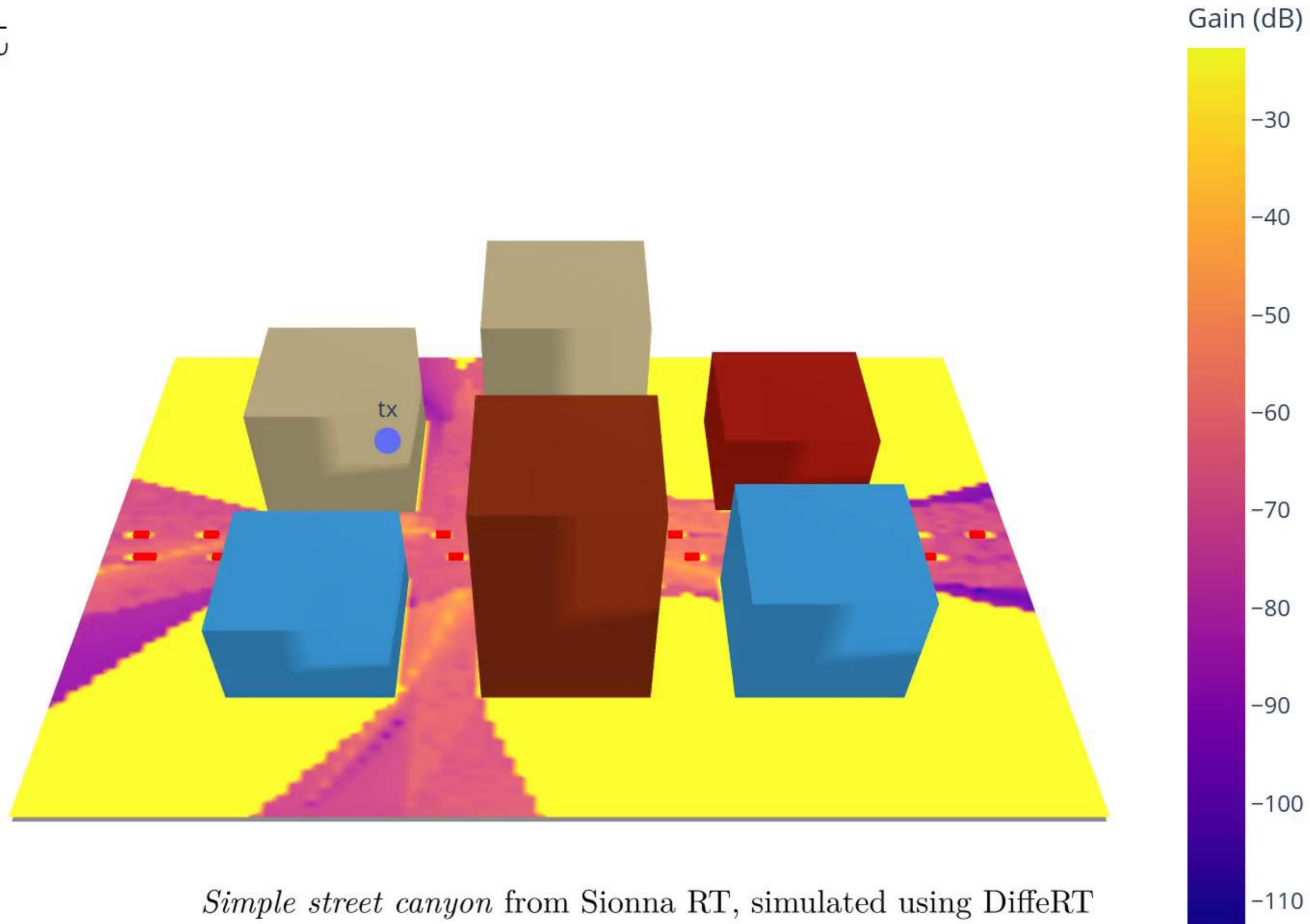
# Context



# Context



# Context



Scene

Scene

TX

Scene

TX

RX

Scene

TX RX Objects

Scene



Tracing of  
ray paths

RX Objects

Tracing of  
ray paths

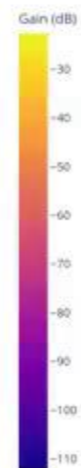


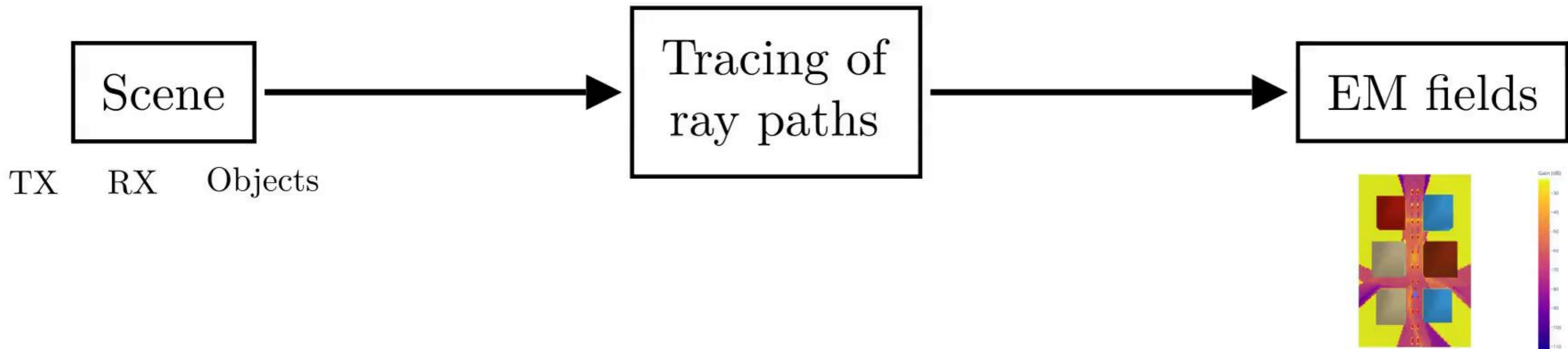
EM fields

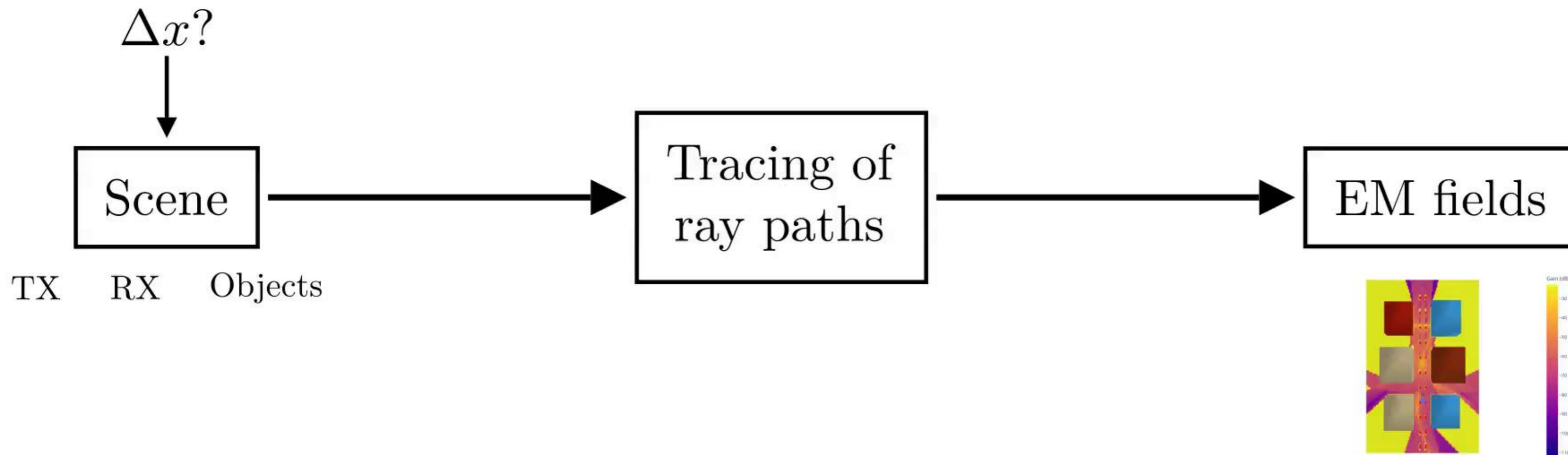
Tracing of  
ray paths

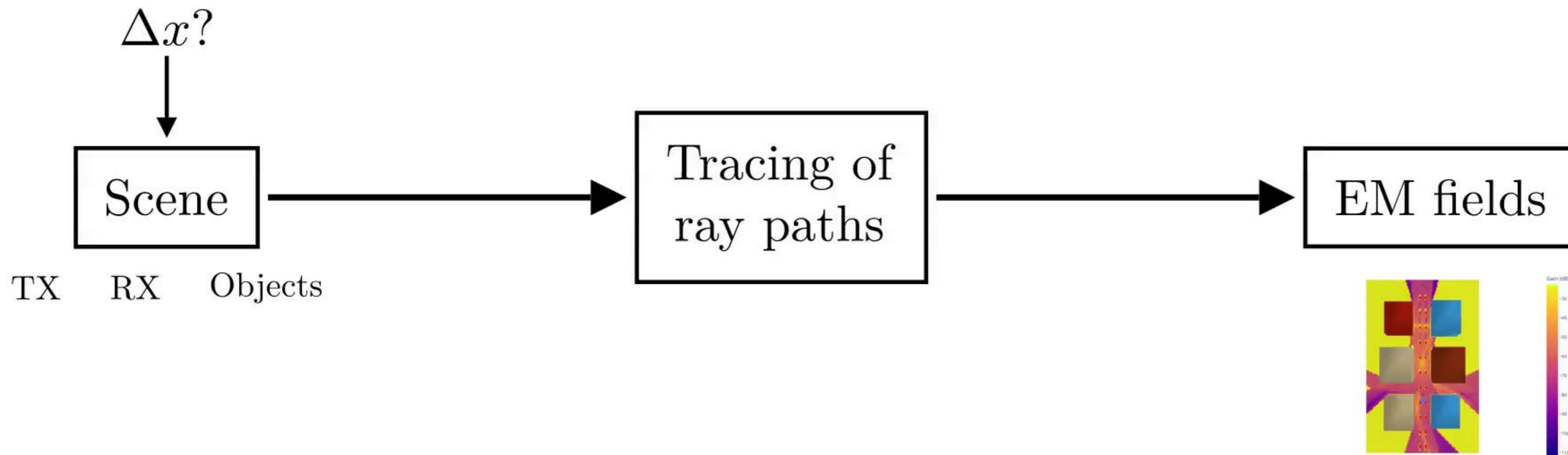


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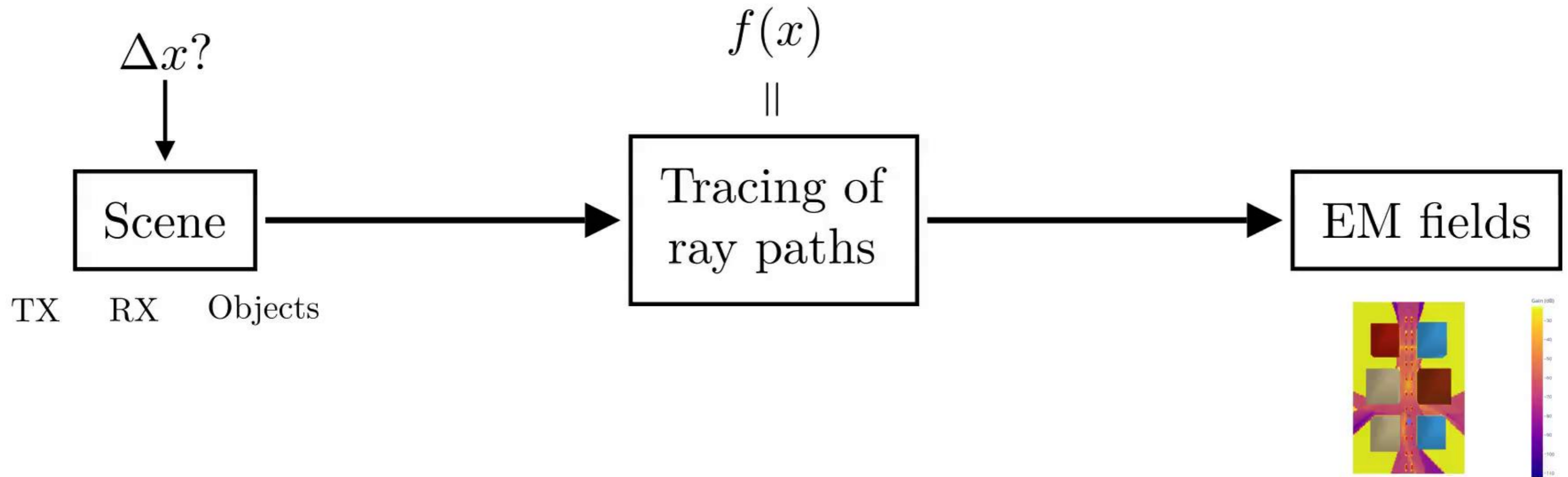






