

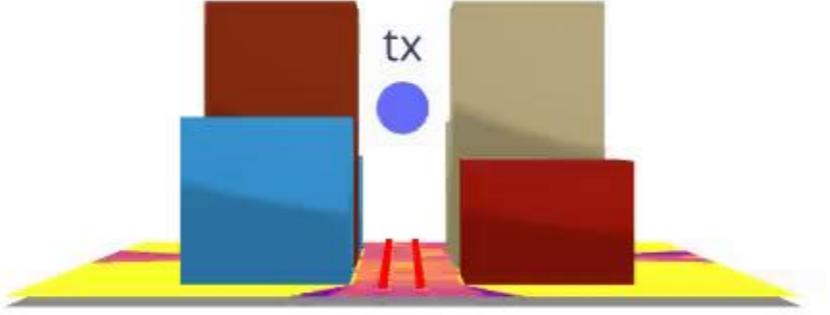


Comparing Differentiable and Dynamic Ray Tracing: Introducing the Multipath Lifetime Map

Jérôme Eertmans - April 1st, EuCAP 2025, Stockholm

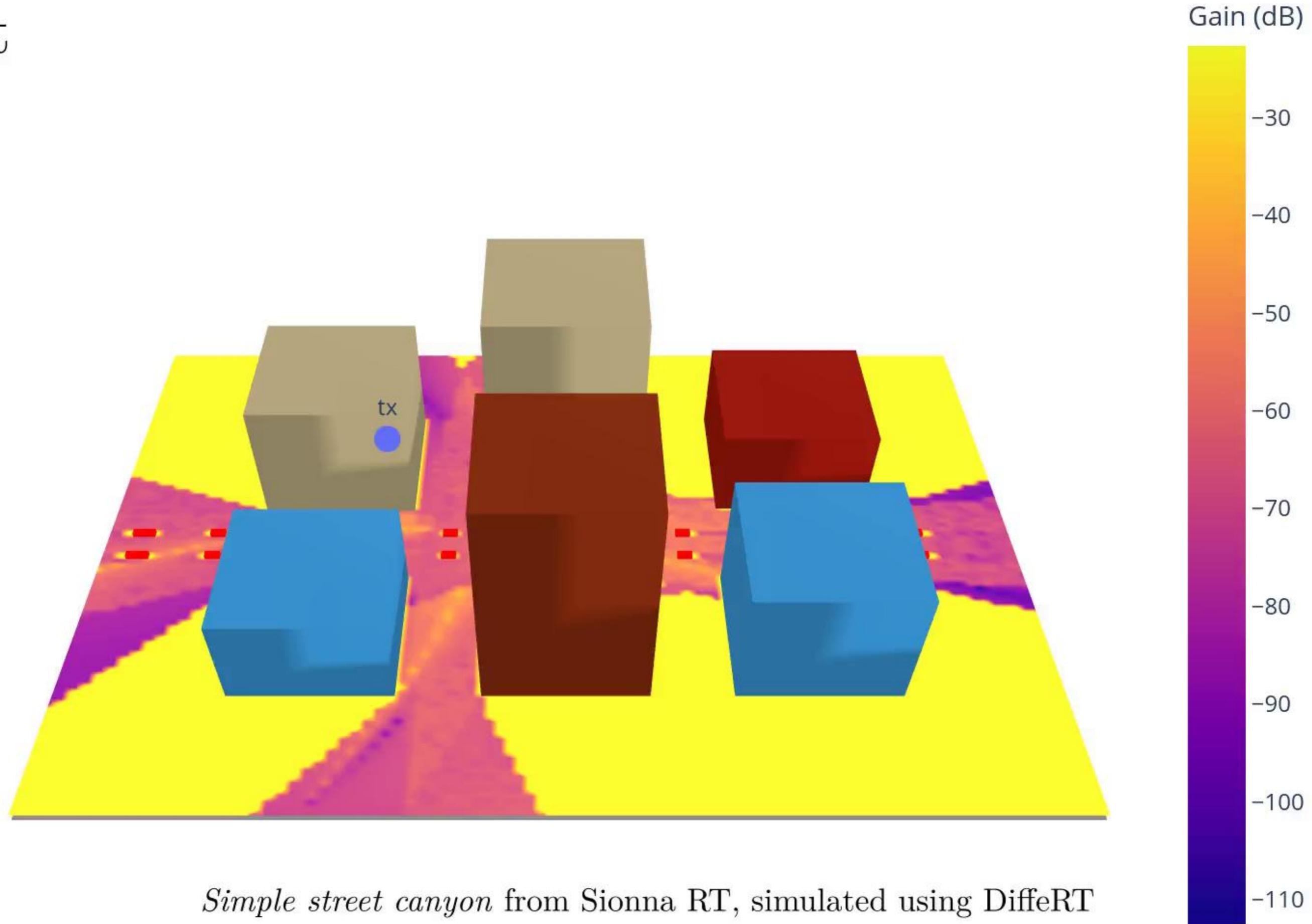
Authors: Jérôme Eertmans, Enrico Maria Vitucci, Vittorio Degli-Esposti,
Laurent Jacques, Claude Oestges

