

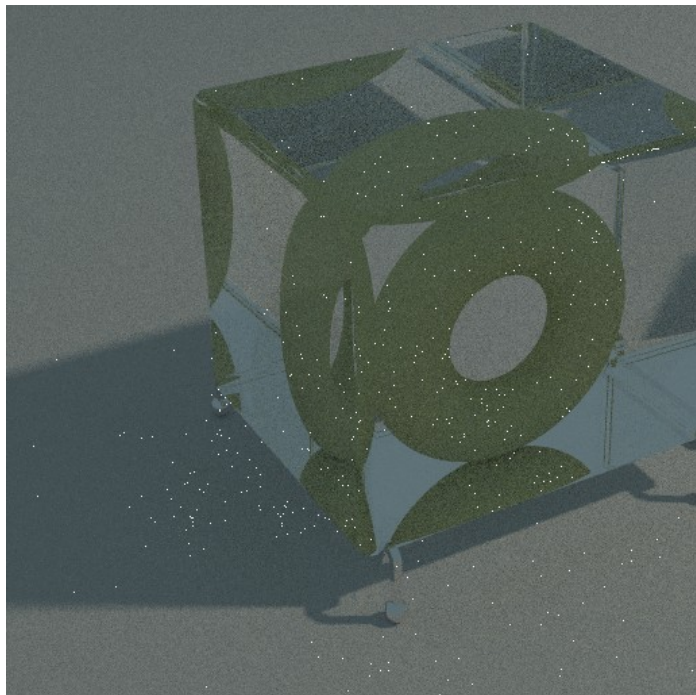
Quantifying the Error of Light Transport Algorithms

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Michael Wimmer¹, Jaakko Lehtinen²

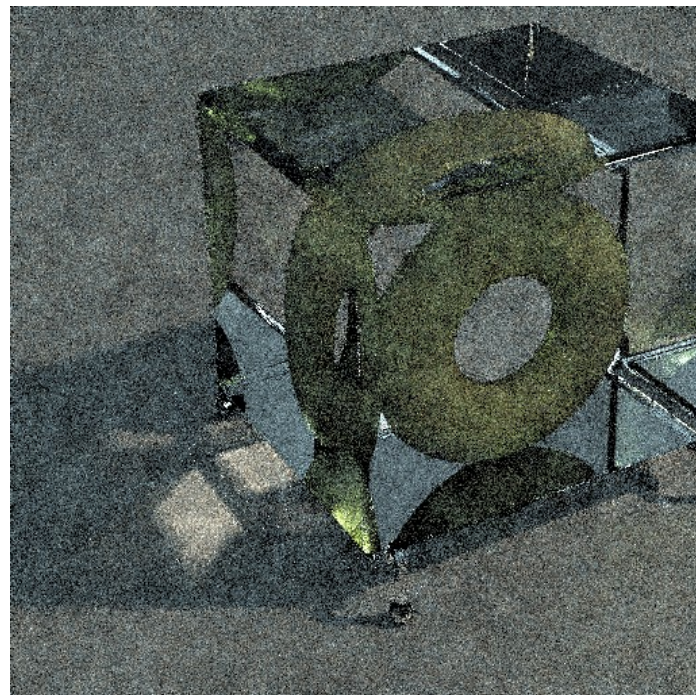
¹TU Wien, ²Aalto University (Helsinki), ³ETH Zürich