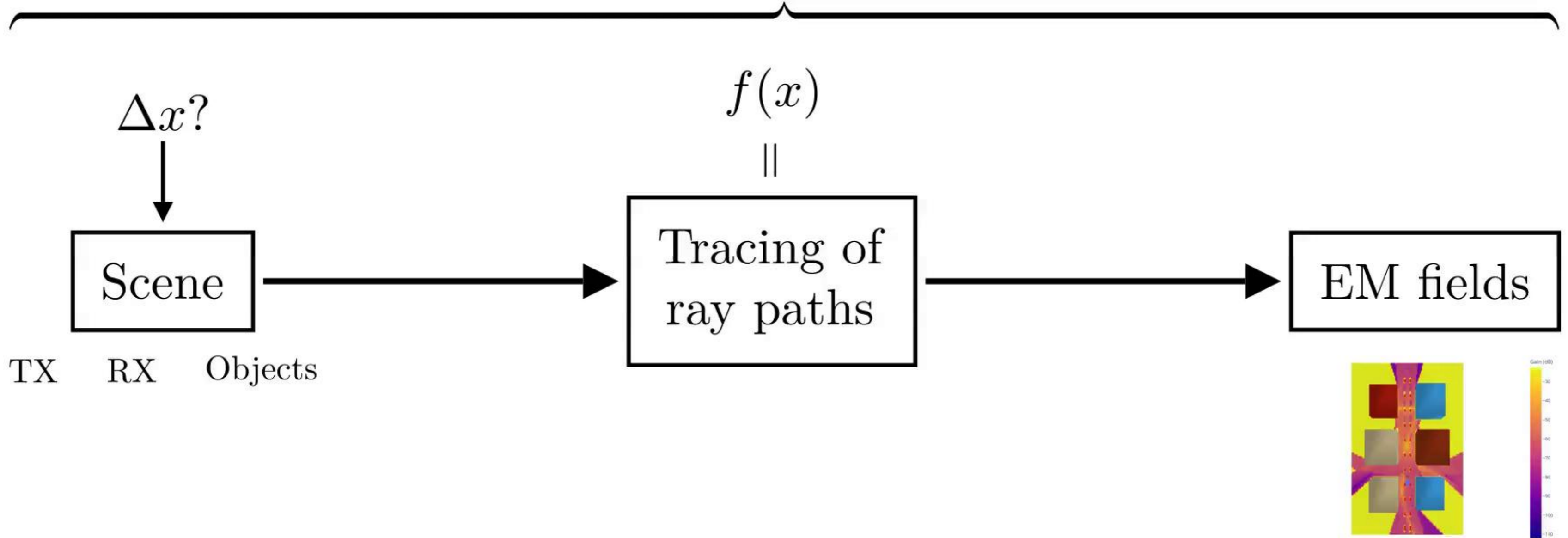


(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives



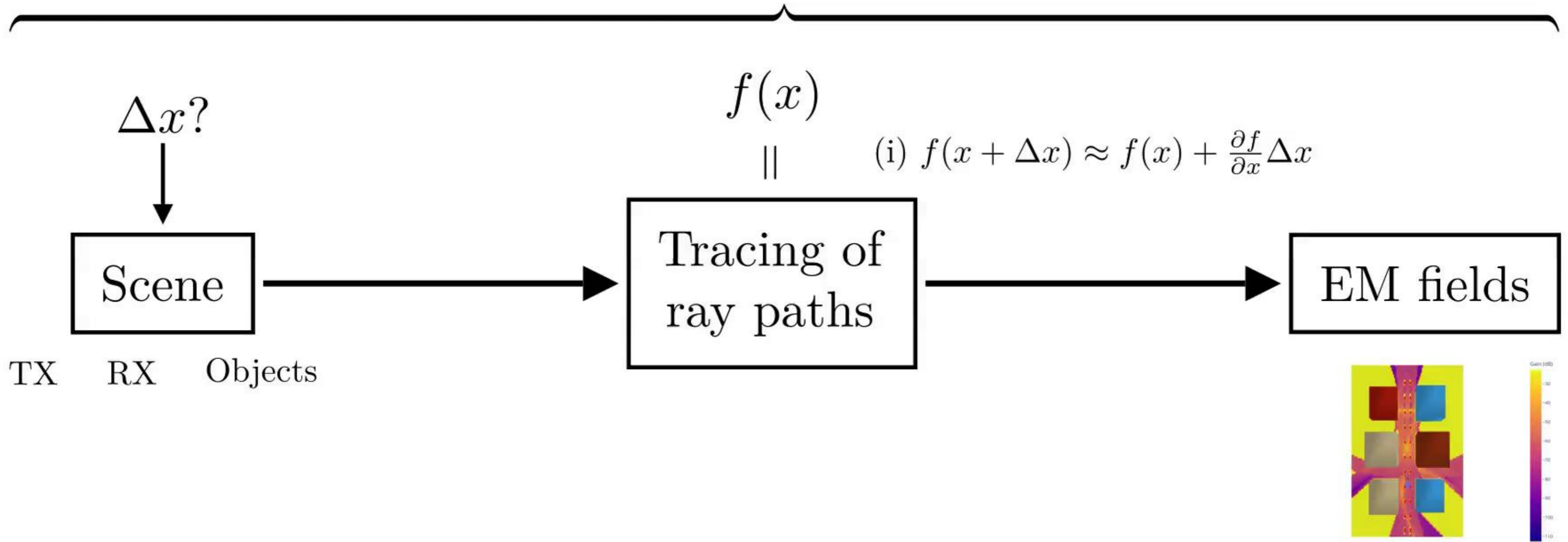
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# Snapshot



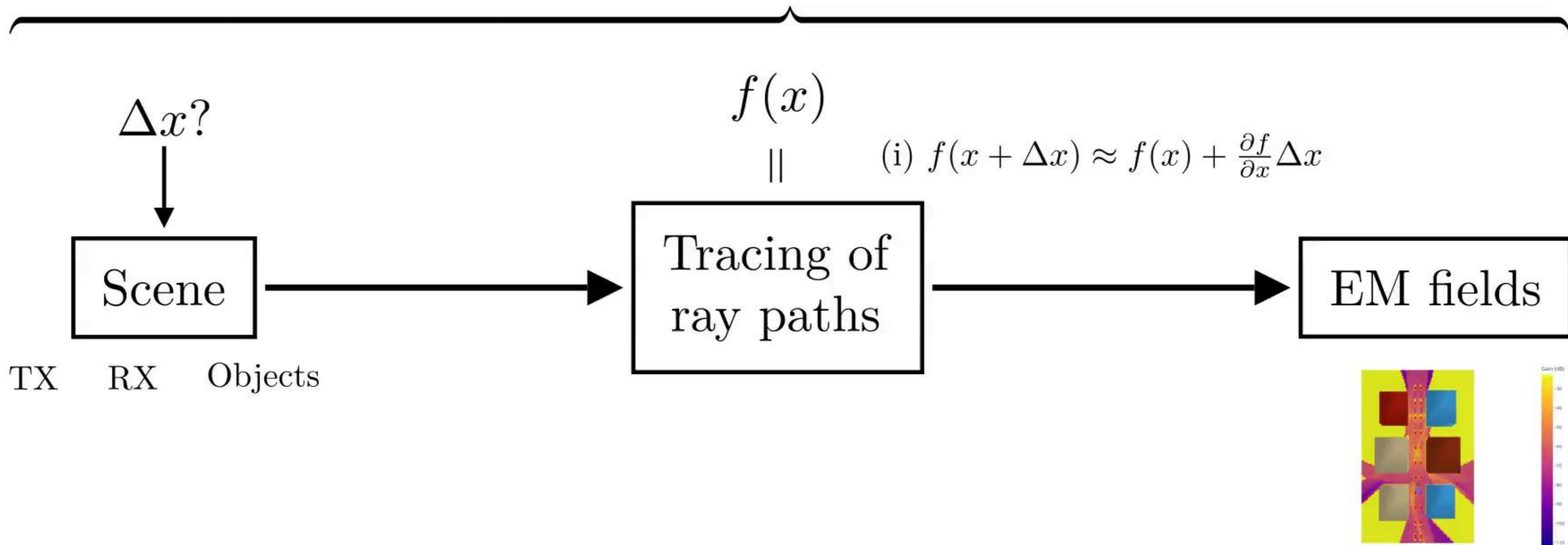
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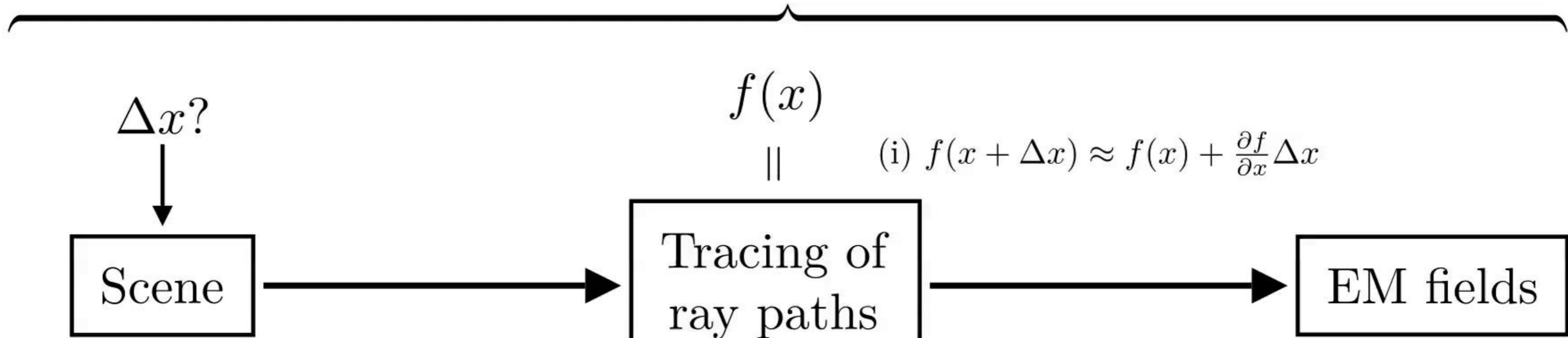
# Snapshot



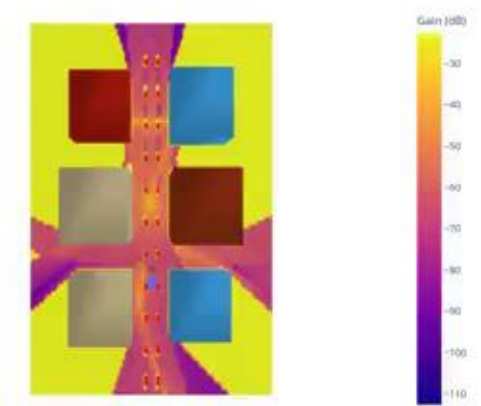
(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives

(ii) Differentiable (Diff.) RT: optimization using automatic differentiation

# Snapshot



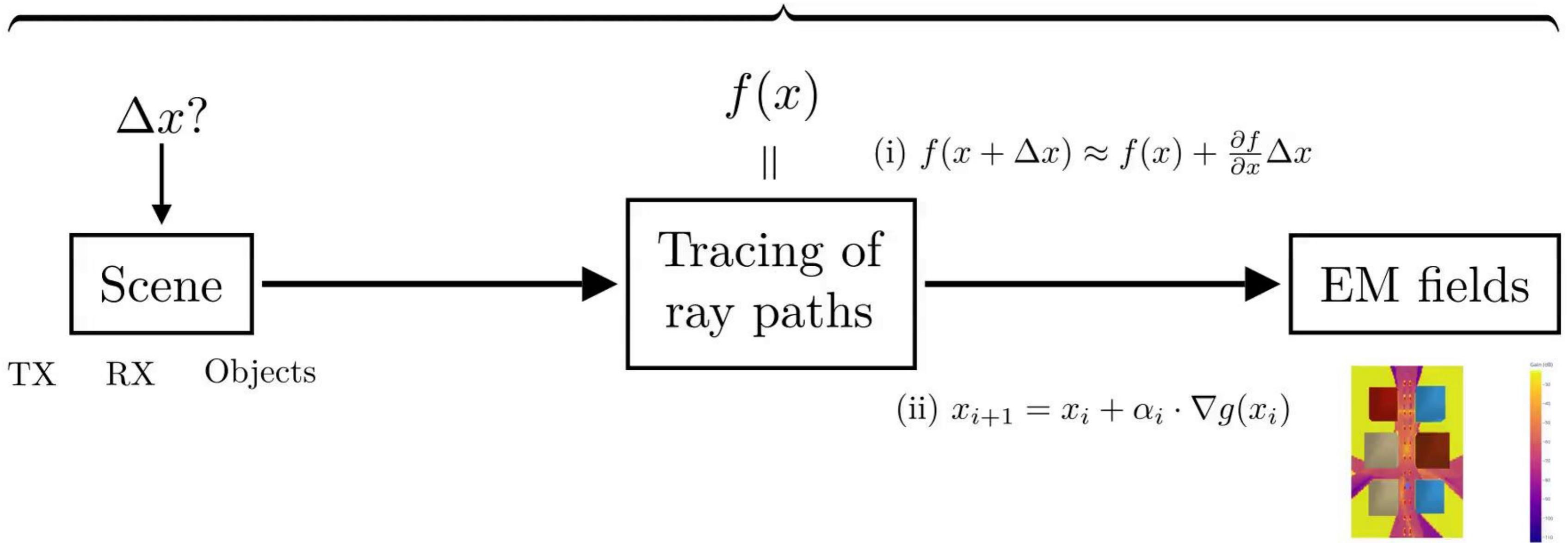
TX RX Objects



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- (ii) Differentiable (Diff.) RT: optimization using automatic differentiation

