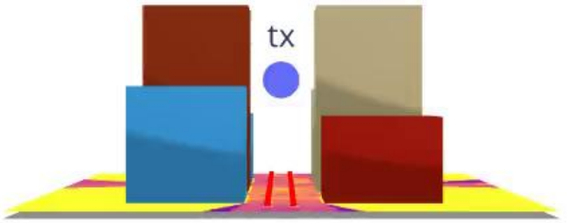
UCLouvain

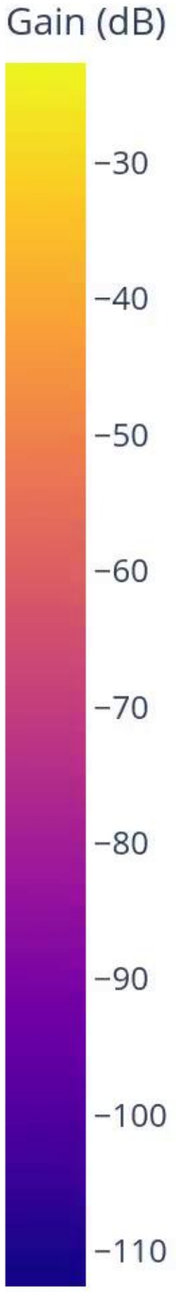
# Comparing Differentiable and Dynamic Ray Tracing: Introducing the Multipath Lifetime Map

Jérome Eertmans - April 1st, EuCAP 2025, Stockholm

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

# Context




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

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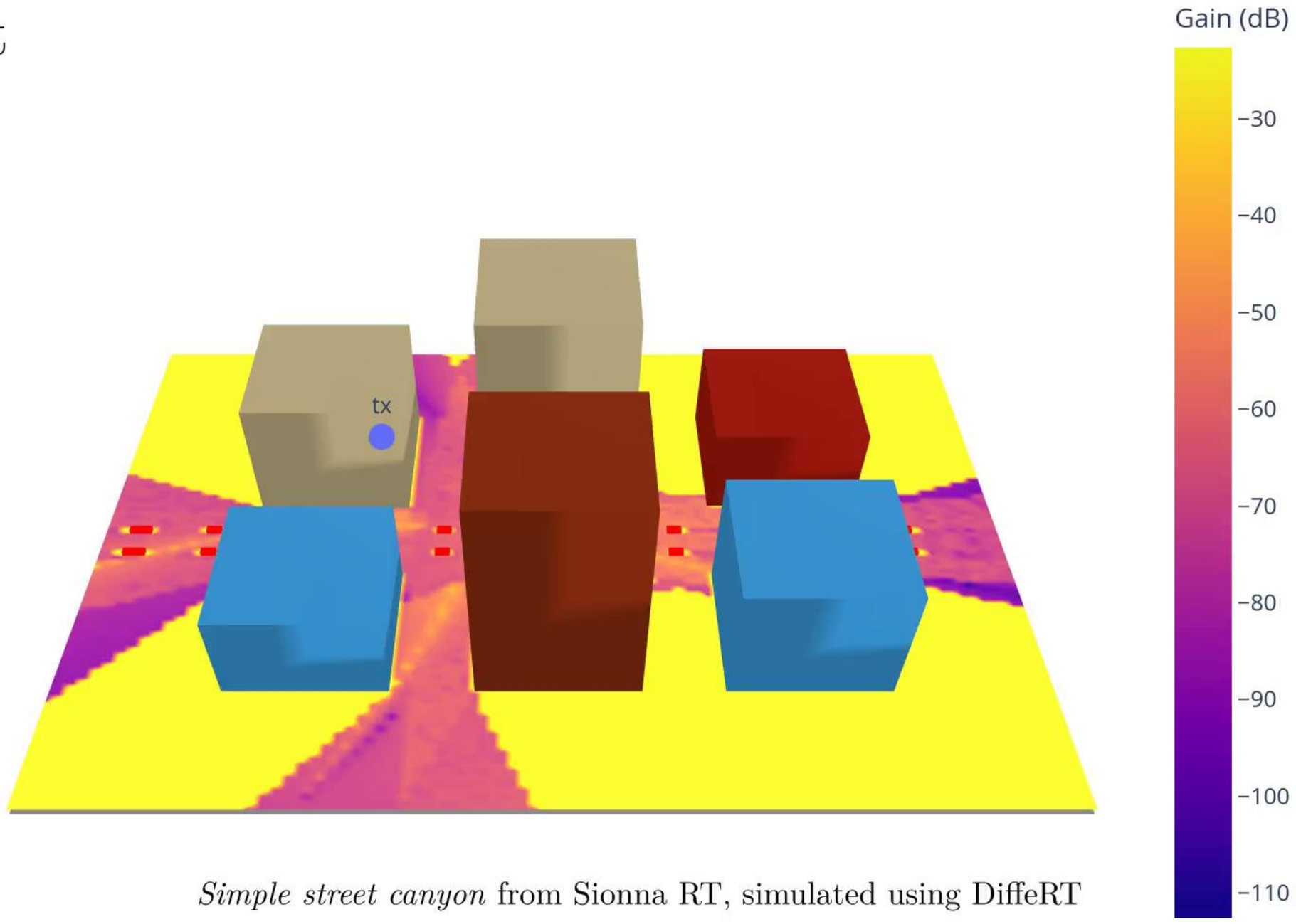


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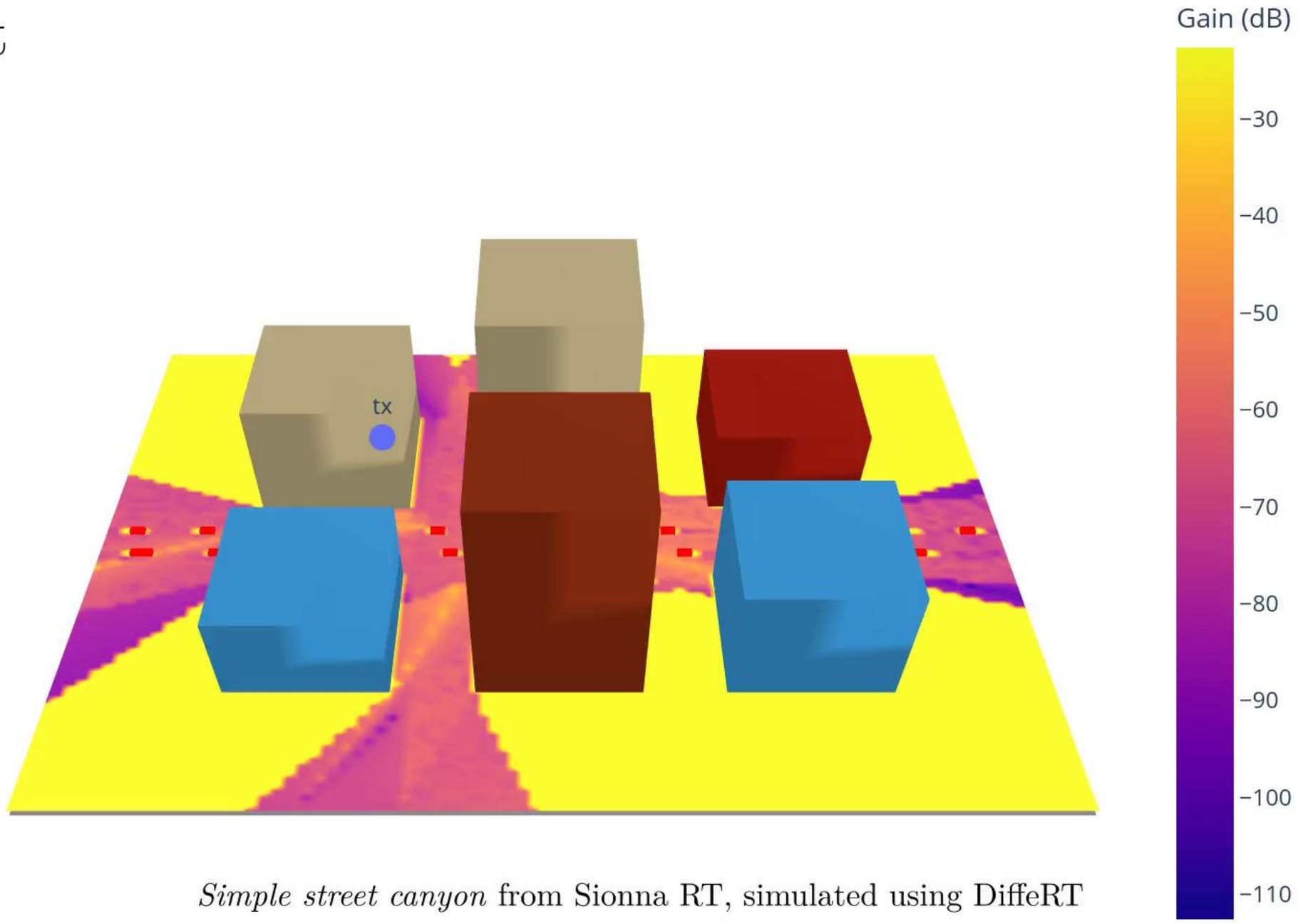