Context

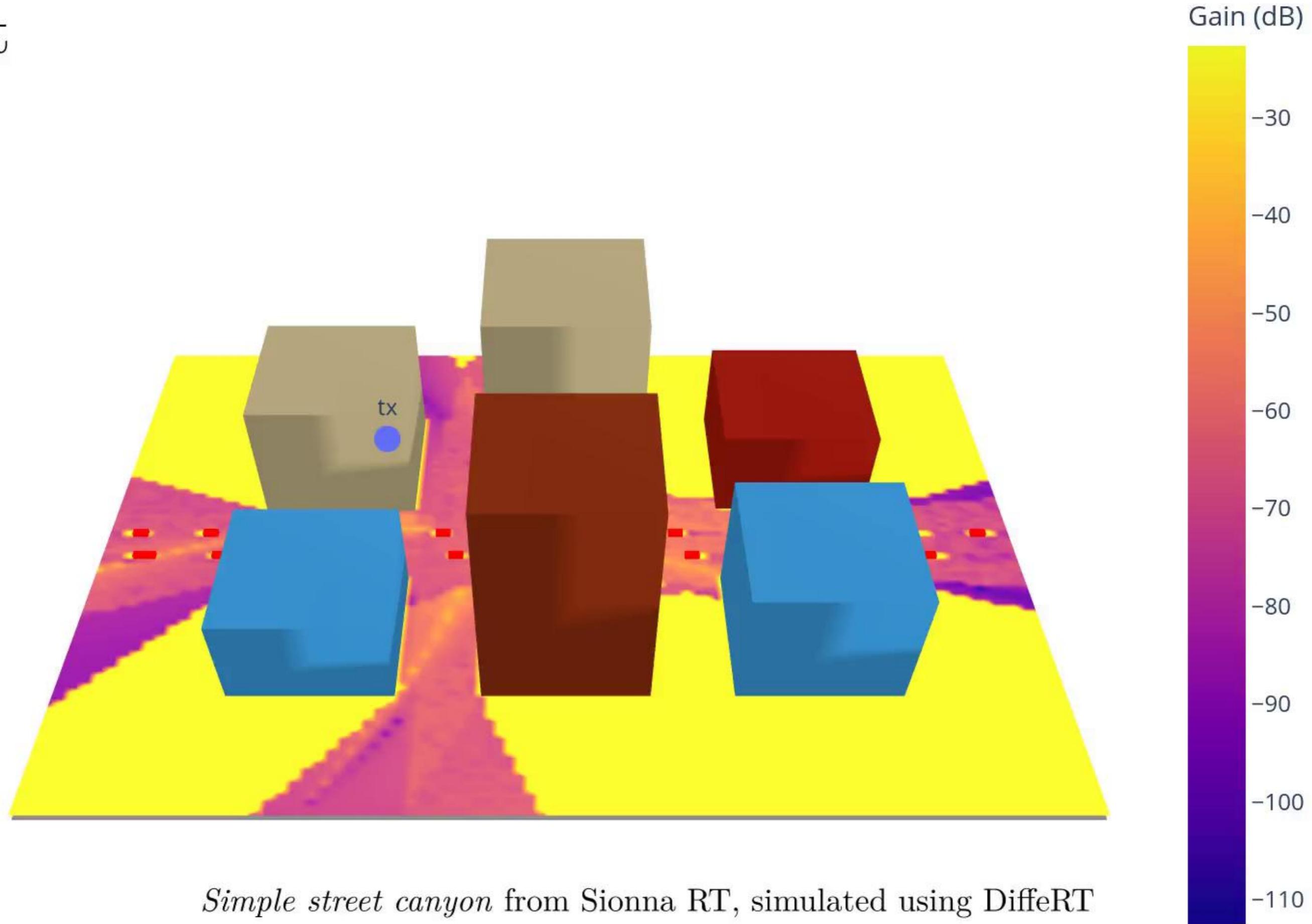


Simple street canyon from Sionna RT, simulated using DiffeRT

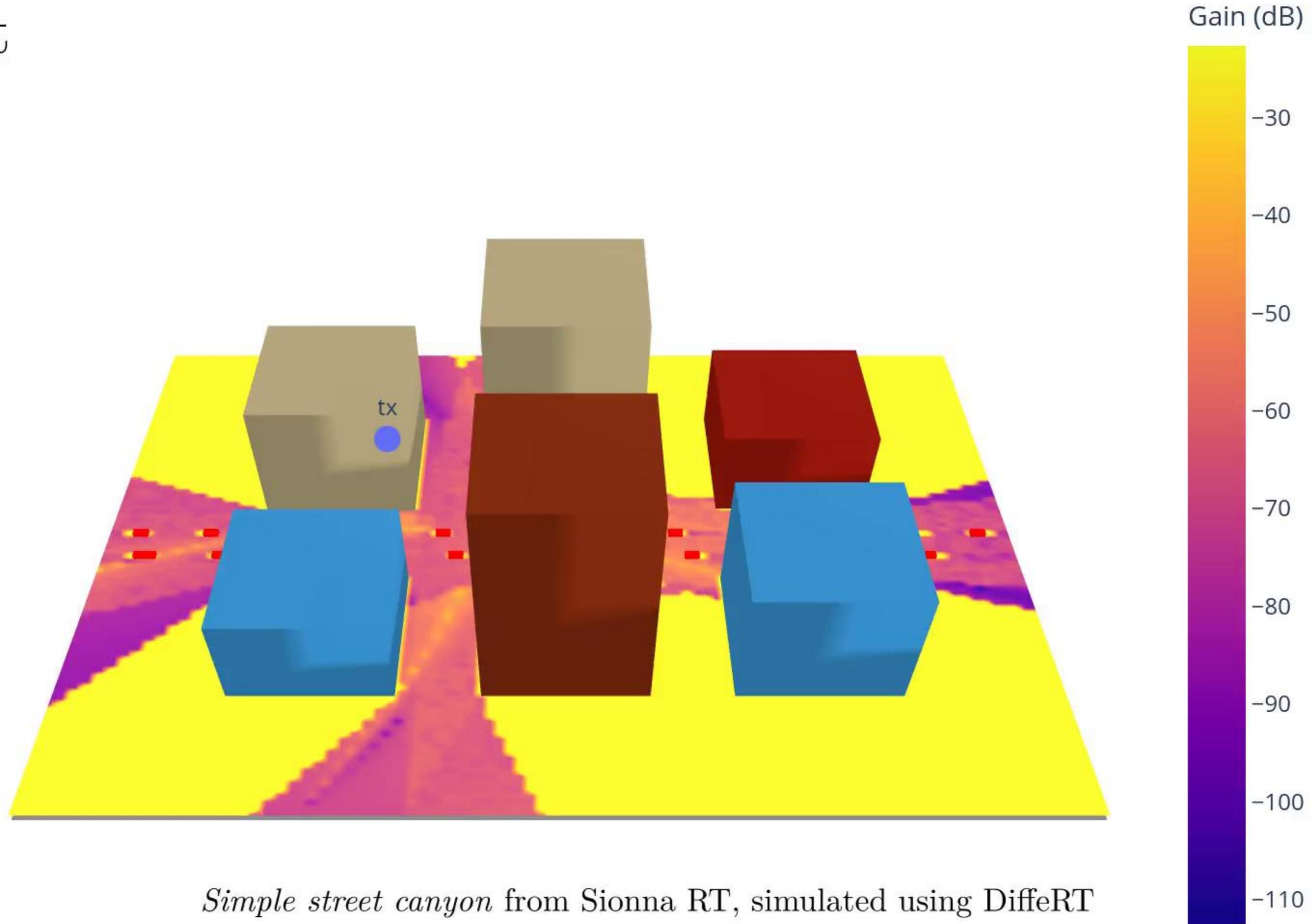
Context



Context



Context



Scene

Scene

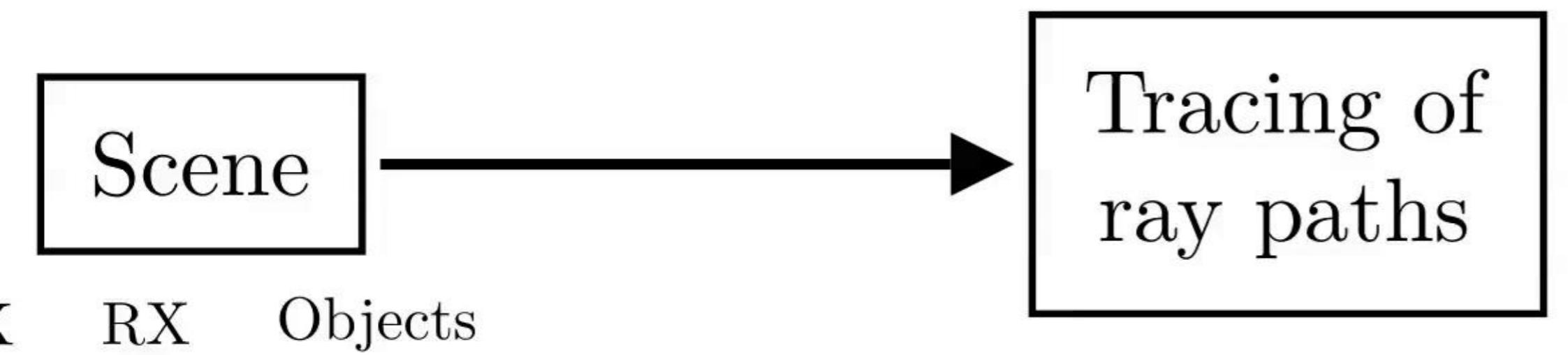
TX

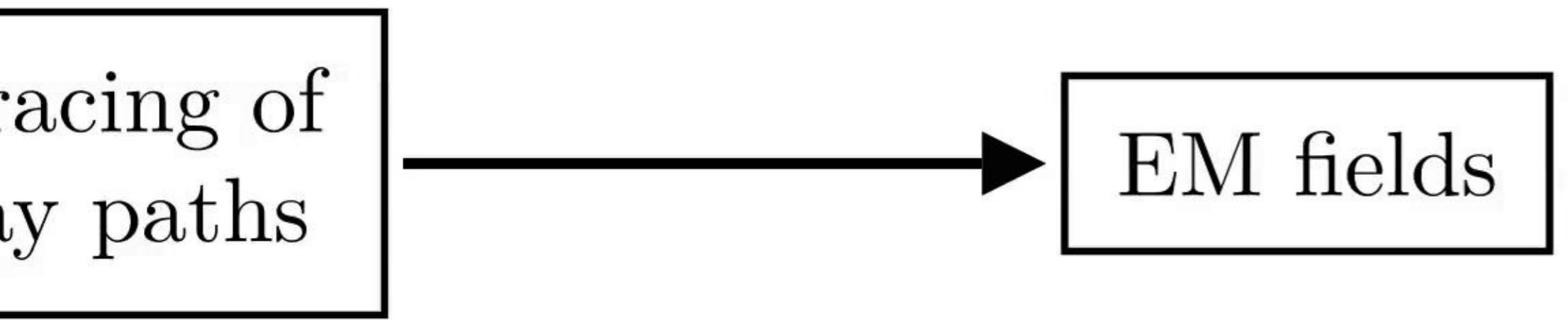
Scene

TX RX

Scene

TX RX Objects

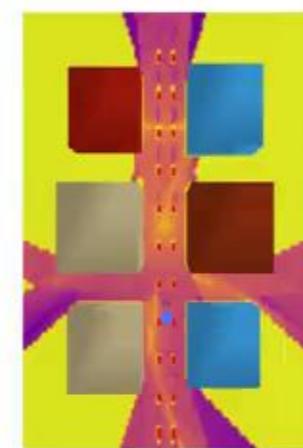


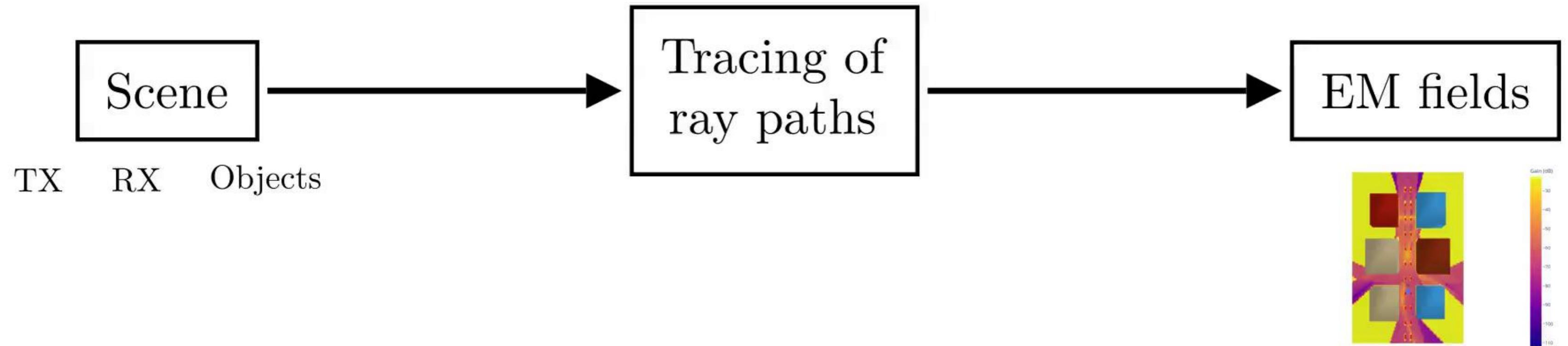


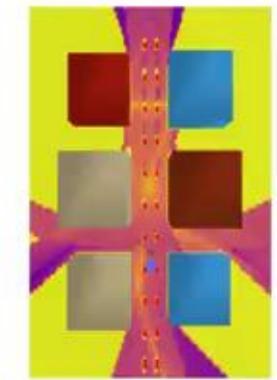
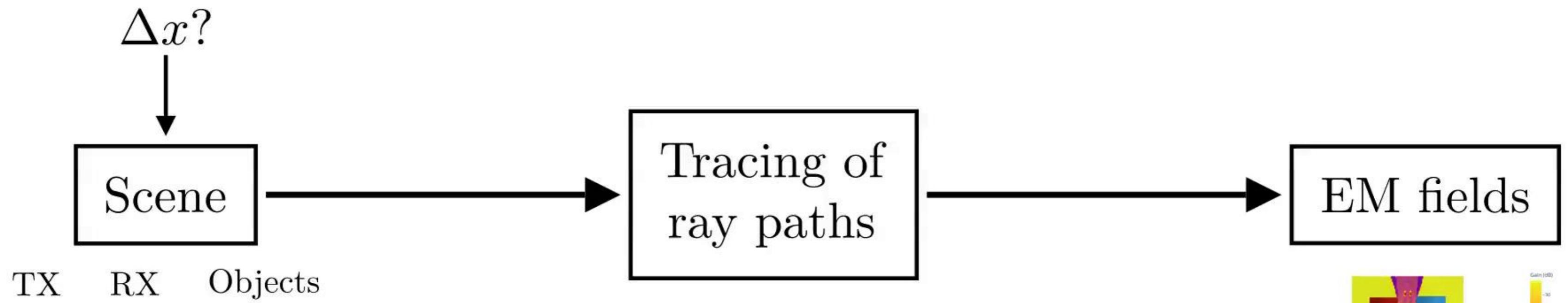
Tracing of
ray paths

