

Learning Steerable Function for Efficient Image Resampling

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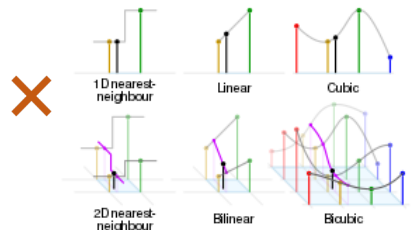
<https://lerf.pages.dev>



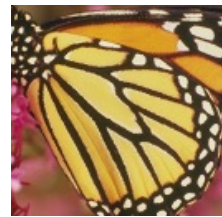
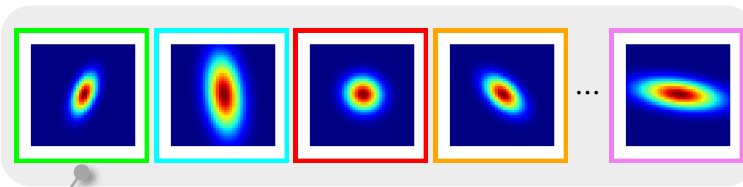
LeRF: Learning Resampling Function

Fixed vs. Learned

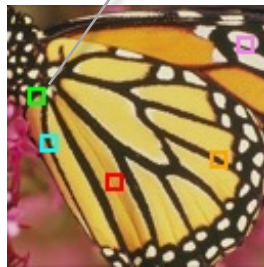
Fixed Bicubic Resampling Function



Learned Steerable Resampling Functions



Downsample



Upsample



Rotation



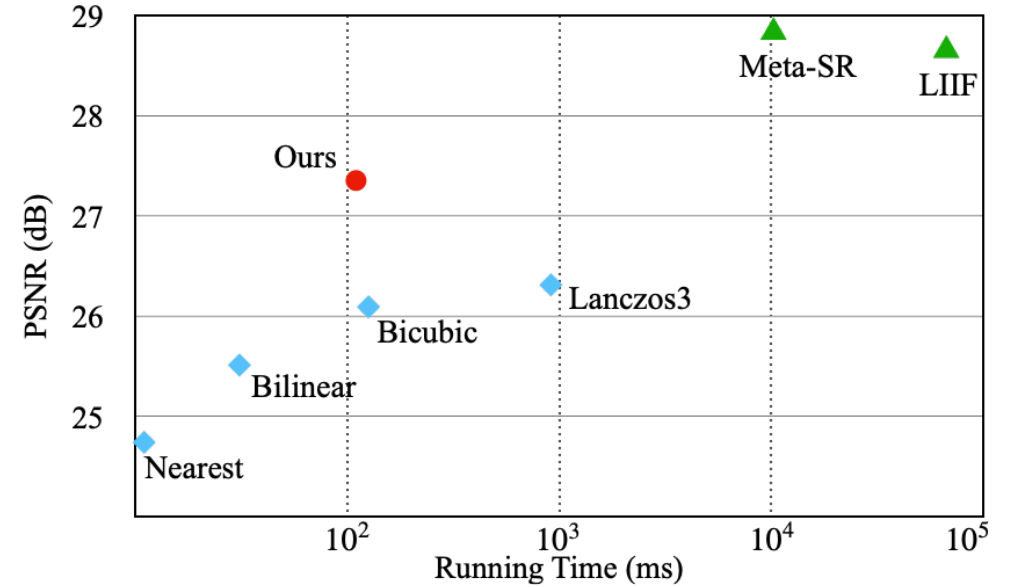
Sheering



Warping

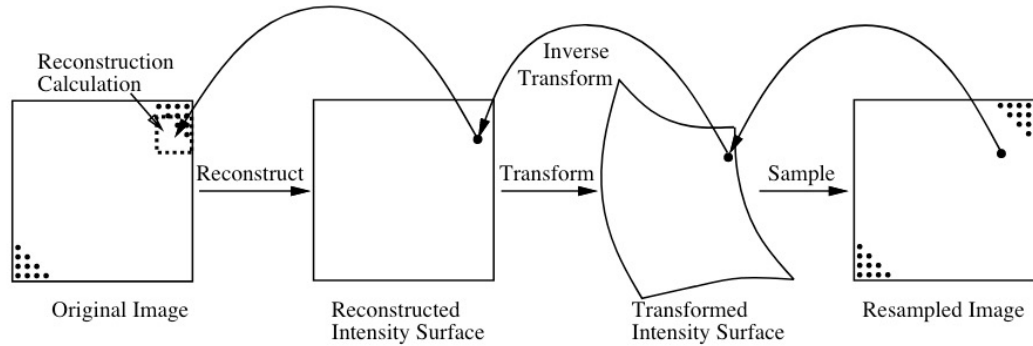
Fast, continuous, better

◆ Interpolation (Mobile) ● LeRF (Mobile) ▲ DNN (Desktop)

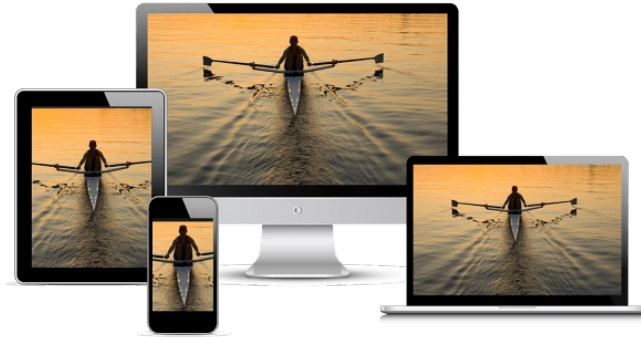


Background: Resampling

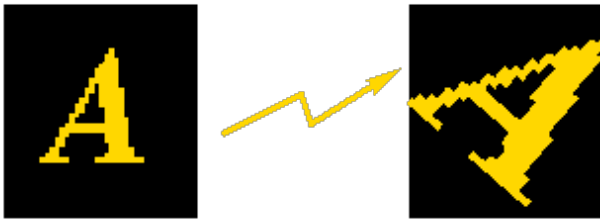
Resampling: discrete \rightarrow continuous \rightarrow discrete



