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Differentiable and Learnable Wireless Simulation with Geometric Transformers

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*Work was completed while an employee at Qualcomm Technologies Netherlands B.V.

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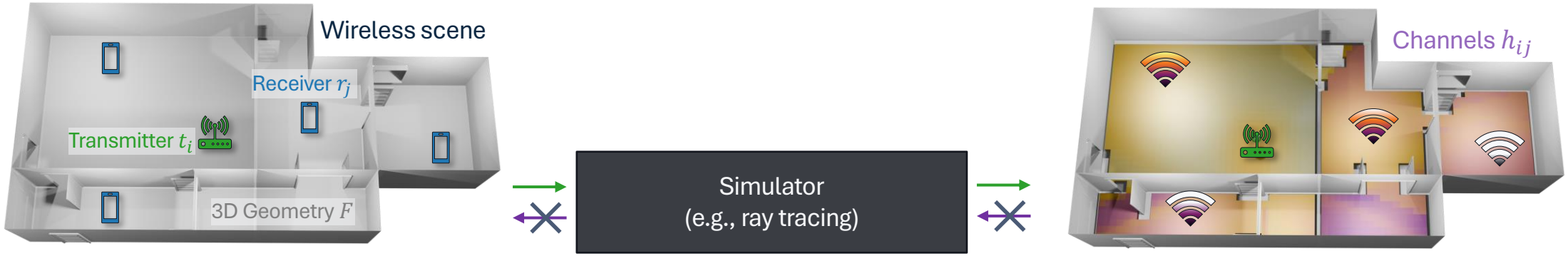
Motivation: Why learn to simulate?



Inverse/optimization problems:

- Tx/Rx localization
- Geometry reconstruction
- Coverage optimization

Simulation is great for forward problems (prediction):

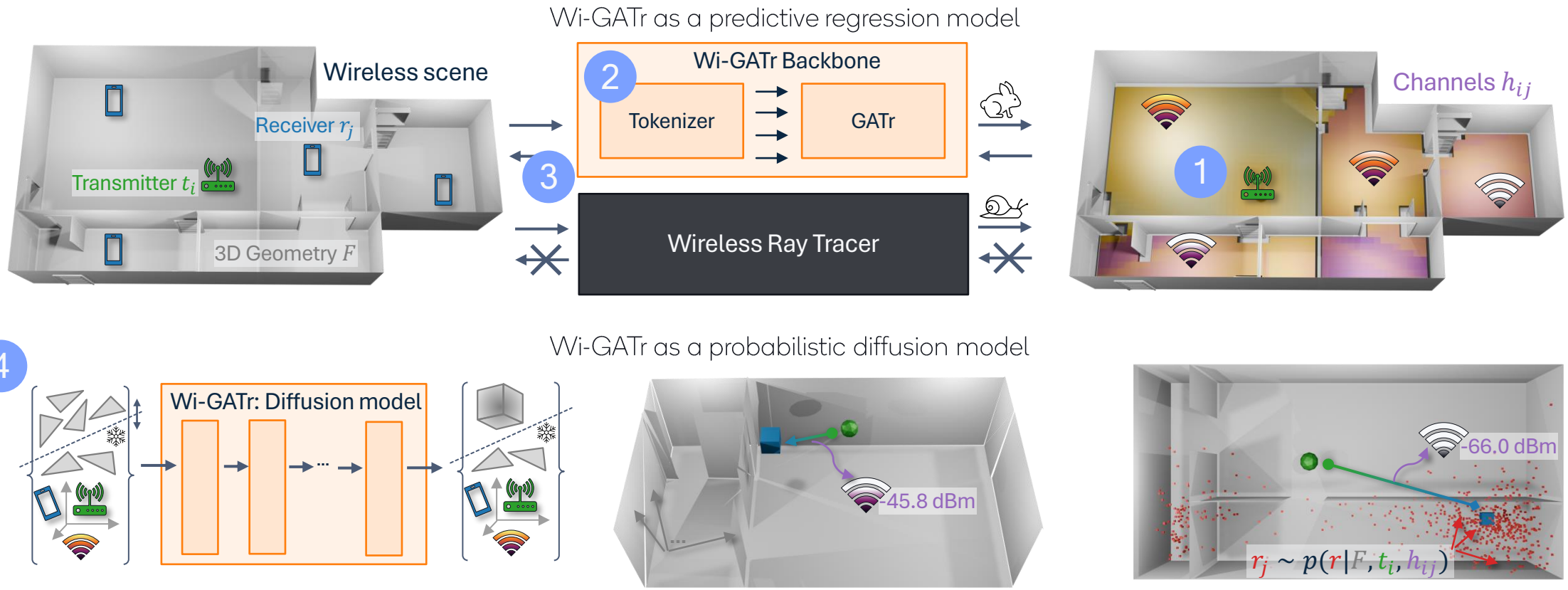
- Large-scale channel parameters (e.g., received power, delay spread).
- Channel impulse response.