$g(x)$

# Snapshot



$\Delta x?$

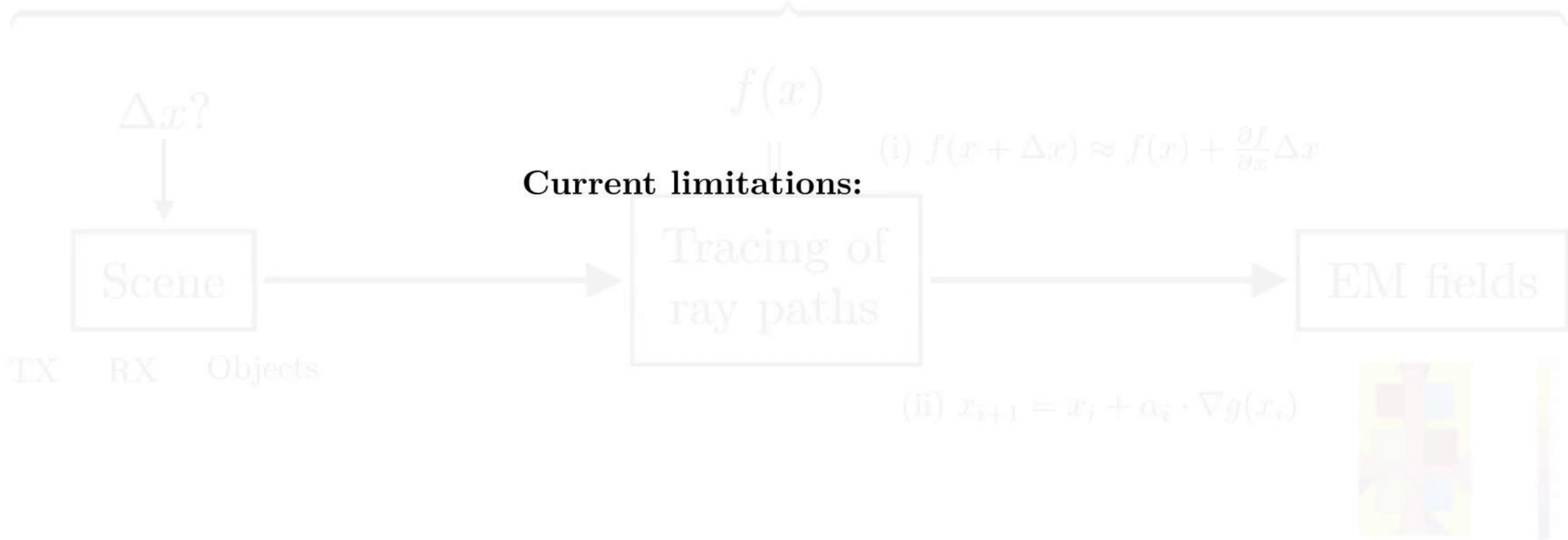
Scene

TX RX Objects

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# Snapshot

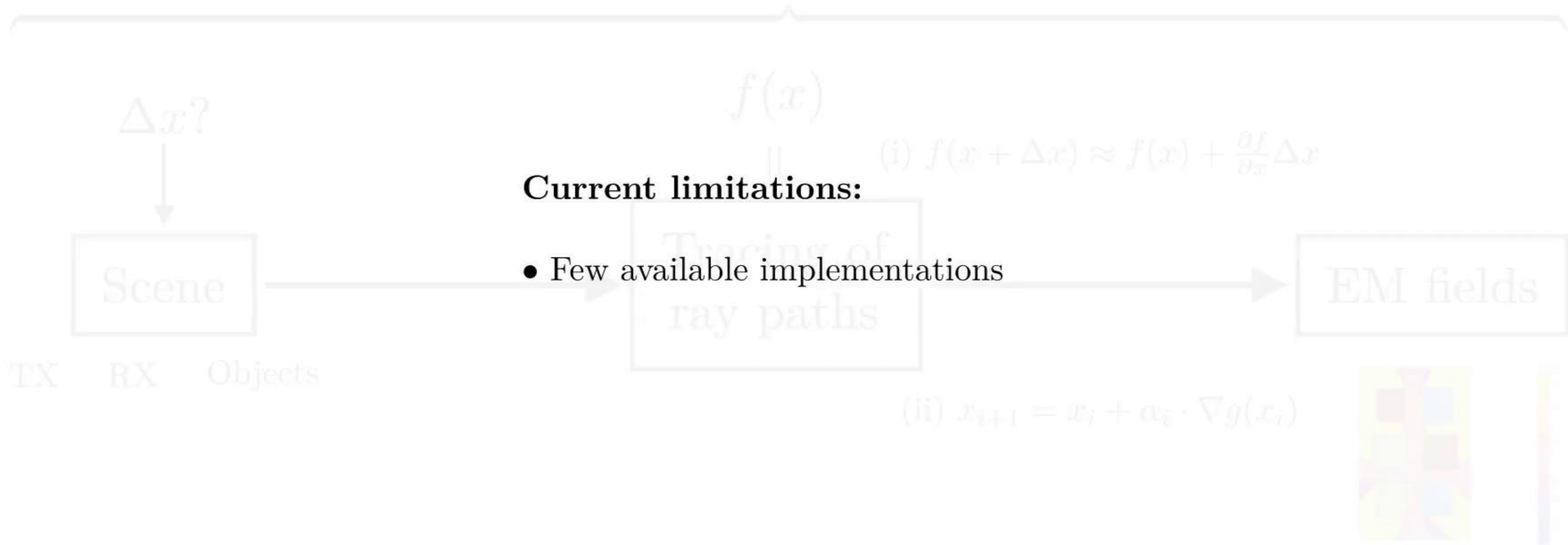


(i) Dynamic (Dyna.) RT: snapshots extrapolation using local derivatives

(ii) Differentiable (Diff.) RT: optimization using automatic differentiation

$g(x)$

# Snapshot



## Current limitations:

- Few available implementations

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(ii) Differentiable (Diff.) RT: optimization using automatic differentiation

$g(x)$

# Snapshot

$$f(x)$$

$$(i) f(x + \Delta x) \approx f(x) + \frac{\partial f}{\partial x} \Delta x$$

## Current limitations:

- Few available implementations
- Lack of comparison and confusion

Scene

EM fields

TX RX Objects

$$(ii) x_{i+1} = x_i + \alpha_i \cdot \nabla g(x_i)$$



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$\Delta x?$   
↓  
Scene

EM fields

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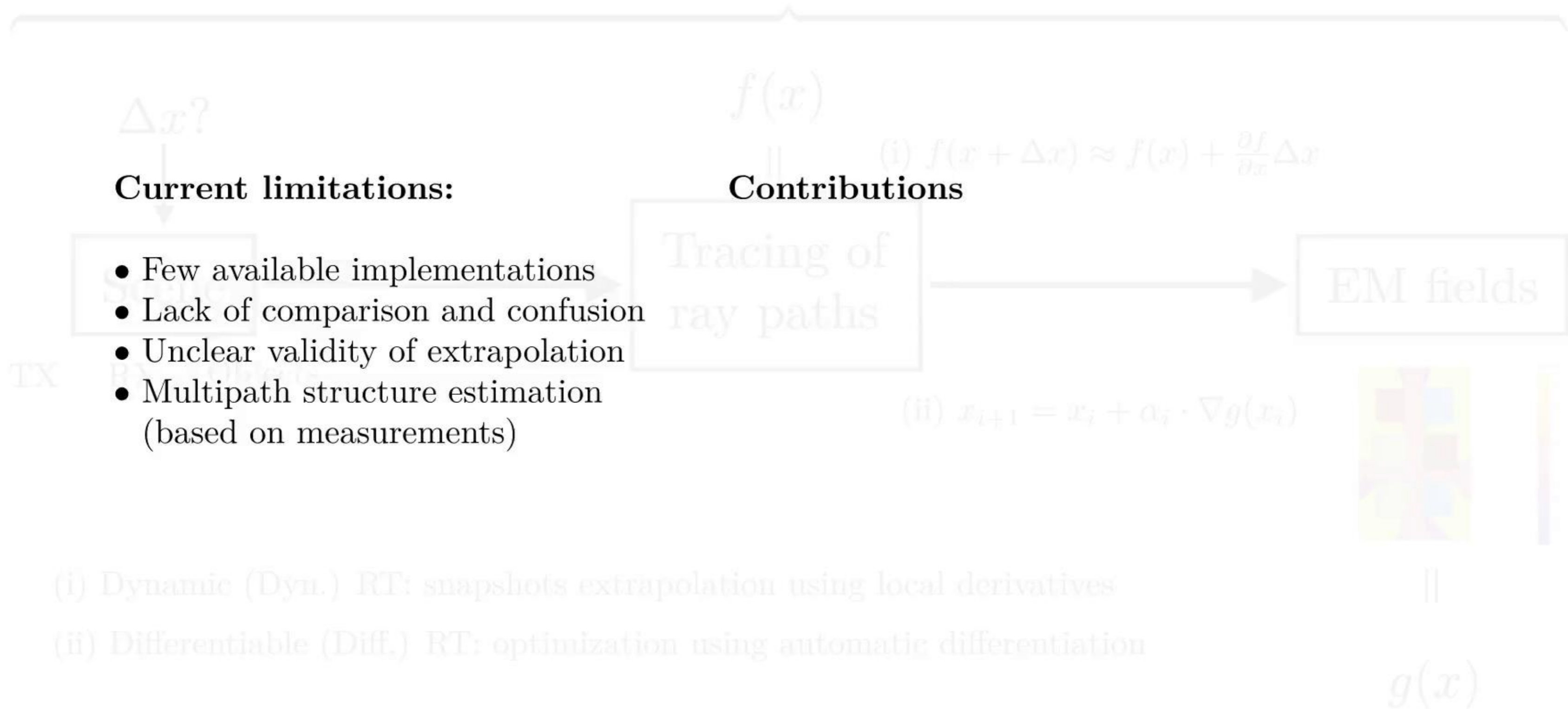


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# Snapshot



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$f(x)$

## Contributions

$$(i) f(x + \Delta x) \approx f(x) + \frac{\partial f}{\partial x} \Delta x$$

Tracing of ray paths

$\Rightarrow$  Provide a qualitative comparison (*details in paper*)

$$(ii) x_{i+1} = x_i + a_i \cdot \nabla g(x_i)$$



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$g(x)$

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## Contributions

Tracing of ray paths

- $\Rightarrow$  Provide a qualitative comparison (*details in paper*)
- $\Rightarrow$  Illustrate the limits of Dyn. RT

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(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives

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$g(x)$

# Snapshot

$\Delta x?$

## Current limitations:

- Few available implementations
- Lack of comparison and confusion
- Unclear validity of extrapolation
- Multipath structure estimation (based on measurements)

$f(x)$

## Contributions

- $\Rightarrow$  Provide a qualitative comparison (*details in paper*)
- $\Rightarrow$  Illustrate the limits of Dyn. RT
- $\Rightarrow$  Introduce simulation tool and metrics to help evaluate the benefits of Dyn. RT