Applications: responsive display, digital zooming

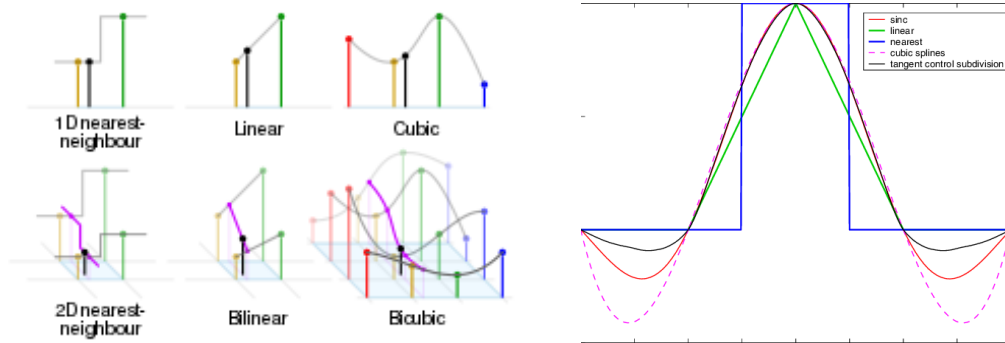


Example: upsample and rotation

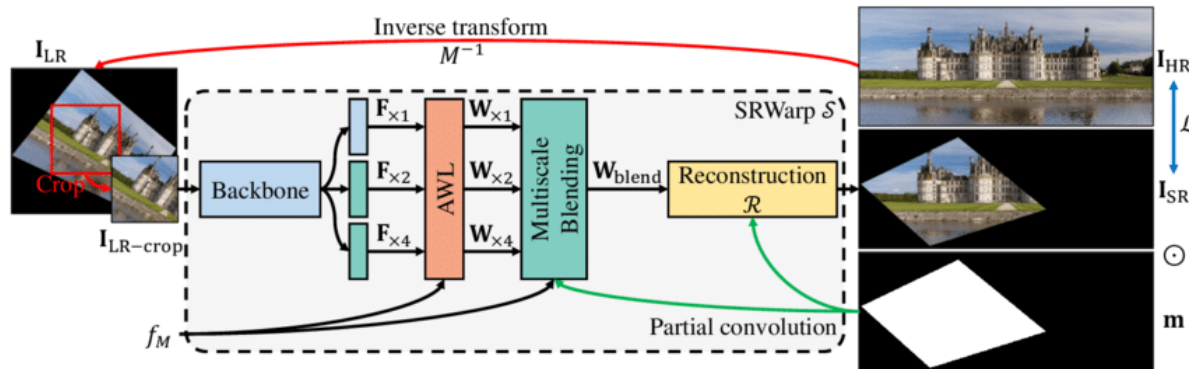
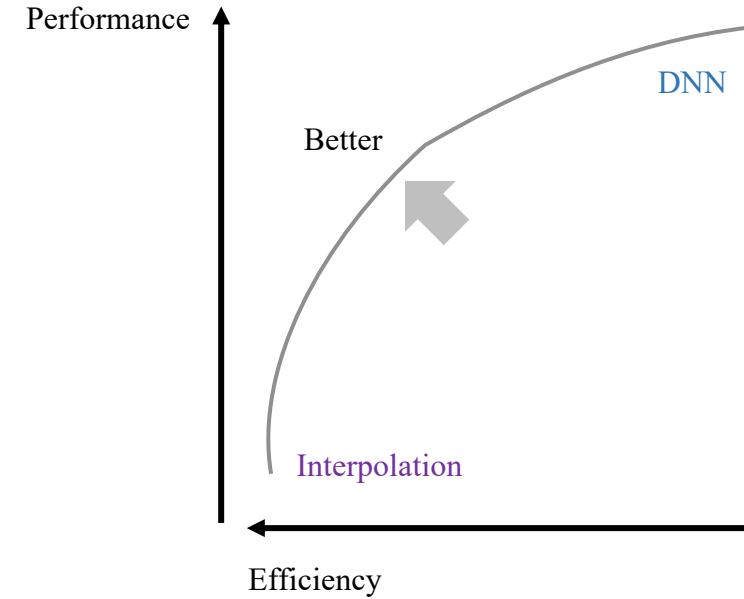


Resampling: Interpolation vs DNN

Resampling via Interpolation



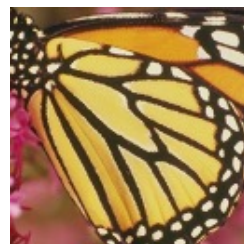
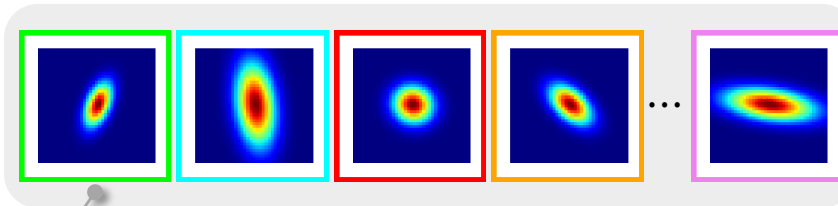
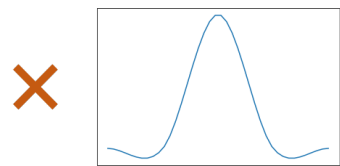
Resampling with DNN