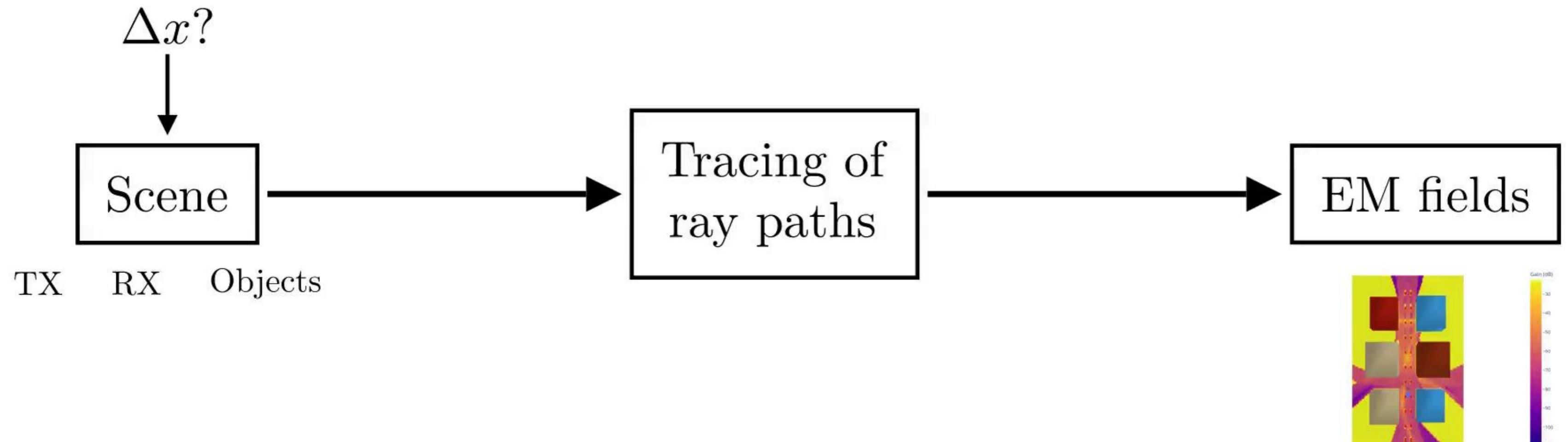


EM fields

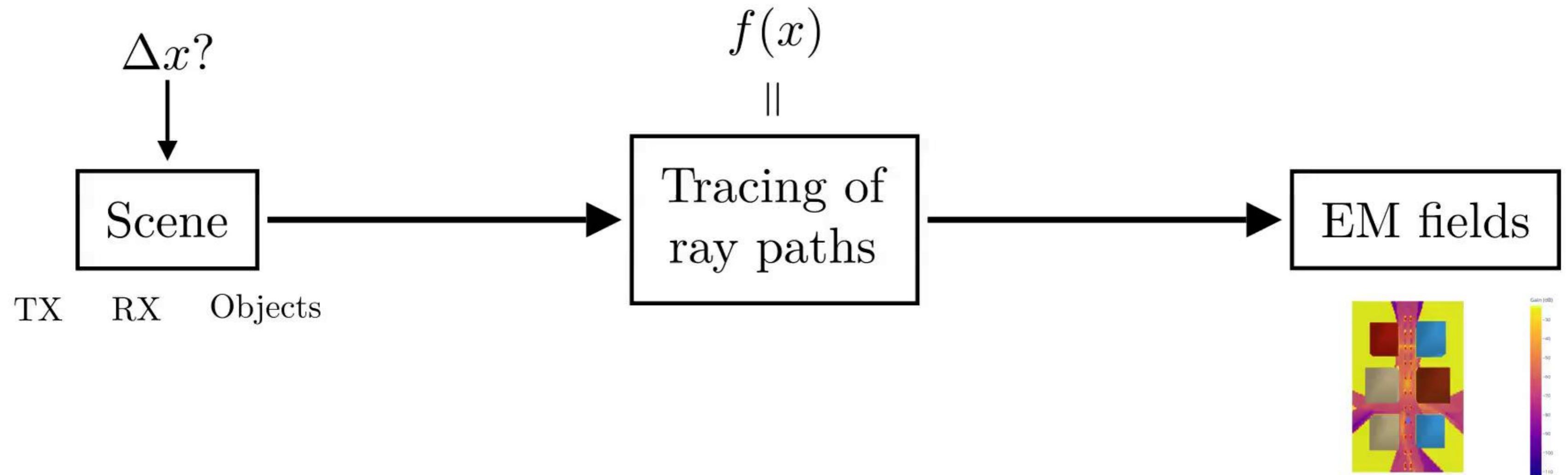




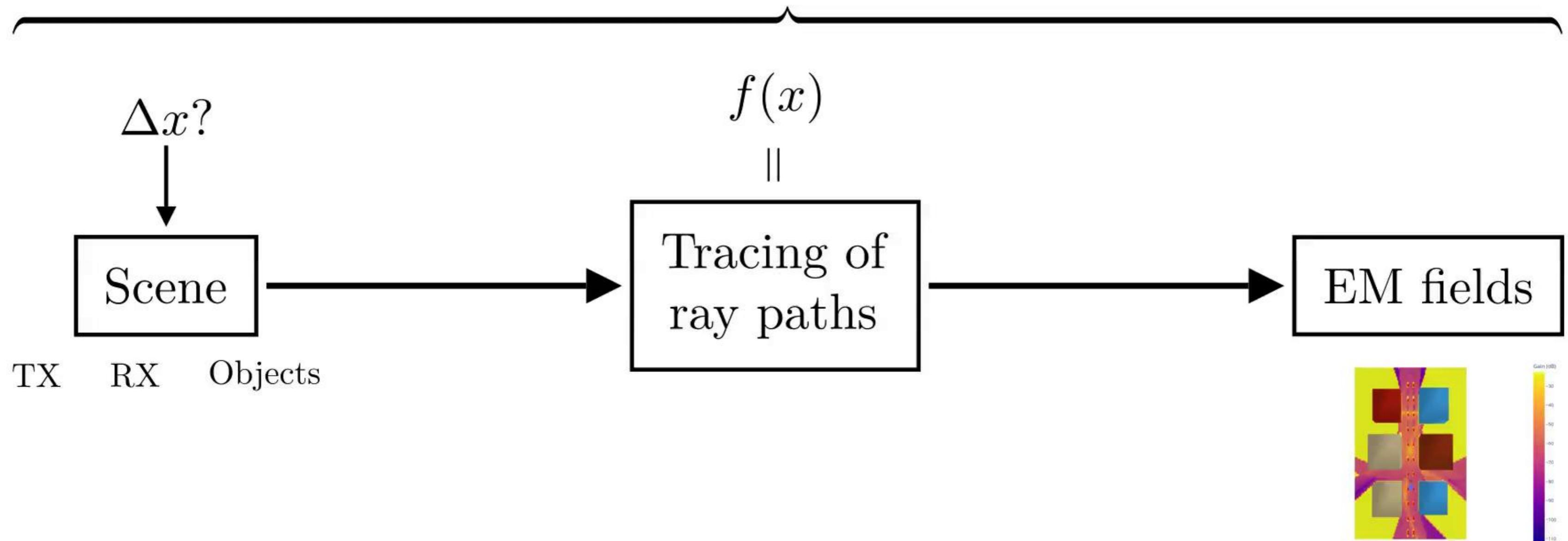




(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives

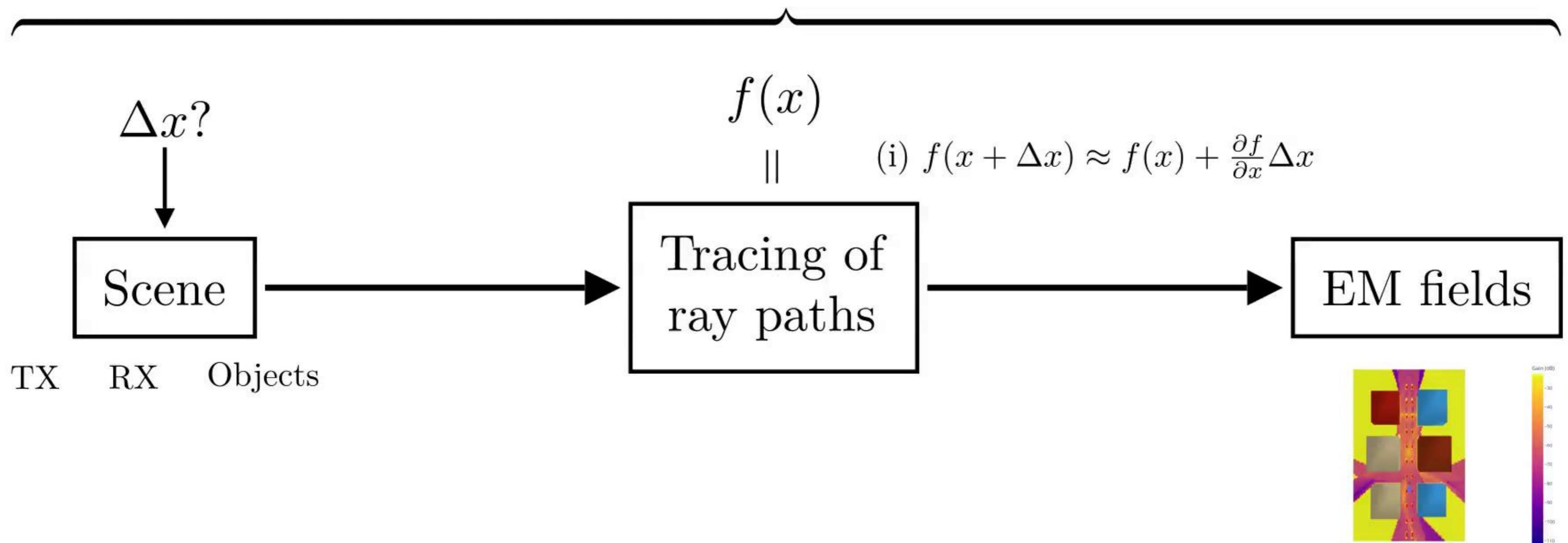


Snapshot



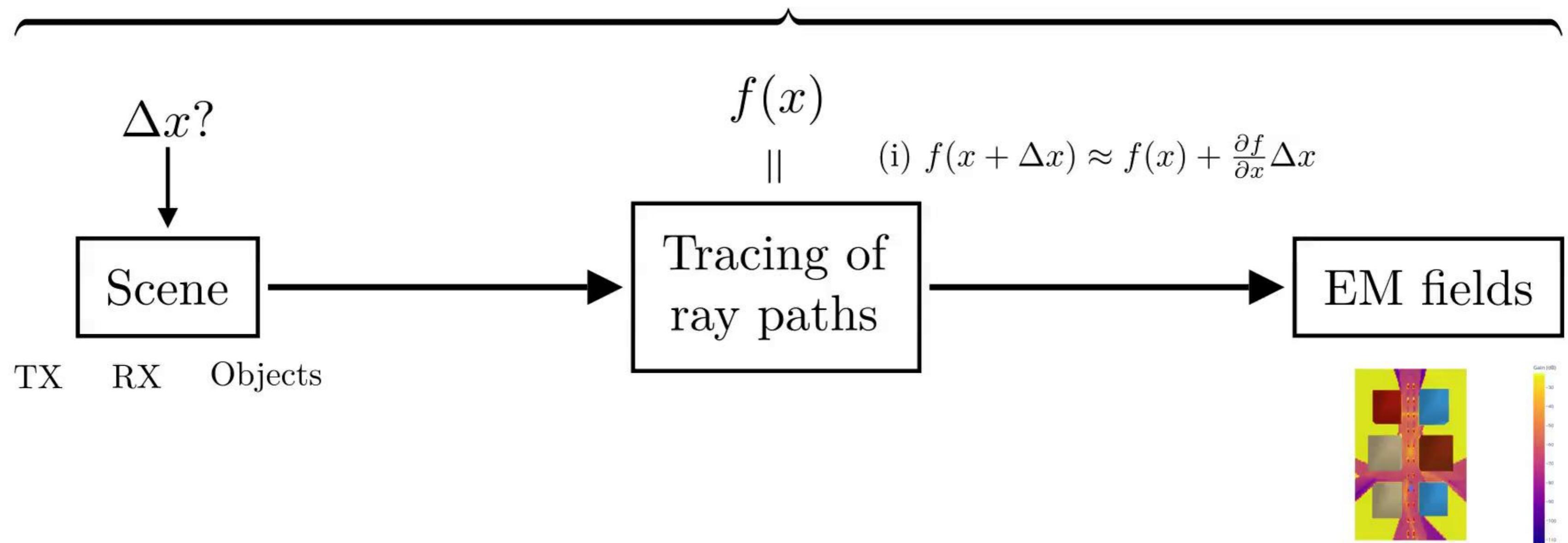
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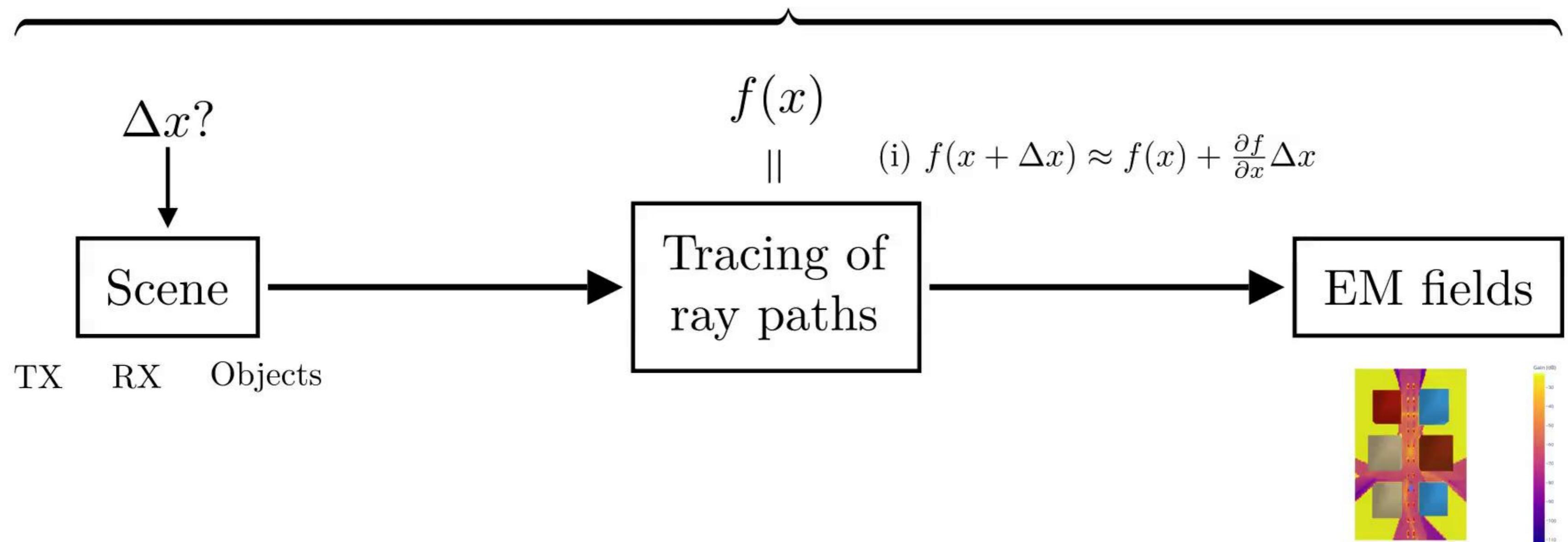
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Snapshot



- (i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives
- (ii) Differentiable (Diff.) RT: optimization using automatic differentiation

Snapshot



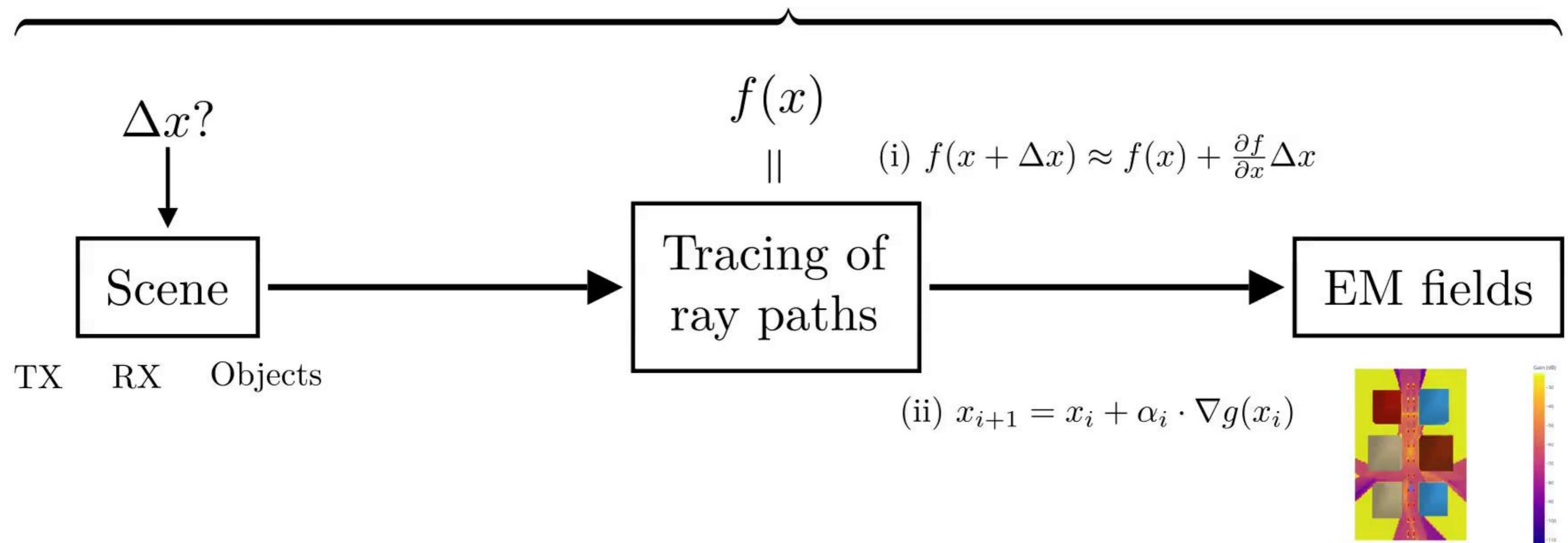
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||