(i)  $f(x + \Delta x) \approx f(x) + \frac{\partial f}{\partial x} \Delta x$

Tracing of ray paths



(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives

(ii) Differentiable (Diff.) RT: optimization using automatic differentiation

$g(x)$

## **Contents:**

## **Contents:**

- Methods comparison

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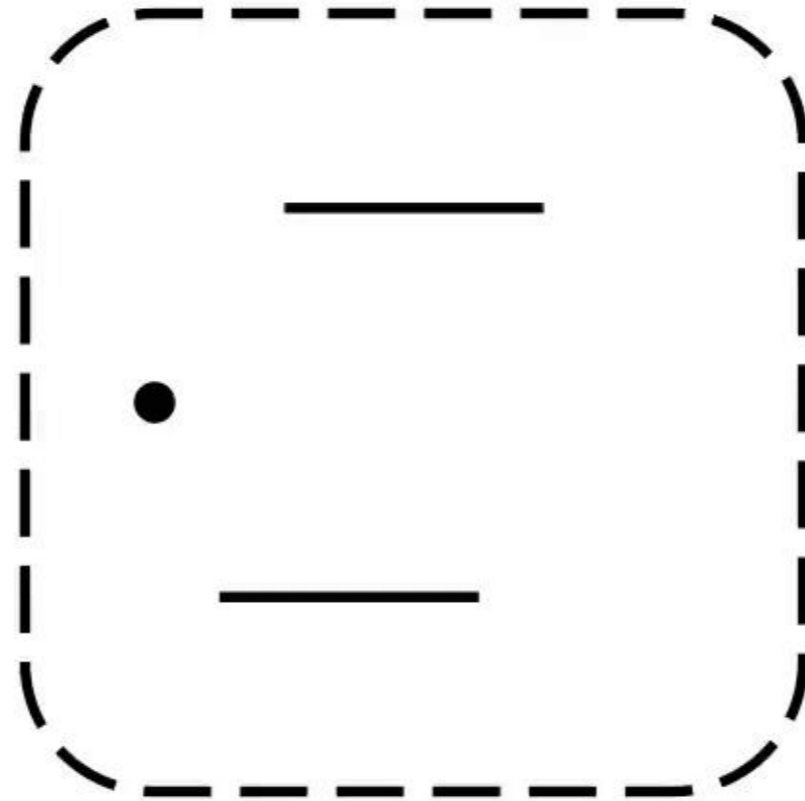
## **Contents:**

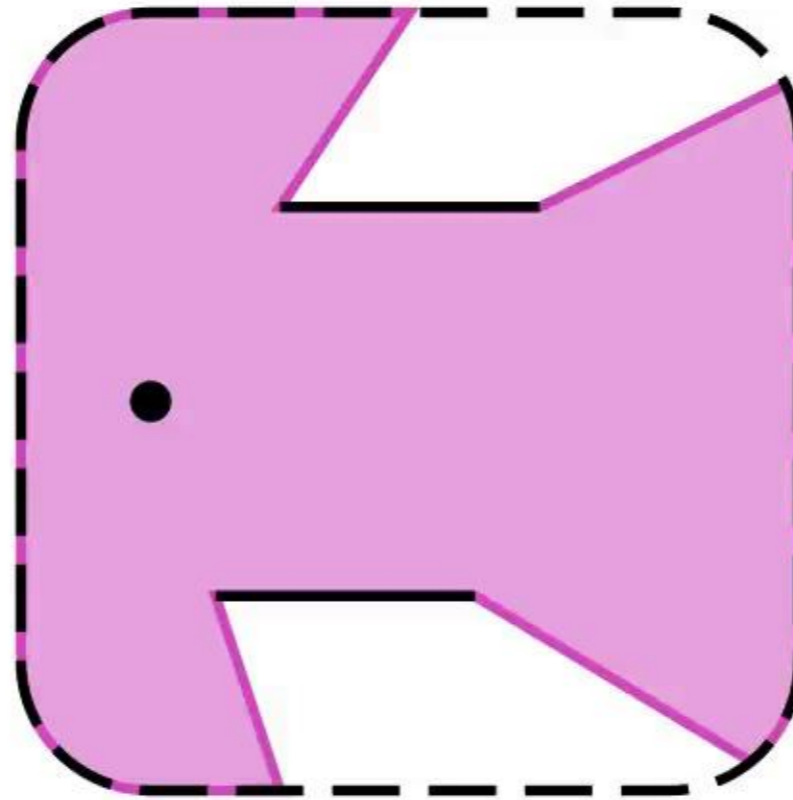
- Methods comparison
- Limits of extrapolation
- Multipath Lifetime Map (MLM) and metrics

## **Contents:**

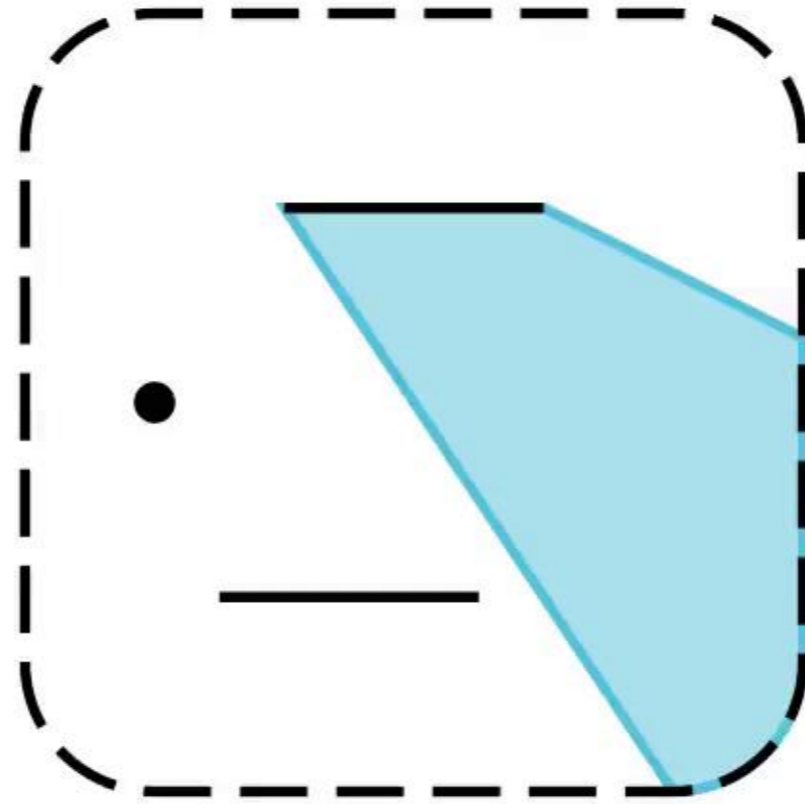
- Methods comparison
- Limits of extrapolation
- Multipath Lifetime Map (MLM) and metrics
- Results of MLMs for a moving RX

	<b>Dyn. RT</b>	<b>Diff. RT</b>
<b>Tools</b>	Unibo's	Sionna DiffeRT (ours)
<b>Differentiation</b>	Manual*	Automatic
<b>Interpretability</b>	High (analytical*)	Low (numerical)