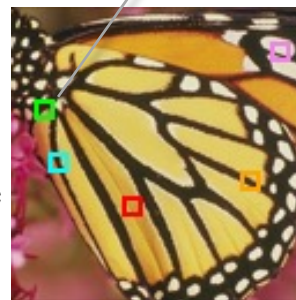
LeRF: Learning Resampling Function

Fixed Bicubic Resampling Function

Learned Steerable Resampling Functions



Downsample



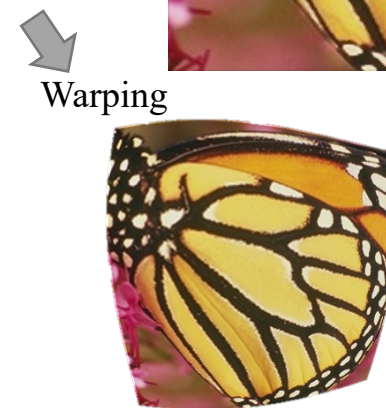
Upsample



Rotation



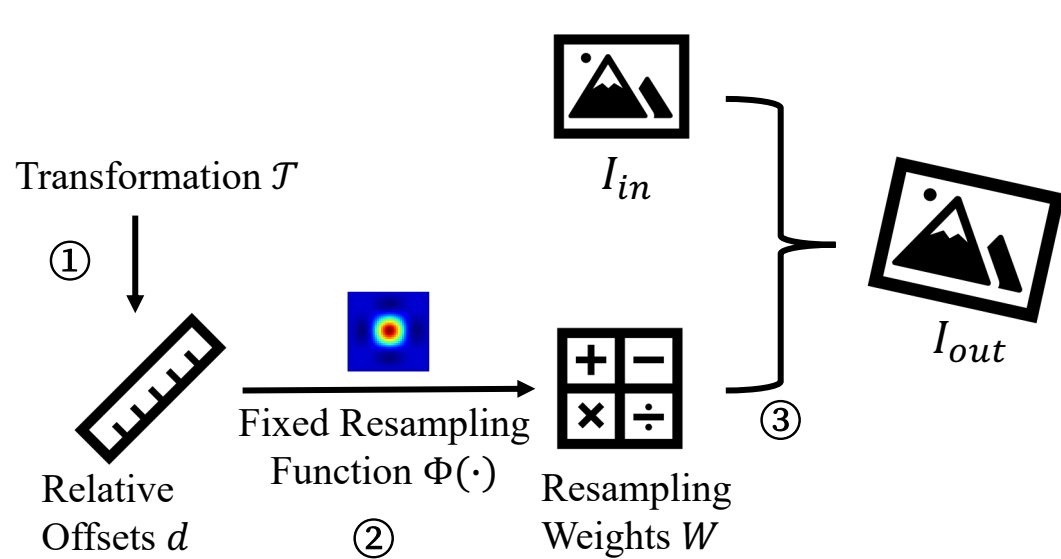
Sheering



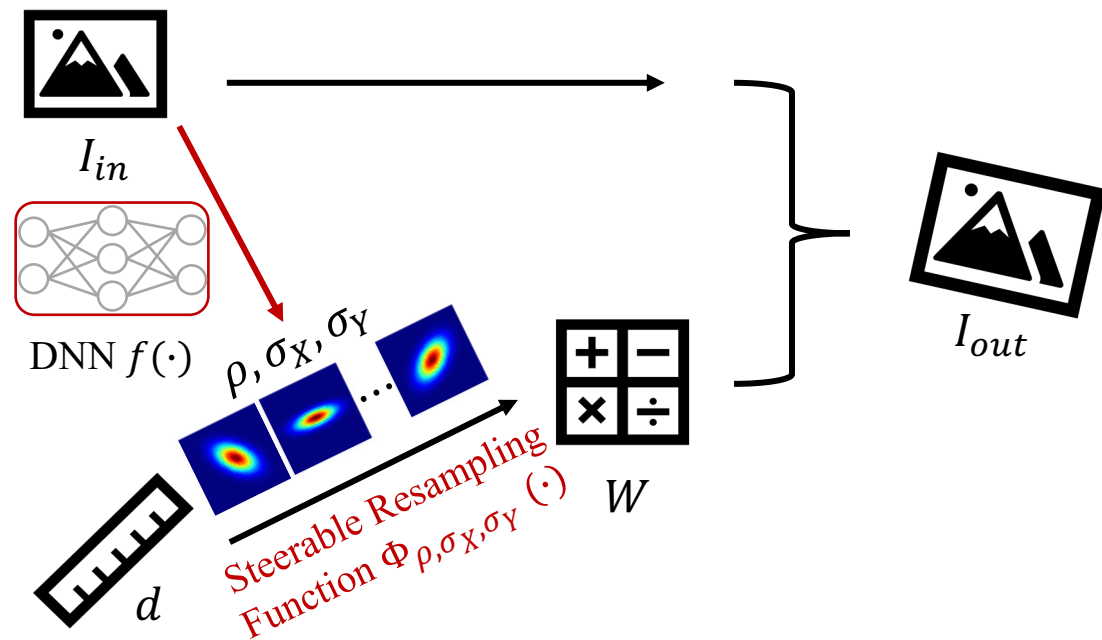
Warping

Fixed vs. Learned Adaptive Resampling

Interpolation: fixed reconstruction



LeRF(Ours): learned adaptive reconstruction