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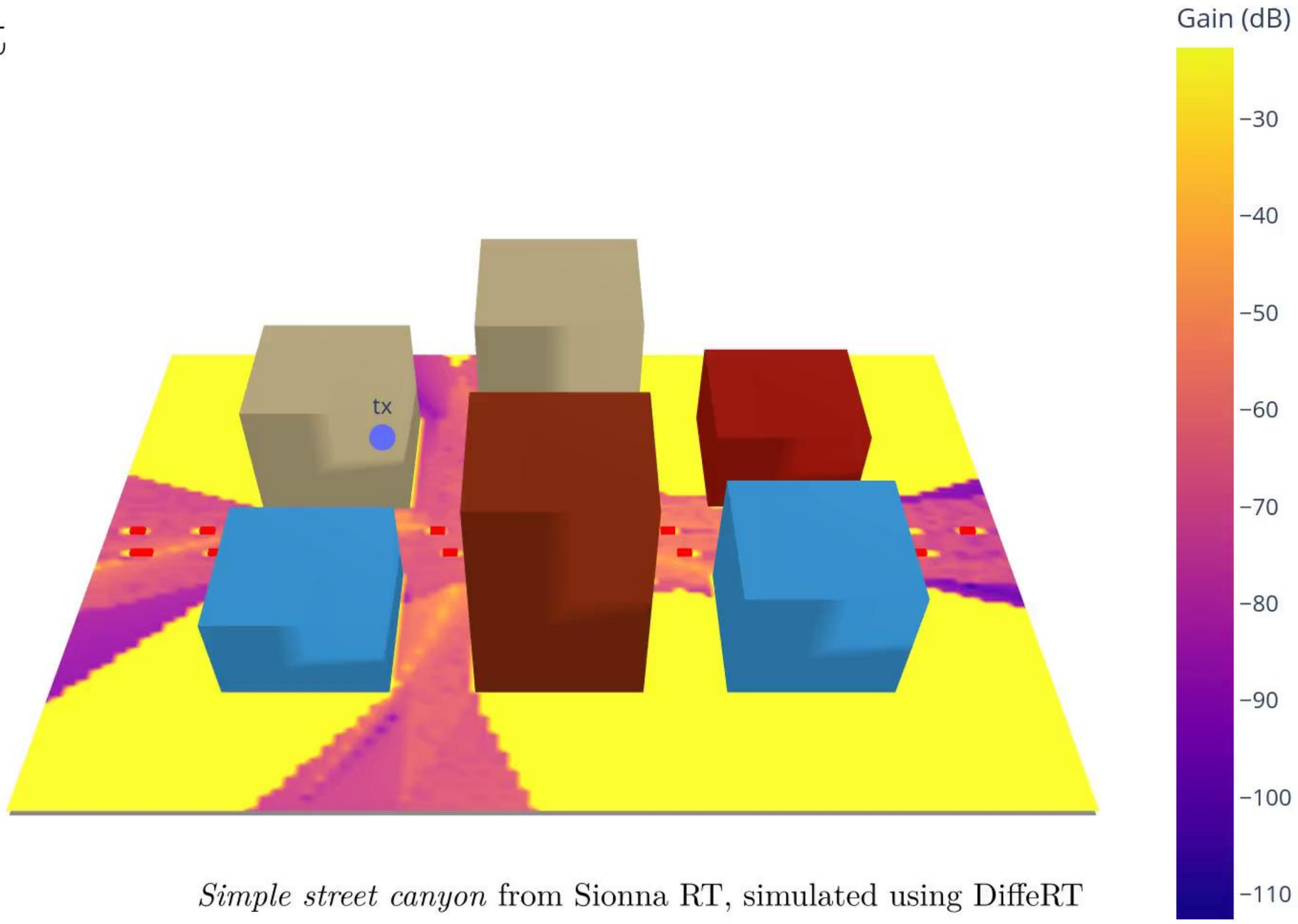


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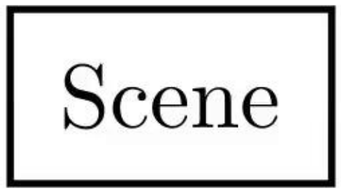
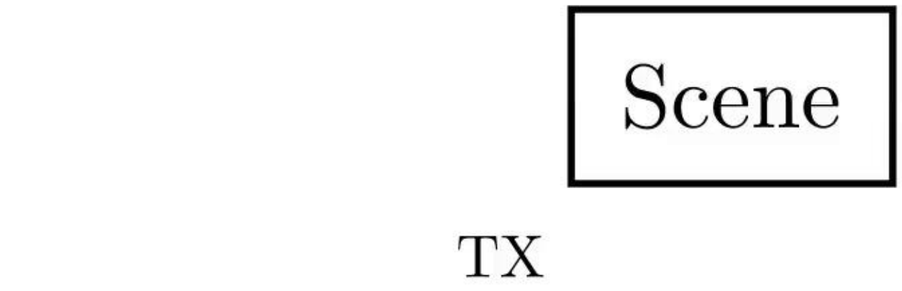
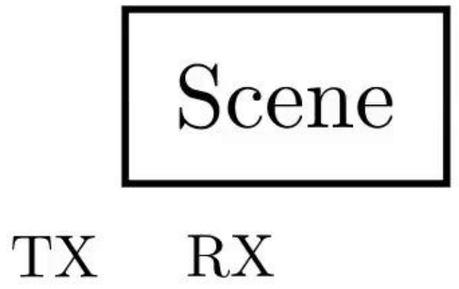
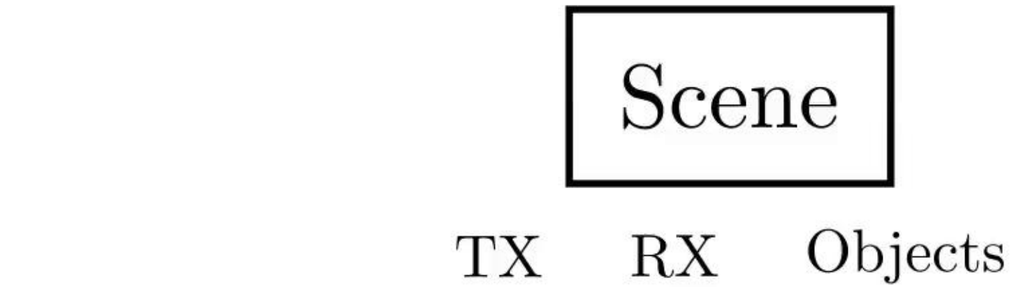
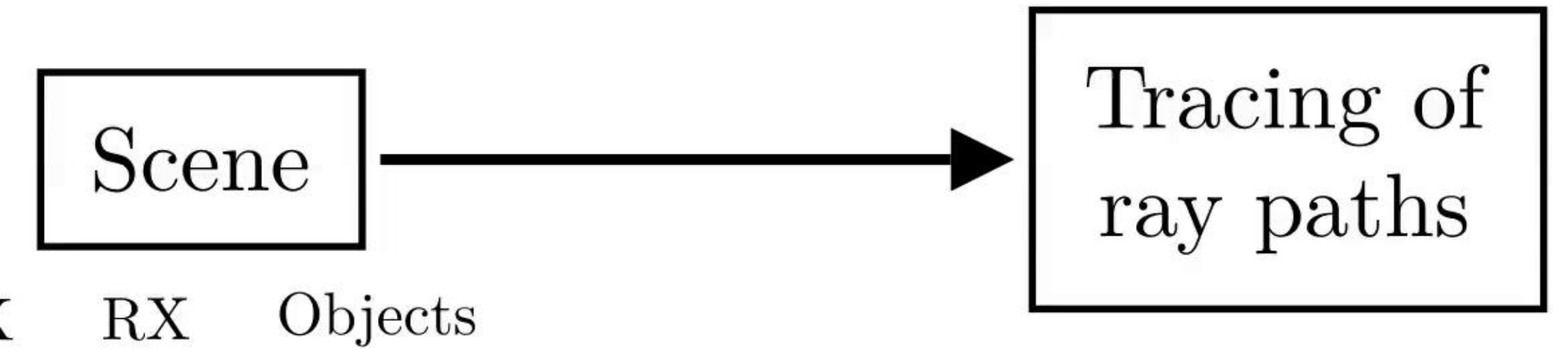
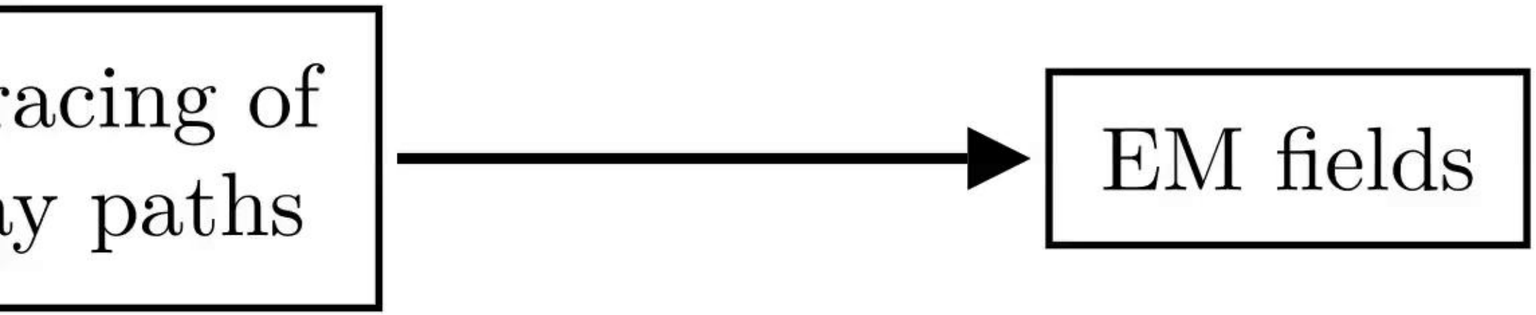