$g(x)$

Snapshot

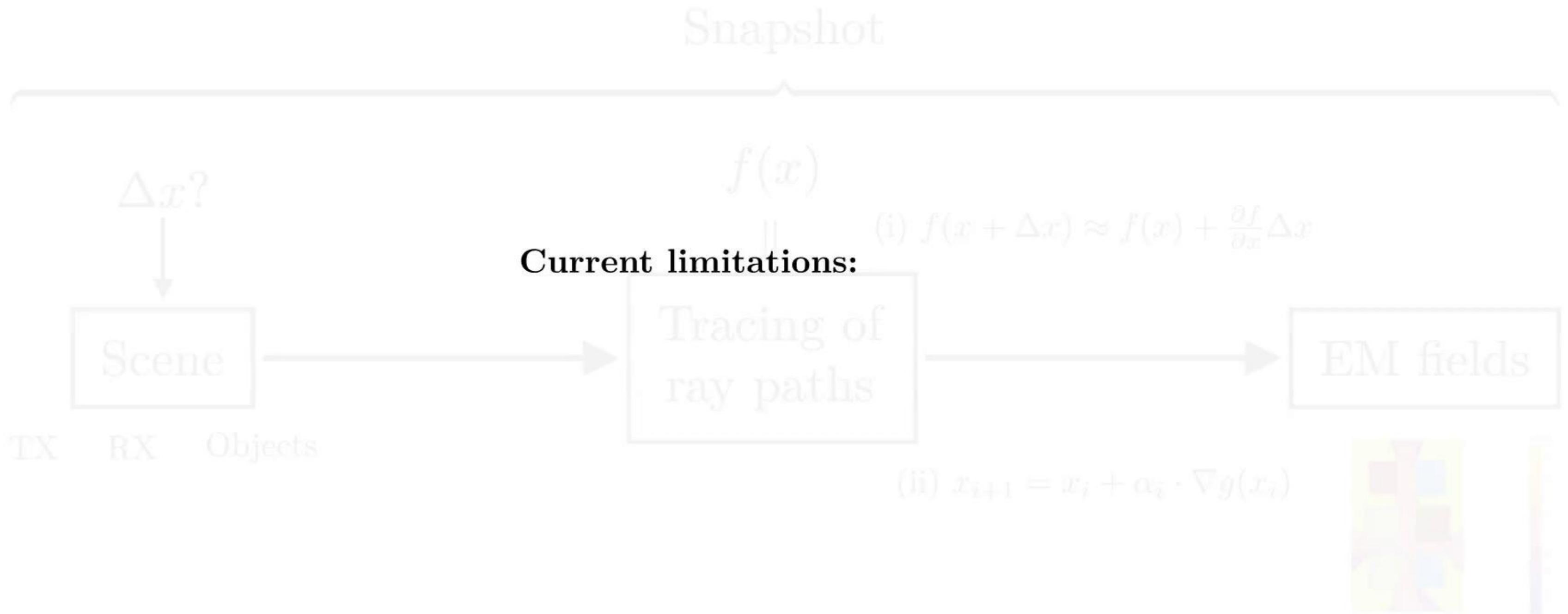


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||

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$g(x)$

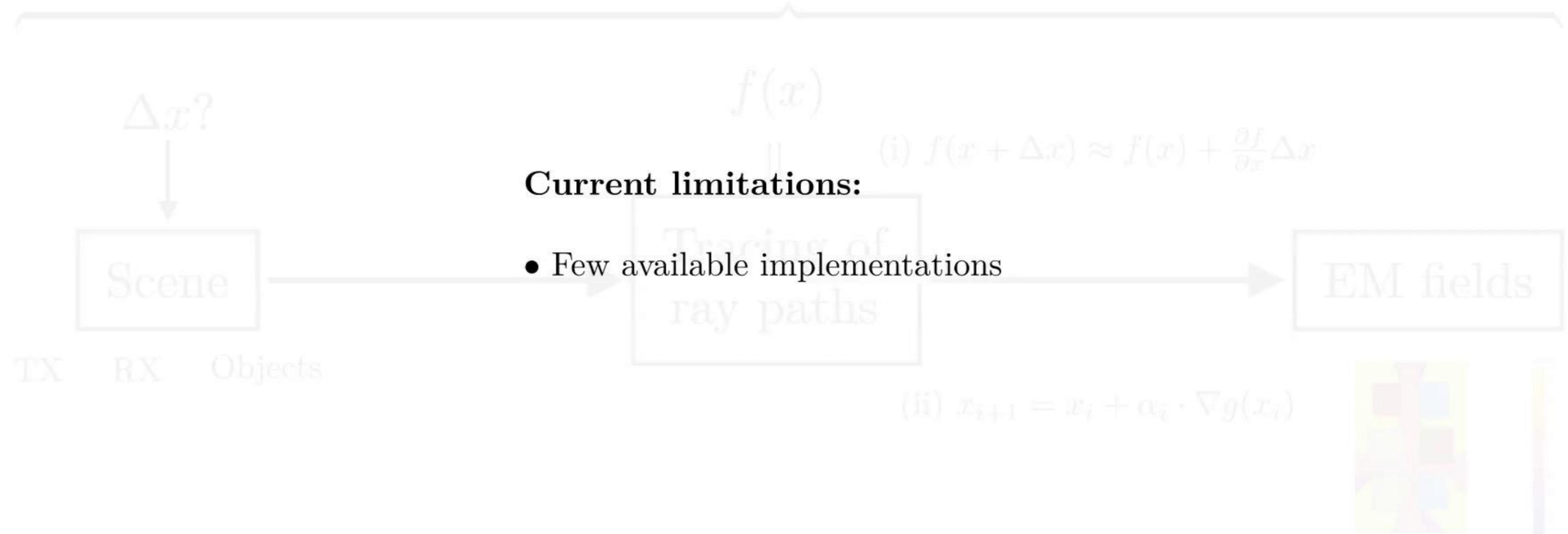


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$$g(x)$$

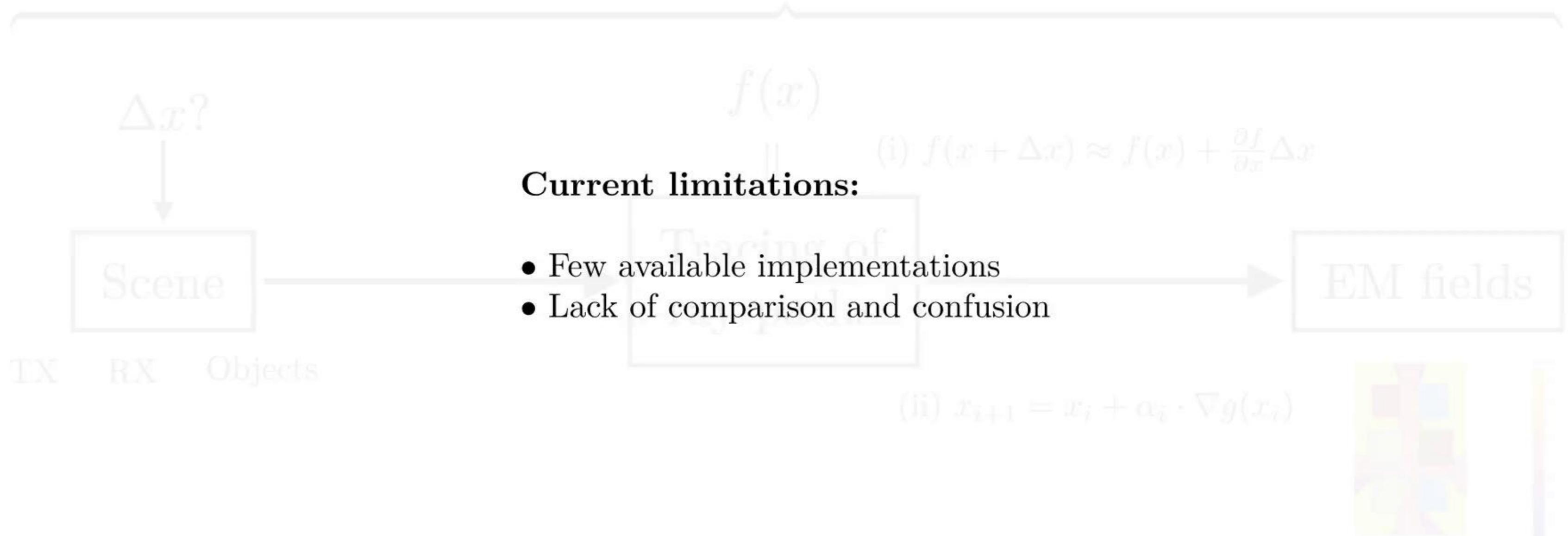
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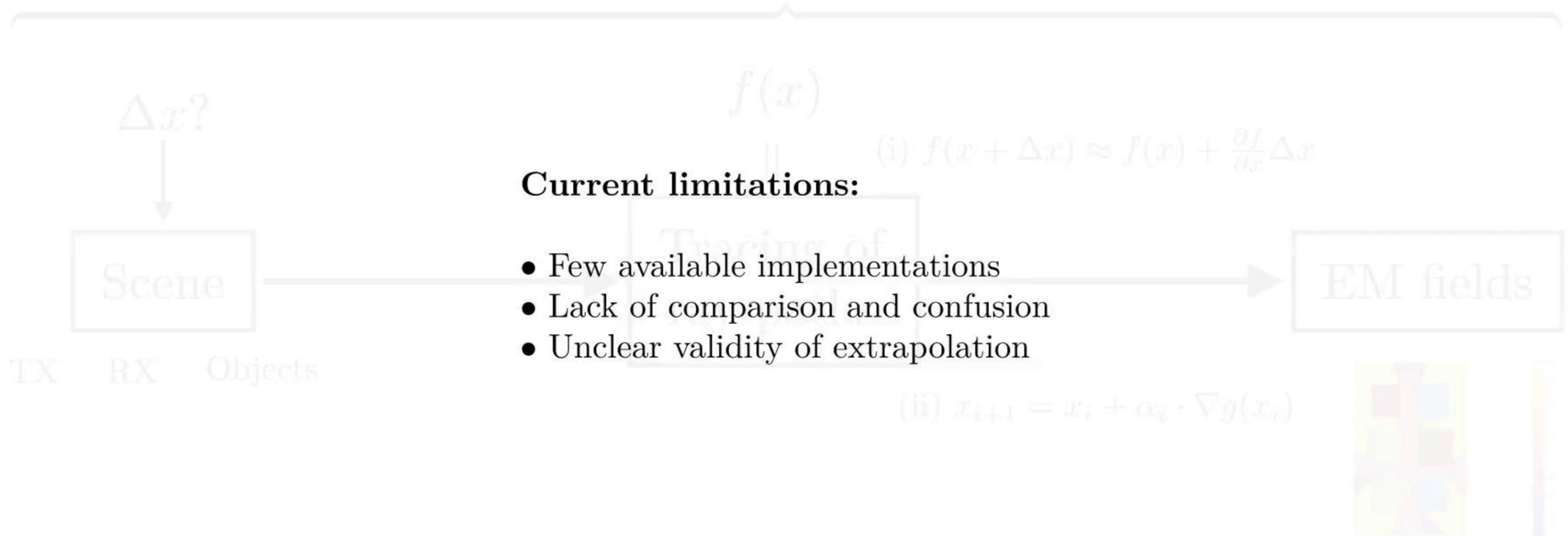


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Snapshot



Current limitations:

- Few available implementations
- Lack of comparison and confusion
- Unclear validity of extrapolation

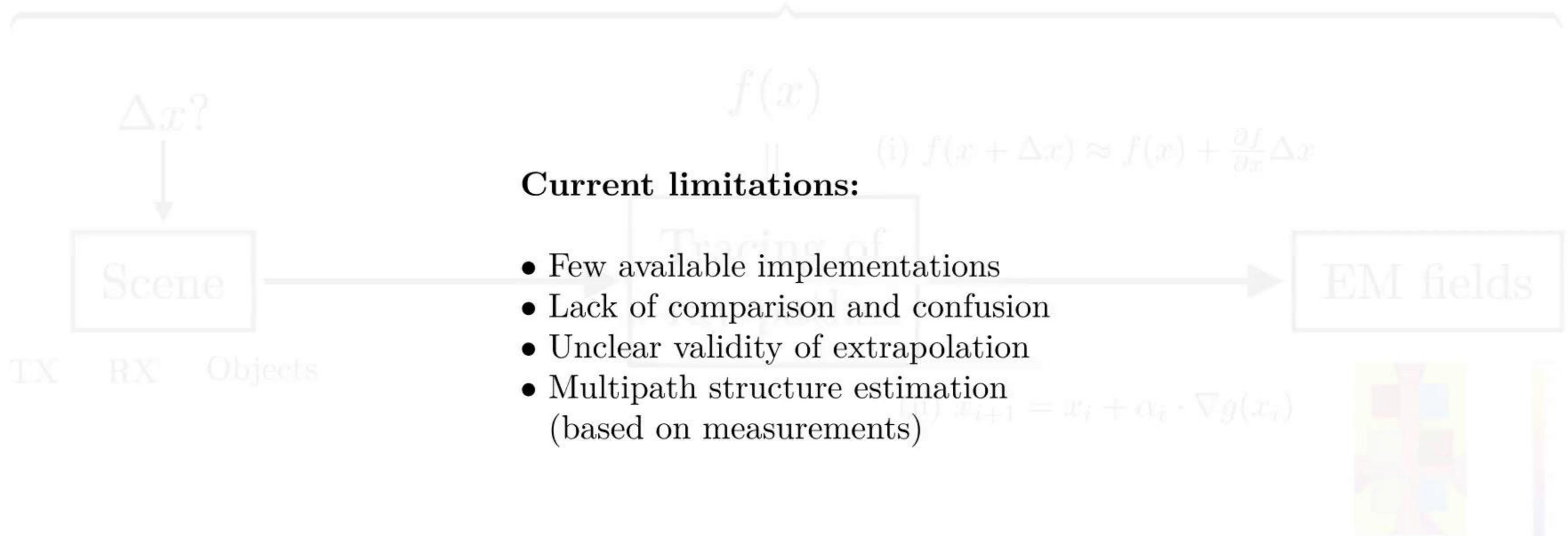
$$(ii) \quad x_{i+1} = x_i + \alpha_i \cdot \nabla g(x_i)$$

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

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$$g(x)$$

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Current limitations:

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- Multipath structure estimation
(based on measurements)

Snapshot

$\Delta x?$

$f(x)$

Contributions

Tracing of
ray paths

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

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EM fields

TX

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⇒ Provide a qualitative comparison (*details in paper*)

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- ⇒ Illustrate the limits of Dyn. RT

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Contributions

Tracing of
ray paths

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

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

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$g(x)$

Contents:

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- Methods comparison

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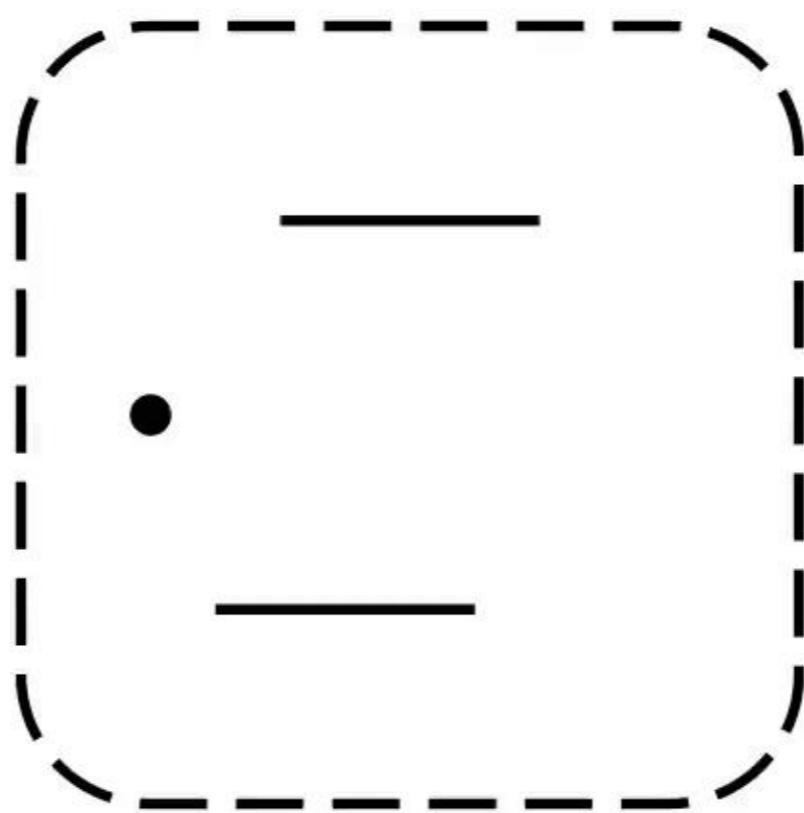
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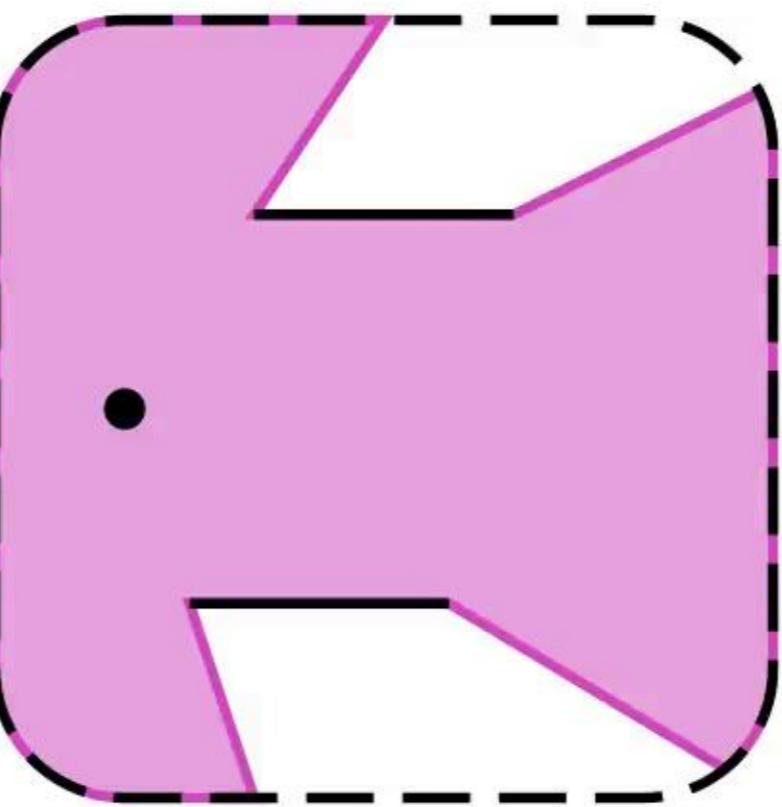
- Methods comparison
- Limits of extrapolation
- Multipath Lifetime Map (MLM) and metrics

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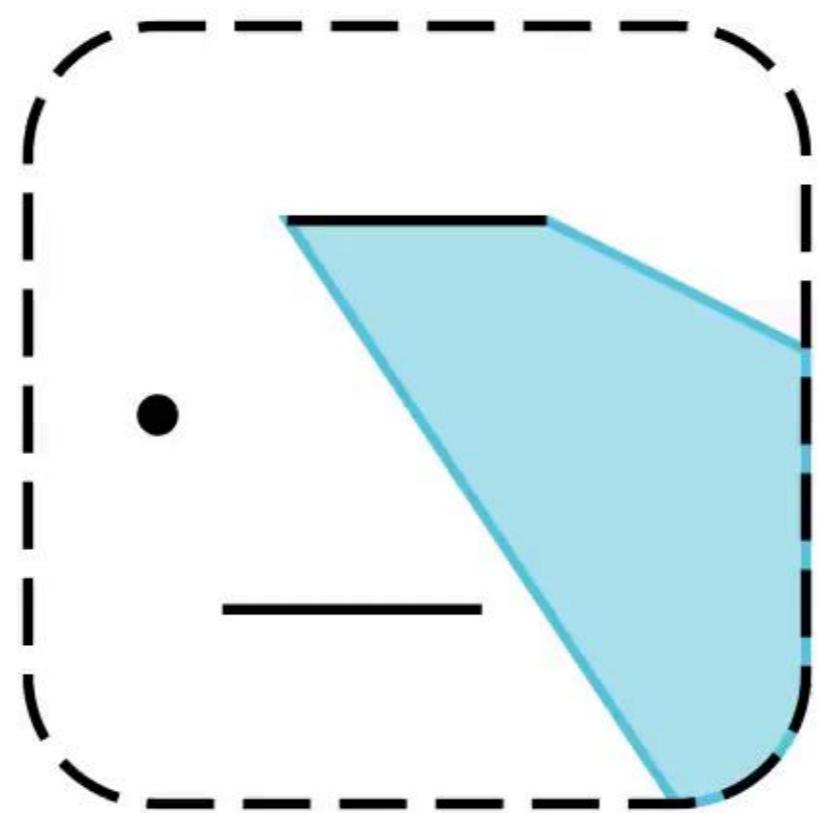
- Methods comparison
- Limits of extrapolation
- Multipath Lifetime Map (MLM) and metrics
- Results of MLMs for a moving RX