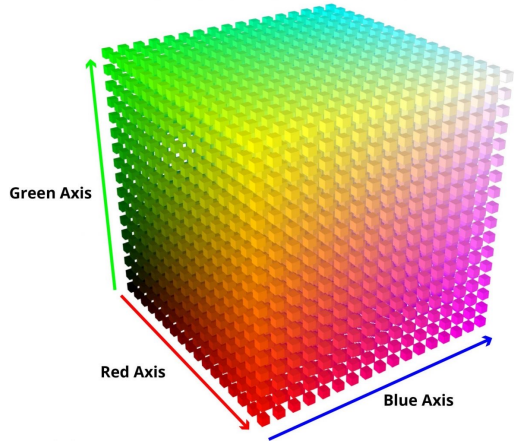
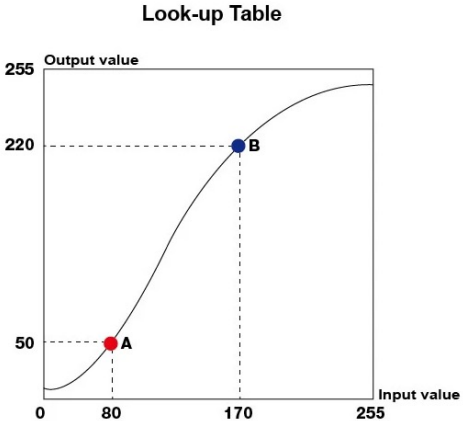
Acceleration with Look-Up Table

A look-up table is composed of index-value pairs. For example, color-to-color pairs.

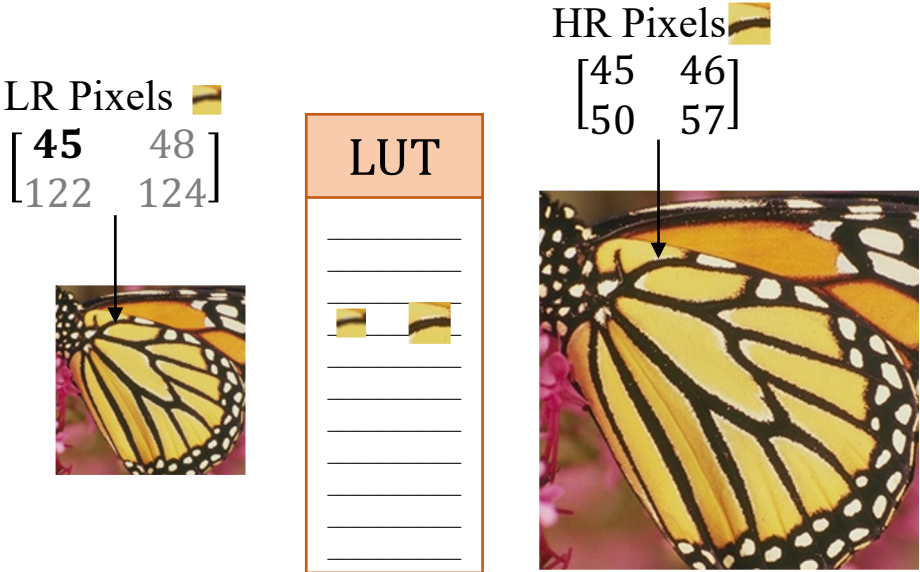
Look-up Table

Input value	Output value
0	5
1	6
2	8
3	10
...	...
79	47
80	50
81	52
169	218
170	220
171	222
...	...
252	248
253	250
254	252
255	254

256 values

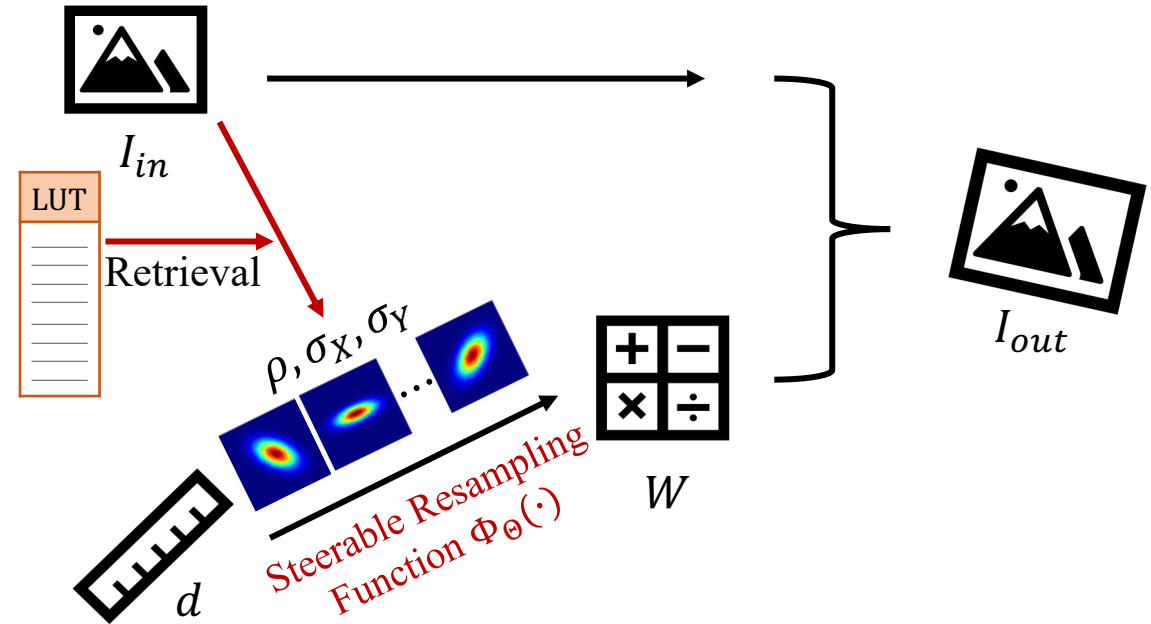
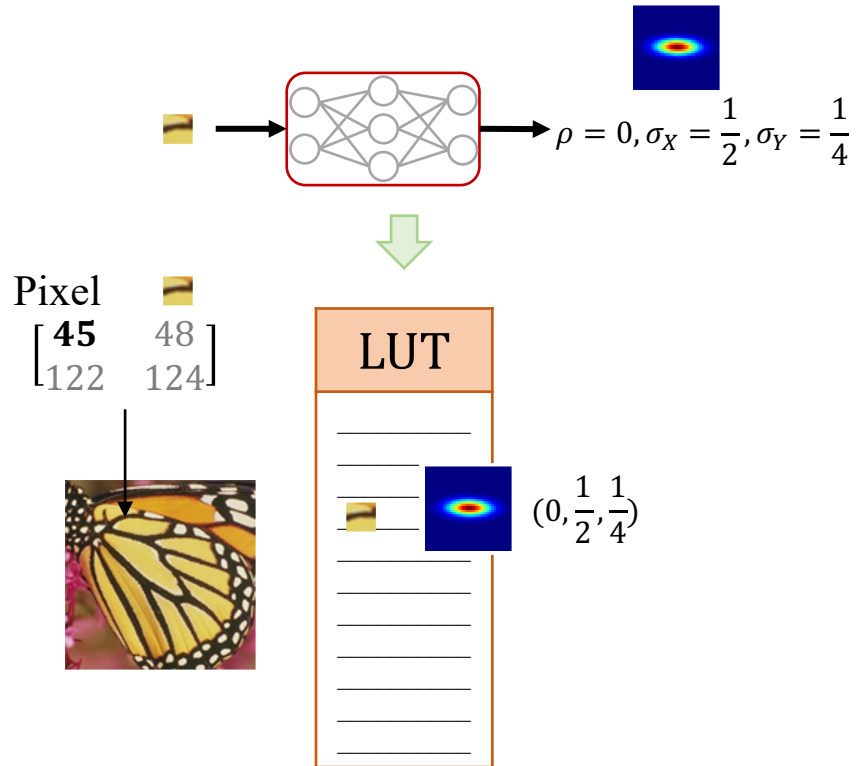