Scene


Scene
TX


Scene
TX
RX


Scene
TX
RX
Objects


Scene
Tracing of ray paths
X
RX
Objects


racing of
ay paths
EM fields

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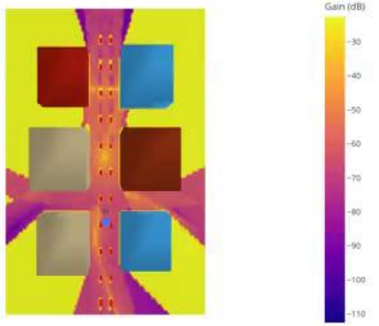

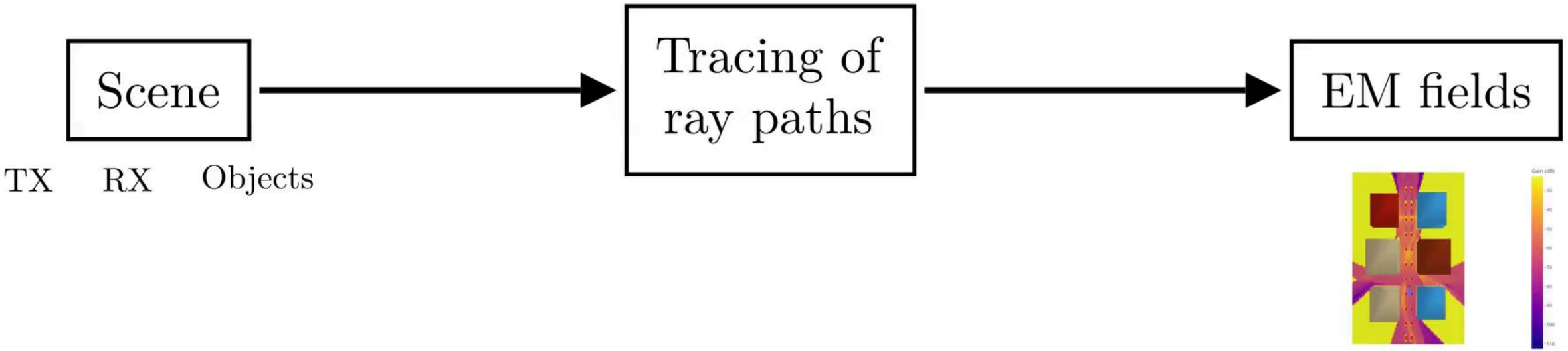
Scene
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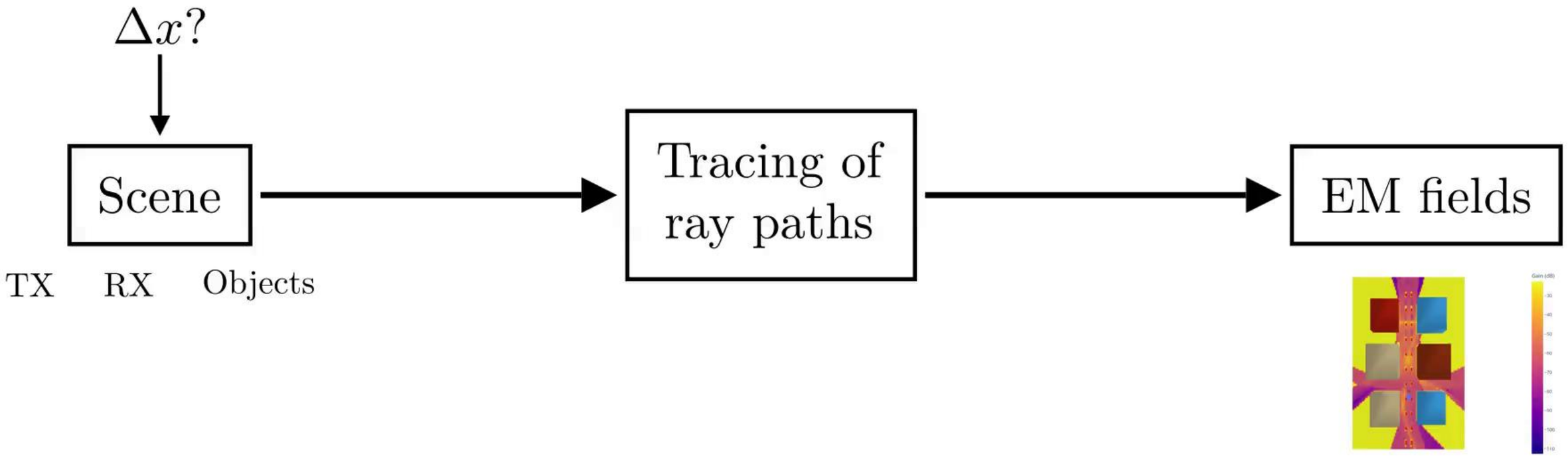
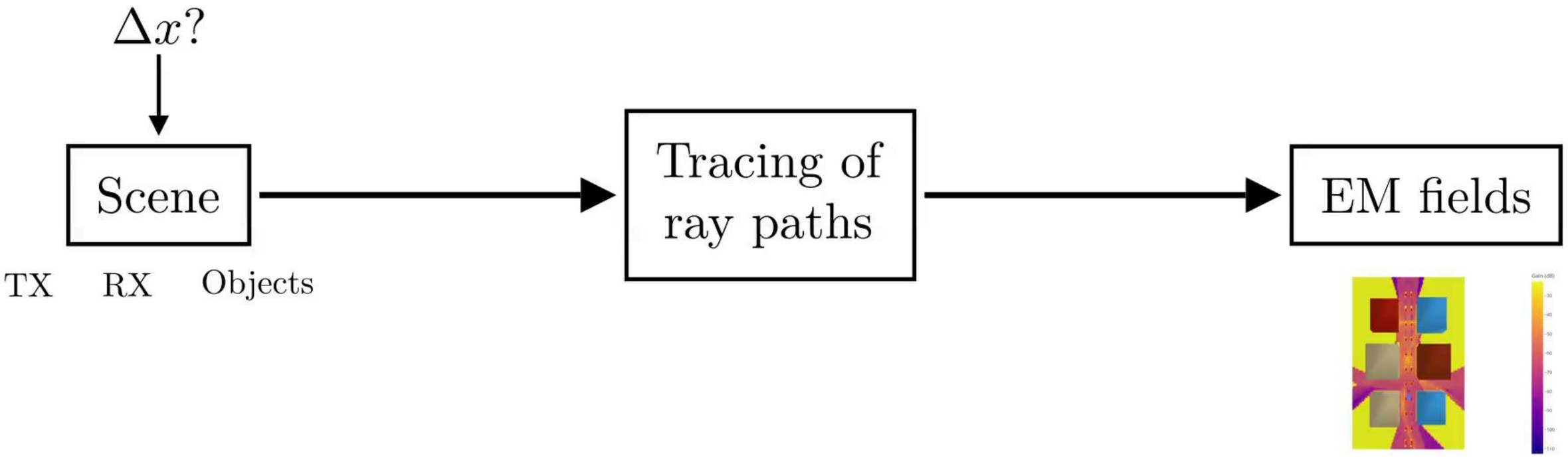
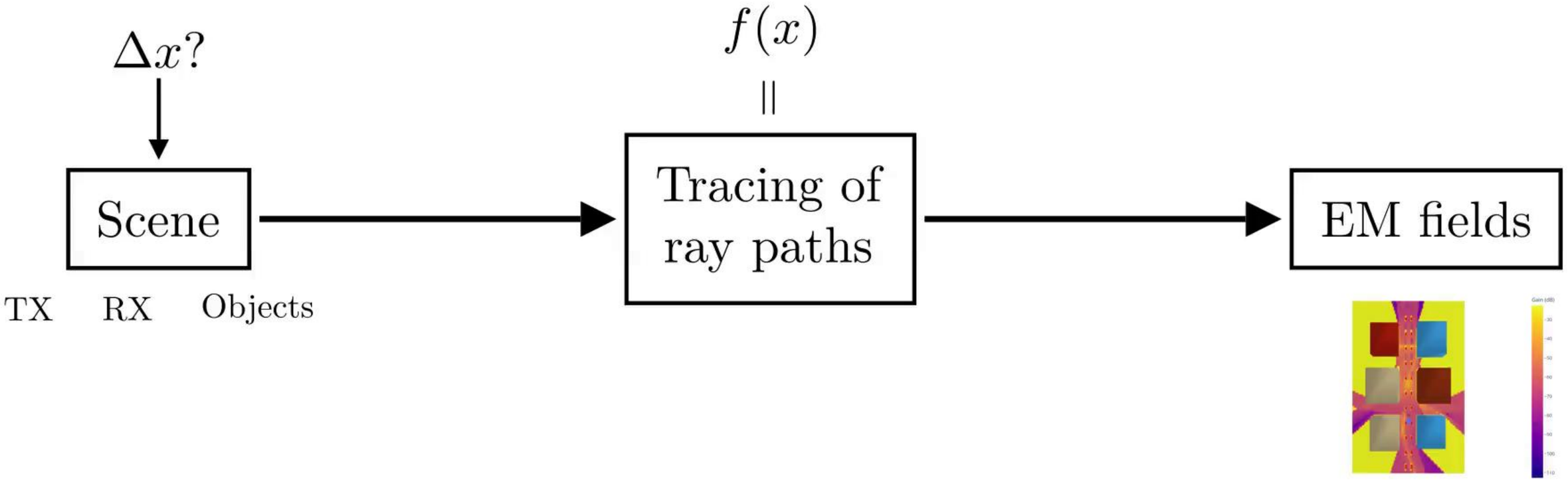