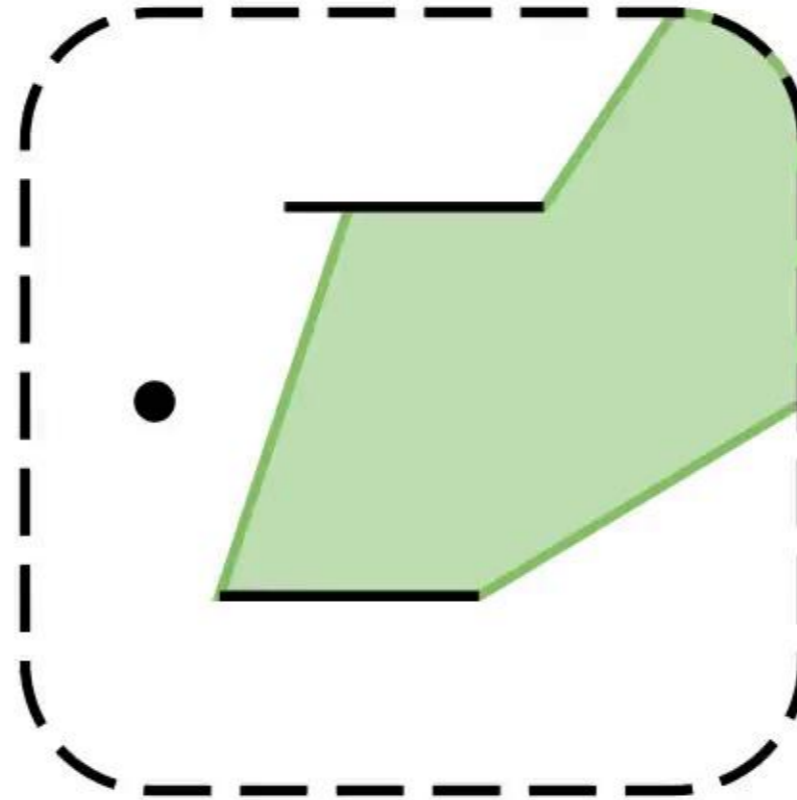




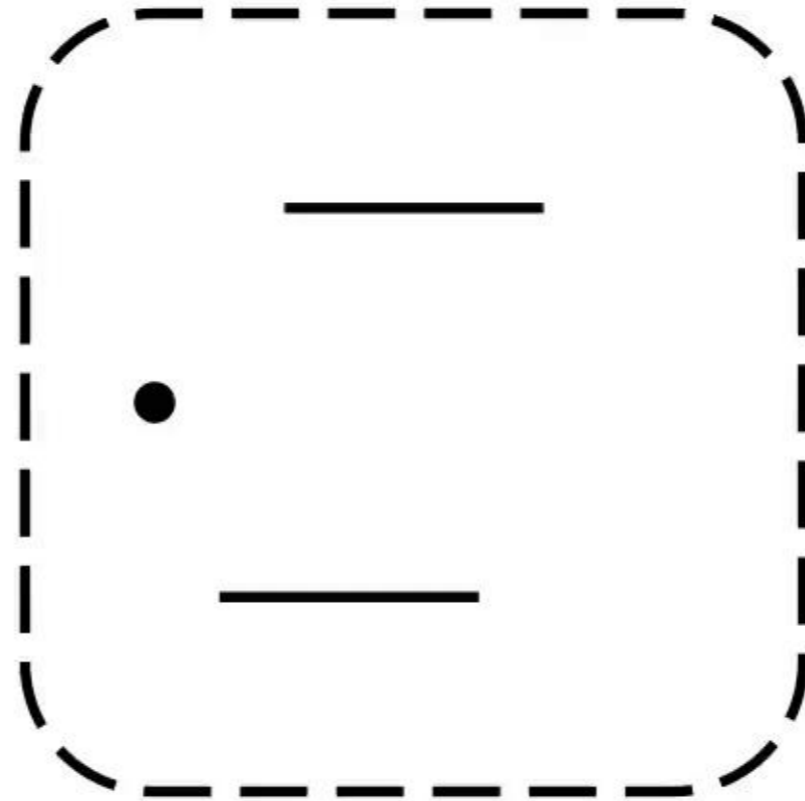
Line-of-sight

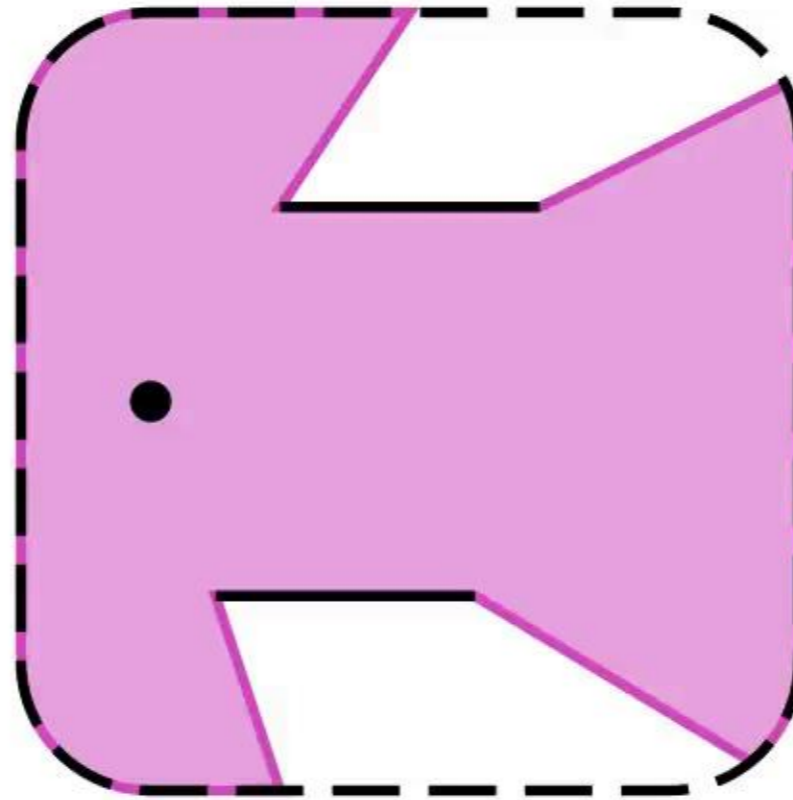


Reflection from  $W_1$

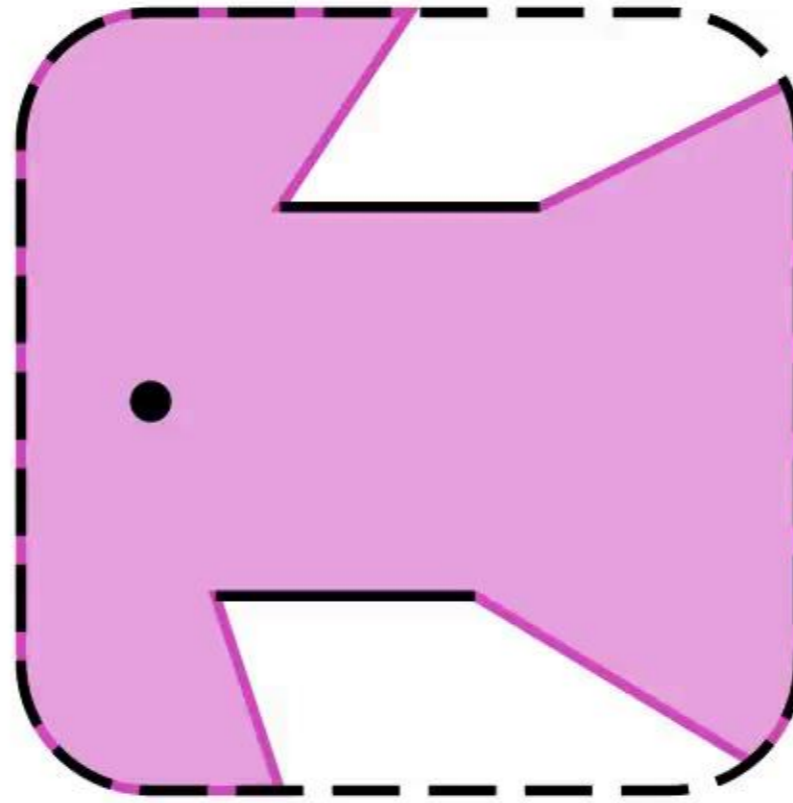


Reflection from  $W_2$



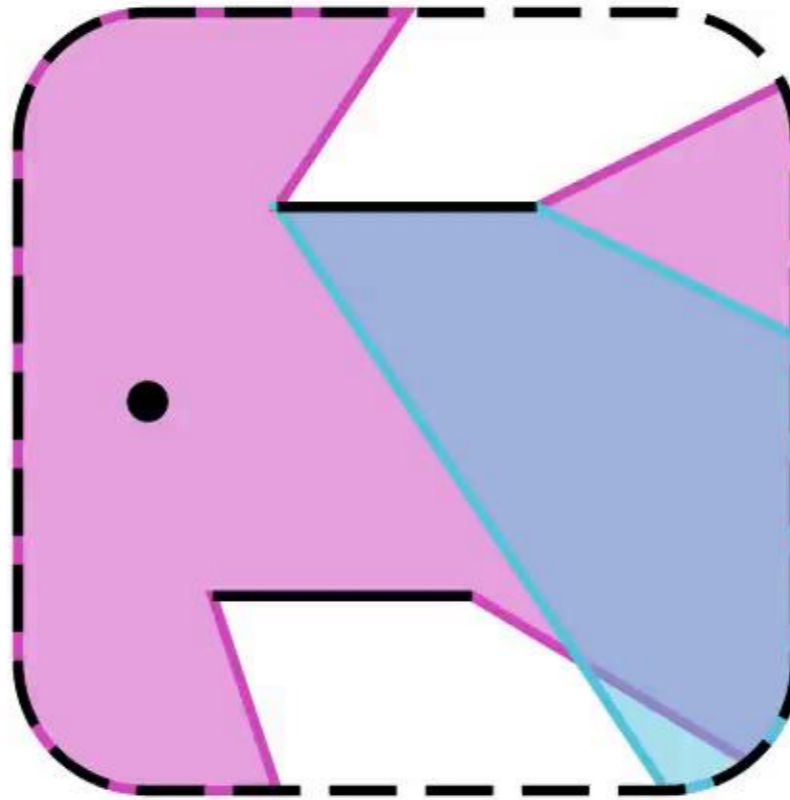


Line-of-sight

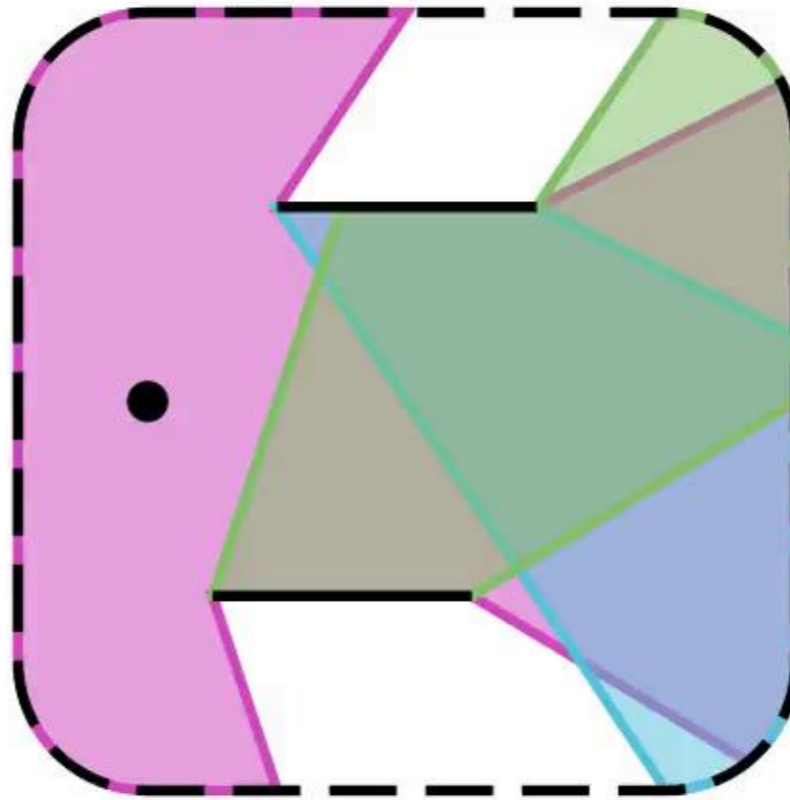


Line-of-sight+

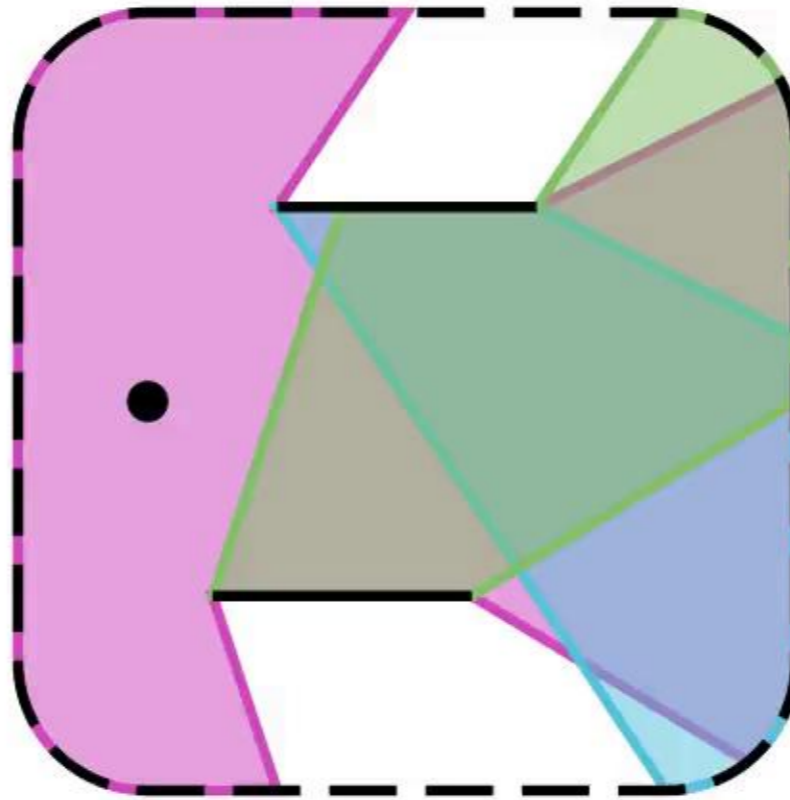




Line-of-sight + Reflection from  $W_1$  +

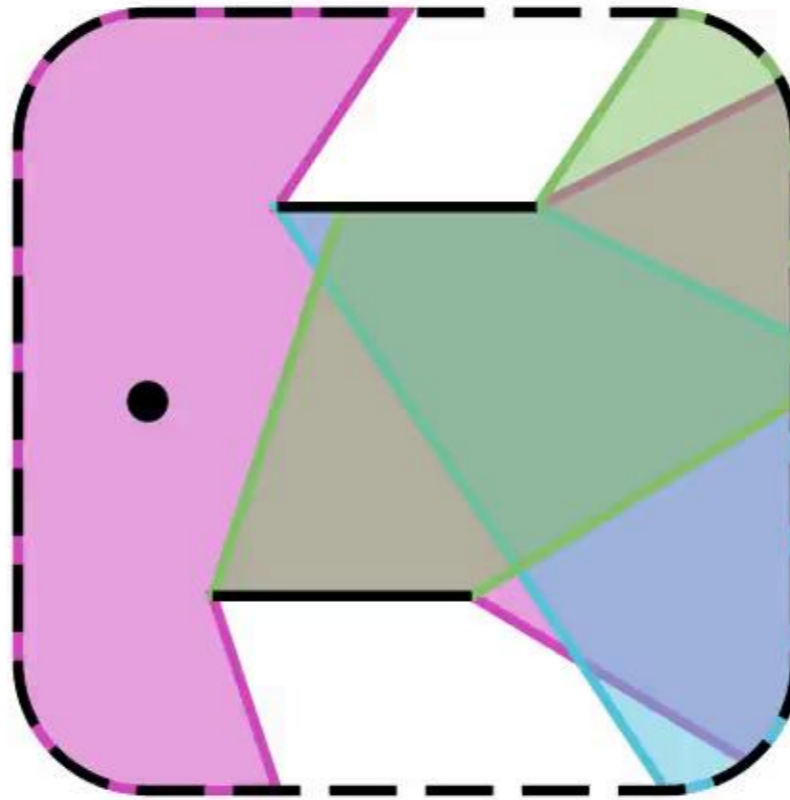


Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$



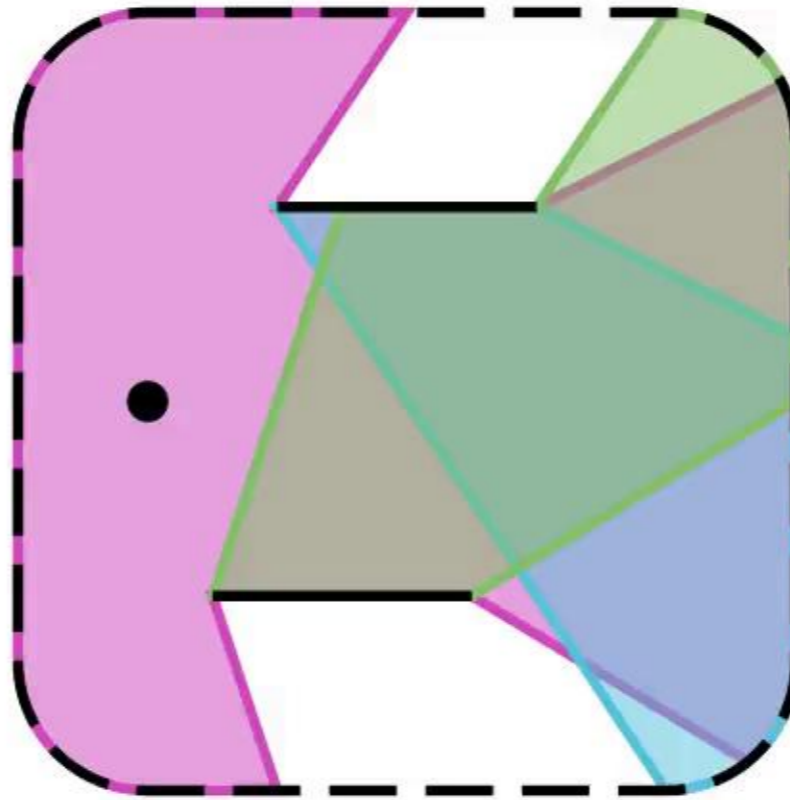
Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

This is a Multipath Lifetime Map (MLM) for a moving RX



Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

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Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