Spatial LUTs stores patch pairs, instead of color mappings.



LUT Acceleration

The predictions of the DNN are cached to pixel-parameter pairs in LUTs.



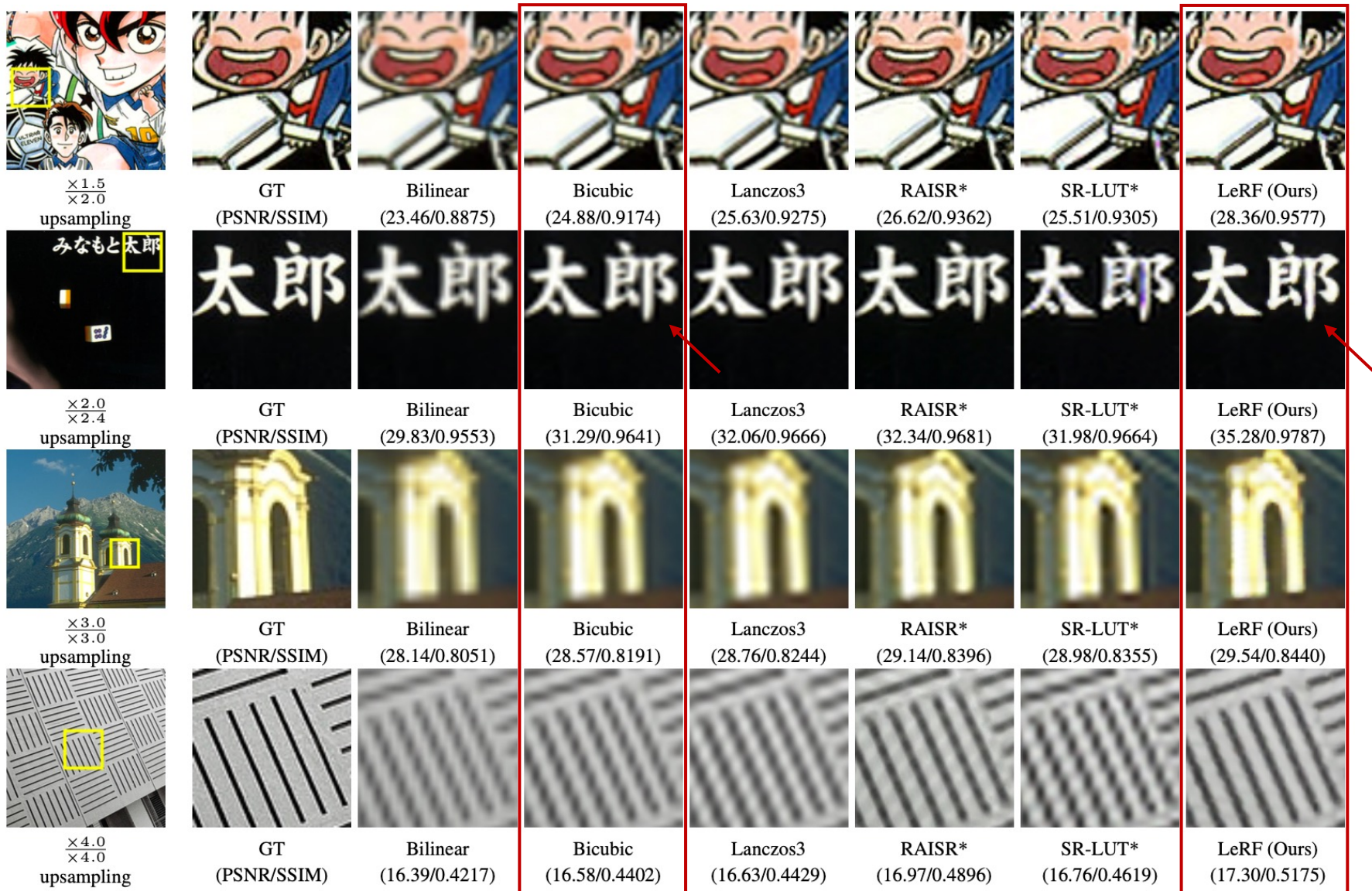
Comparision in Arbitrary-Scale Upsampling