$\Delta x$?
Scene
TX
RX
Objects
Tracing of ray paths
EM fields




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

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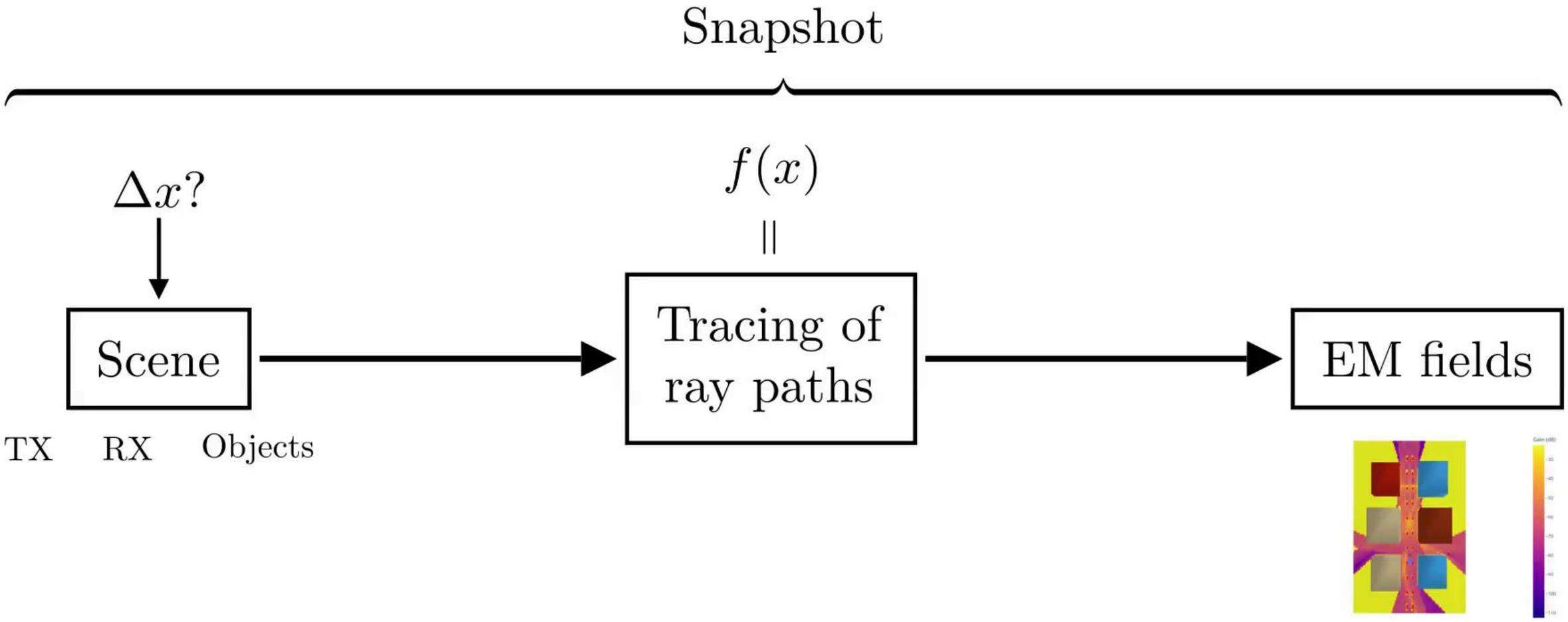


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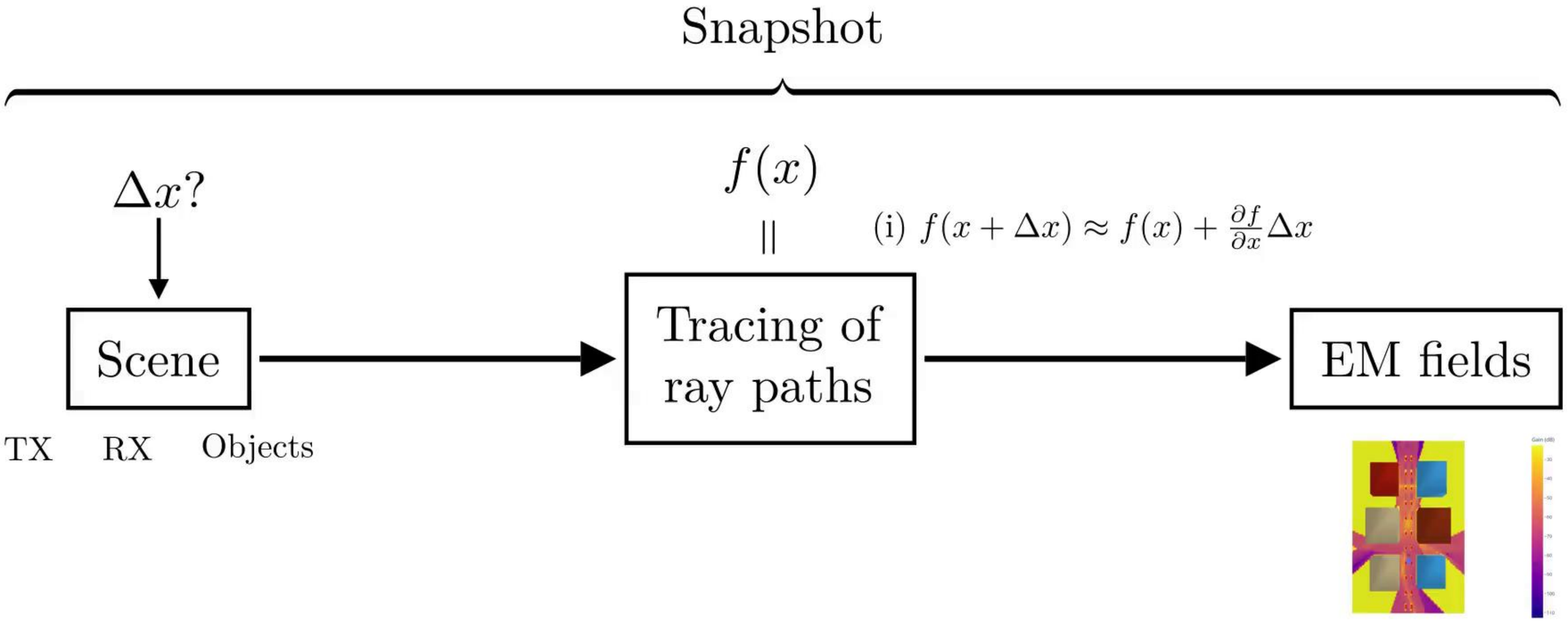


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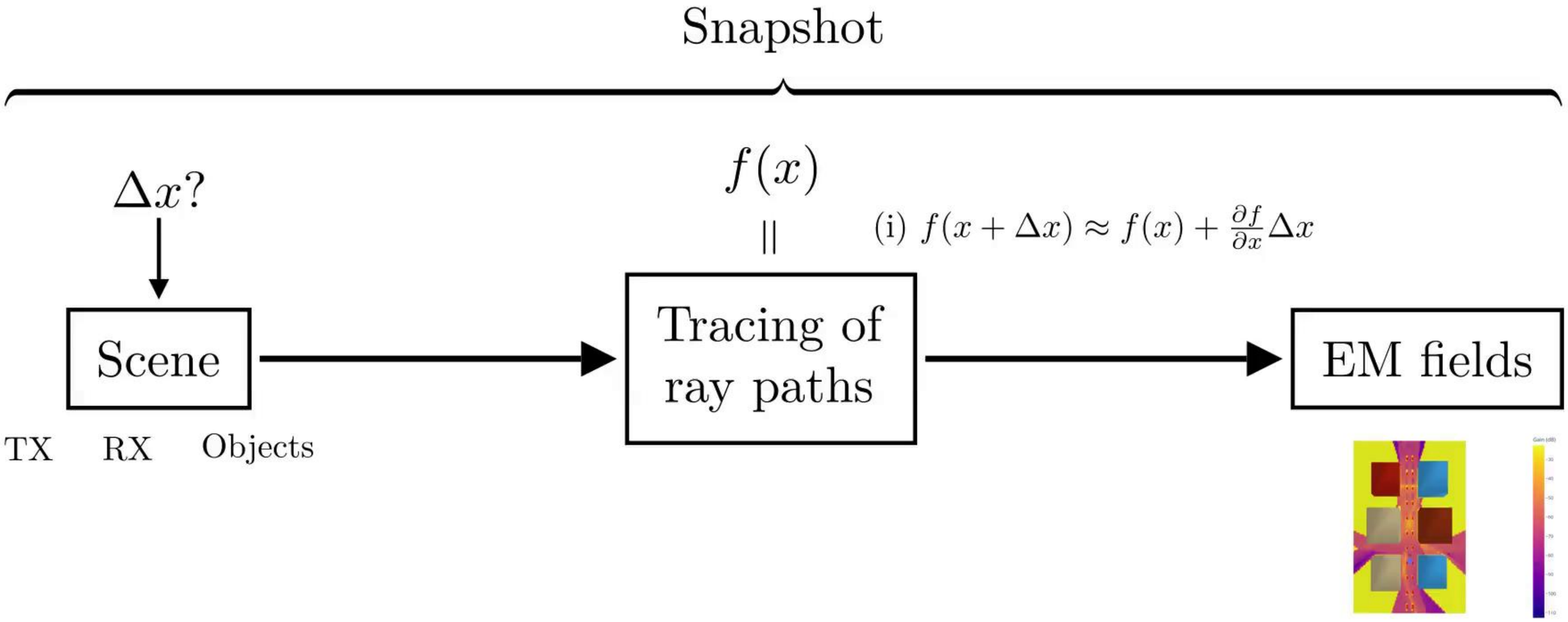



(i) Dynamic (Dyn.) RT: snapshots extrapolation using local derivatives

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

Snapshot

$\Delta x$?