Motivation

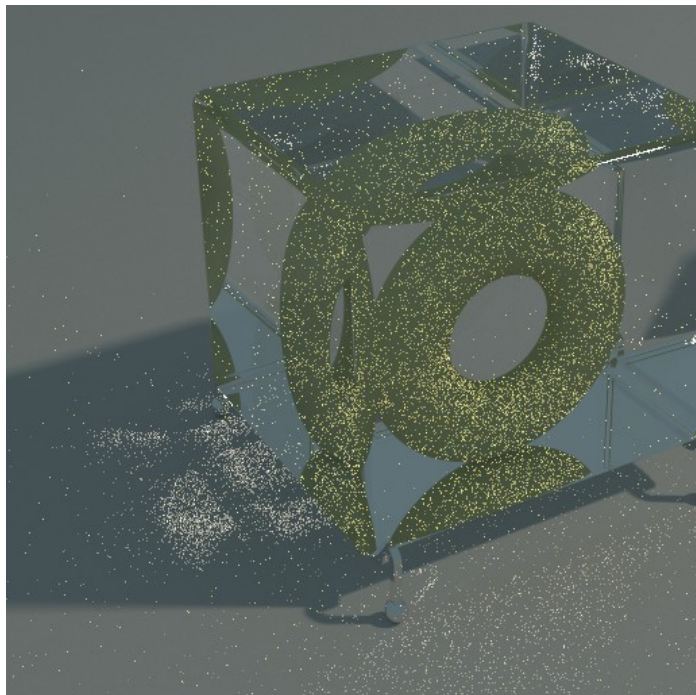


PT

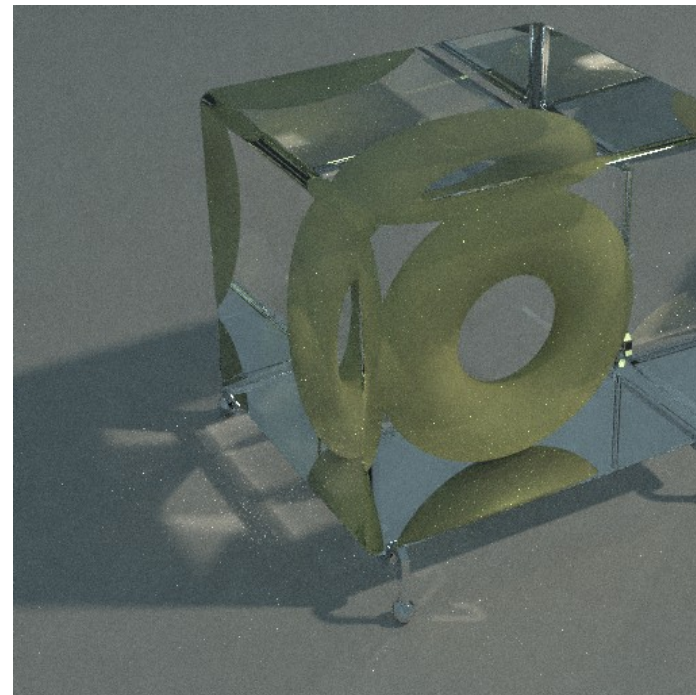


MLT

Motivation

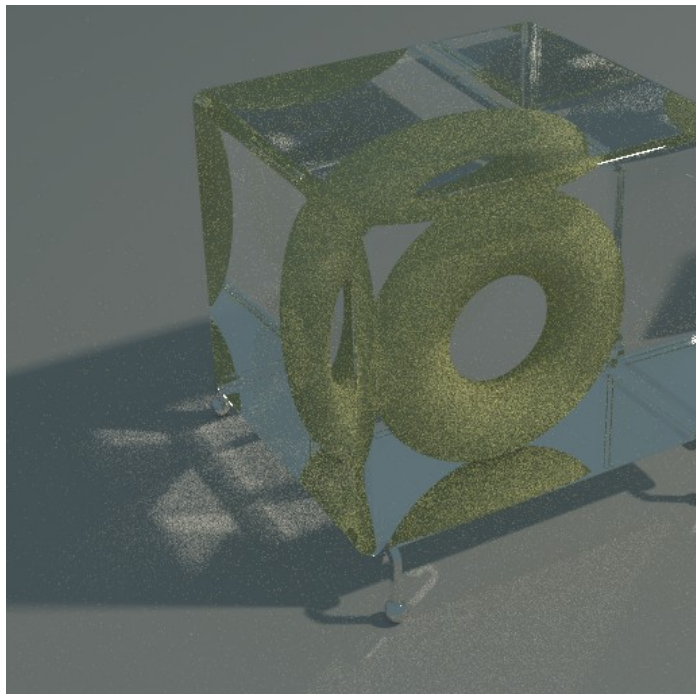


PT

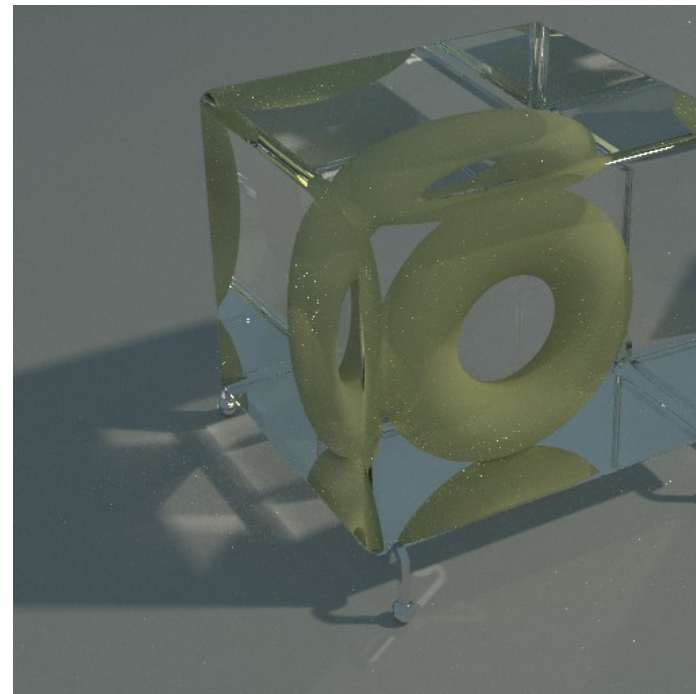


MLT

Motivation

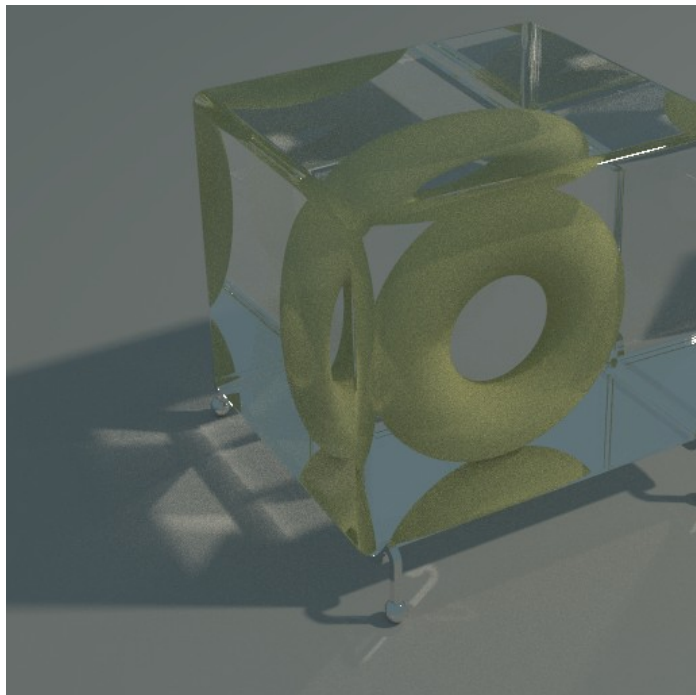


PT

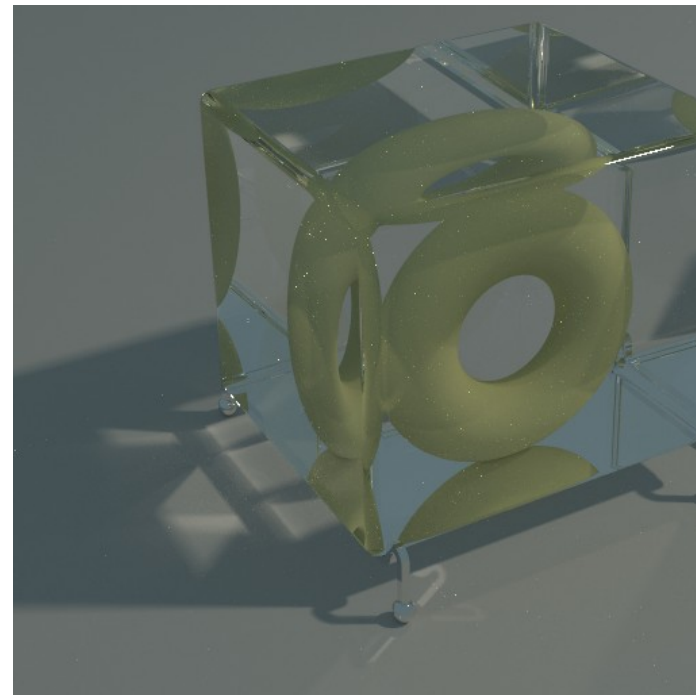


MLT

Motivation



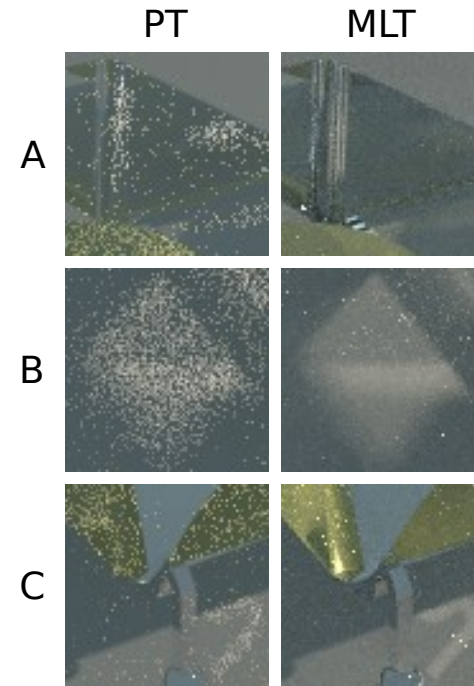
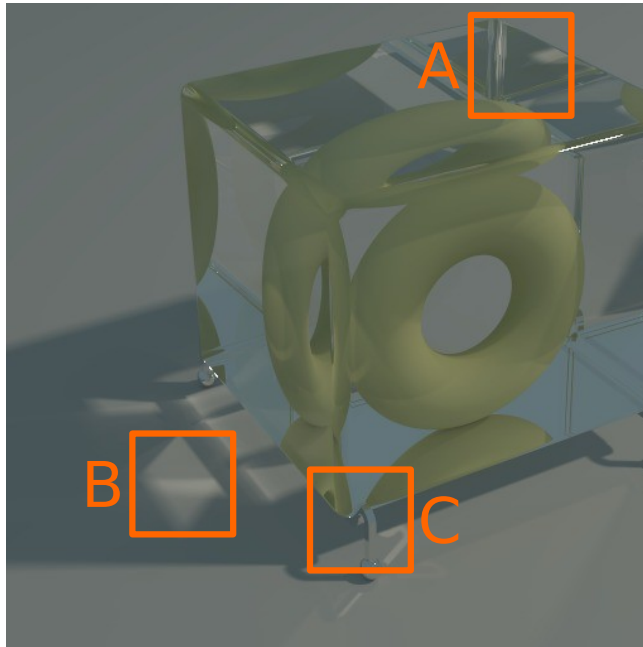
PT



MLT

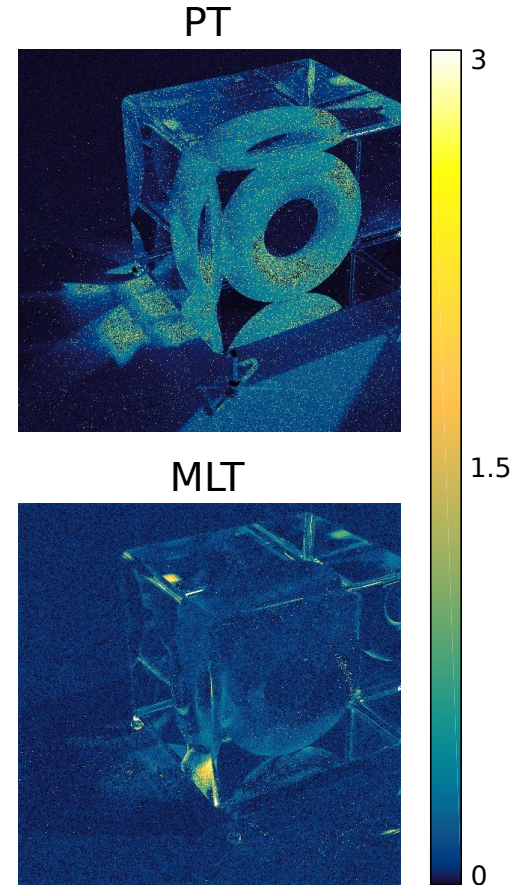
Motivation / State of the Art

- Renderings and details



Motivation / State of the Art

- Renderings and details
- Error, for instance $\text{abs}(R - I)$



Motivation / State of the Art

- Renderings and details
- Error, for instance $\text{abs}(R - I)$
- *Simple error metrics like MSE or friends*

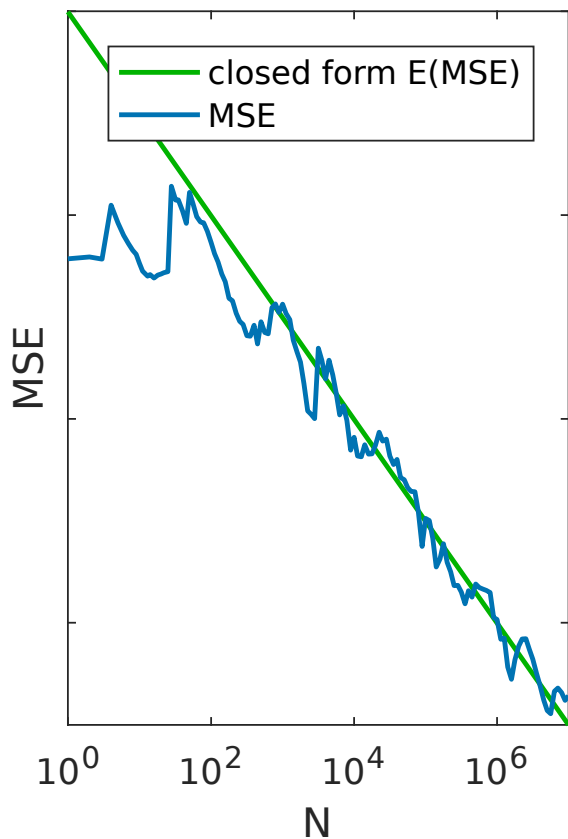
Torus 5 min.	PT	MLT
MSE	0.00213	0.00278
RMSE	0.00462	0.00528
Relative MSE	0.1077	0.1446
Relative RMSE	0.3282	0.3802
PSNR	74.83	73.68