Method	Set5				Set14				BSDS100				Urban100				Manga109			
	$\frac{\times 1.5}{\times 1.5}$	$\frac{\times 1.5}{\times 2.0}$	$\frac{\times 2.0}{\times 2.0}$	$\frac{\times 2.0}{\times 2.4}$	$\frac{\times 1.5}{\times 1.5}$	$\frac{\times 1.5}{\times 2.0}$	$\frac{\times 2.0}{\times 2.0}$	$\frac{\times 2.0}{\times 2.4}$	$\frac{\times 1.5}{\times 1.5}$	$\frac{\times 1.5}{\times 2.0}$	$\frac{\times 2.0}{\times 2.0}$	$\frac{\times 2.0}{\times 2.4}$	$\frac{\times 1.5}{\times 1.5}$	$\frac{\times 1.5}{\times 2.0}$	$\frac{\times 2.0}{\times 2.0}$	$\frac{\times 2.0}{\times 2.4}$	$\frac{\times 1.5}{\times 1.5}$	$\frac{\times 1.5}{\times 2.0}$	$\frac{\times 2.0}{\times 2.0}$	$\frac{\times 2.0}{\times 2.4}$
Nearest	31.34	31.07	30.84	29.63	29.15	28.84	28.57	27.70	28.99	28.72	28.40	27.62	26.21	25.91	25.62	24.78	28.59	28.36	28.14	26.87
Bilinear	34.99	33.19	32.23	31.49	31.68	30.26	29.24	28.70	30.92	29.66	28.67	28.20	28.24	26.91	25.96	25.46	32.45	30.33	29.16	28.28
Bicubic	36.76	34.68	33.64	32.70	33.07	31.45	30.32	29.62	32.14	30.67	29.54	28.93	29.50	27.95	26.87	26.22	34.76	32.13	30.81	29.61
Lanczos2	36.83	34.74	33.70	32.74	33.13	31.50	30.36	29.65	32.19	30.71	29.58	28.95	29.55	28.00	26.91	26.25	34.87	32.22	30.89	29.66
Lanczos3	37.61	35.31	34.23	33.24	<u>33.75</u>	<u>31.97</u>	30.76	30.02	32.74	31.11	29.89	29.23	30.12	28.42	27.25	26.55	<u>36.12</u>	<u>33.06</u>	<u>31.63</u>	30.28
RAISR* [33]	35.50	35.49	<u>35.57</u>	33.38	31.84	31.67	<u>31.71</u>	<u>30.22</u>	30.87	30.68	<u>30.66</u>	29.42	28.77	<u>28.60</u>	<u>28.64</u>	<u>27.01</u>	33.81	<u>33.74</u>	33.88	<u>30.61</u>
SR-LUT* [15]	<u>37.74</u>	<u>35.52</u>	<u>34.47</u>	<u>33.45</u>	33.53	31.79	30.59	29.86	<u>33.06</u>	<u>31.40</u>	30.15	<u>29.45</u>	<u>30.24</u>	28.55	27.39	26.69	35.31	32.30	30.96	29.58
LeRF (Ours)	38.30	36.60	35.71	34.74	34.59	33.06	31.98	31.10	33.76	32.08	30.83	30.09	31.86	30.08	28.86	27.99	36.57	34.79	33.88	32.67
Meta-SR [12]	41.29	-	38.12	-	37.47	-	33.99	-	35.79	-	32.32	-	35.85	-	32.98	-	42.92	-	39.22	-
LIIF [4]	41.22	38.99	38.08	36.99	37.44	35.31	33.96	32.95	35.75	33.68	32.28	31.45	36.70	34.08	32.84	31.70	42.77	40.19	39.13	37.69