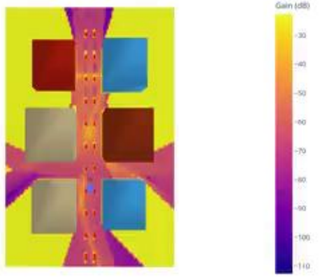
$f(x)$

||

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

Scene → Tracing of ray paths → EM fields

TX RX Objects



||

$g(x)$

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

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

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$\Delta x$?

$f(x)$

||

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

Scene

Tracing of ray paths

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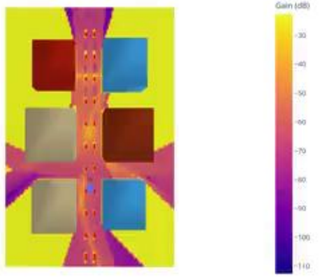
TX RX Objects

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



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$g(x)$

**Current limitations:**

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

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

⇒ Illustrate the limits of Dyn. RT

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**Contributions**

⇒ 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

**Contents:**

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- Methods comparison

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- Limits of extrapolation

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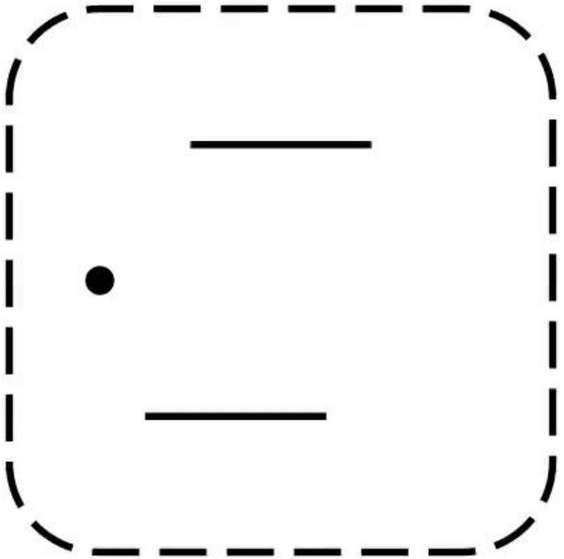
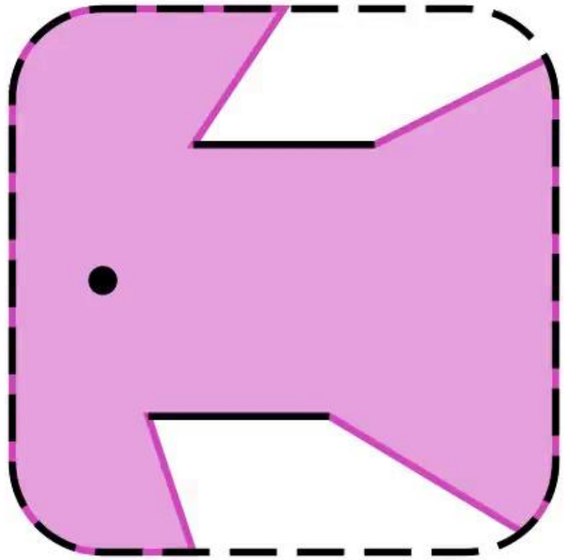
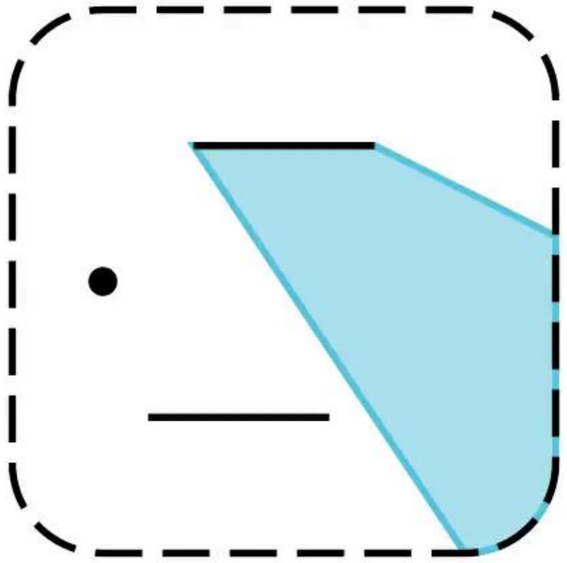
- Results of MLMs for a moving RX