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

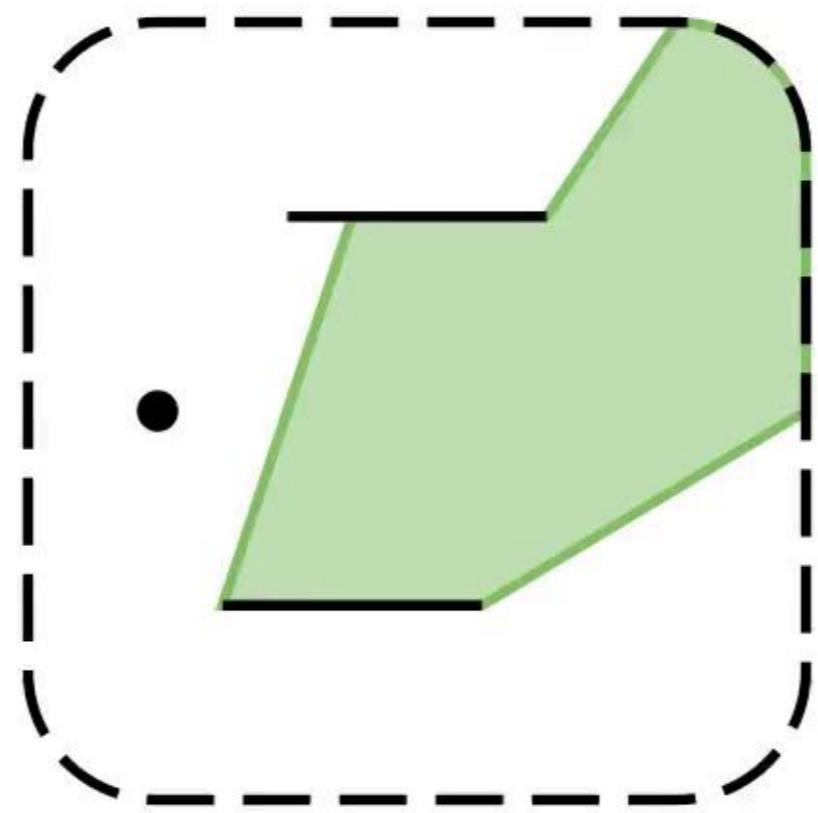




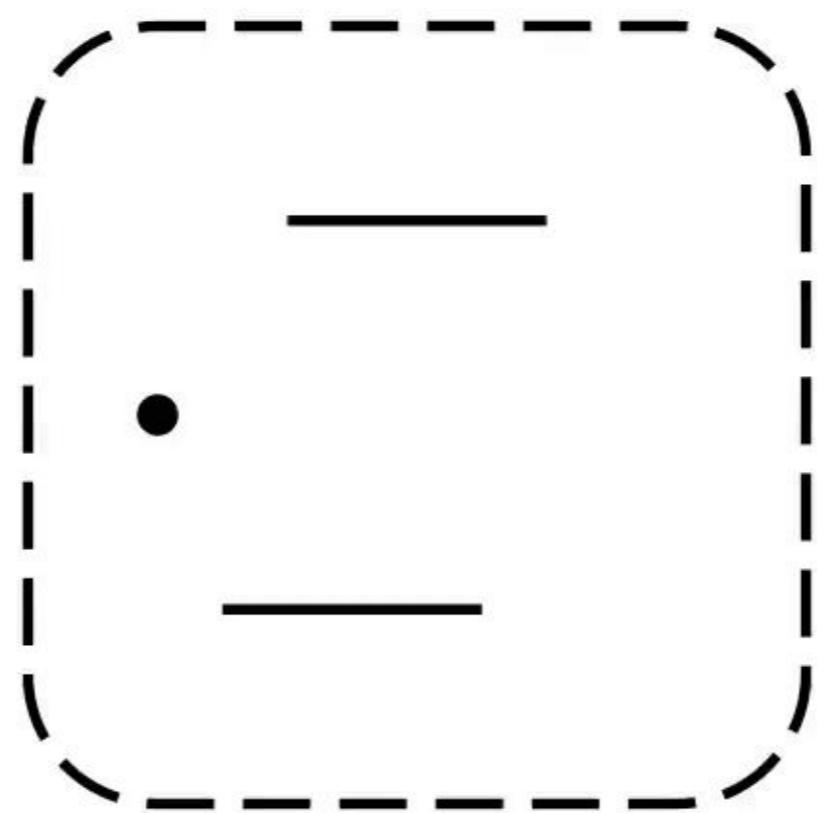
Line-of-sight

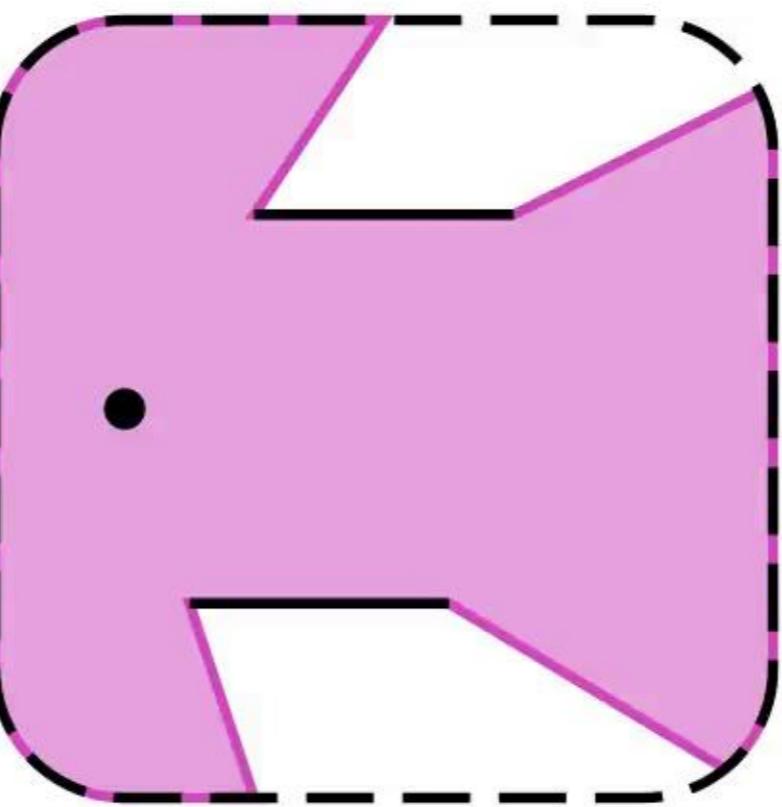


Reflection from W_1

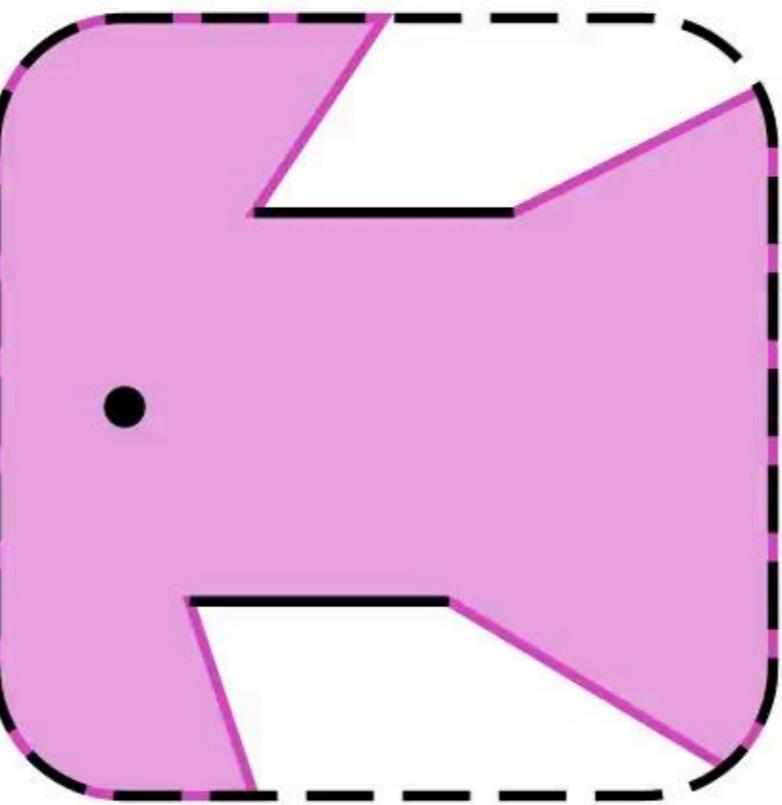


Reflection from W_2

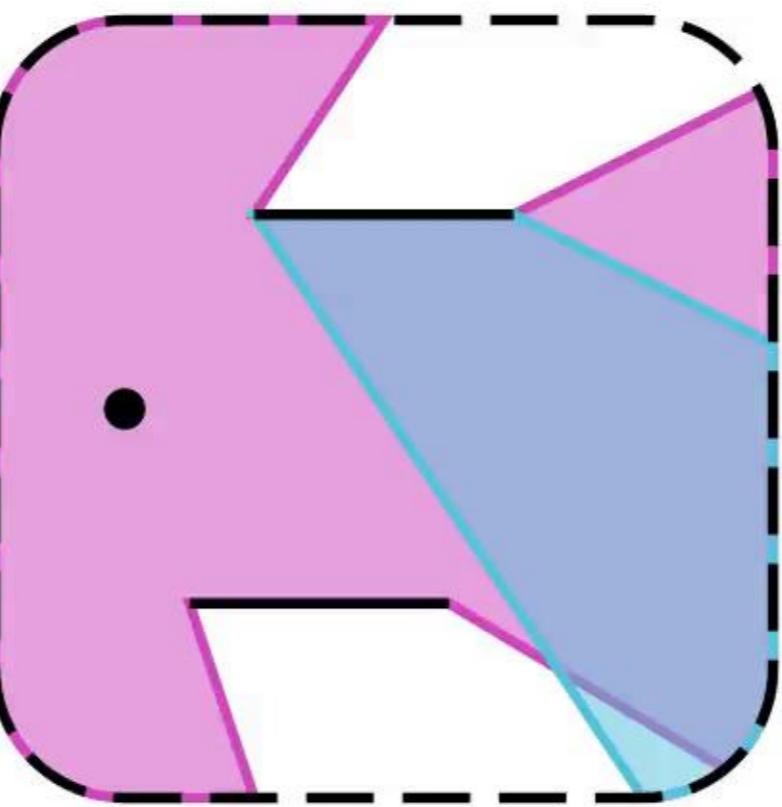




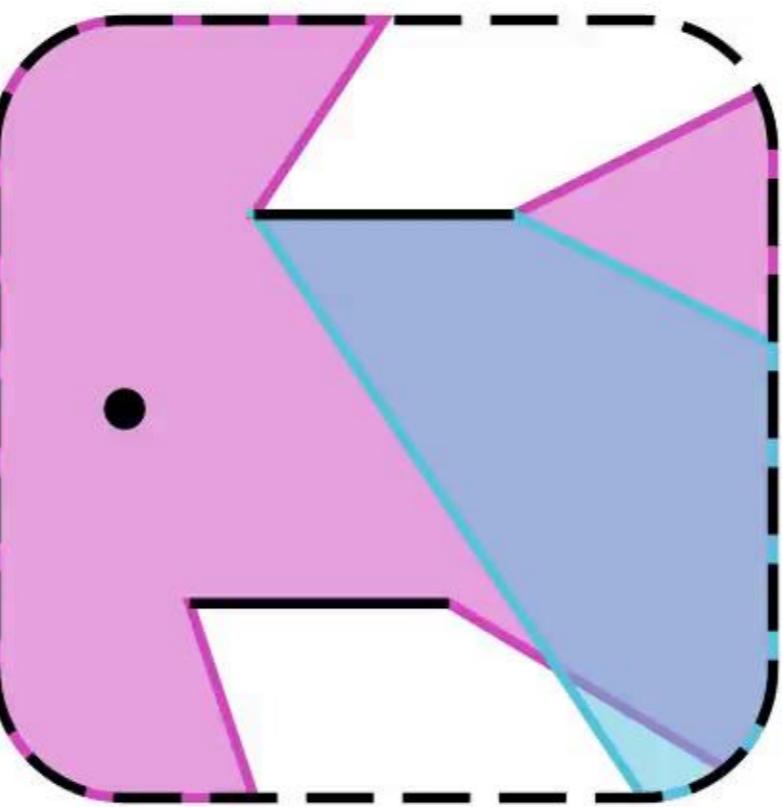
Line-of-sight



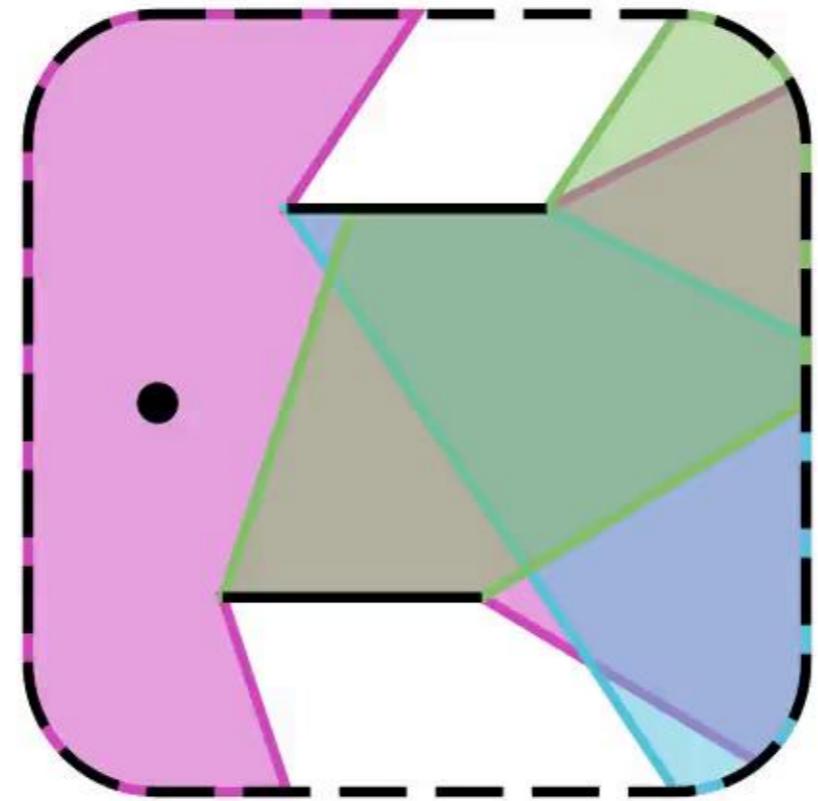
Line-of-sight +



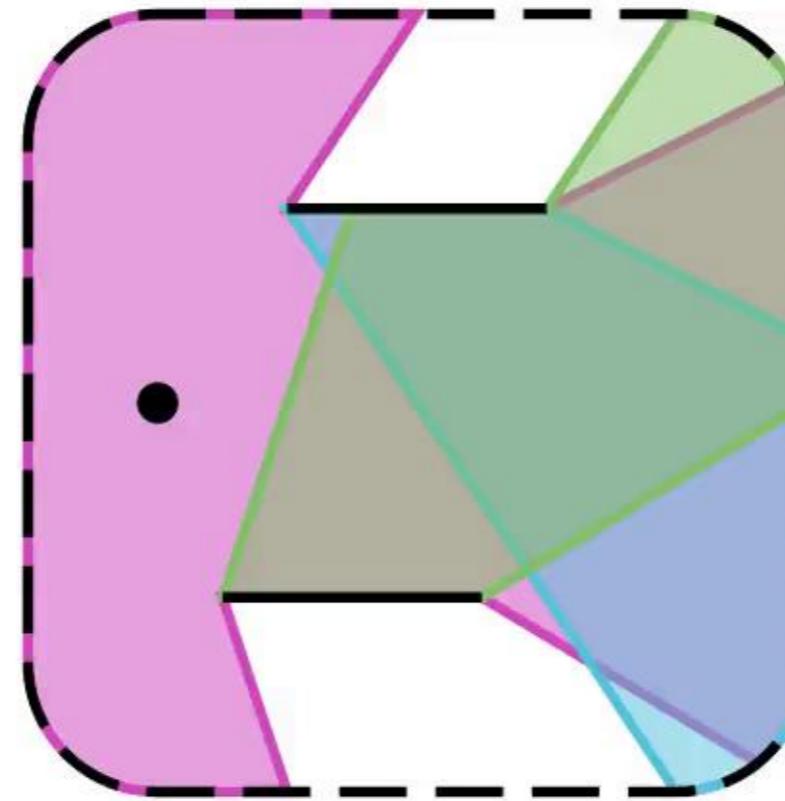
Line-of-sight+Reflection from W_1



Line-of-sight+Reflection from W_1+

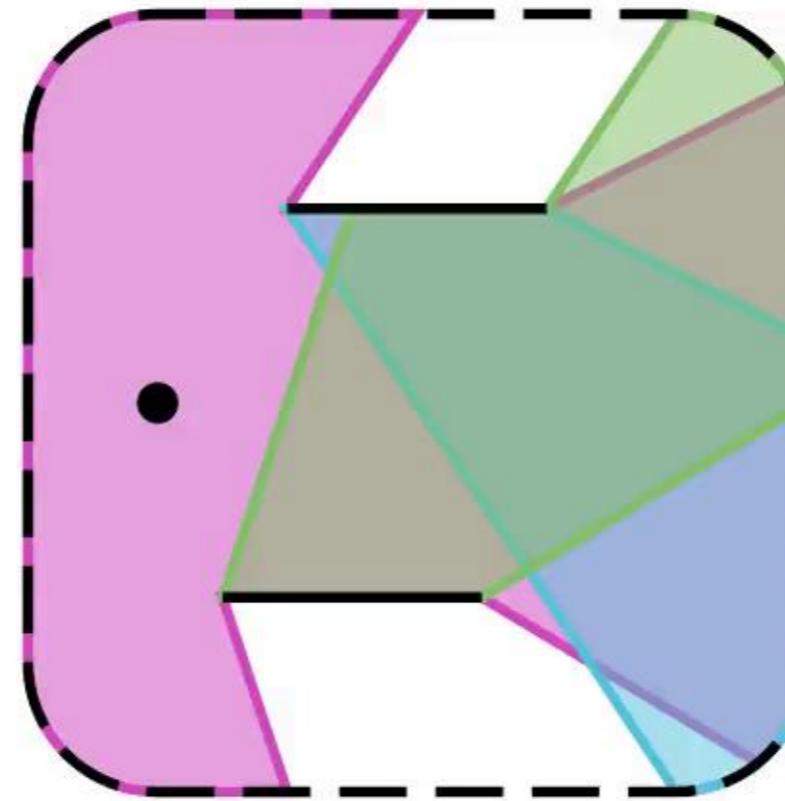


Line-of-sight + Reflection from W_1 + Reflection from W_2