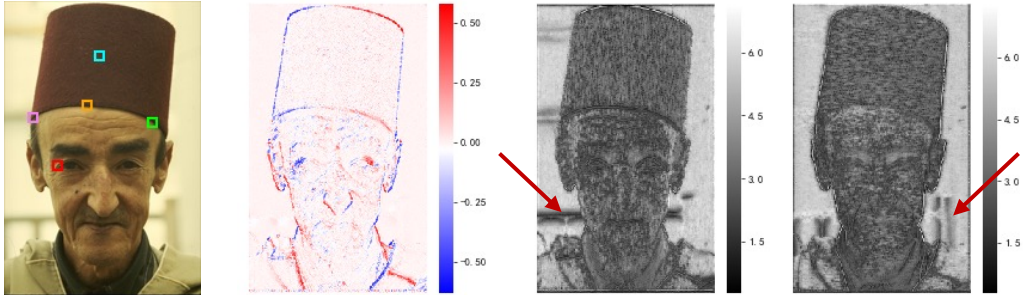
3dB gain

Method	Set5				Set14				BSDS100				Urban100				Manga109			
	$\frac{\times 2.0}{\times 3.0}$	$\frac{\times 3.0}{\times 3.0}$	$\frac{\times 3.0}{\times 4.0}$	$\frac{\times 4.0}{\times 4.0}$	$\frac{\times 2.0}{\times 3.0}$	$\frac{\times 3.0}{\times 3.0}$	$\frac{\times 3.0}{\times 4.0}$	$\frac{\times 4.0}{\times 4.0}$	$\frac{\times 2.0}{\times 3.0}$	$\frac{\times 3.0}{\times 3.0}$	$\frac{\times 3.0}{\times 4.0}$	$\frac{\times 4.0}{\times 4.0}$	$\frac{\times 2.0}{\times 3.0}$	$\frac{\times 3.0}{\times 3.0}$	$\frac{\times 3.0}{\times 4.0}$	$\frac{\times 4.0}{\times 4.0}$	$\frac{\times 2.0}{\times 3.0}$	$\frac{\times 3.0}{\times 3.0}$	$\frac{\times 3.0}{\times 4.0}$	$\frac{\times 4.0}{\times 4.0}$
Nearest	28.87	27.91	26.88	26.25	27.07	26.08	25.33	24.74	27.12	26.17	25.57	25.03	24.25	23.34	22.68	22.17	26.12	25.04	24.06	23.43
Bilinear	30.43	29.53	28.27	27.55	27.94	27.04	26.16	25.51	27.60	26.77	26.11	25.53	24.81	23.99	23.26	22.68	27.21	26.16	24.95	24.19
Bicubic	31.41	30.39	29.12	28.42	28.70	27.63	26.75	26.09	28.18	27.20	26.53	25.95	25.43	24.45	23.71	23.14	28.20	26.95	25.67	24.90
Lanczos2	31.44	30.41	29.14	28.44	28.72	27.64	26.77	26.10	28.20	27.21	26.54	25.96	25.45	24.47	23.73	23.15	28.23	26.97	25.70	24.92
Lanczos3	31.85	30.79	29.49	28.78	<u>29.04</u>	27.91	27.01	26.31	28.43	27.39	26.70	26.10	25.71	24.68	23.92	23.32	28.70	27.38	26.02	25.21
RAISR* [33]	<u>32.35</u>	<u>31.87</u>	<u>29.91</u>	<u>29.65</u>	<u>29.04</u>	<u>28.62</u>	<u>27.10</u>	<u>26.86</u>	28.24	<u>27.84</u>	26.68	<u>26.42</u>	<u>25.92</u>	<u>25.50</u>	<u>24.08</u>	<u>23.89</u>	<u>29.30</u>	<u>28.73</u>	<u>26.40</u>	<u>26.12</u>
SR-LUT* [15]	32.04	31.00	29.70	29.00	28.88	27.84	26.95	26.30	<u>28.62</u>	27.54	<u>26.84</u>	26.21	25.83	24.78	24.00	23.39	28.03	26.74	25.39	24.72
LeRF (Ours)	33.17	32.02	30.86	30.15	30.06	28.84	28.05	27.35	29.15	28.00	27.31	26.70	26.90	25.68	24.88	24.23	30.86	29.48	28.10	27.25
Meta-SR [12]	-	34.71	-	32.48	-	30.56	-	28.83	-	29.26	-	27.73	-	28.91	-	26.69	-	34.37	-	31.32
LIIF [4]	35.63	34.59	33.17	32.37	31.68	30.39	29.45	28.65	30.47	29.24	28.42	27.73	30.23	28.80	27.55	26.66	35.73	34.17	32.29	31.19

Visual Comparison



Visualization of Learned Resampling Functions

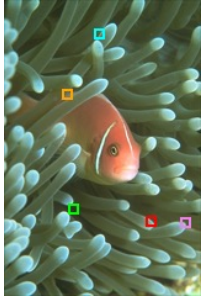
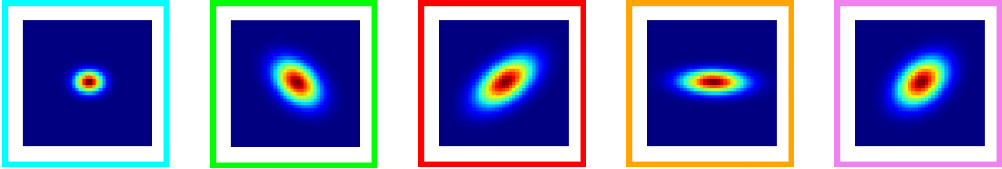