Motivation / Closer Look at MSE

- Render for some time, e.g., 1 hour
- Compute MSE using a high quality reference

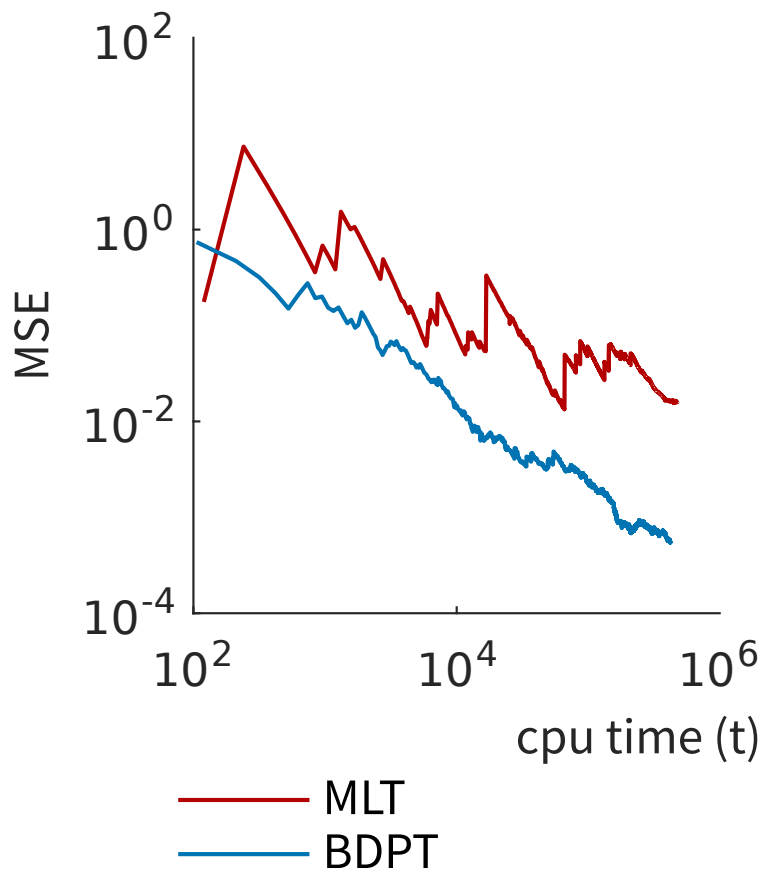
$$\text{MSE}(\langle I \rangle) = \frac{1}{M} \sum_{m=0}^M (\langle I_m \rangle - I_m)^2$$

Motivation / Closer Look at MSE



- Render for some time, e.g., 5 minutes
- Compute MSE using a high quality reference
- MSE depends on N, but does not converge

Motivation / Closer Look at MSE



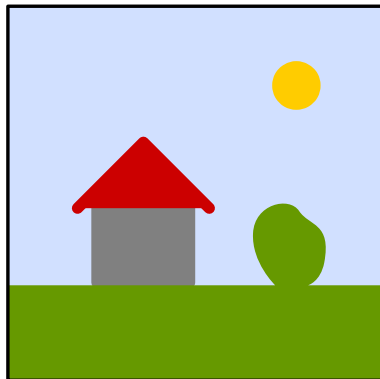
- Render for some time, e.g., 5 minutes
- Compute MSE using a high quality reference
- MSE depends on N, but does not converge

Motivation / Goals

- Convergence with N
- Notion of how reliable for a given instance
- Behaviour: frequency content and outliers

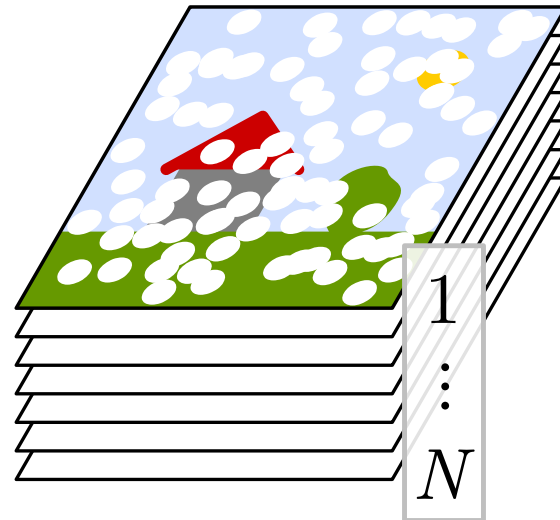
Proxy Algorithm

original



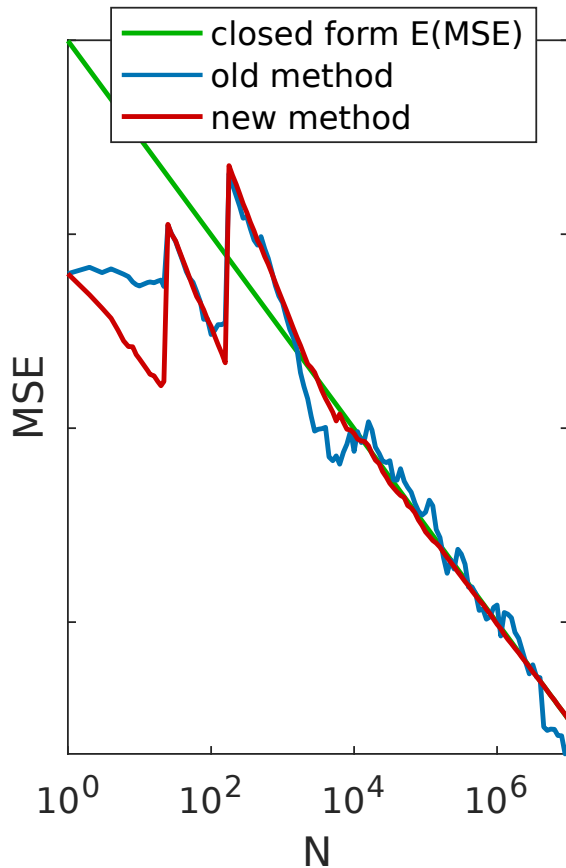
VS.

proxy short renders



$$\langle I' \rangle_N = \frac{1}{N} \sum_{n=1}^N \langle I^n \rangle_1$$

Proxy Algorithm



- Estimate $E(\text{MSE})$

- old

$$\frac{1}{M} \sum_{m=0}^M \left(\frac{1}{N} \sum_{n=0}^N \langle I_m^n \rangle_1 - I_m \right)^2$$

- new

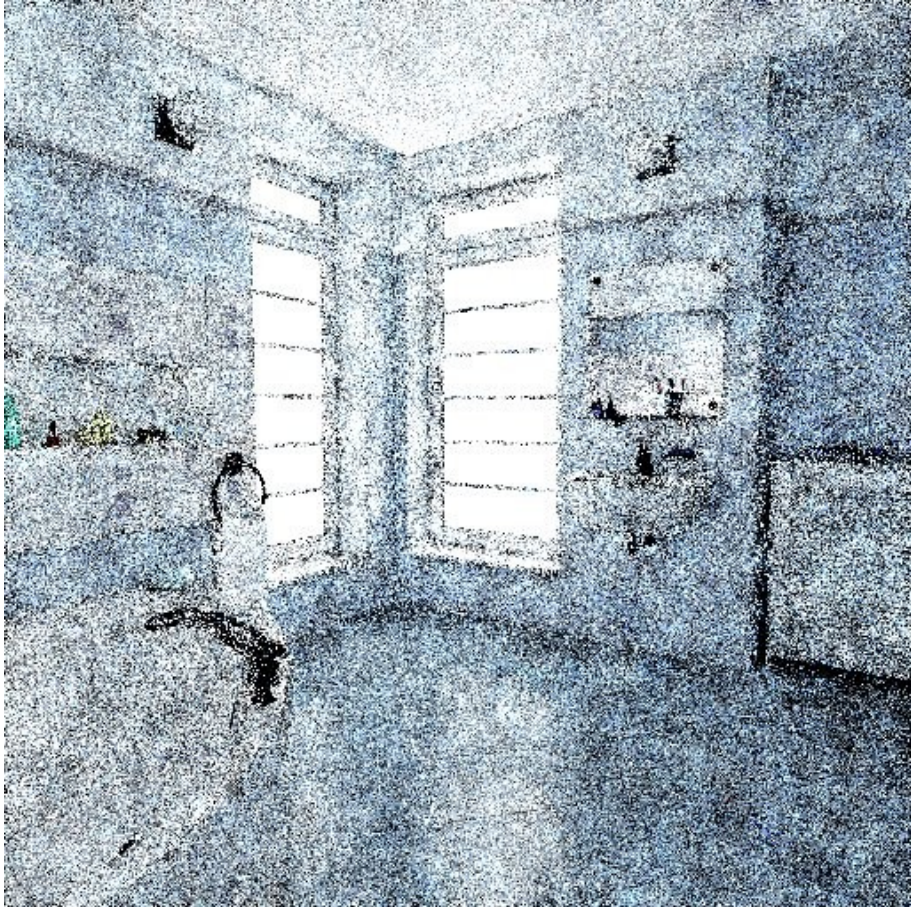
$$\frac{1}{(N-1)M} \sum_{n=0}^N \sum_{m=0}^M \left(\langle I_m^n \rangle_1 - \langle I'_m \rangle_N \right)^2$$