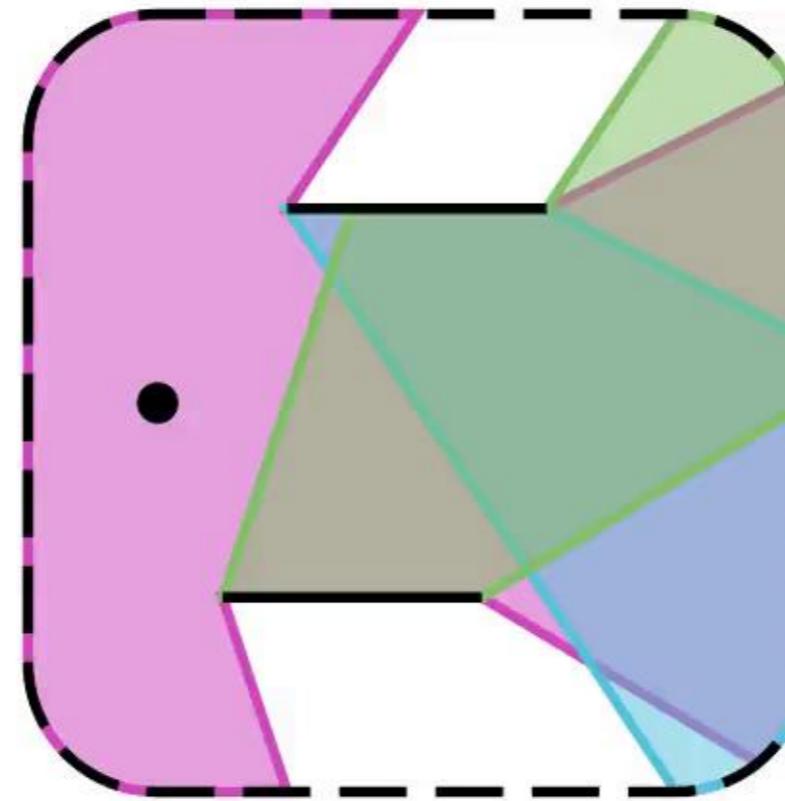
Line-of-sight + Reflection from W_1 + Reflection from W_2

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



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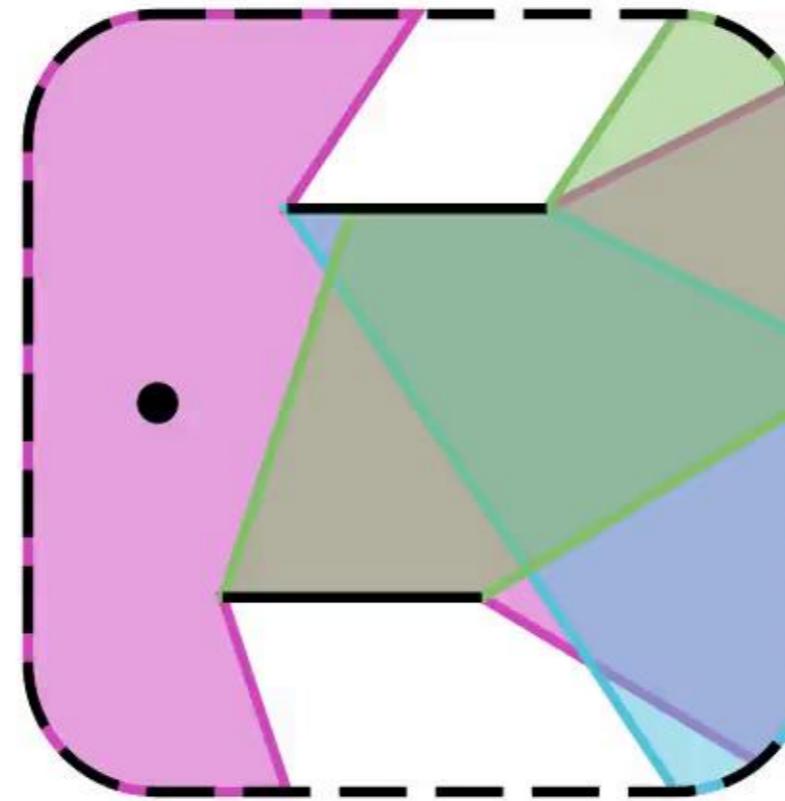
For each cell C_i , we compute:

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

where

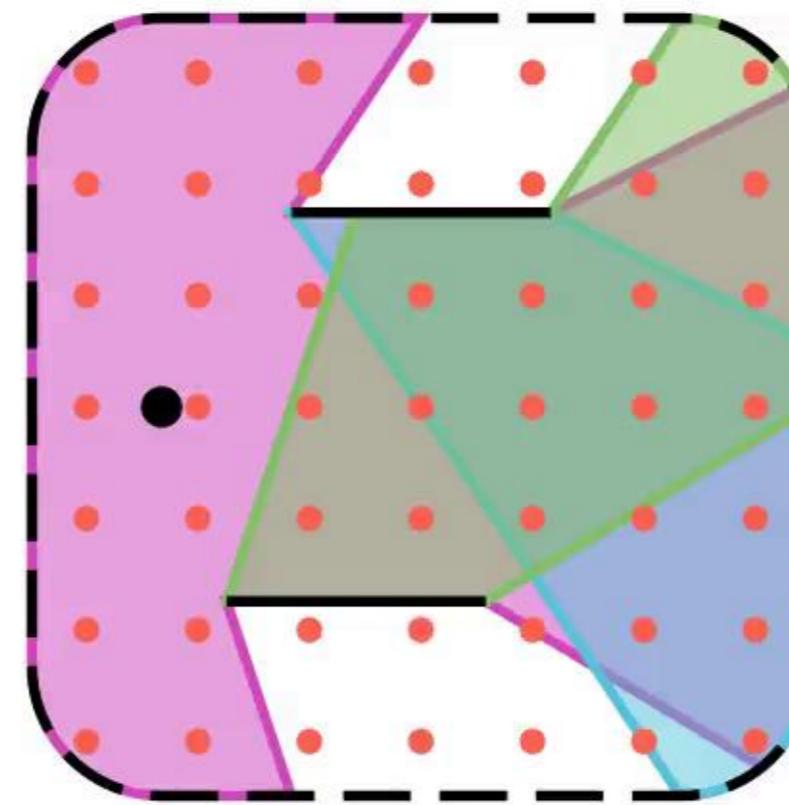
$$d_i(x) = \min_{y \notin C_i} \text{dist}(x, y), \quad (1)$$

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



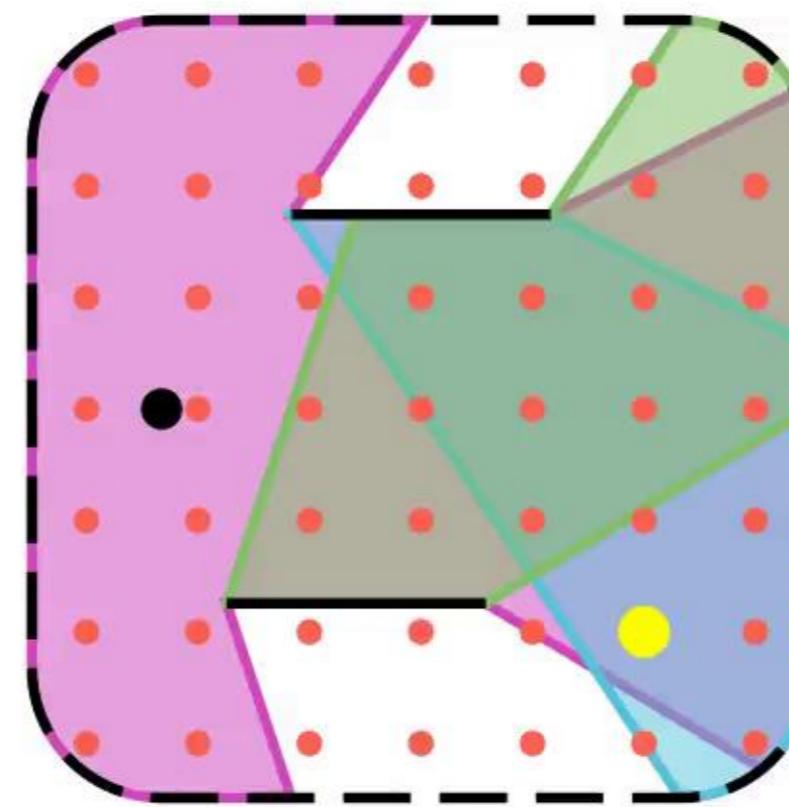
Line-of-sight + Reflection from W_1 + Reflection from W_2