Sim2real problem:

- Simulation ≠ Measurement
- Learn to close gap?

We **do not aim to replace** physics-based simulation in **existing use-cases**,
we **augment** physics-based simulation for **novel use-cases**!
Applicable to other domains: Material discovery, Chip design, and many more

Wi-GATr Contributions



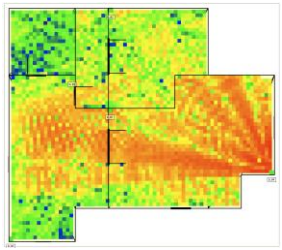
1. Simulate large-scale dataset of diverse indoor scenes
2. Introduce the Wi-GATr backbone model incorporating the symmetries of wireless propagation
3. Solve inverse problems through differentiability
4. Model the joint probability of the scene using diffusion (forward + inverse)

WiPTR dataset and Model

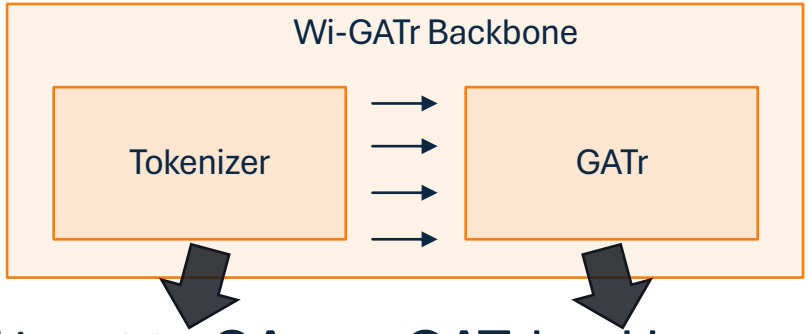
Wi-PTR dataset

- 12k floor layouts
  Up to 15 Tx locations
  Up to 200 Rx locations, total >5.5M channels
- ~2 months of SoTA GPU ray tracing

Wireless InSite
Ray Tracing



Screenshot of Wireless InSite



Embed input to GA:

- 3D Mesh faces as points and plane
- Rx/Tx location and orientation
- Rx-Tx Link token as output (cf. "class") token

GATr backbone:

- E(3)-equivariance (rotation, translation, mirroring)
  ➔Agnostic to coordinate frame.
- Permutation equivariant
  ➔Agnostic to mesh order.

Results: Regression model

Performance validation

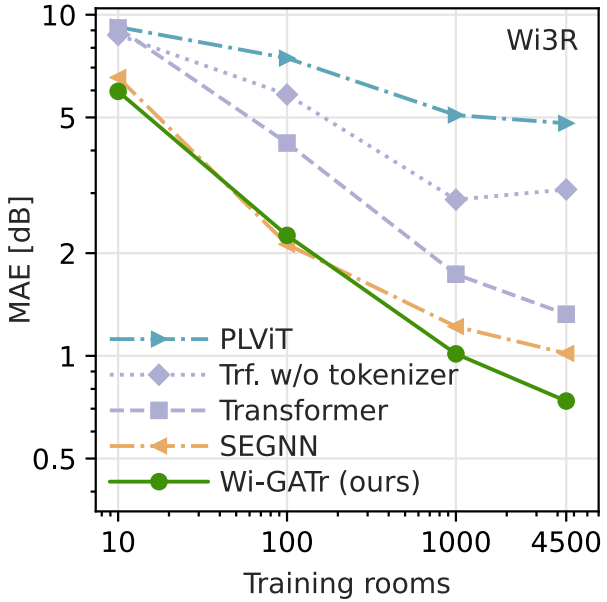
- Most accurate surrogate
- 30x faster than ground truth ray tracer