Proxy Algorithm



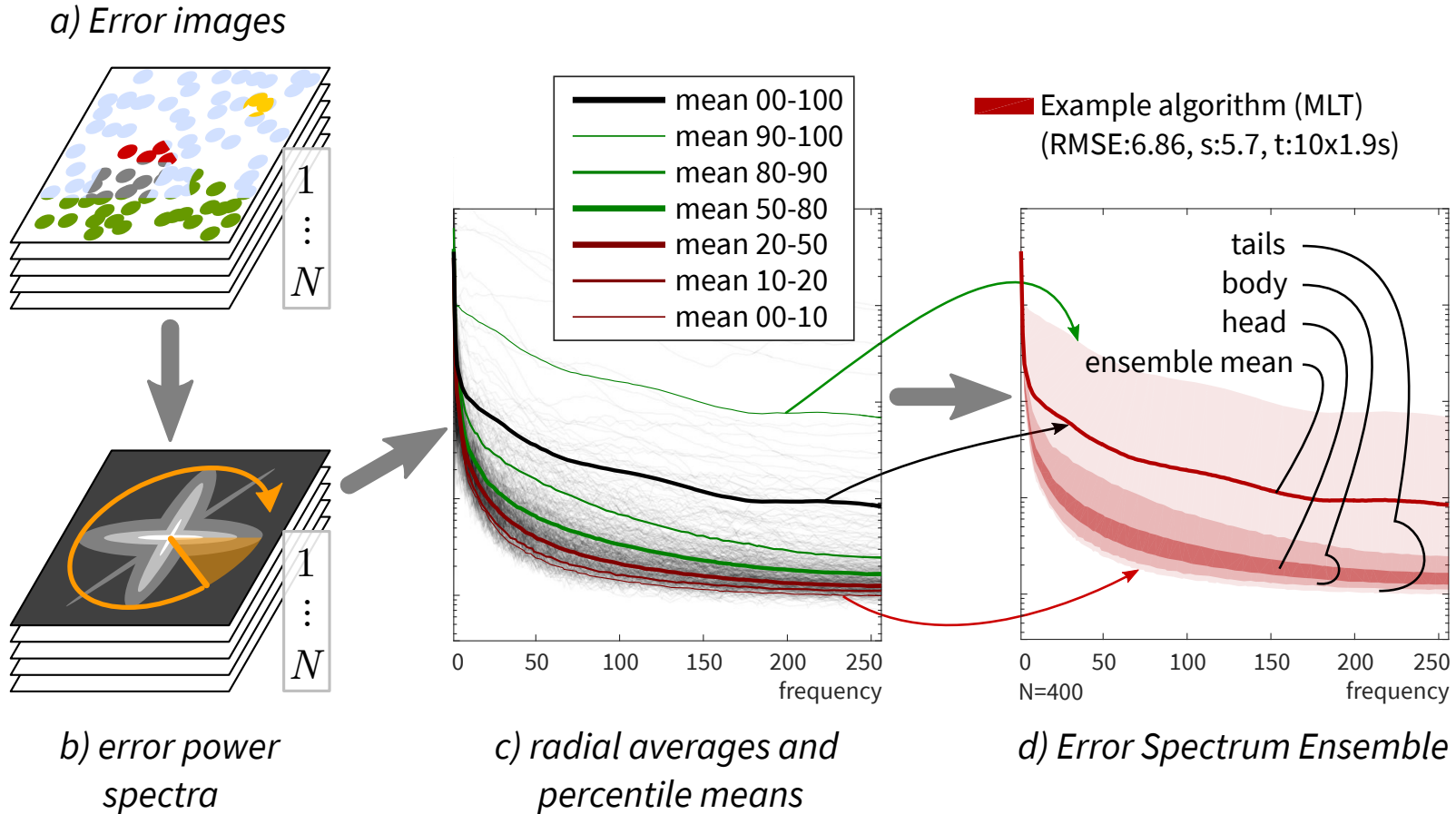
- Estimate $E(\text{MSE})$
- Estimate per-pixel standard deviation

Proxy Algorithm

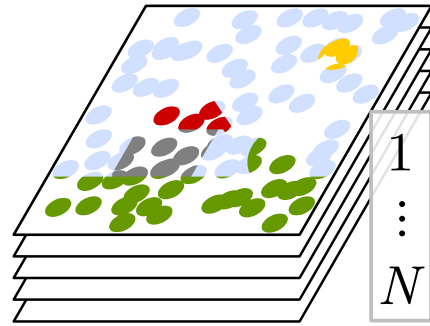


- Estimate $E(\text{MSE})$
- Estimate per-pixel standard deviation
- Behaviour / frequency content of error and outliers via short renderings

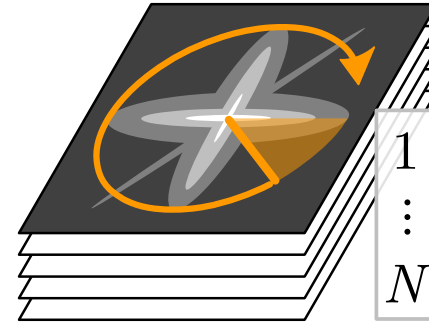
Error Spectrum Ensemble (ESE)



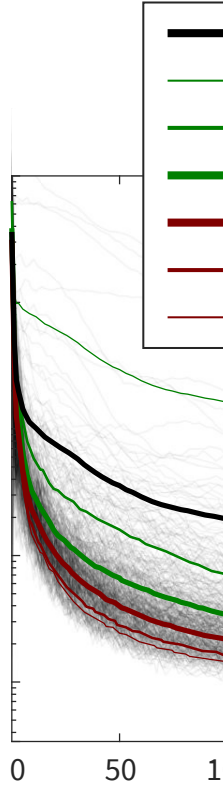
Error Spectrum Ensemble (ESE)



a) Error images

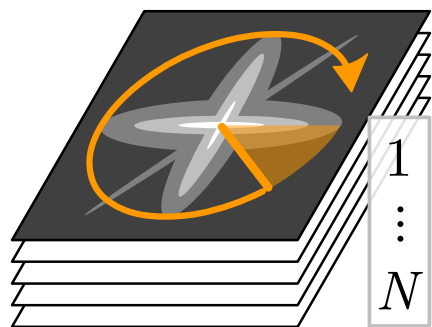


b) error power spectra

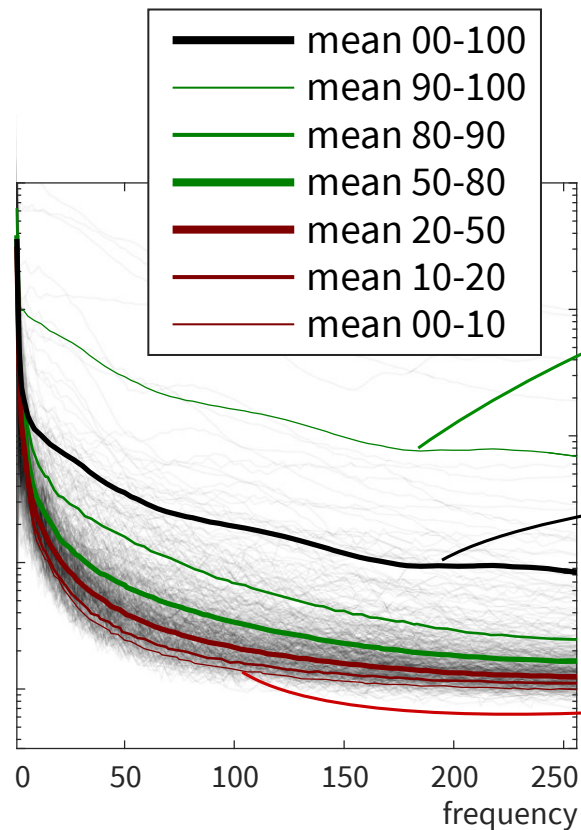


c) radiation percentage

Error Spectrum Ensemble (ESE)