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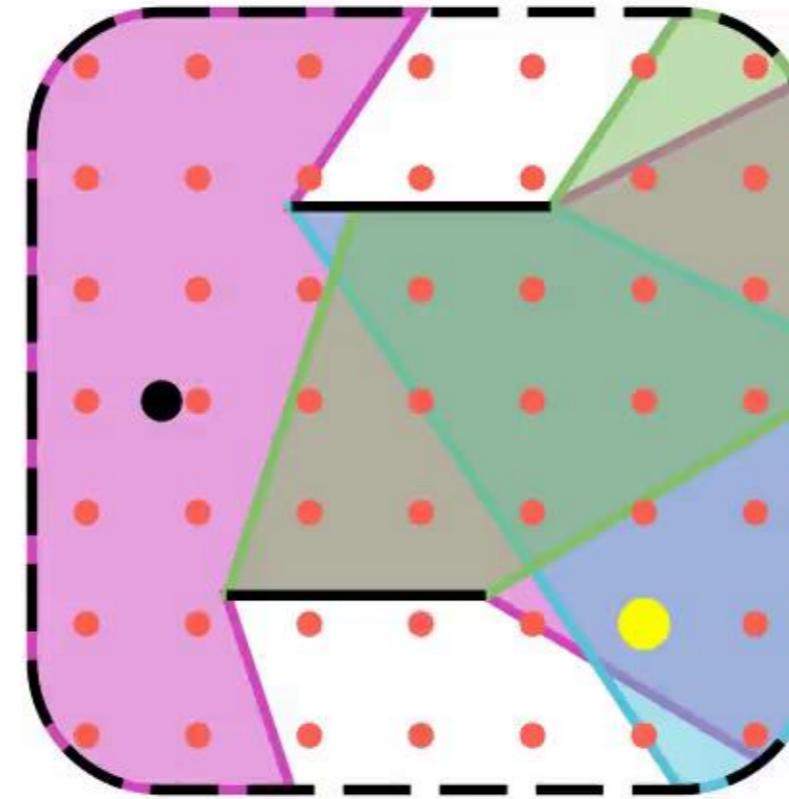
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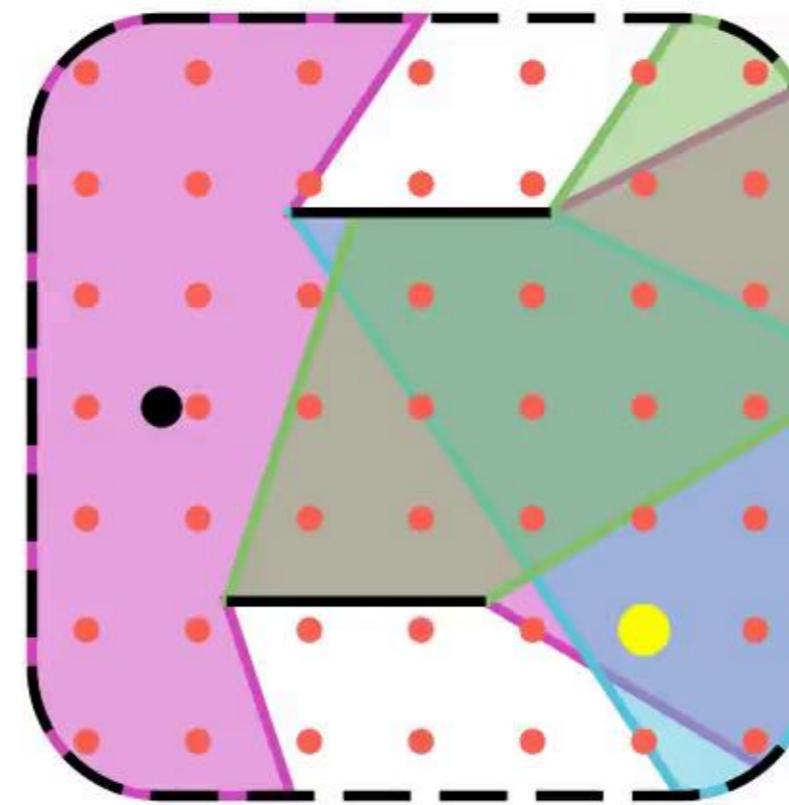
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1

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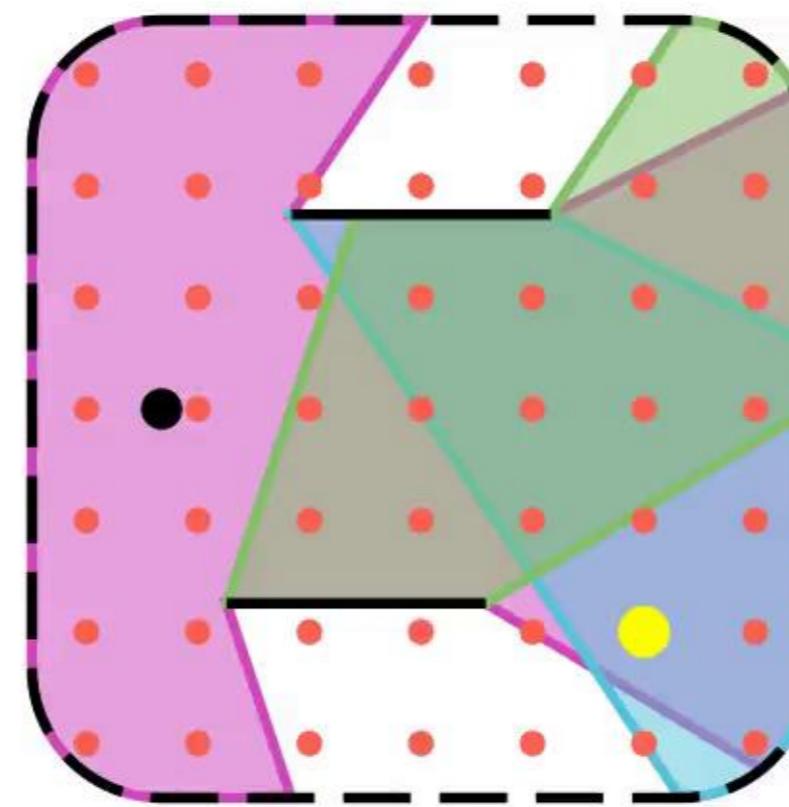


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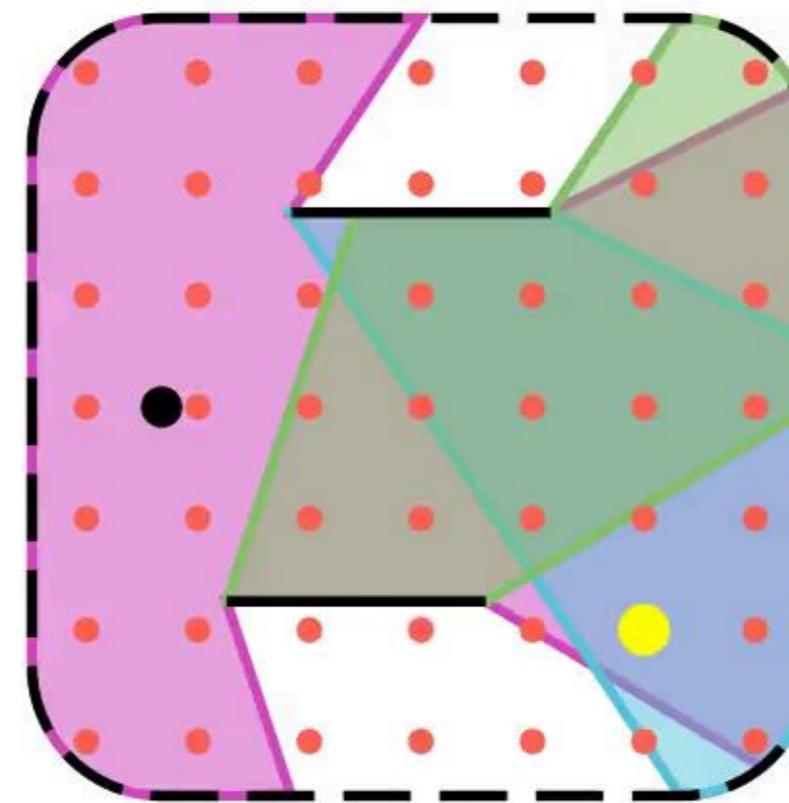
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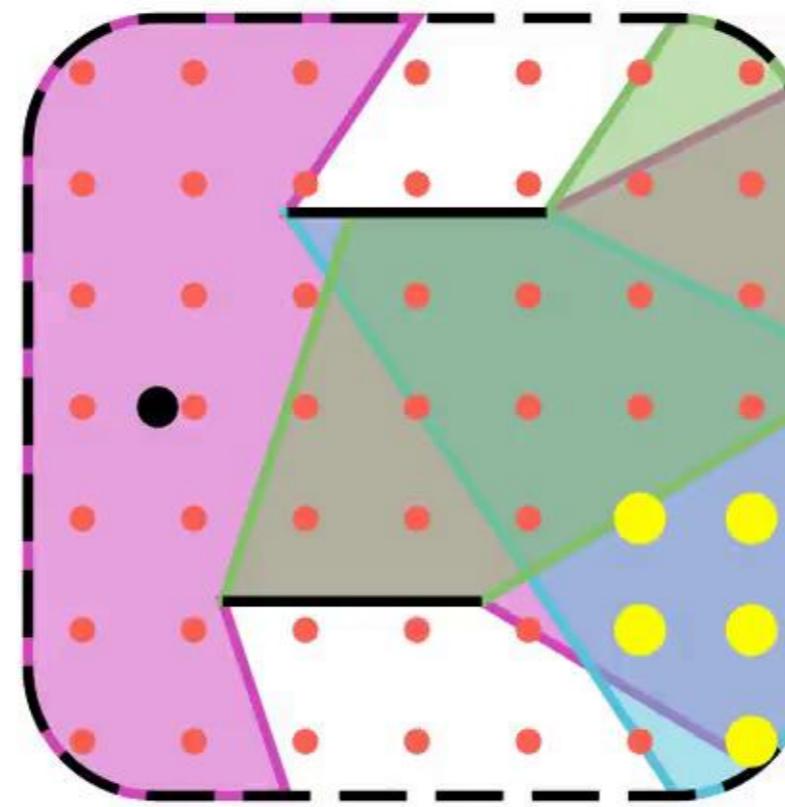
1