Input

ρ

$1/\sigma_x$

$1/\sigma_y$

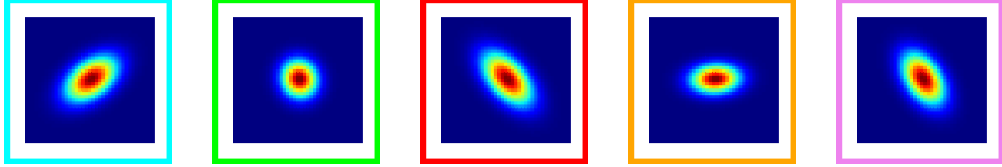


Input

ρ

$1/\sigma_x$

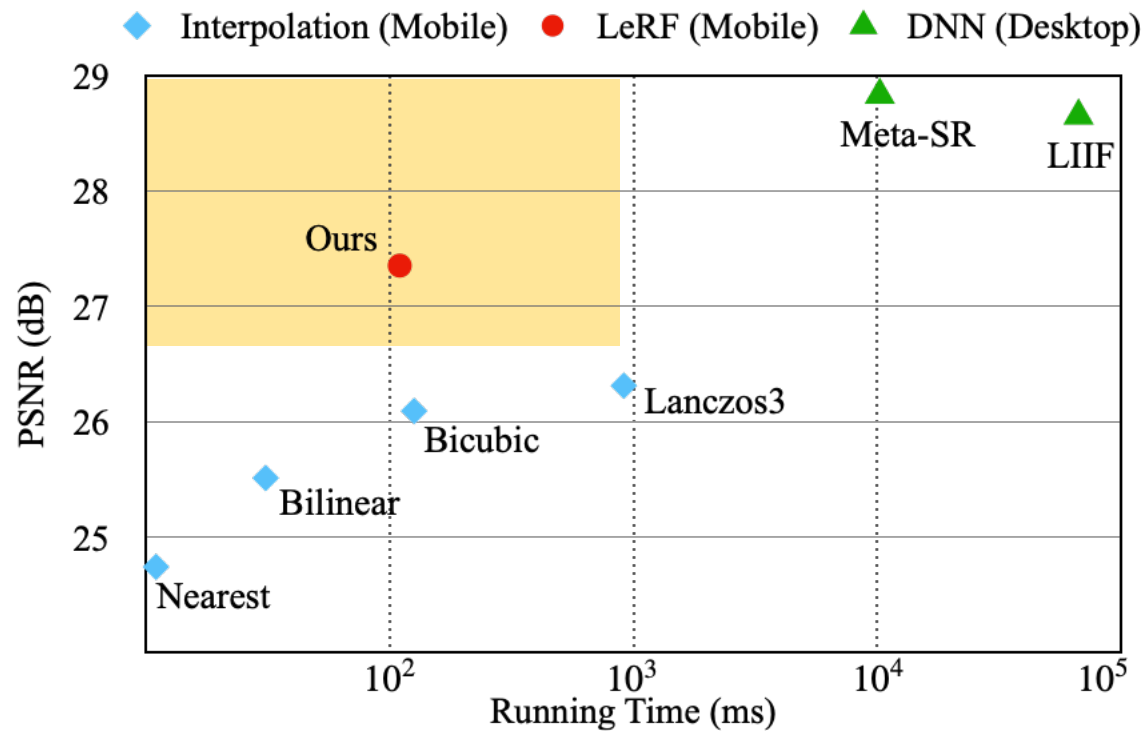
$1/\sigma_y$



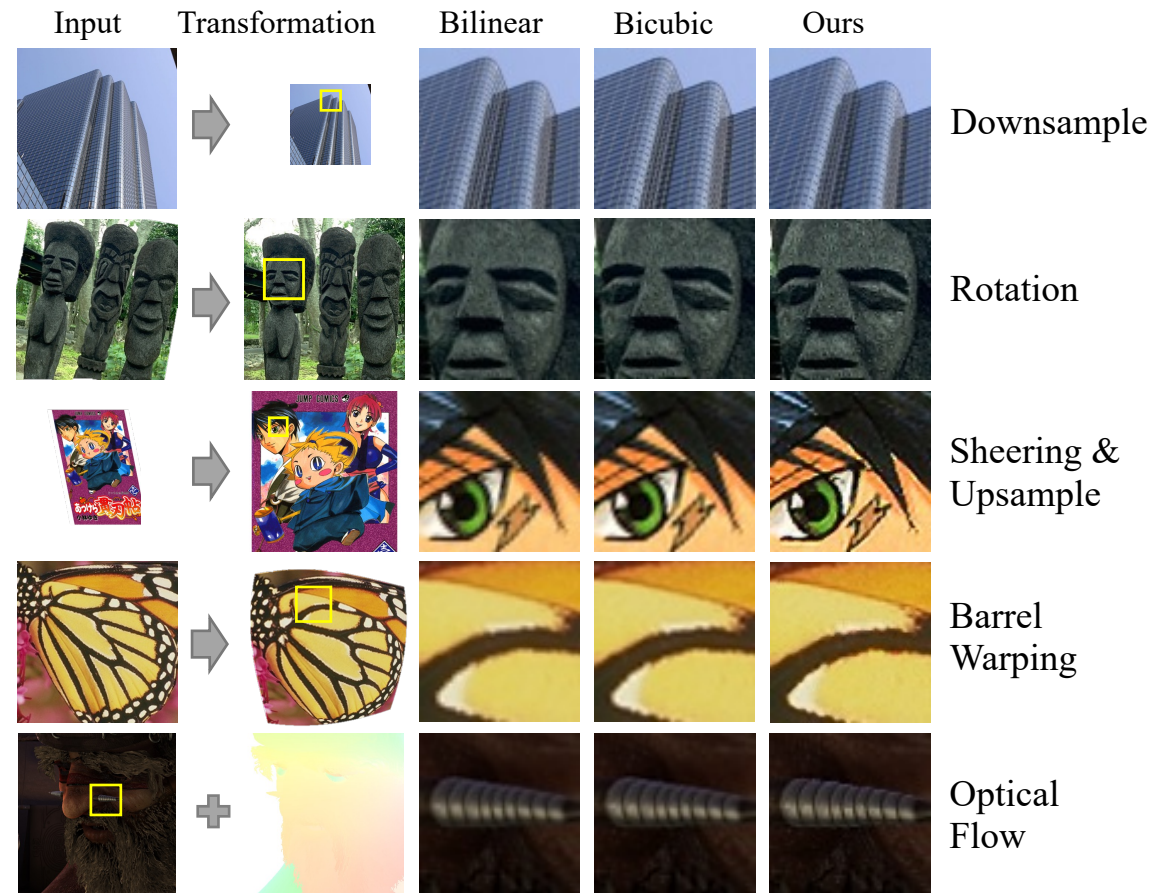
Efficiency: RunTime, MACs, and Storage

- ✓ Fast
- ✓ Continuous
- ✓ Better

Method	RunTime (ms)	MACs	Storage Size	PSNR/SSIM (dB)/-
Nearest	11	-	-	24.74/0.6553
Bilinear	31	14.74M	-	25.51/0.6824
Bicubic	126	51.61M	-	26.09/0.7056
Lanczos2	494	110.59M	-	26.10/0.7058
Lanczos3	914	165.89M	-	26.31/0.7130
RAISR* [33]	3,744	-	3.19MB	26.86/0.7357
SR-LUT* [15]	137	53.33M	81.56KB	26.30/0.7256
LeRF (Ours)	110	57.94M	1.67MB	27.35/0.7475
MetaSR [12]	10,260	1.68T	85.59MB	28.83/0.7876
LIIF [4]	67,080	2.54T	255.76MB	28.65/0.7878



Generalization to Arbitrary Transformation



Continuous Resampling Results

Continuous upsampling

Arbitrary homographic transformation

Upsample x1.00

Bicubic



LeRF (Ours)



Bicubic



LeRF (Ours)



Thanks

Code and model at
<https://lerf.pages.dev>