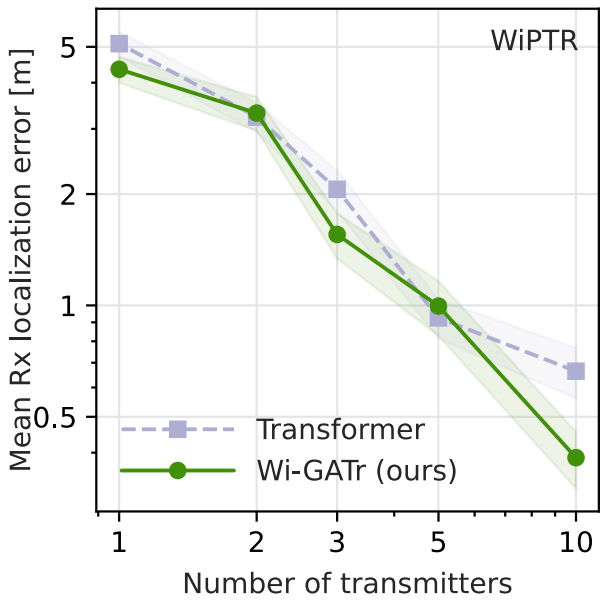
Inverse problems

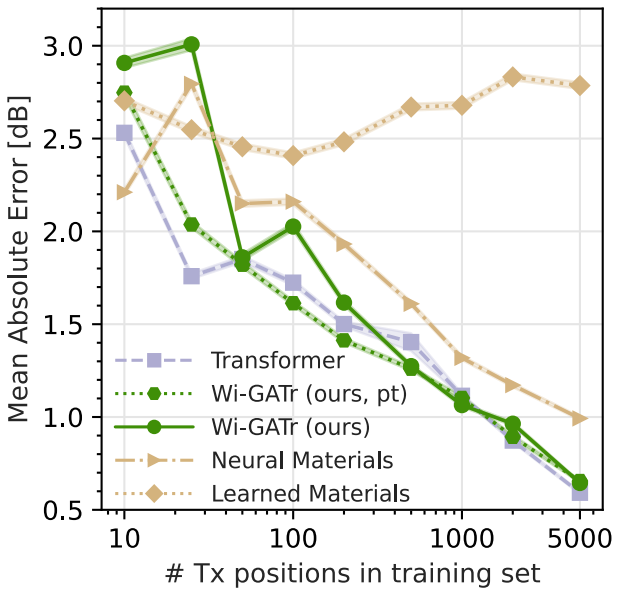
- Better than Transformer
- Other baselines failed

Sim2real gap reduction

- SoTA on DICHASUS dataset.
- Outperforms hybrid ray tracer ("Neural Materials")





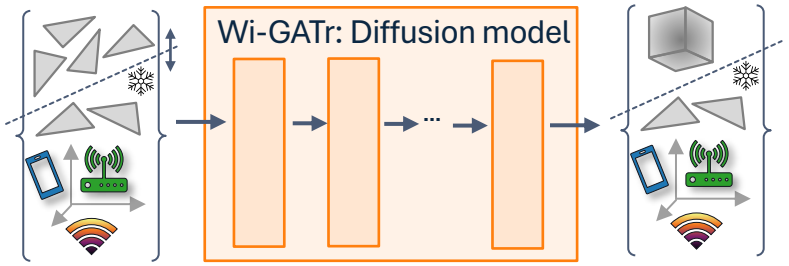


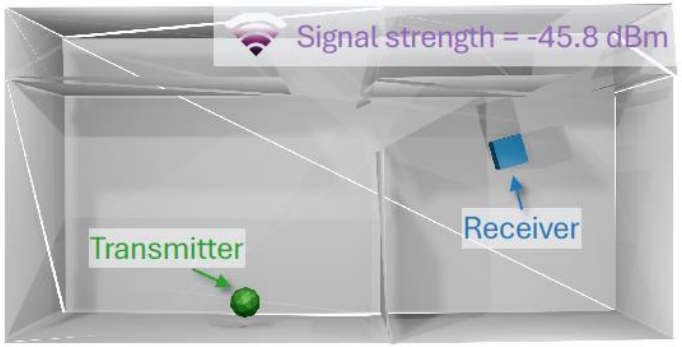
Hoydis, Jakob, et al. "Learning radio environments by differentiable ray tracing." IEEE TMLCN 2024

Brandstetter, Johannes, et al. "Geometric and physical quantities improve e (3) equivariant message passing." ICLR 2021

Results: Joint probabilistic model (Diffusion Model)

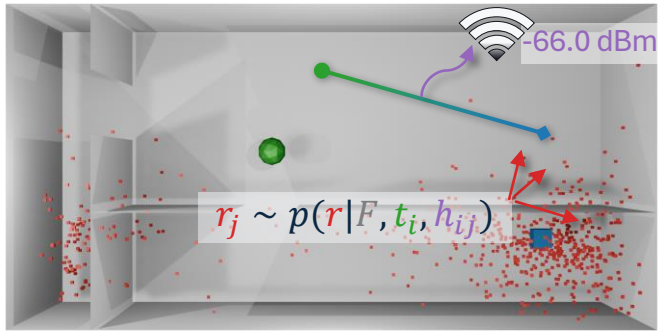
Generative Model formulation

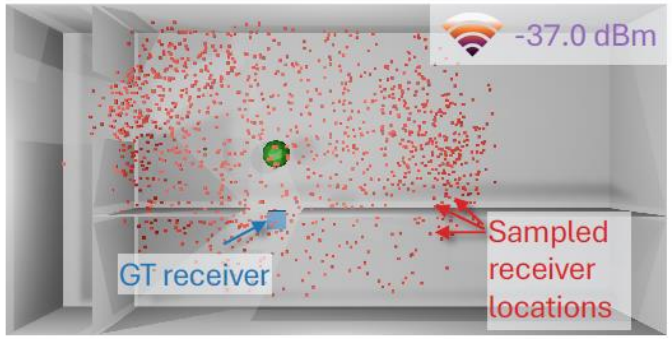




Generate new plausible scenes from joint distribution.