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

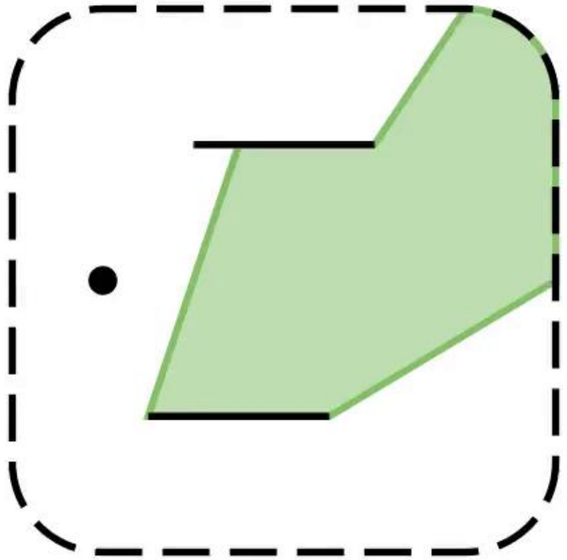




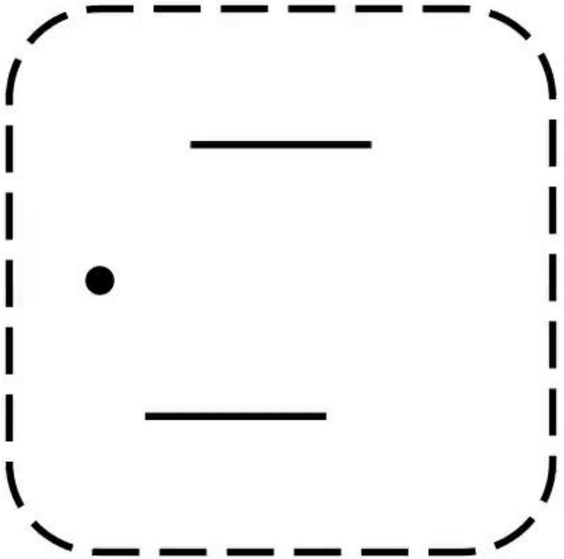
Line-of-sight

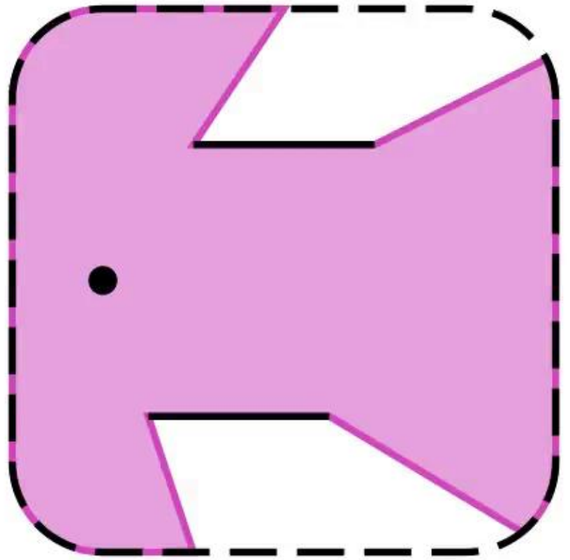


Reflection from $W_1$

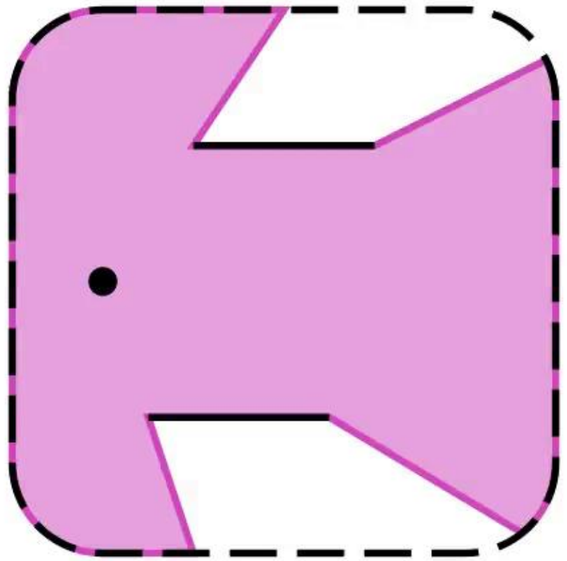


Reflection from $W_2$

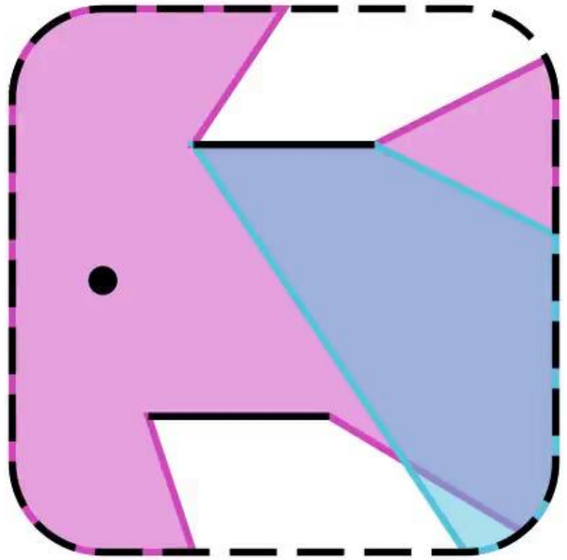




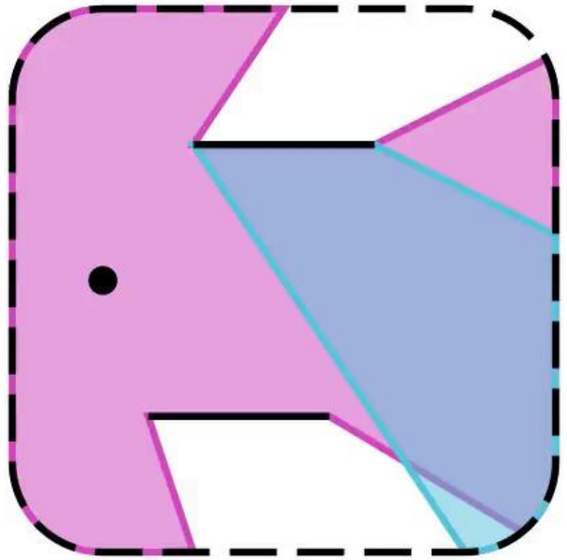
Line-of-sight



Line-of-sight+



Line-of-sight+Reflection from $W_1$



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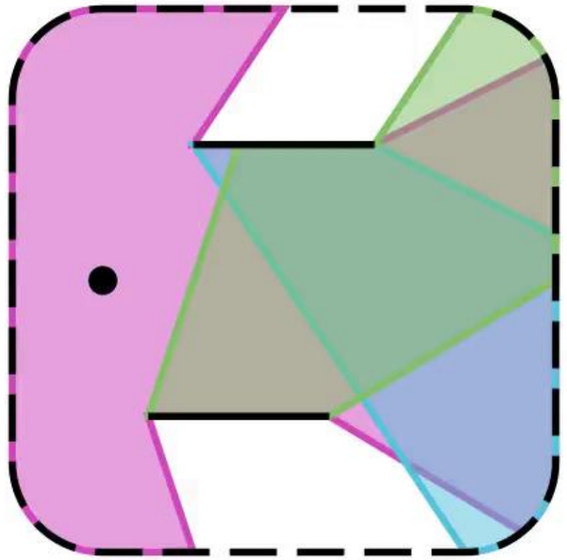
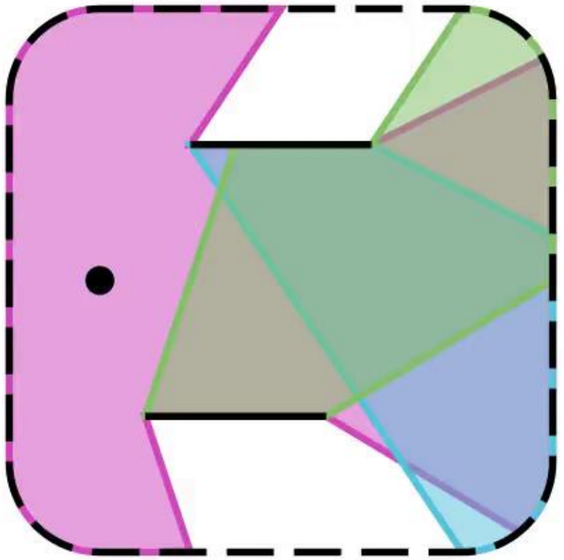
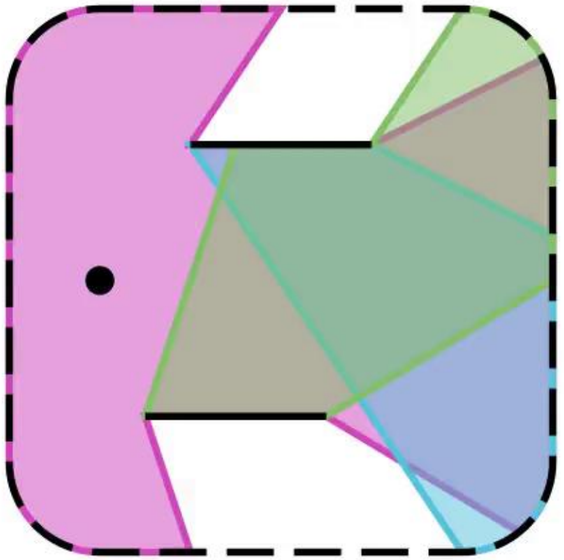


Line-of-sight+Reflection from $W_1$+Reflection from $W_2$



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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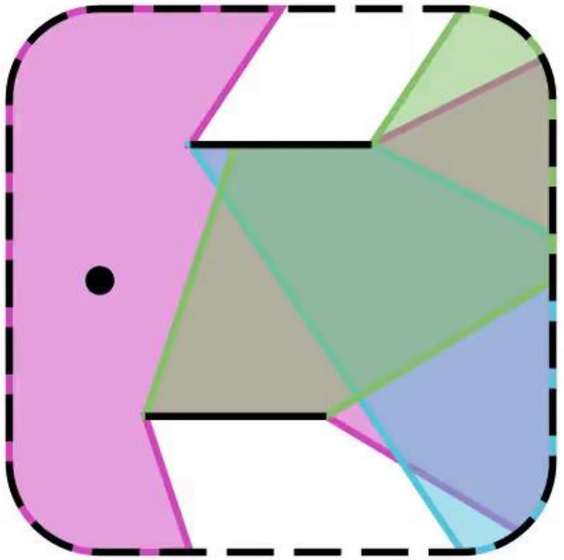


Line-of-sight+Reflection from $W_1$+Reflection from $W_2$

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

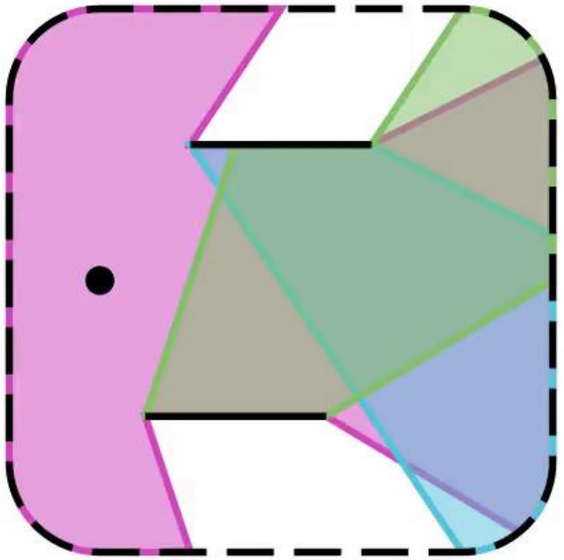
For each cell $C_i$, we compute:

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

where

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

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



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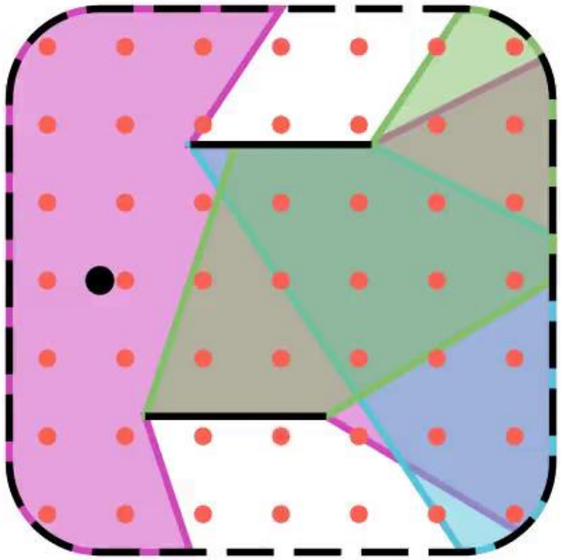

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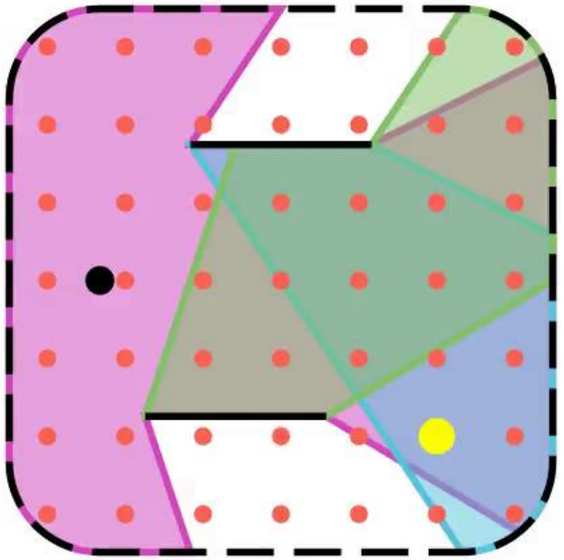

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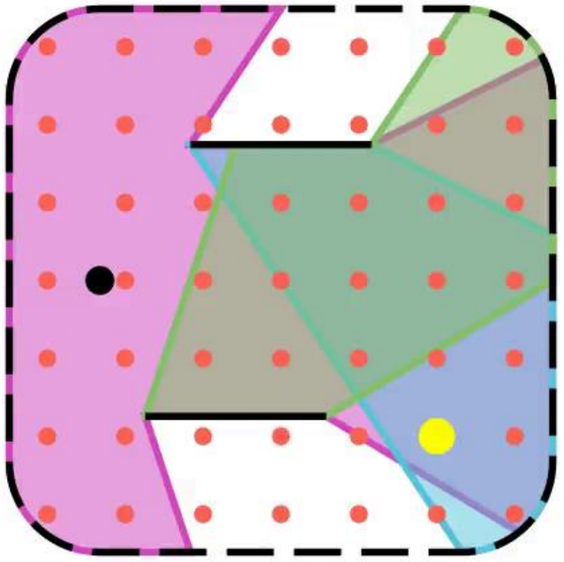