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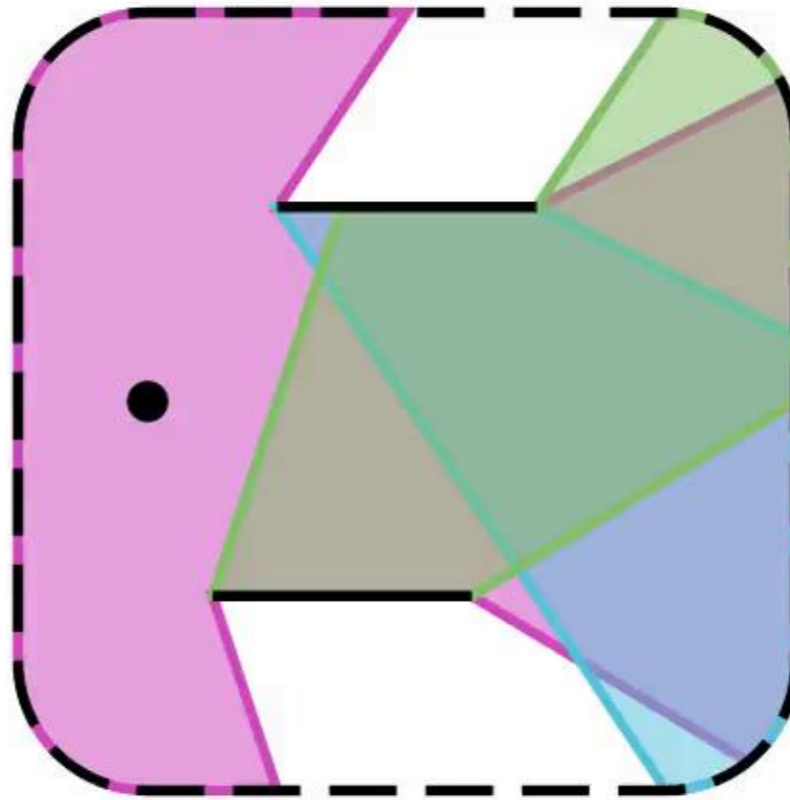
For each cell  $C_i$ , we compute:

- the **area covered by each multipath cell**,  $S_i = \text{area}(C_i)$ ;
- and the **average minimal inter-cell distance**,  $\overline{d}_i$ ;

where

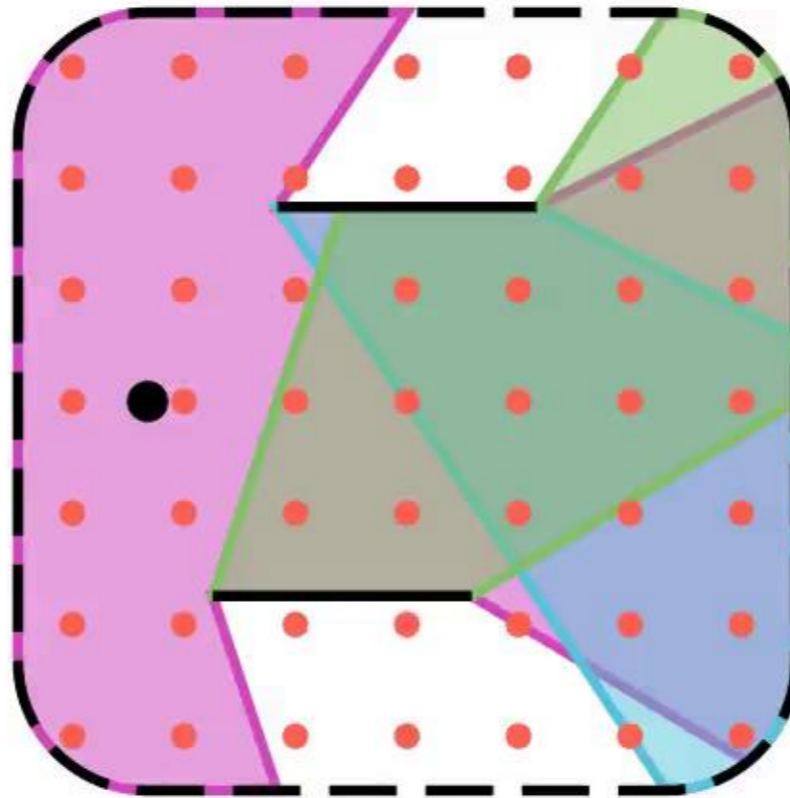
$$d_i(x) = \min_{y \notin C_i} \text{dist}(x, y), \quad (1)$$

i.e., the minimum distance an object  $x$  has to travel to leave  $C_i$ .



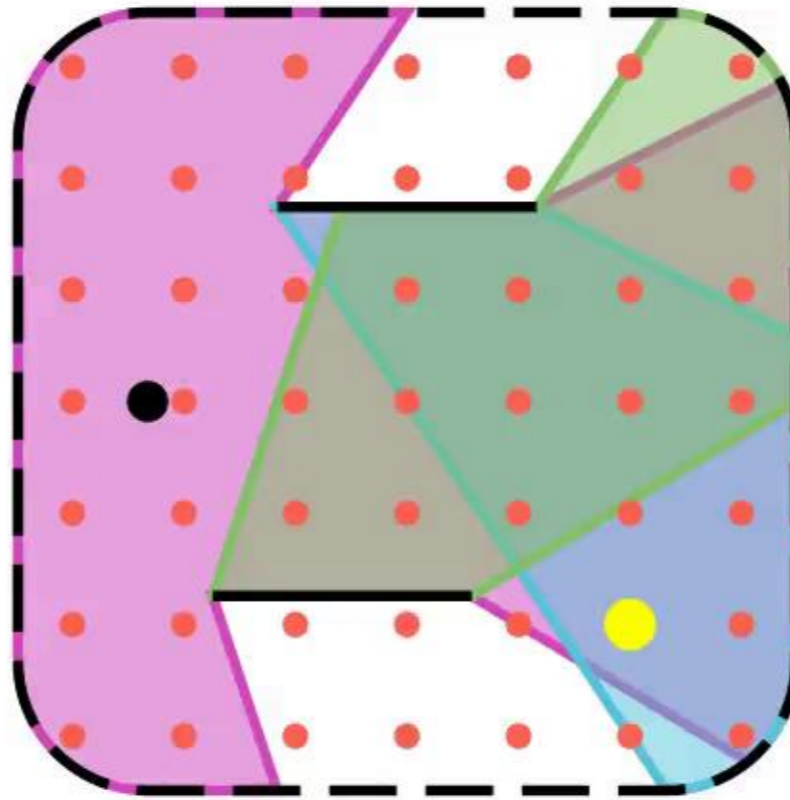
Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

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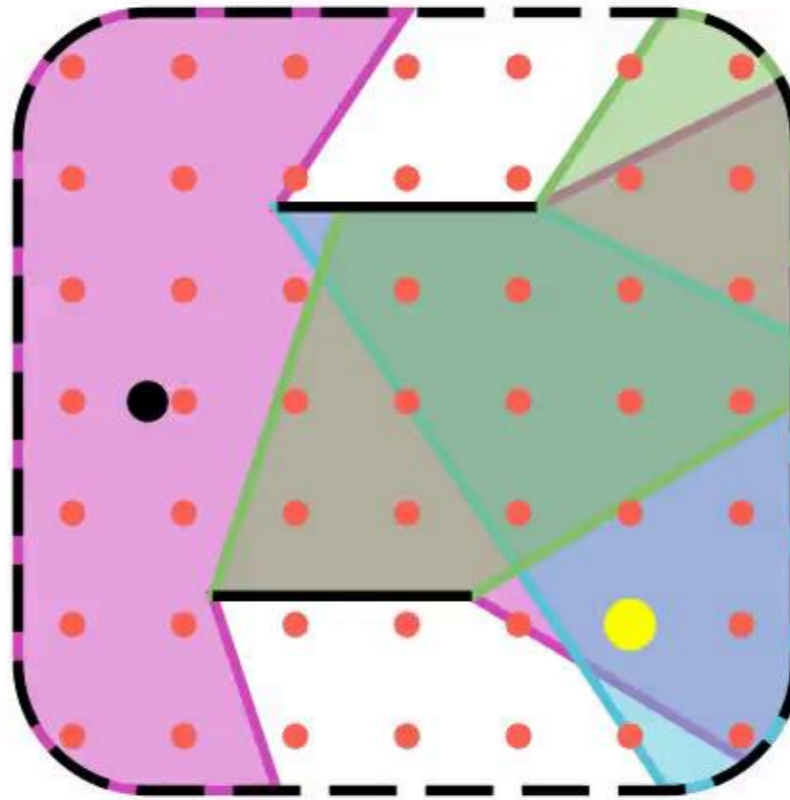
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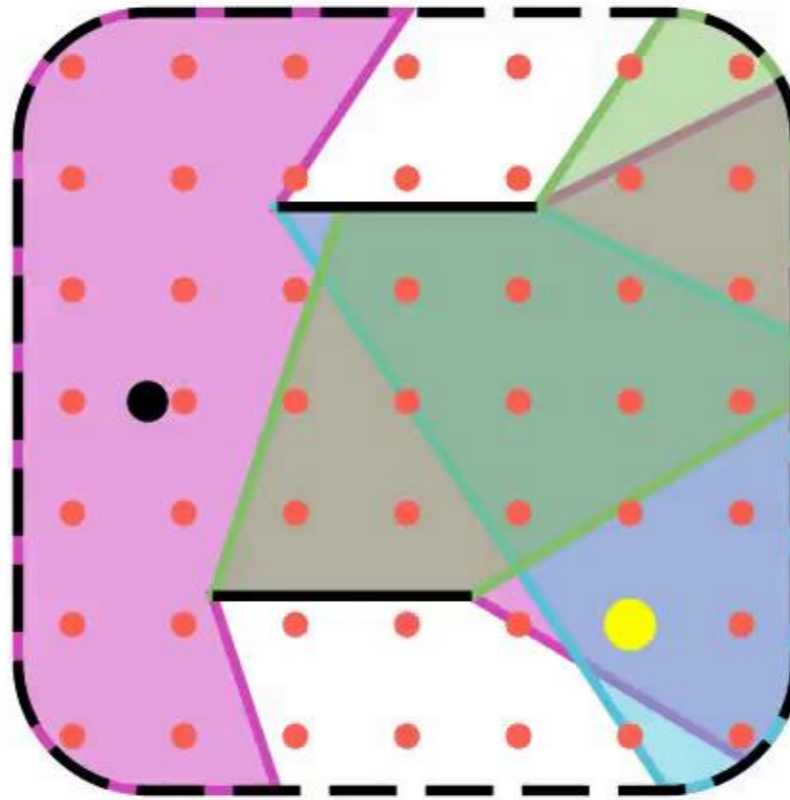
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Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

1

This is a Multipath Lifetime Map (MLM) for a moving RX

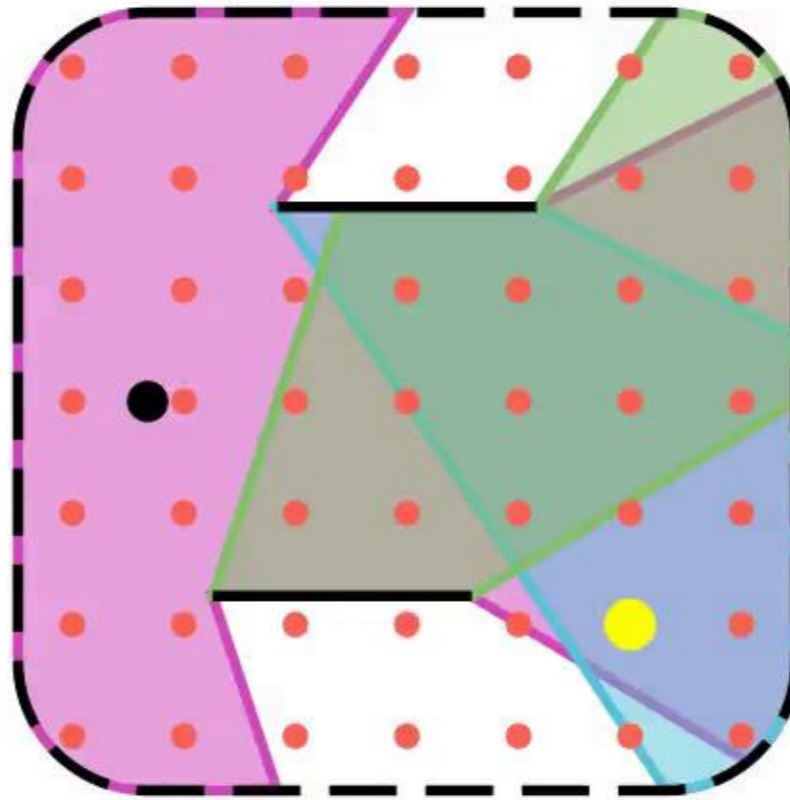


Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

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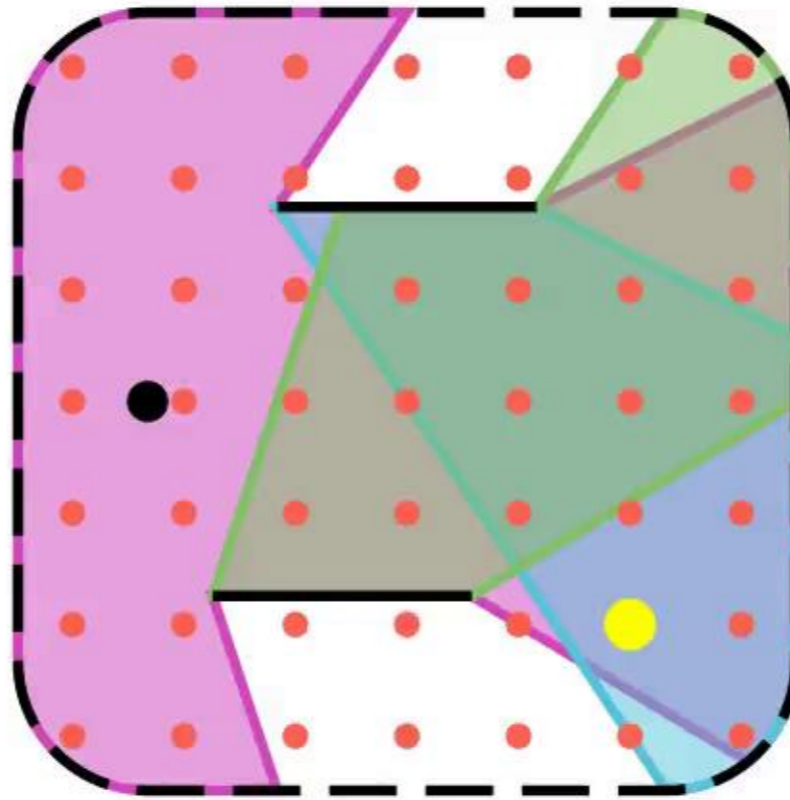
Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