1

0

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S_i



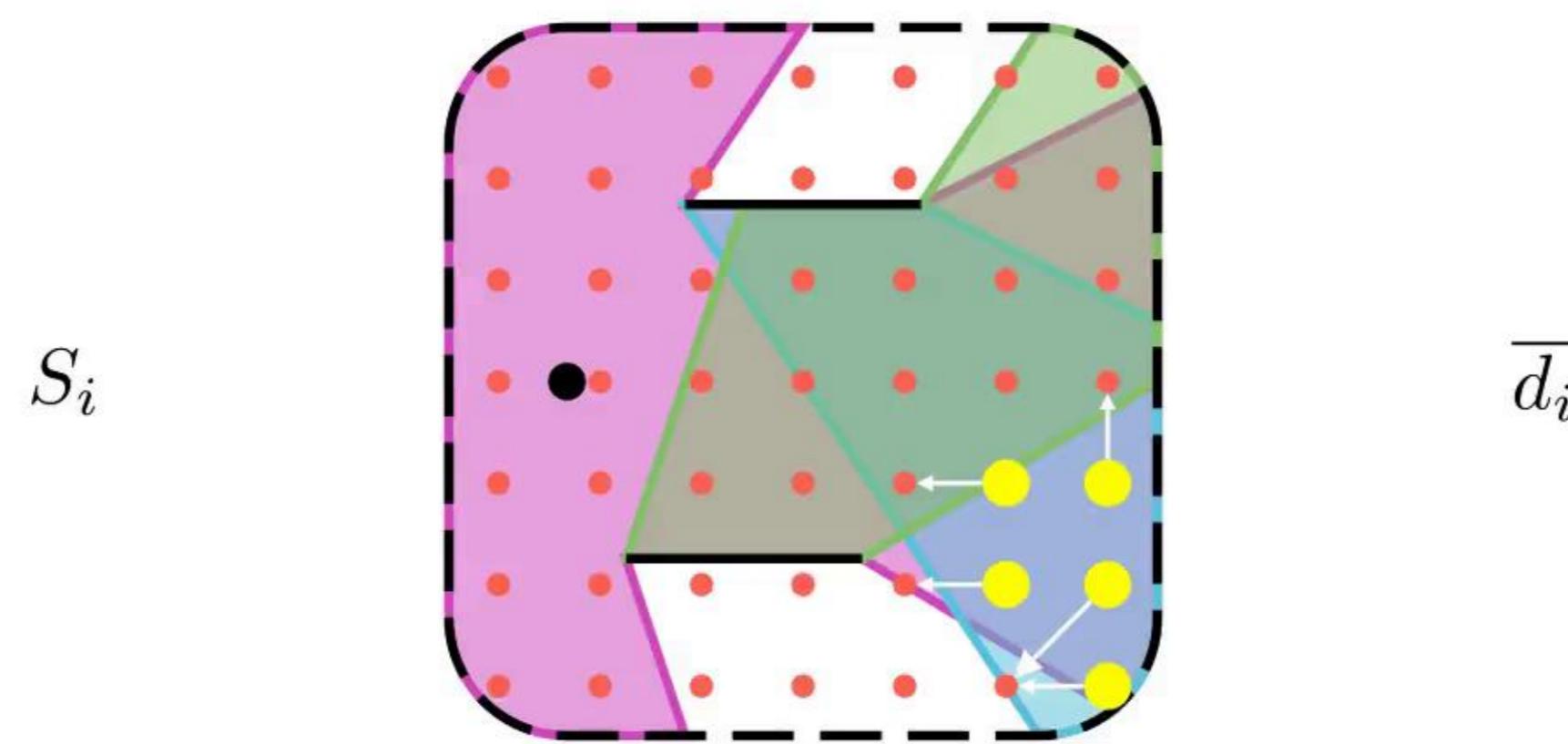
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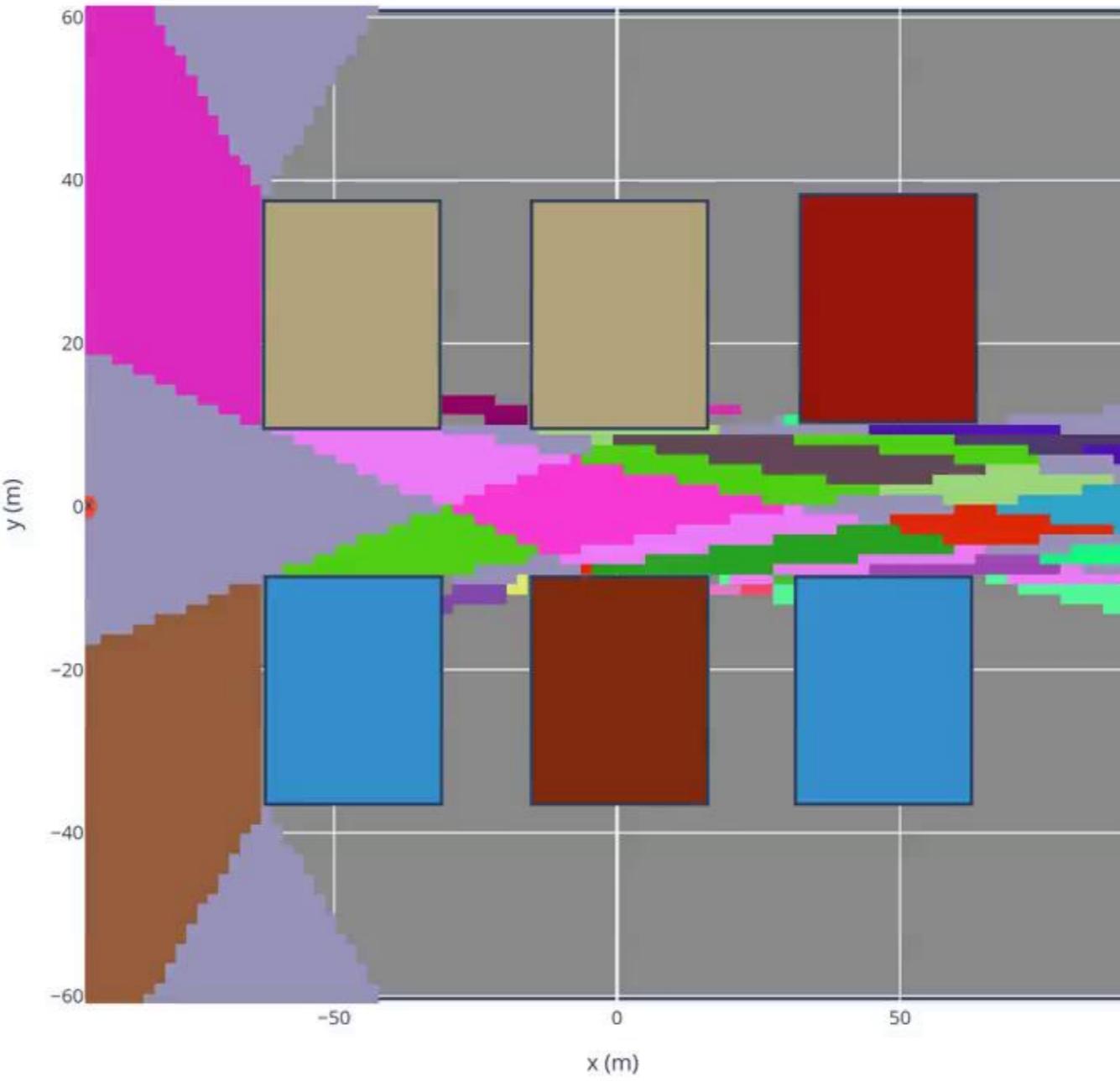
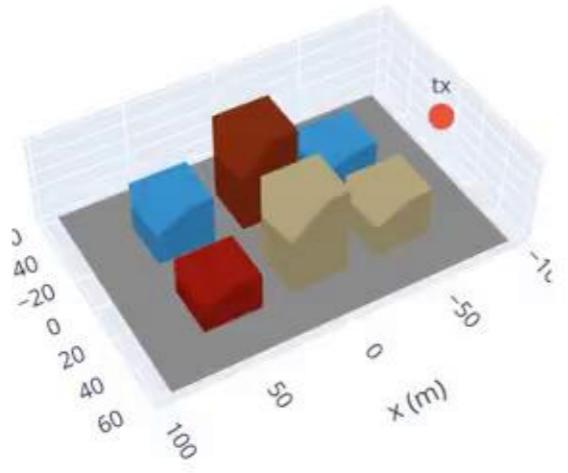
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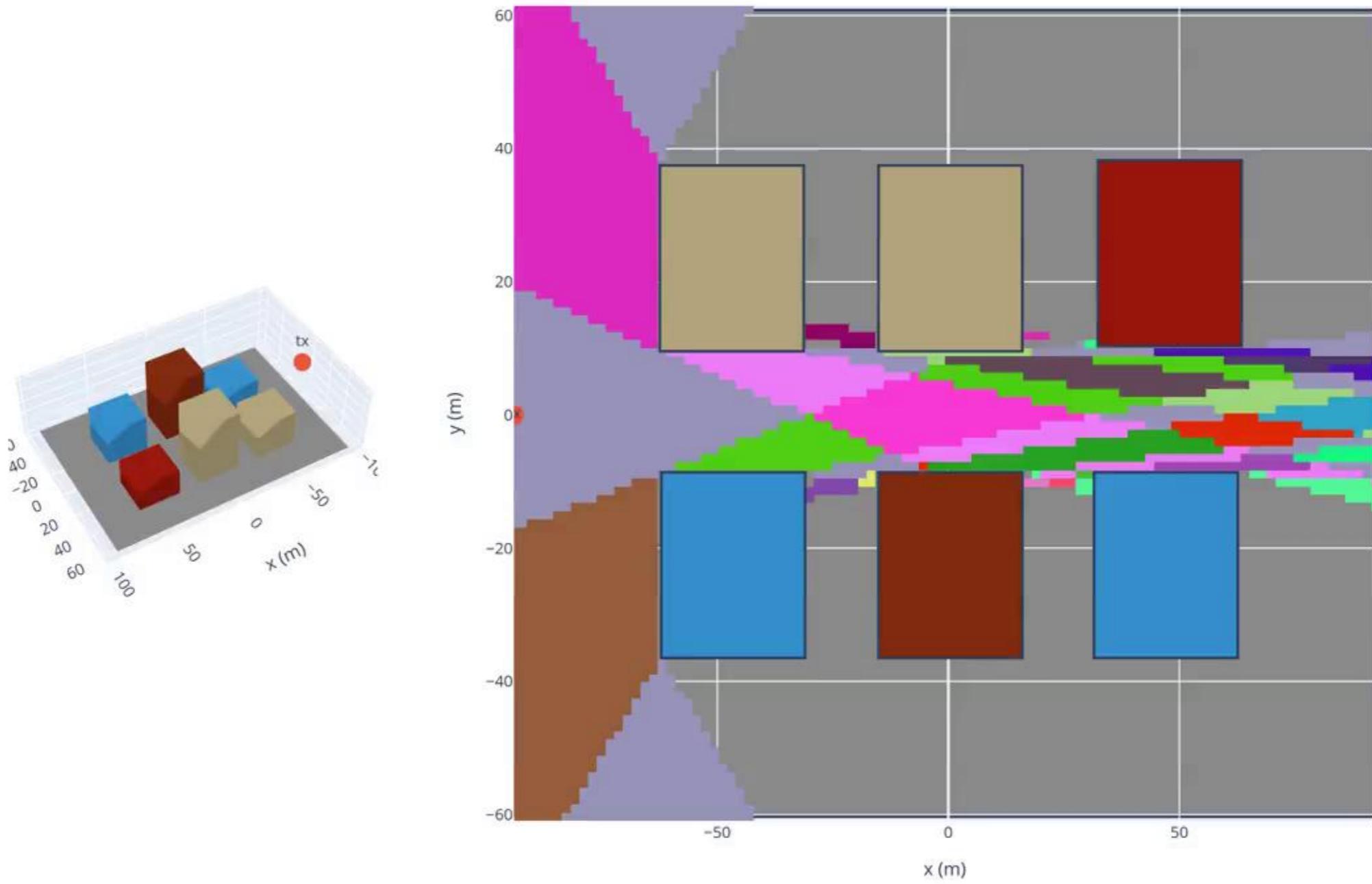
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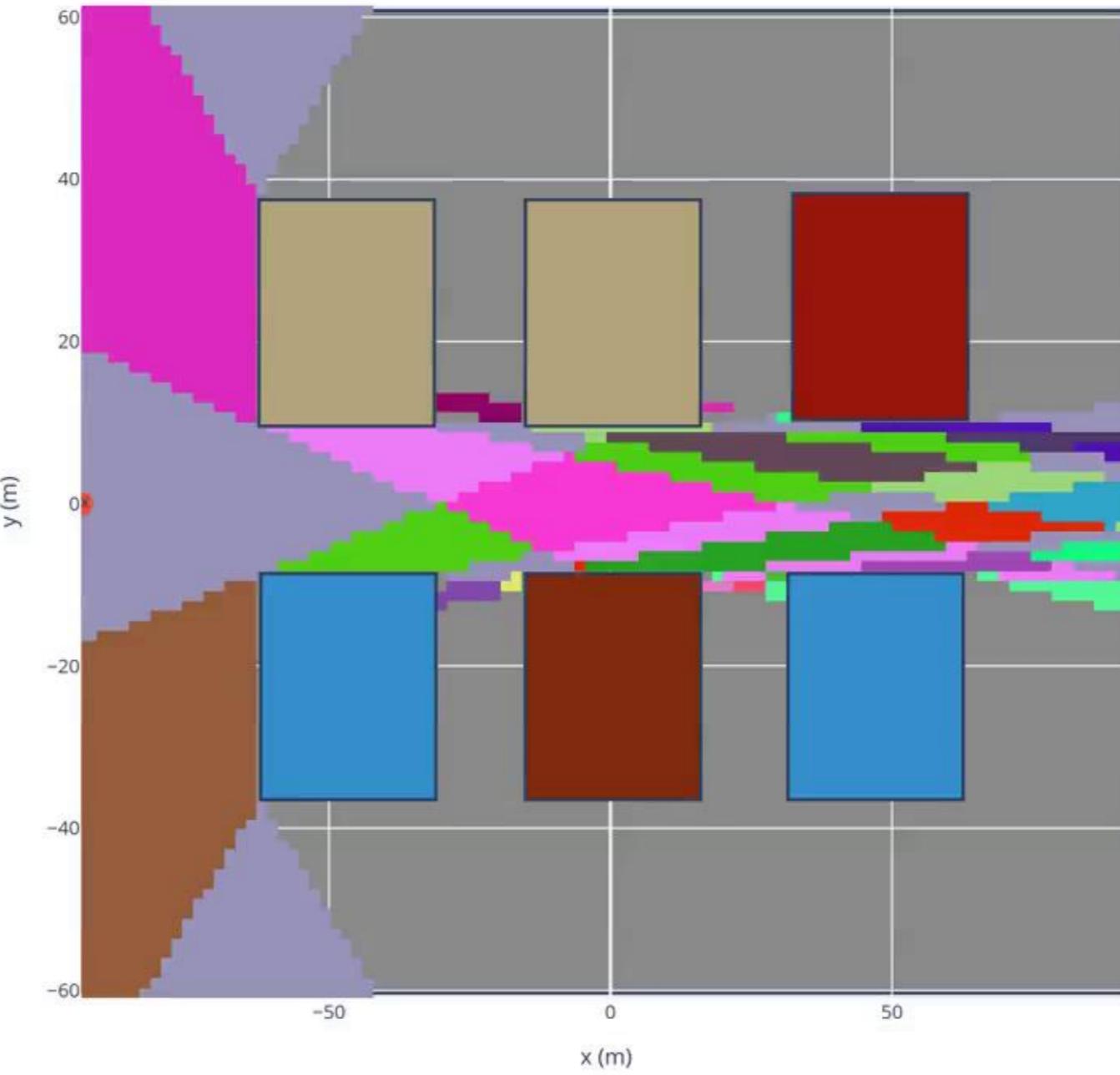
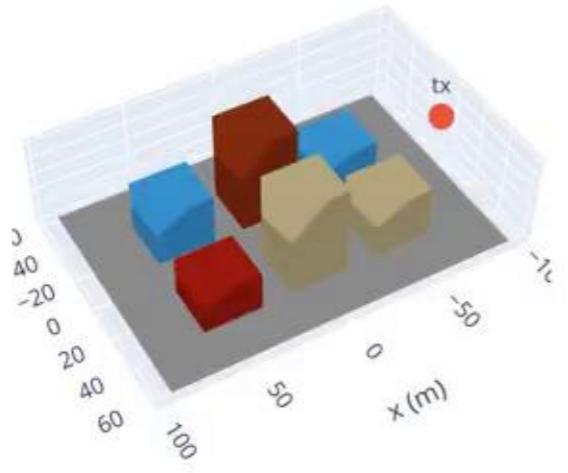
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Take away messages:

- Dyn. and Diff. RT are different techniques leveraging derivatives
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 - Diff. RT targets optimization (e.g., ML) problems
- Visualizing MLMs highlights the complexity of multipath clusters
- 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.

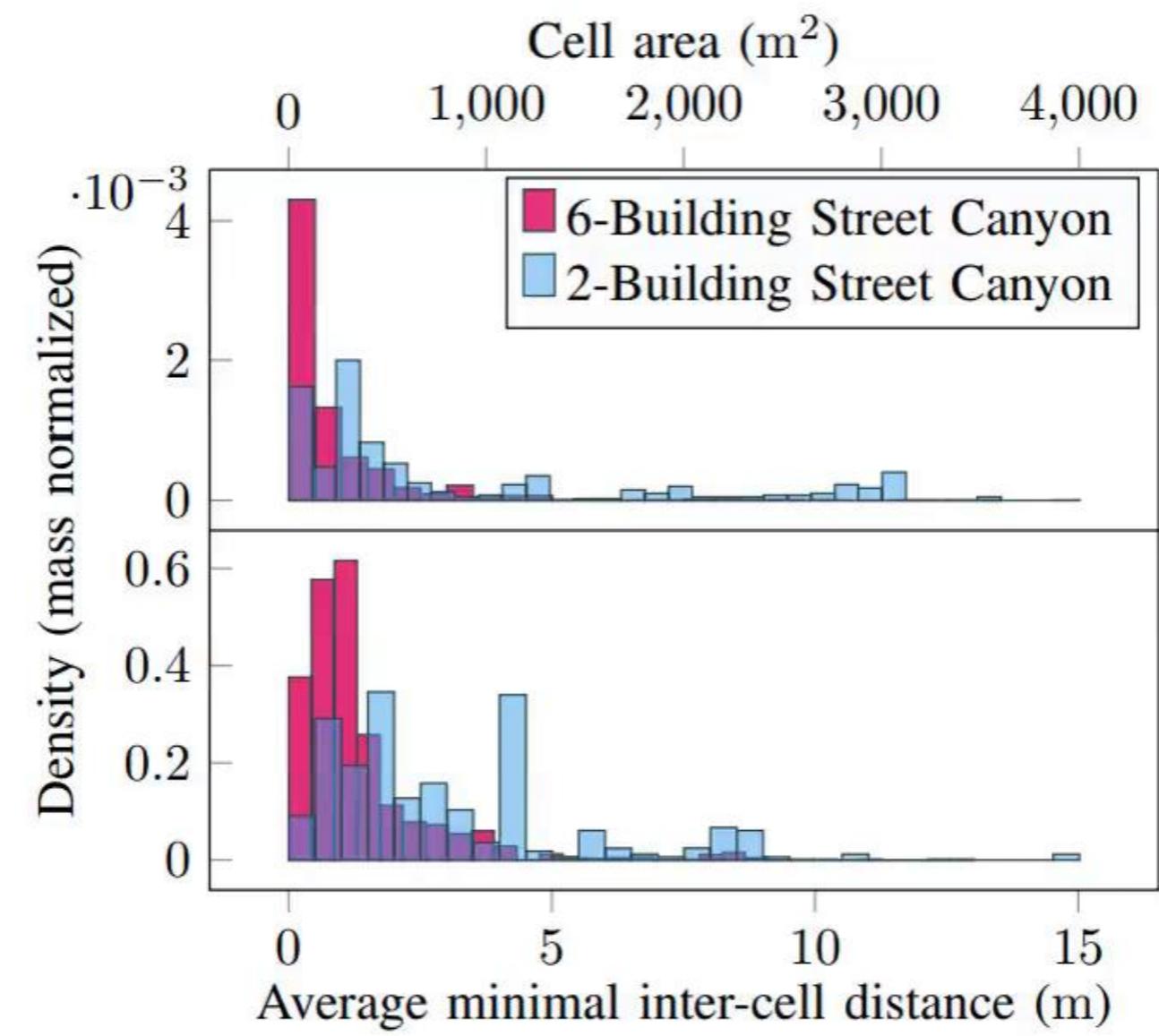


TABLE I
 MEAN AND MEDIAN VALUES OVER ALL 50 SIMULATION SNAPSHOTS AND
 CELLS.

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