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1

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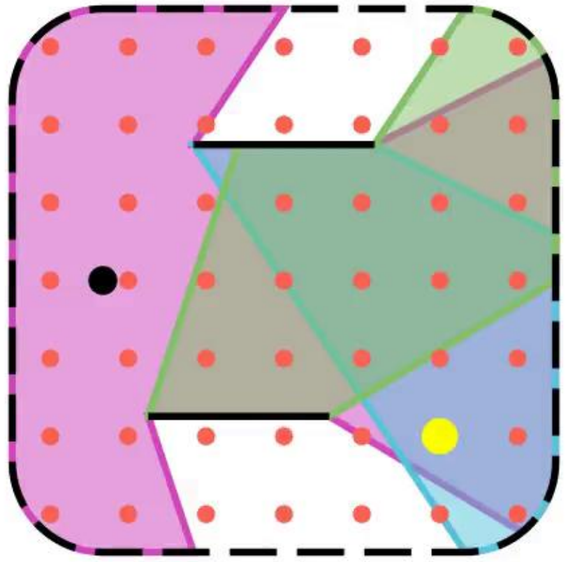

Line-of-sight+Reflection from $W_1$+Reflection from $W_2$

1 1

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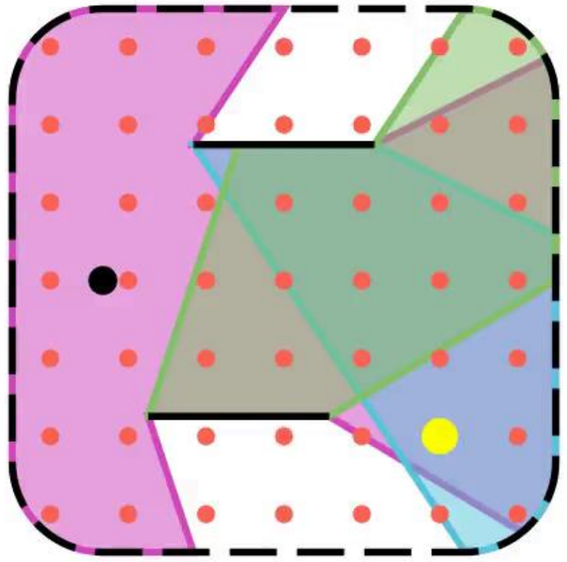

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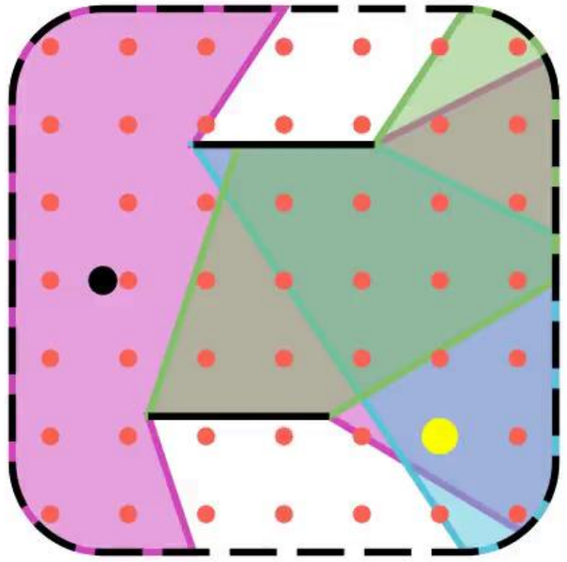

Line-of-sight+Reflection from $W_1$+Reflection from $W_2$

1 1 0

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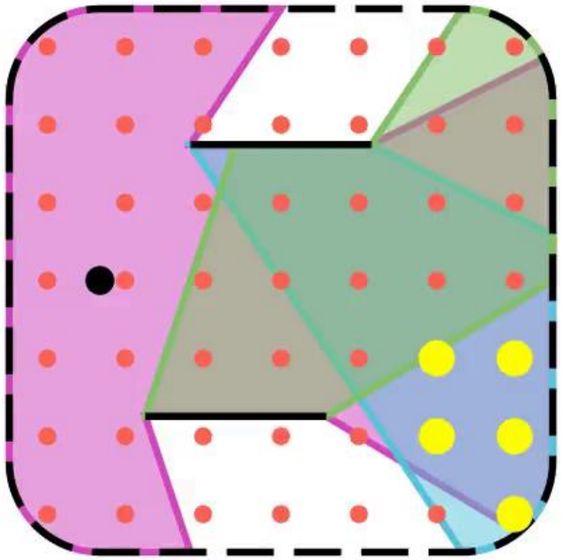
$S_i$



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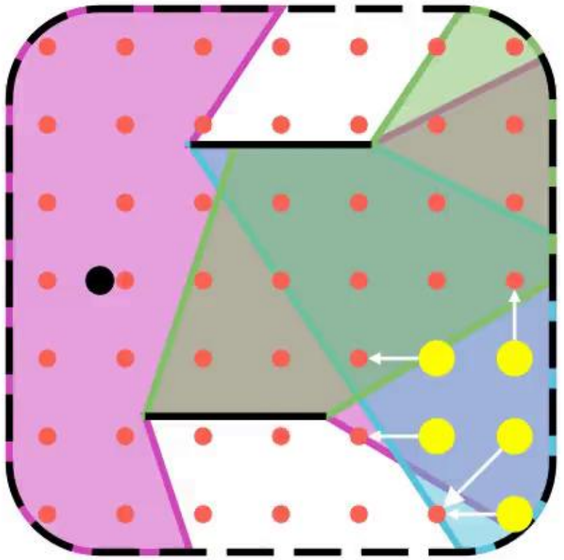