1

1

0

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Line-of-sight + Reflection from  $W_1$  + Reflection from  $W_2$

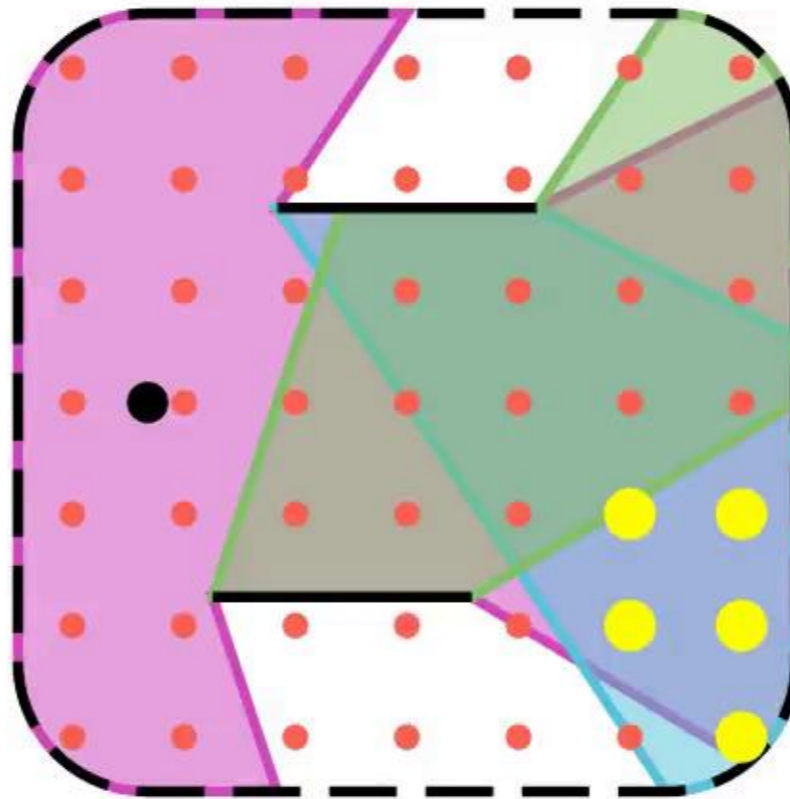
1

1

0

This is a Multipath Lifetime Map (MLM) for a moving RX

$S_i$



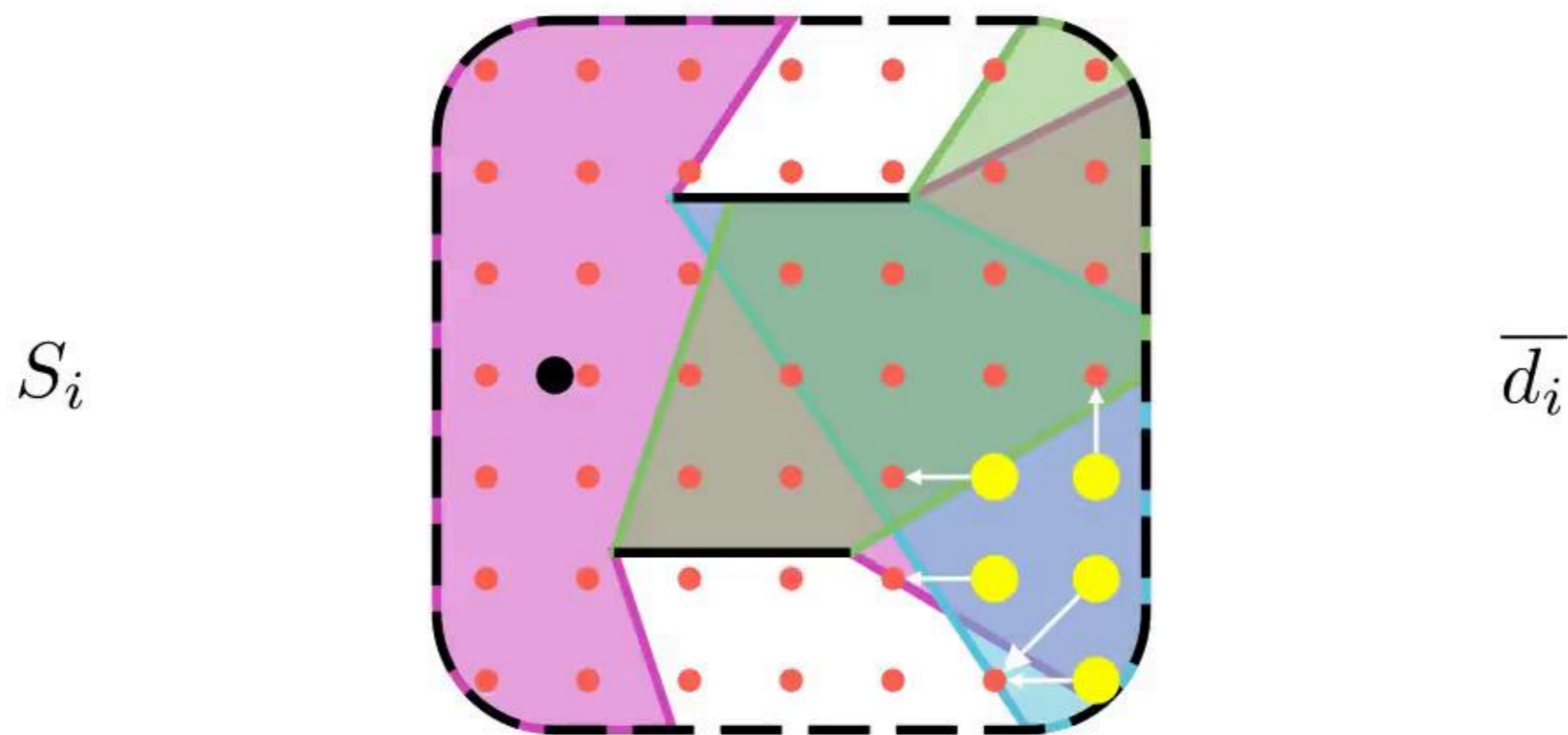
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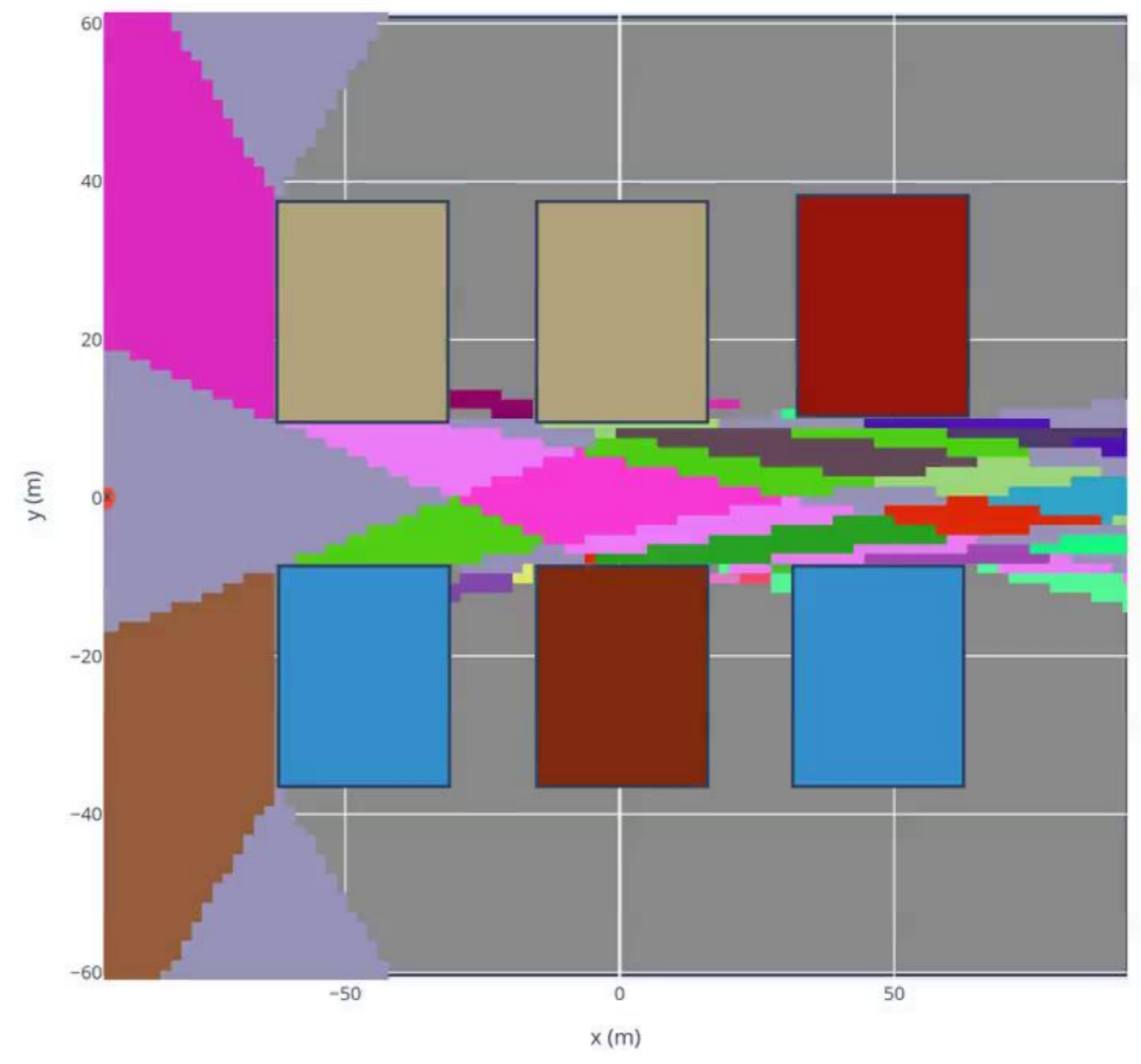
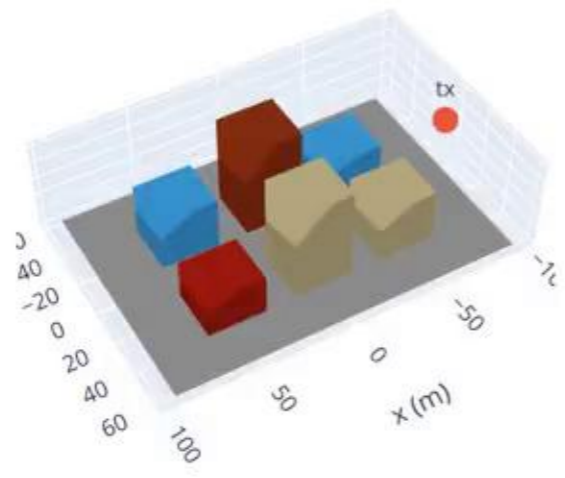
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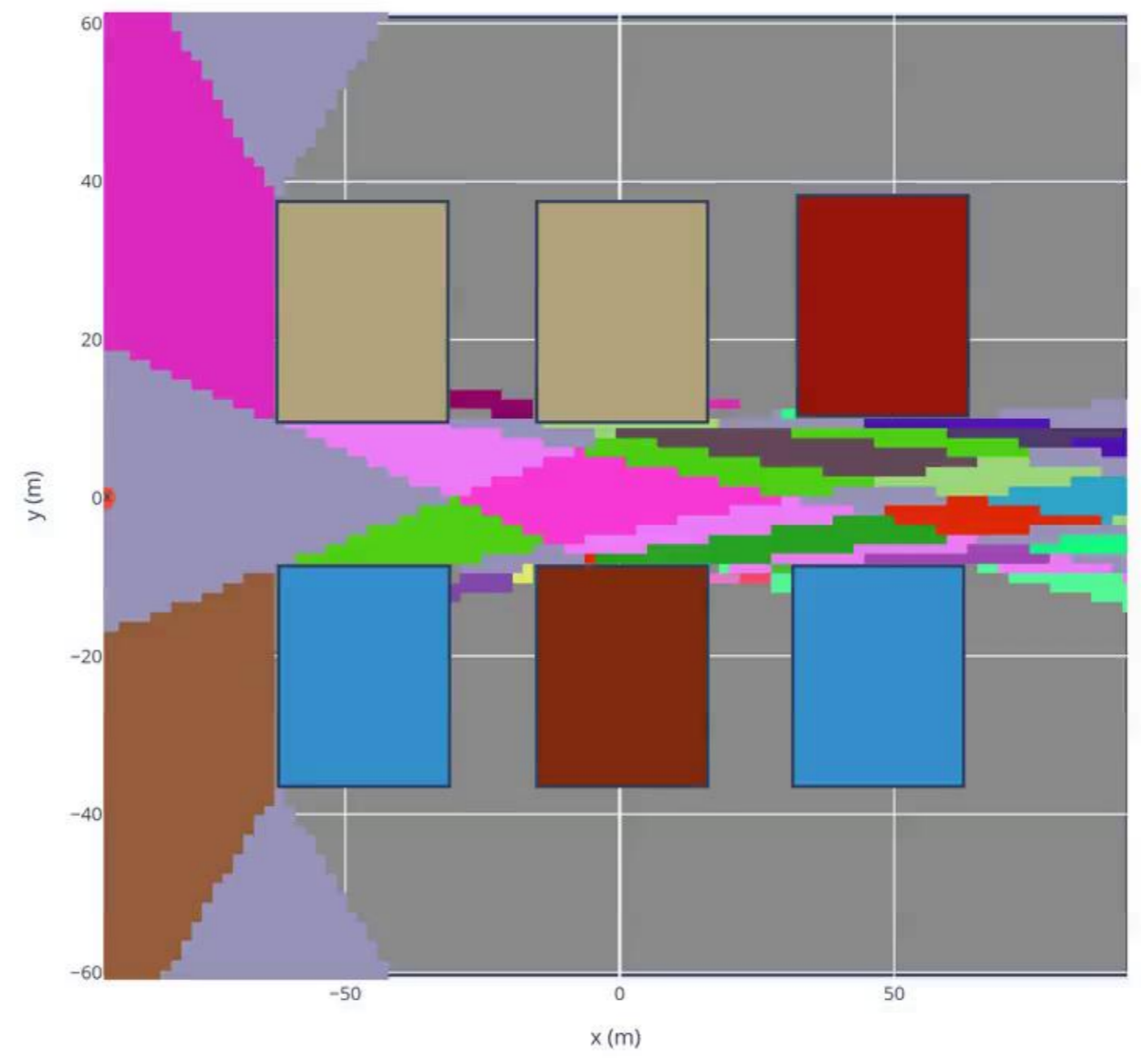
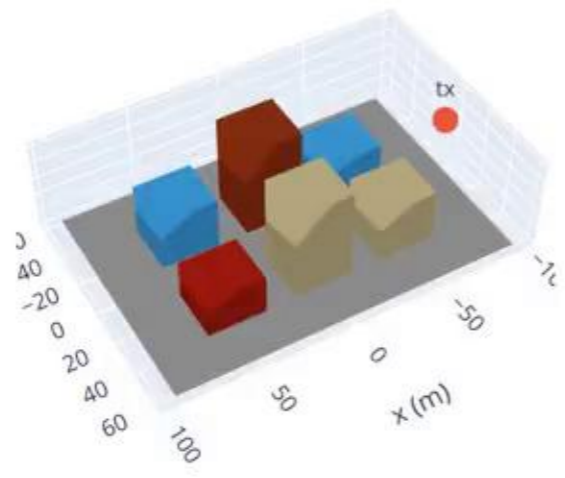
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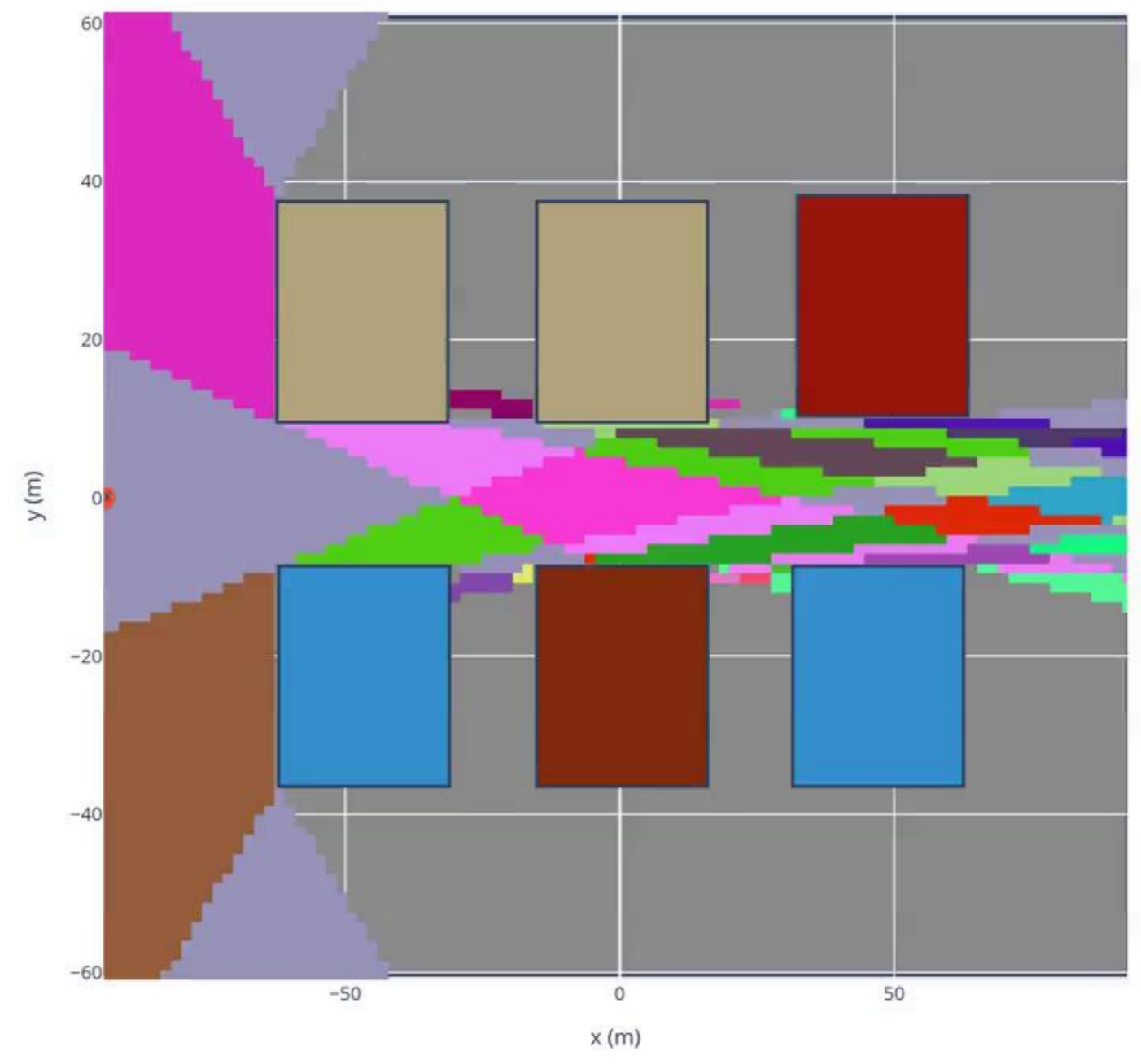
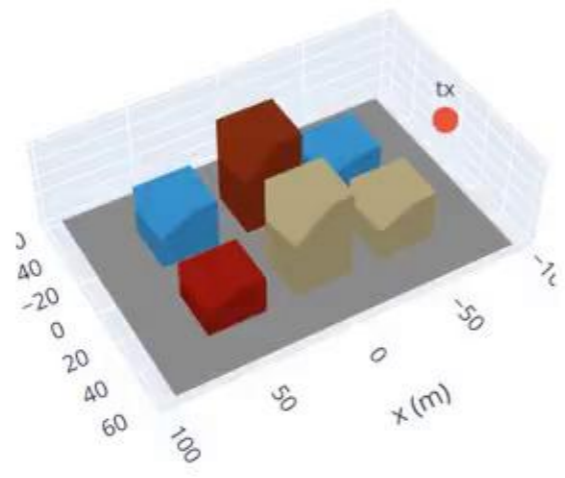
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**Take away messages:**