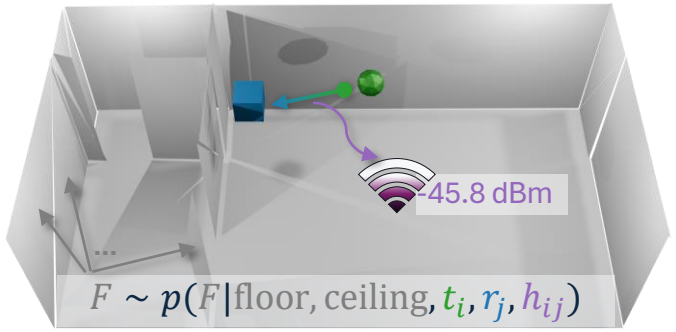
Generation: Rx Localization

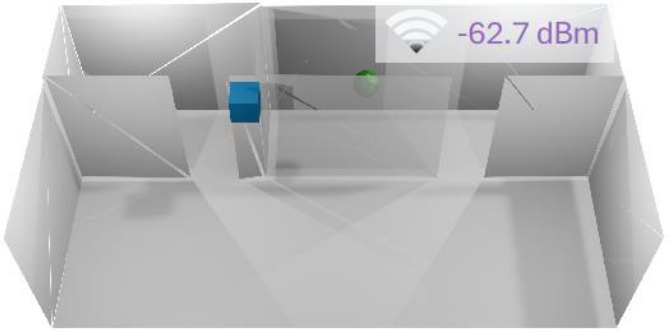




Sample from multi-modal conditional distribution.

Generation: 3D Geometry

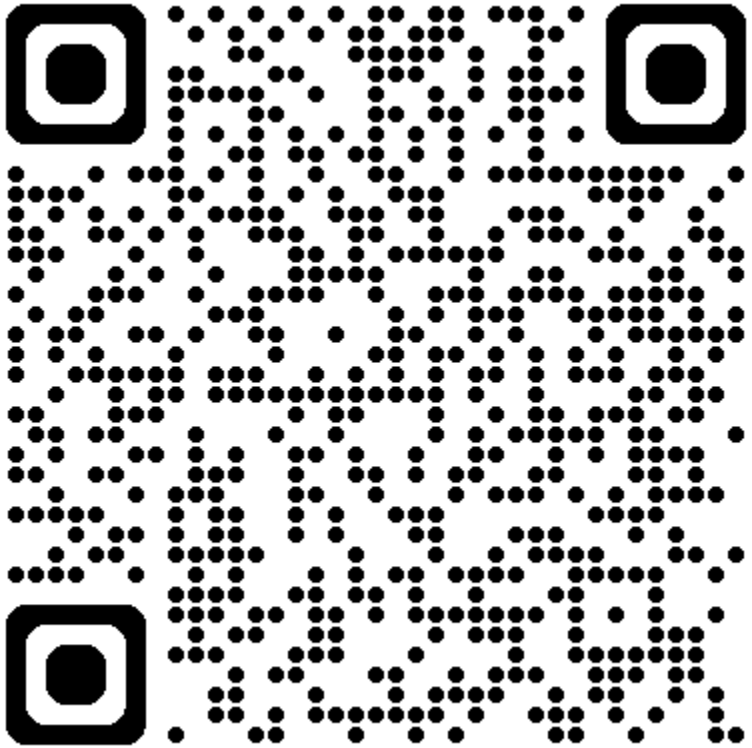




Reconstruct missing geometry elements.

Conclusions

- **Introduce backbone model for wireless problems**
  - Data-efficiency through physics-informed equivariance
  - Expressive thanks to transformer architecture
  - Agnostic to choice of coordinate frame and mesh order
- **Enable novel use-cases for wireless simulation**
  - Receiver localization
  - Geometry reconstruction
- **Perform fast and accurately**
  - Up to 30x faster inference than baseline wireless ray tracer
  - Higher accuracy than other neural surrogate models
  - Better calibration to measurements than hybrid ray tracer



Find our code & data at:
https://github.com/Qualcomm-AI-research/Wi-GATr
https://github.com/Qualcomm-AI-research/WiInSim

Thank you

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