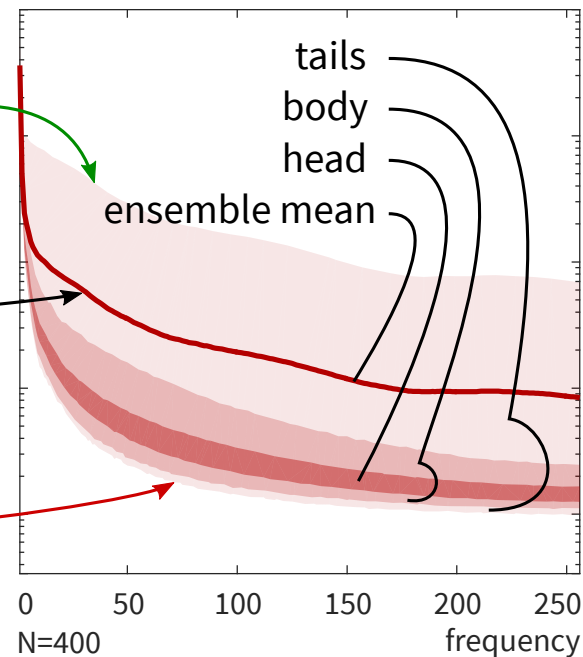


b) error power spectra



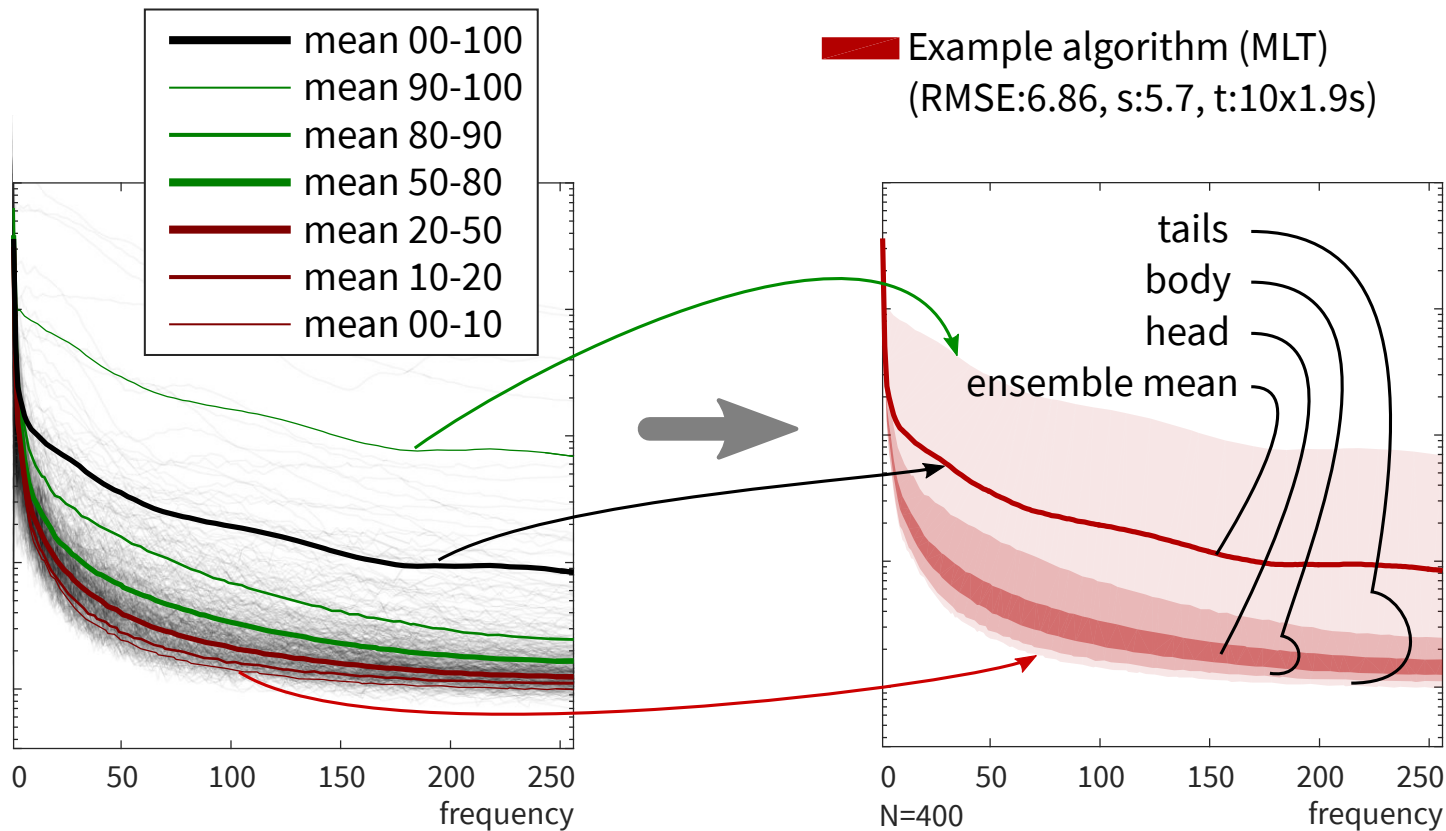
c) radial averages and percentile means

Example algorithm (MLT)
(RMSE:6.86, s:5.7, t:10x1.9s)



d) Error Spectrum Ensemble

Error Spectrum Ensemble (ESE)