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- MLMs are not limited to moving RXs: moving TXs, rotating walls, etc.
- Related metrics are only a **tool** to help you evaluate the benefits of Dyn. RT



Interactive tutorial



jeertmans/DiffeRT

Slides made with Manim Slides, free and open source tool.

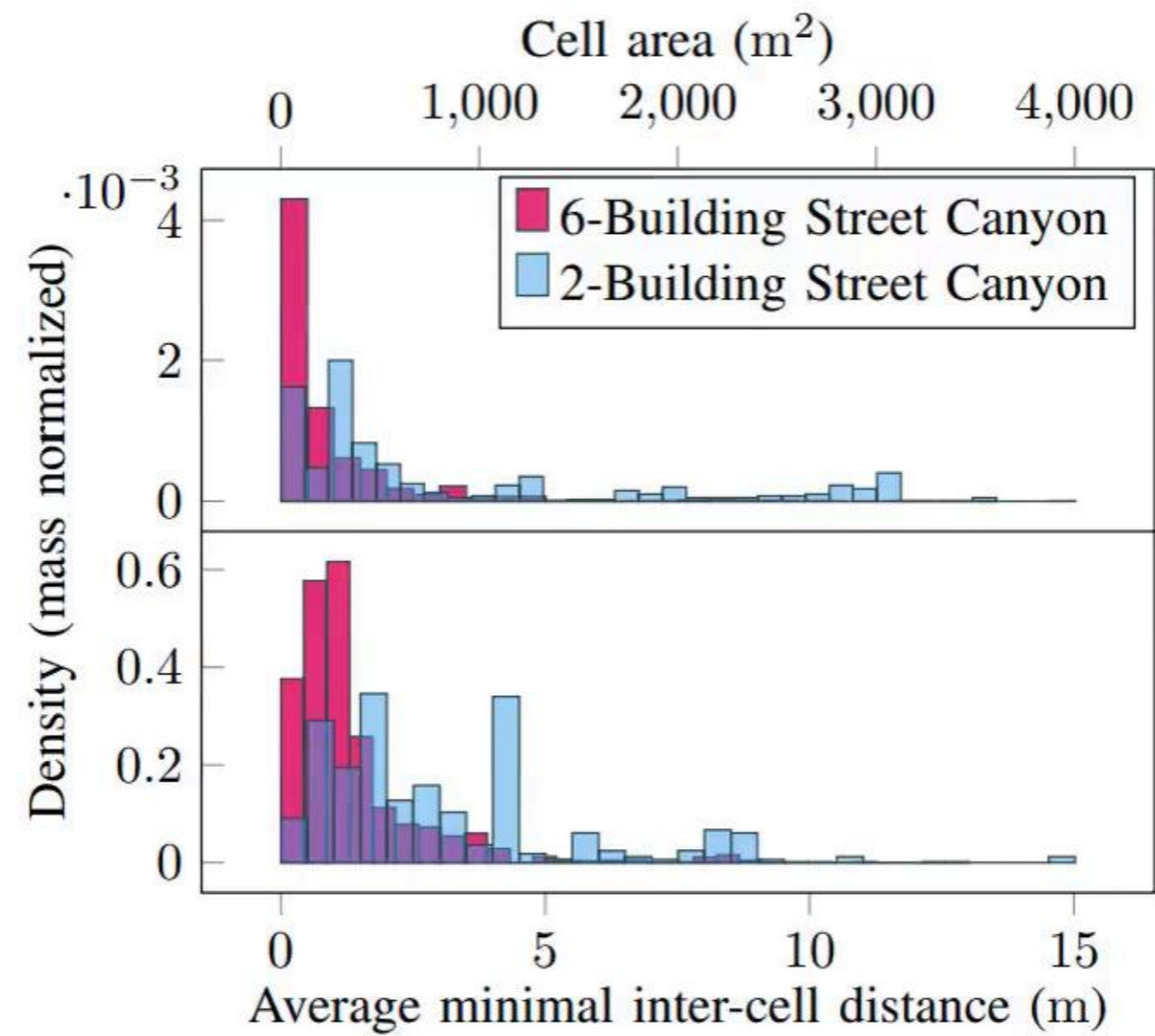


TABLE I  
 MEAN AND MEDIAN VALUES OVER ALL 50 SIMULATION SNAPSHOTS AND  
 CELLS.

	6B		2B	
	$S$ (m <sup>2</sup> )	$\bar{d}$ (m)	$S$ (m <sup>2</sup> )	$\bar{d}$ (m)
Mean	225.62	1.40	840.56	3.08
Median	86.43	1.00	371.38	2.30