$\overline{d_i}$

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

1 1 0

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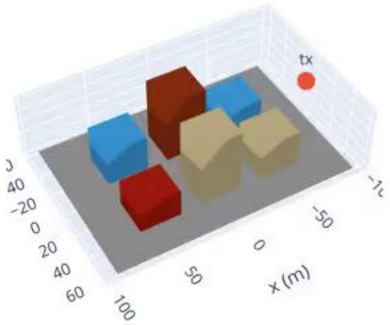
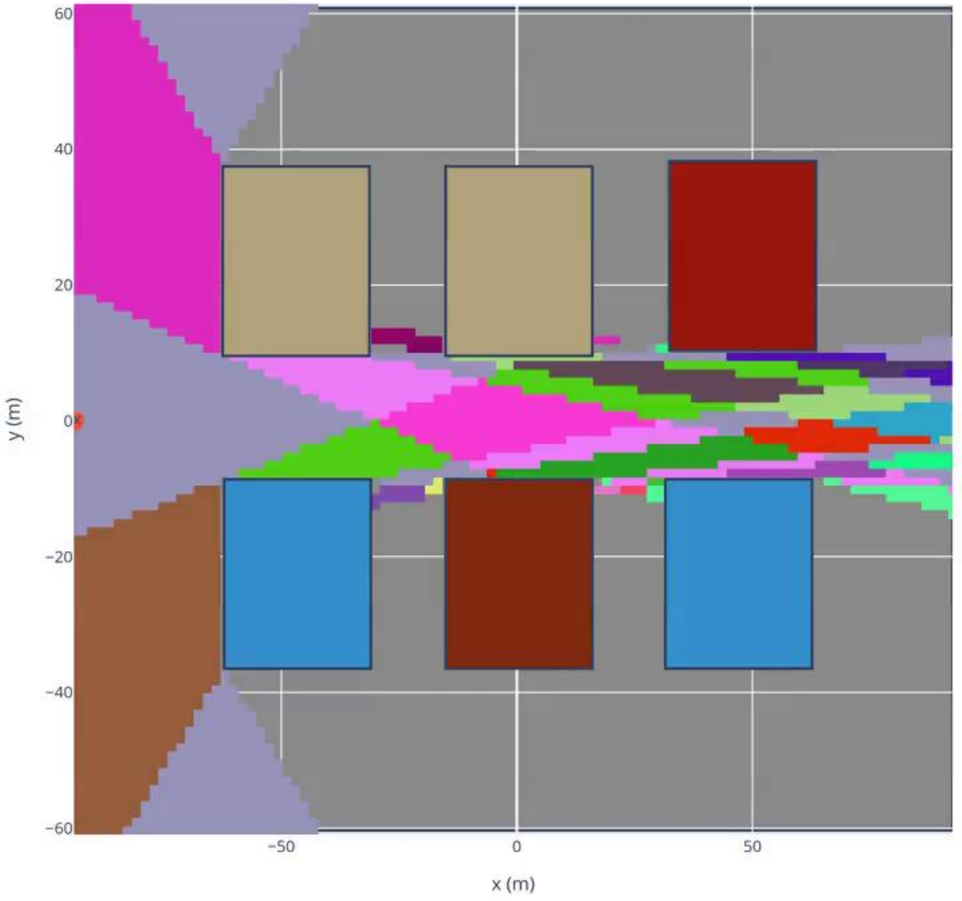
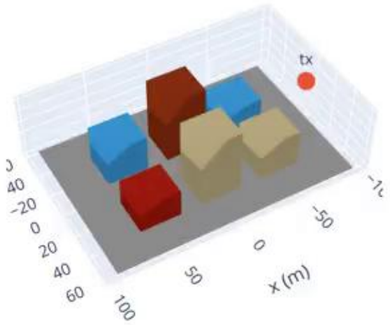
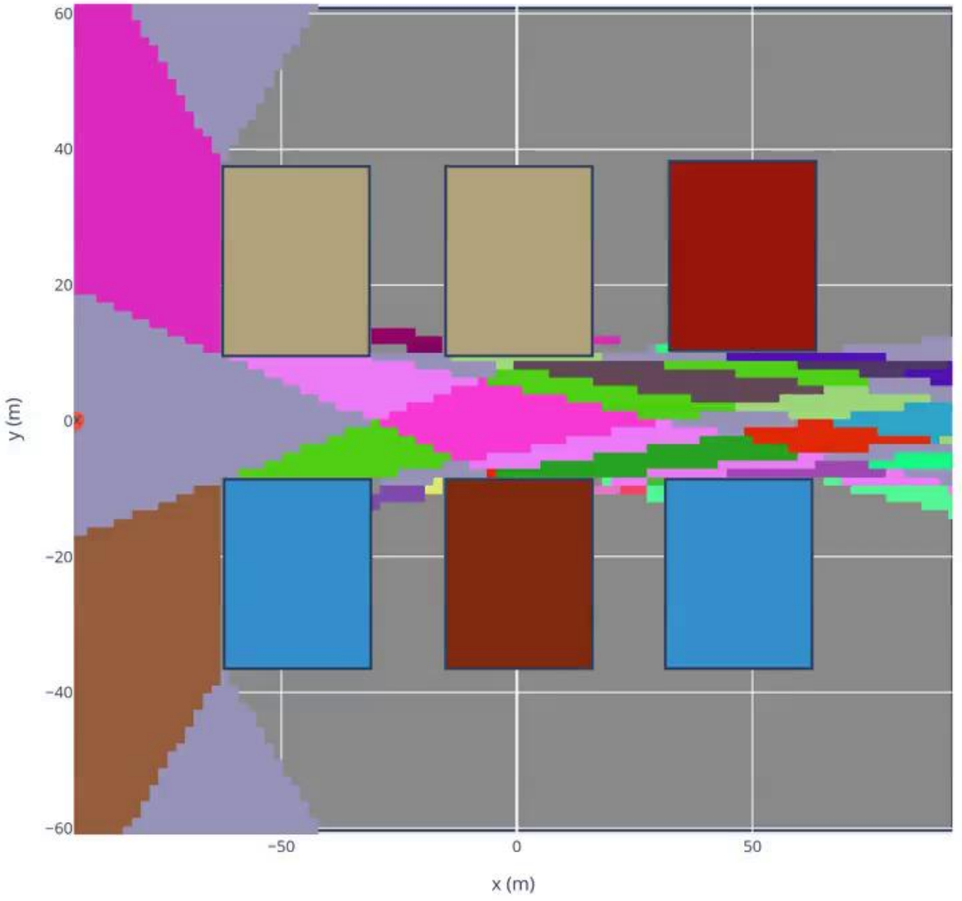
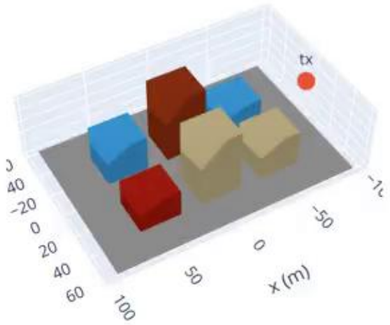
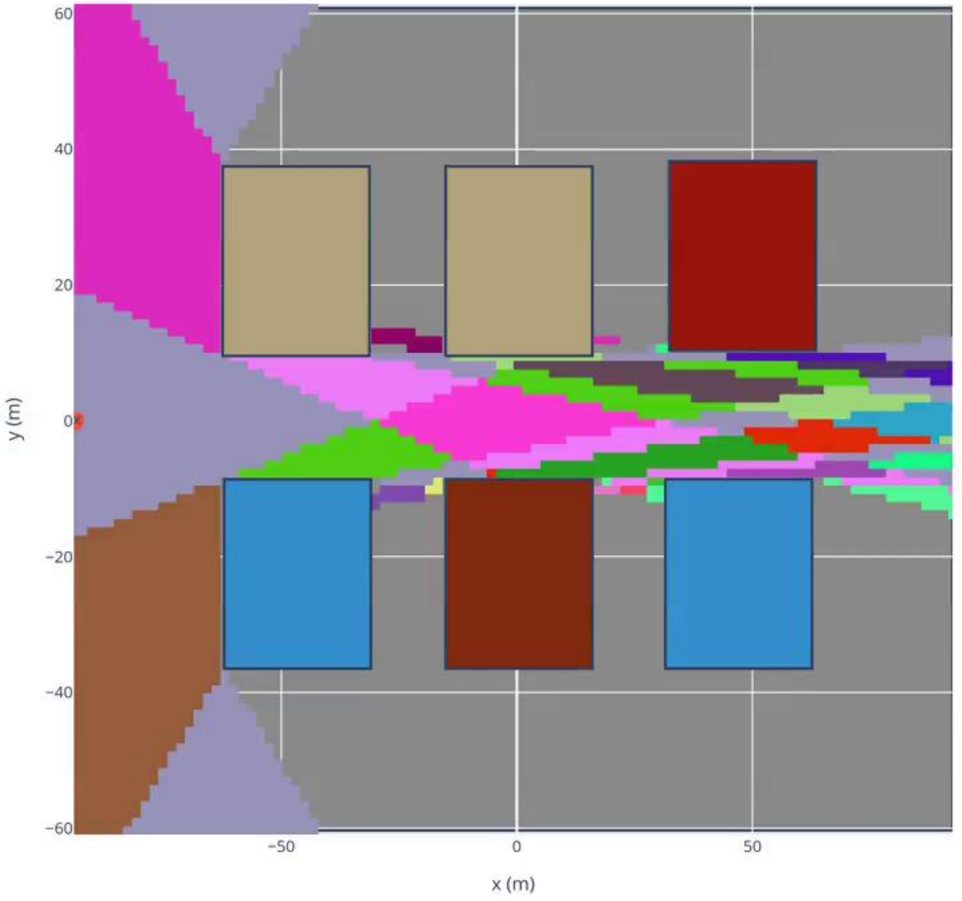

tx
x (m)


60
40
20
0
−20
−40
−60
y (m)
−50
0
50
x (m)


tx
x (m)


60
40
20
0
−20
−40
−60
y (m)
−50
0
50
x (m)


tx
x (m)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- 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.

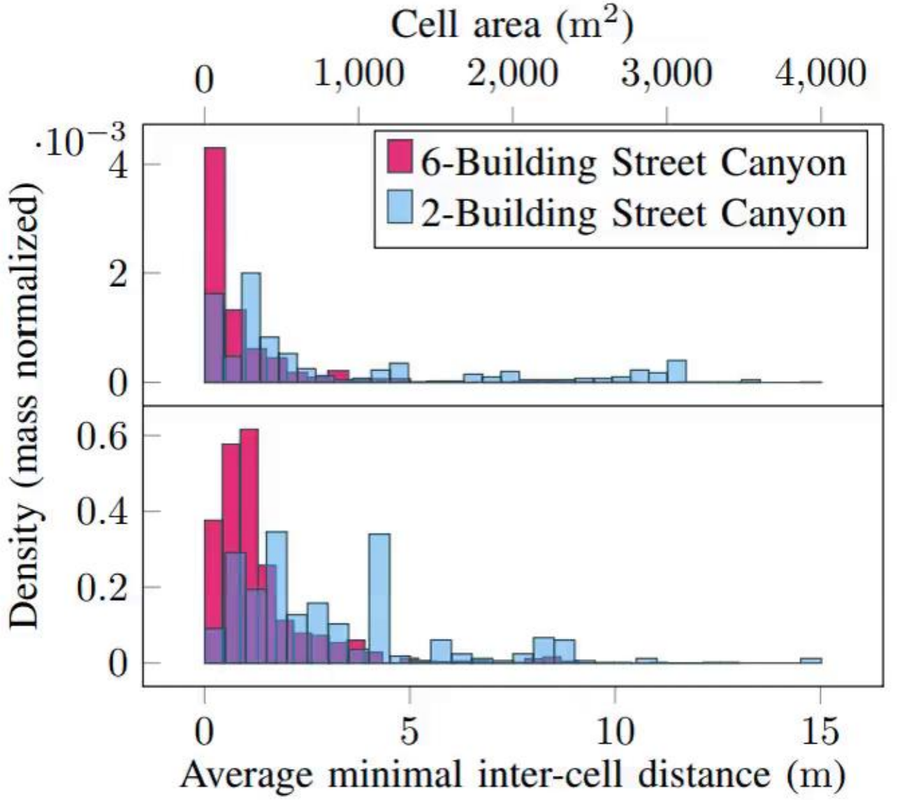
Cell area (m²)
0
1,000
2,000
3,000
4,000
·10⁻³
4
2
0
6-Building Street Canyon
2-Building Street Canyon
Density (mass normalized)
0.6
0.4
0.2
0
0
5
10
15
Average minimal inter-cell distance (m)

TABLE I

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

| | 6B | | 2B | |
|---|---|---|---|---|
| | $S$ ($\mathrm{m}^2$) | $\overline{d}$ (m) | $S$ ($\mathrm{m}^2$) | $\overline{d}$ (m) |
| Mean | 225.62 | 1.40 | 840.56 | 3.08 |
| Median | 86.43 | 1.00 | 371.38 | 2.30 |