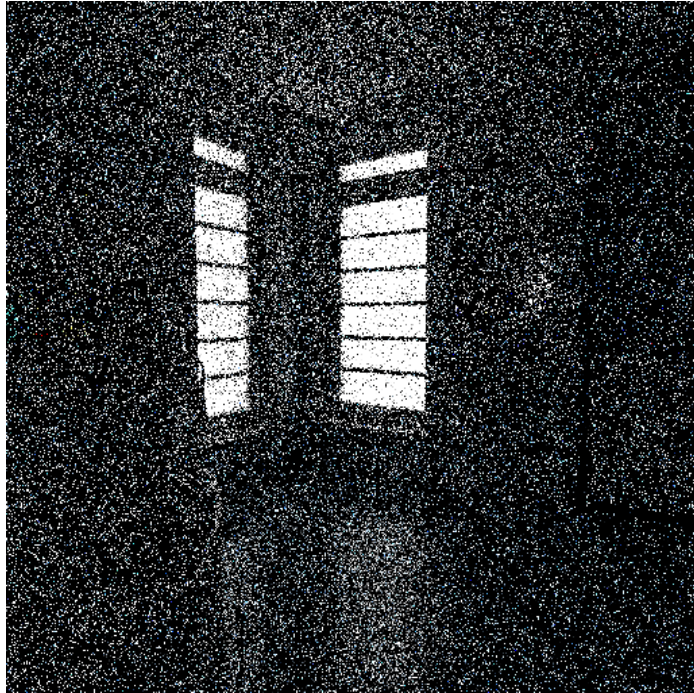
c) radial averages and percentile means

d) Error Spectrum Ensemble

Example / Bathroom



Example / Bathroom



PT



MLT

Example / Bathroom



PT



MLT

Example / Bathroom



PT



MLT

Example / Bathroom

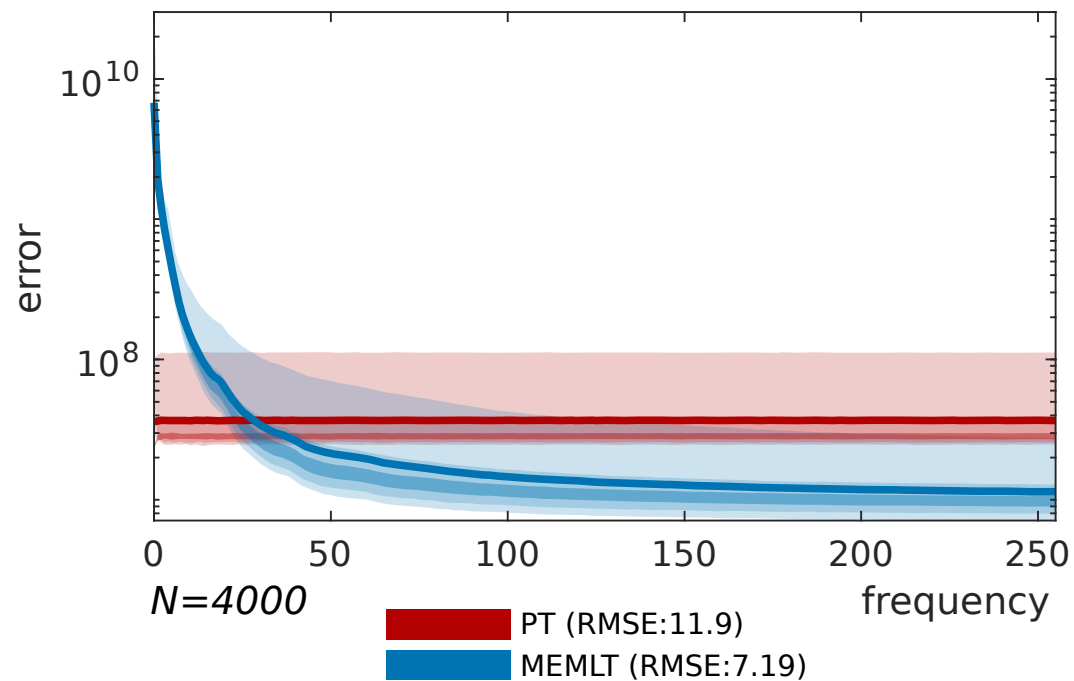


PT

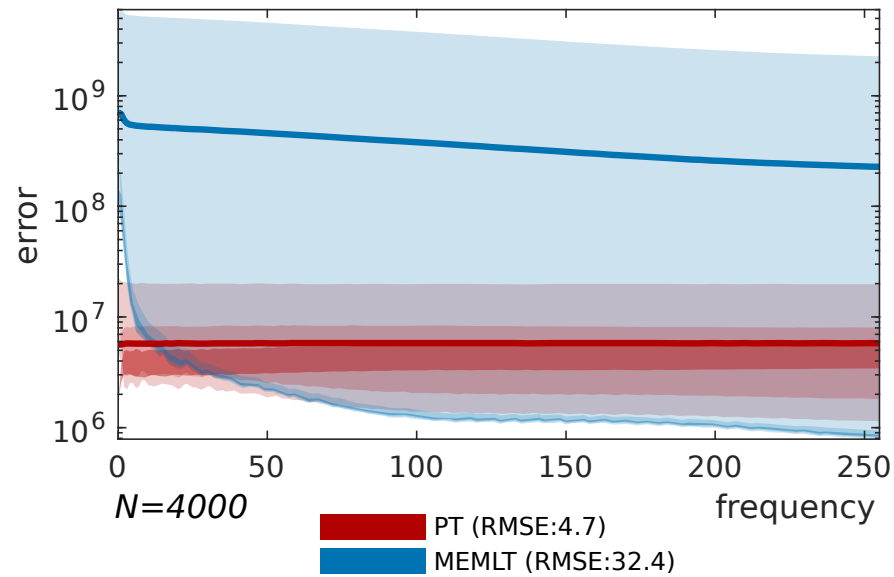


MLT

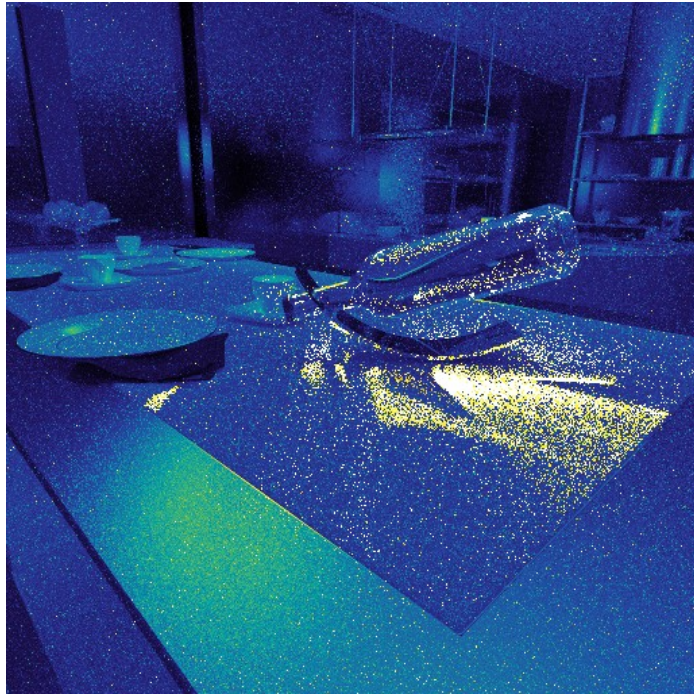
Example / Bathroom



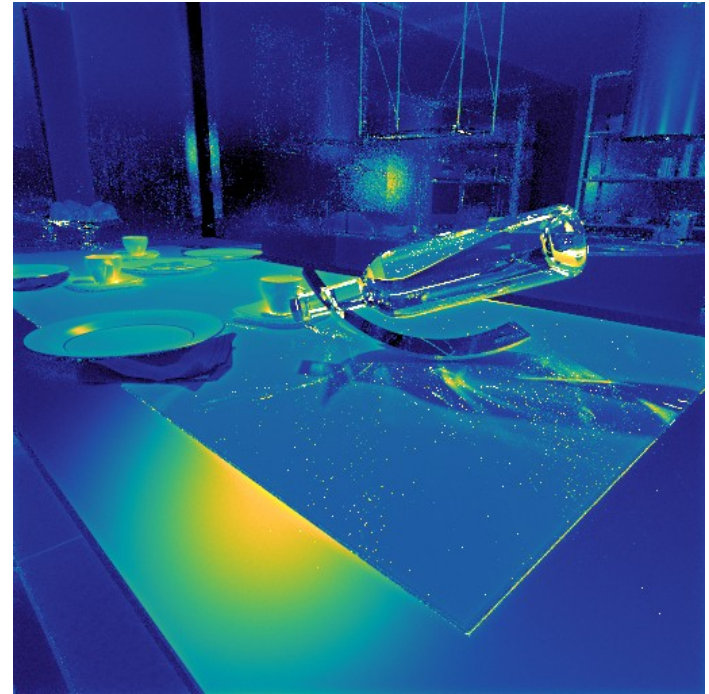
Example / Bottle



Example / Bottle

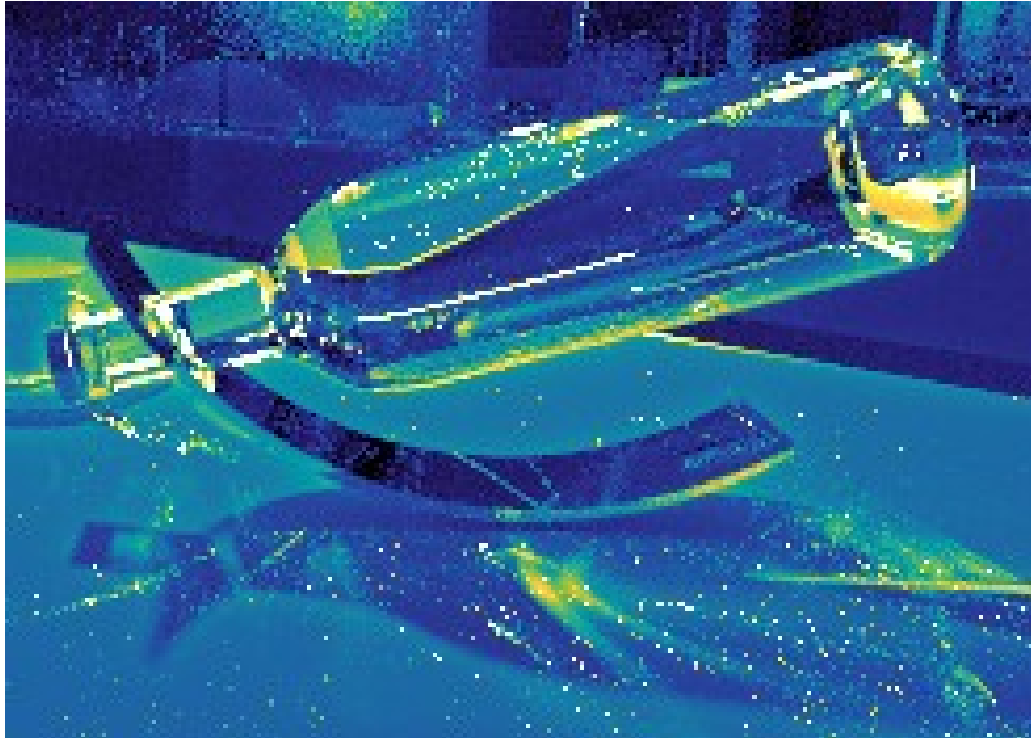


PT



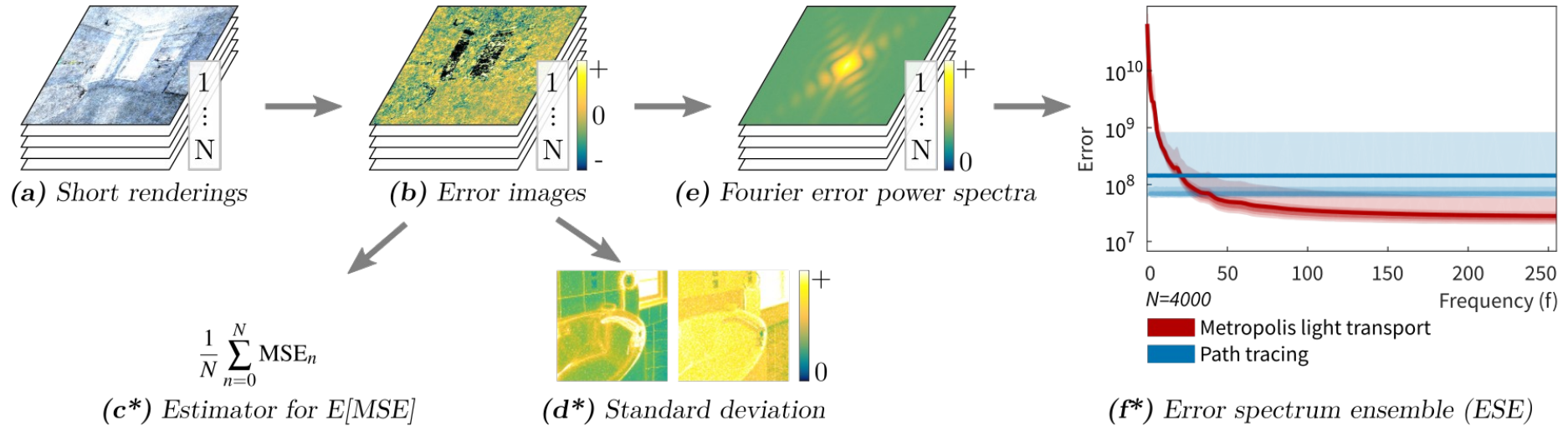
MLT

Example / Bottle



MLT

Conclusion / Summary



Conclusion / Limitations und Future Work

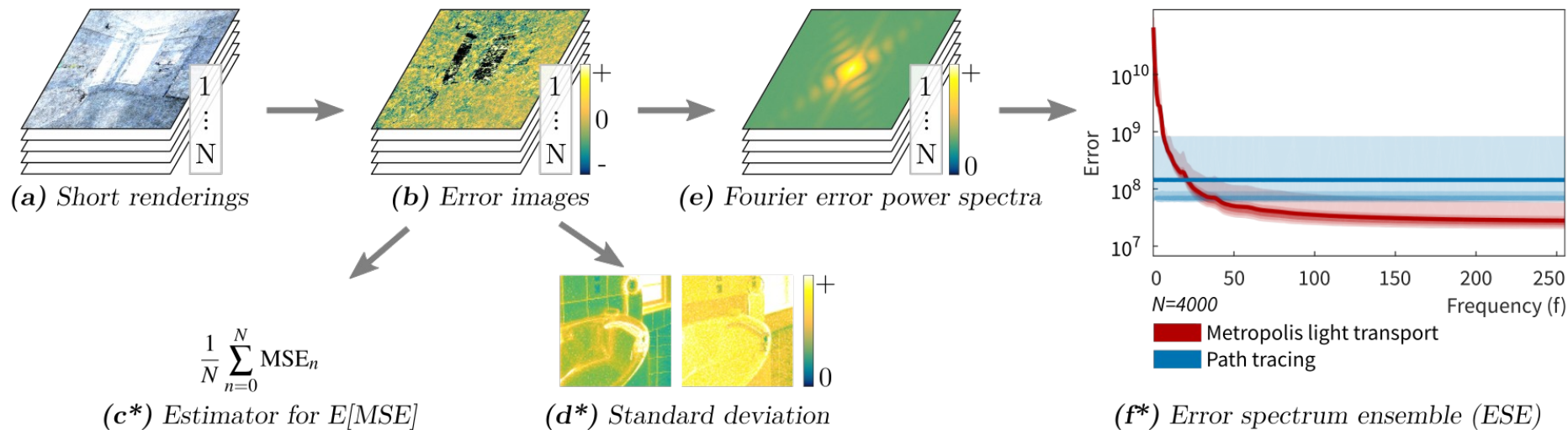
Limitations:

- Proxy algorithm limits convergence rate based on CLT
- High complexity compared to scalar metrics like MSE
- Computation cost (short renderings + 10s of minutes)

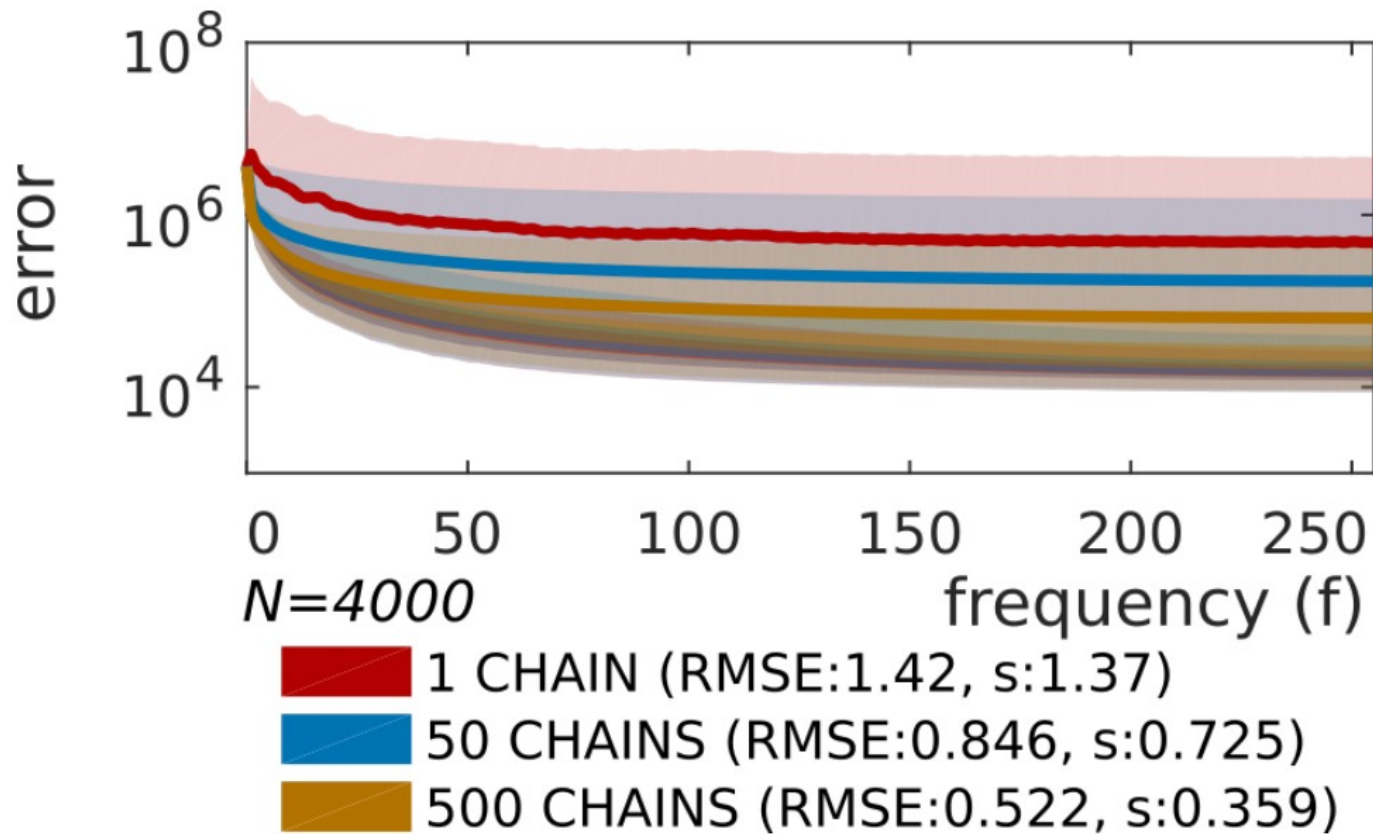
Future work:

- Local pixel correlation
- Convergence of biased but consistent algorithms

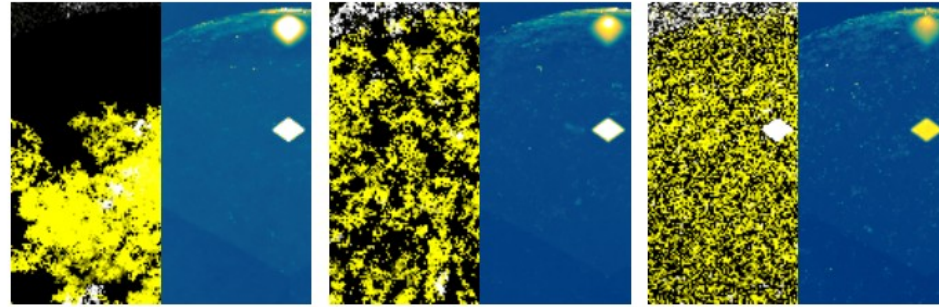
End / Questions



Breaking up of MLT chains (Veatch Door)



Changing PSSMLT Parameters (Box / large mutations)

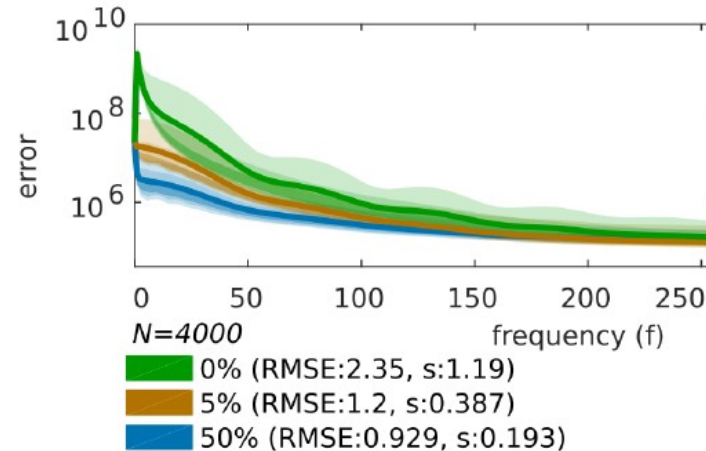


(a) Large mutations 0%

(b) 5%

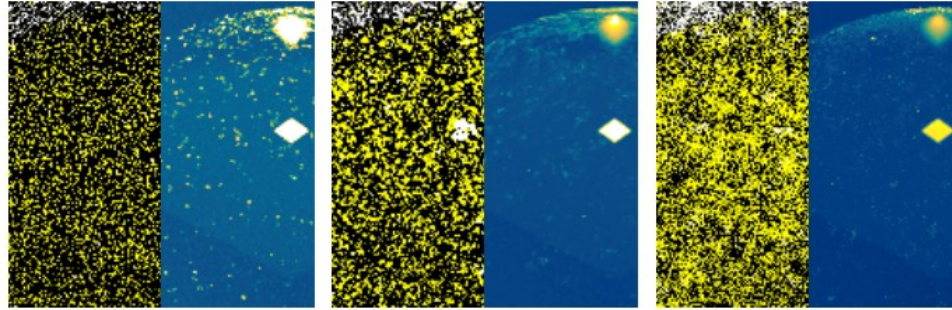
(c) 50%

Example short renderings on the left and SDpp on the right



(d) Error Spectrum Ensemble

Changing PSSMLT Parameters (Box / small mutations)

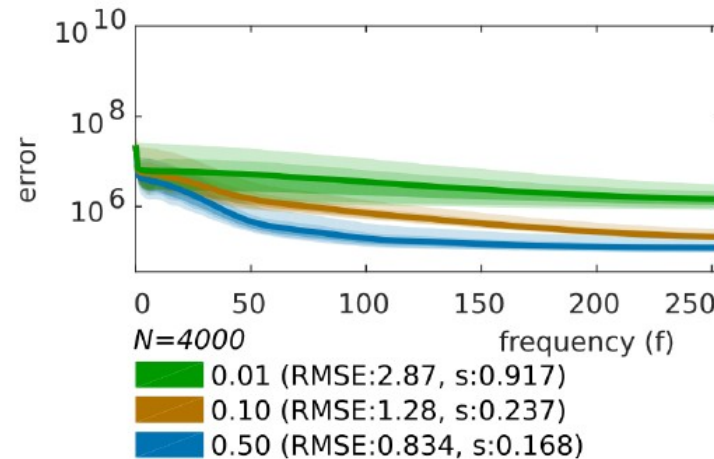


(a) Mutation size 0.01

(b) 0.10

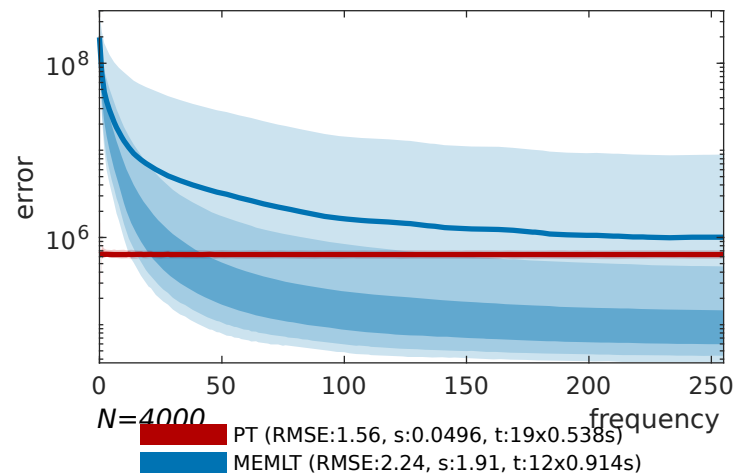
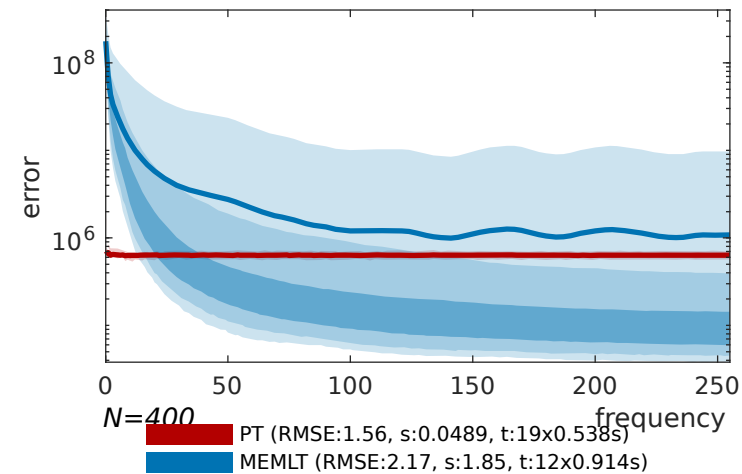
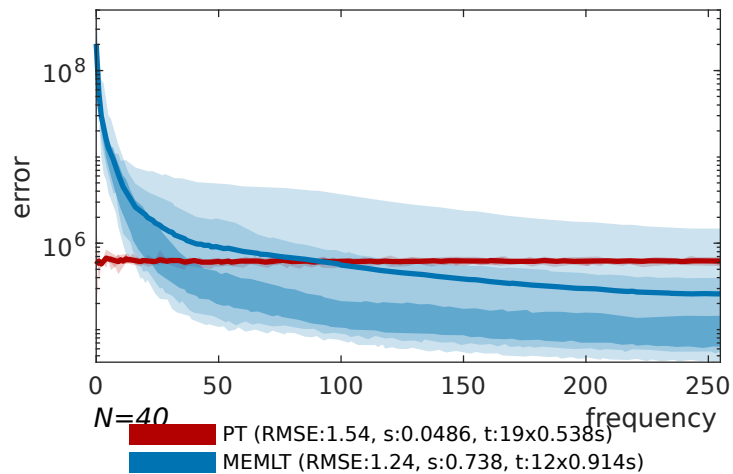
(c) 0.50

Example short renderings on the left and SDpp on the right

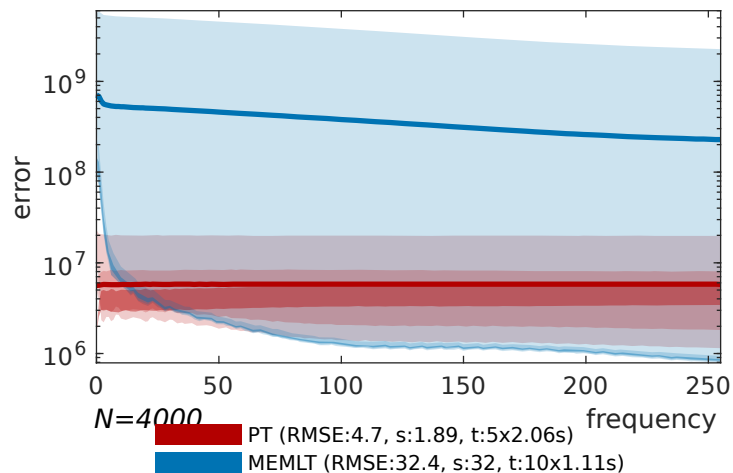
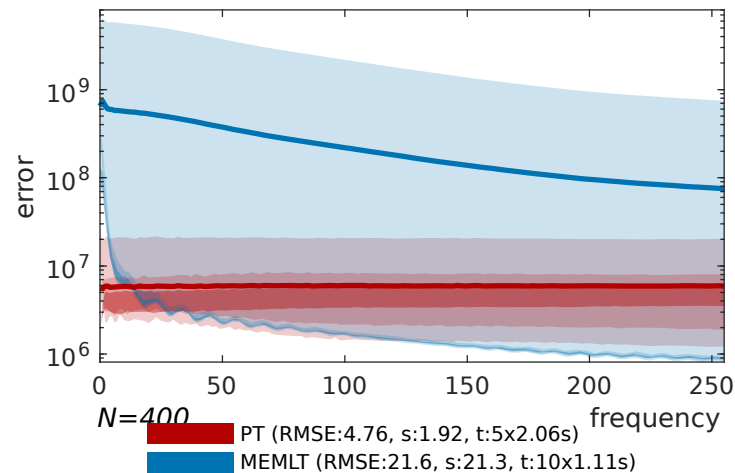
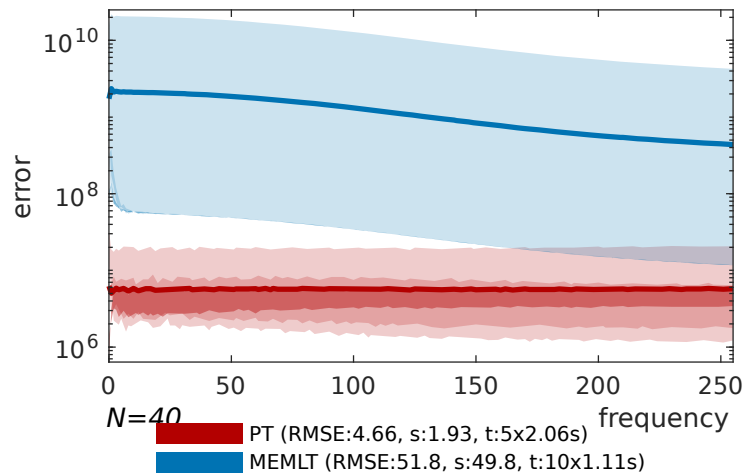


(d) Error Spectrum Ensemble

Smaller N of short renderings (Torus)



Smaller N of short renderings (Bottle)



Biased but consistent algorithm

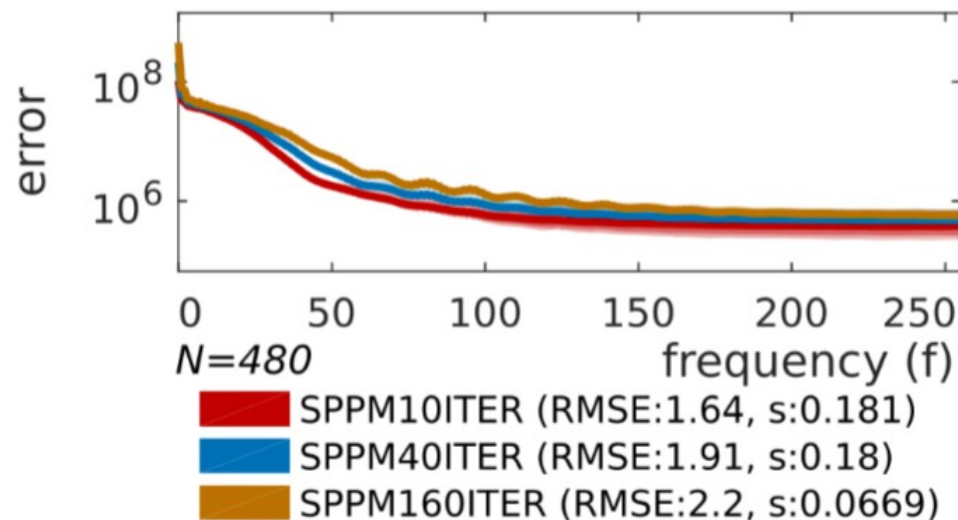


Figure 6: *ESE of the door scene (Figure 7c) for SPPM, which is consistent but biased (T is 10 iterations). The ensemble means perfectly overlap if the convergence rate is $1/T$. In this instance, we see that this is the case for low frequencies. Middle and higher frequencies have a convergence rate below $1/T$, because the $16T$ line is on top.*