Lightweight and Accurate Recursive Fractal Network for Image Super-Resolution

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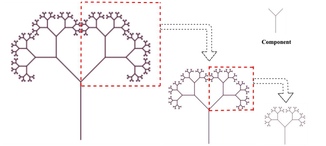
Fractal



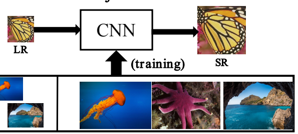
The fractal structure is usually defined as "a rough or fragmentary geometry, it can be divided into several parts, and each part is (at least approximately) an overall reduced shape". It has the following characteristics:

(a). self-similarity.

(b). infinitely fine structure.

(c). can be defined by a simple method and generated by recursion and iteration.

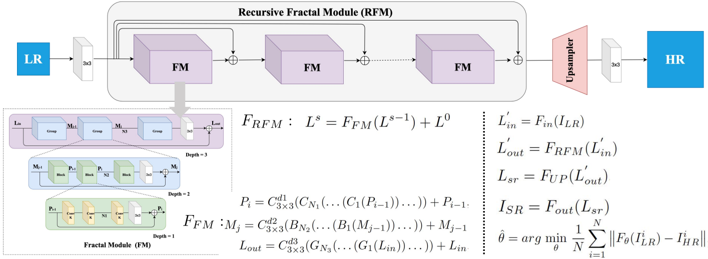
Objective



(I). We aim to explore a lightweight and accurate SISR framework.

(II). We aim to simplify the design of network structure by introducing the fractal structure.

Model



$$F_{RFM}: \quad L^s = F_{FM}(L^{s-1}) + L^0$$

$$P_i = C^{d1}_{3\times3}(C_{N_1}(\ldots(C_1(P_{i-1}))\ldots)) + P_{i-1}$$

$$F_{FM}: M_j = C^{d2}_{3\times3}(B_{N_2}(\ldots(B_1(M_{j-1}))\ldots)) + M_{j-1}$$

$$L_{out} = C^{d3}_{3\times3}(G_{N_3}(\ldots(G_1(L_{in}))\ldots)) + L_{in}$$

$$L'_{in} = F_{in}(I_{LR})$$

$$L'_{out} = F_{RFM}(L'_{in})$$

$$L_{sr} = F_{UP}(L'_{out})$$

$$I_{SR} = F_{out}(L_{sr})$$

$$\hat{\theta} = arg\min_{\theta} \frac{1}{N}\sum_{i=1}^{N} \|F_\theta(I^i_{LR}) - I^i_{HR}\|_1$$

Contributions

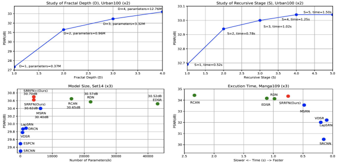
(1). We propose a fractal module (FM) to simplify the model design, which can generate an infinite number of new structures via a simple component.

(2). We develop a Super Resolution Recursive Fractal Network, which introduces the fractal module and recursive learning mechanism to maximize the model performance.

(3). SRRFN achieves superior results with fewer parameters and faster execution time. Especially, it achieves state-of-the-art results in BD and DN degrade models.

(4). We introduced the fractal structure to simplify the design of the network structure. Meanwhile, the fractal structure can be easily integrated with modern modules to create unlimited possibilities.

Analysis



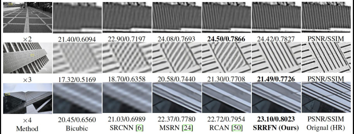
Algorithm	Scale	Parameters	Set5 [3] PSNR / SSIM / Time	Set14 [45] PSNR / SSIM / Time	BSDS100 [2] PSNR / SSIM / Time	Urban100 [15] PSNR / SSIM / Time	Manga109 [31] PSNR / SSIM / Time	Average PSNR / SSIM / Time
RCAN [50]	×2	15.44M	**38.27 / 0.9614** / 0.60s	**34.12 / 0.9216** / 1.11s	**32.41 / 0.9027** / 0.75s	**33.34 / 0.9384** / 3.78s	**39.44 / 0.9786** / 4.55s	**35.52 / 0.9405** / 2.16s
SRRFN (Ours)	×2	4.06M	38.18 / 0.9612 / 0.21s	33.97 / 0.9210 / 0.35s	32.35 / 0.9018 / 0.24s	33.04 / 0.9361 / 1.07s	39.23 / 0.9781 / 1.25s	35.35 / 0.9396 / 0.61s
RCAN [50]	×3	15.63M	**34.74 / 0.9299** / 0.34s	**30.65 / 0.8482** / 0.55s	**29.32 / 0.8111** / 0.41s	**29.09 / 0.8702** / 1.89s	**34.44 / 0.9499** / 2.33s	**31.65 / 0.8818** / 1.10s
SRRFN (Ours)	×3	4.24M	**34.74** / 0.9296 / 0.17s	30.62 / 0.8478 / 0.23s	29.29 / 0.8100 / 0.16s	28.98 / 0.8689 / 0.62s	34.36 / 0.9491 / 0.79s	31.60 / 0.8811 / 0.39s
RCAN [50]	×4	15.59M	**32.63 / 0.9002** / 0.30s	**28.87 / 0.7889** / 0.40s	**27.77 / 0.7436** / 0.30s	**26.82 / 0.8087** / 1.21s	**31.22 / 0.9173** / 1.50s	**29.46 / 0.8317** / 0.74s
SRRFN (Ours)	×4	4.21M	32.56 / 0.8993 / 0.16s	28.86 / 0.7882 / 0.19s	27.75 / 0.7424 / 0.16s	26.78 / 0.8071 / 0.47s	**31.22** / 0.9159 / 0.58s	29.43 / 0.8318 / 0.31s

Results

	Algorithm	Scale	Set5 [3] PSNR / SSIM	Set14 [45] PSNR / SSIM	BSDS100 [2] PSNR / SSIM	Urban100 [15] PSNR / SSIM	Manga109 [31] PSNR / SSIM	Average PSNR / SSIM
BI	Bicubic	×2	33.66 / 0.9299	30.24 / 0.8688	29.56 / 0.8431	26.88 / 0.8403	30.80 / 0.9339	30.23 / 0.8832
	SRCNN [6]	×2	36.66 / 0.9542	32.45 / 0.9067	31.36 / 0.8879	29.50 / 0.8946	35.60 / 0.9663	33.11 / 0.9219
	LapSRN [21]	×2	37.52 / 0.9591	33.08 / 0.9130	31.80 / 0.8950	30.41 / 0.9101	37.27 / 0.9740	34.02 / 0.9302
	VDSR [18]	×2	37.53 / 0.9590	33.05 / 0.9130	31.90 / 0.8960	30.77 / 0.9140	37.22 / 0.9750	34.09 / 0.9314
	MemNet [35]	×2	37.78 / 0.9597	33.28 / 0.9142	32.08 / 0.8978	31.31 / 0.9195	37.72 / 0.9740	34.43 / 0.9330
	SRMDNF [47]	×2	37.79 / 0.9601	33.32 / 0.9159	32.05 / 0.8985	31.33 / 0.9204	38.07 / 0.9761	34.51 / 0.9342
	MSRN [24]	×2	38.07 / 0.9608	33.68 / 0.9184	32.22 / 0.9002	32.32 / 0.9304	38.64 / 0.9771	34.99 / 0.9374
	D_DBPN []	×2	38.09 / 0.9600	33.85 / 0.9190	32.27 / 0.9000	32.55 / 0.9324	38.89 / 0.9775	35.13 / 0.9378
	MDSR [26]	×2	38.11 / 0.9602	33.85 / 0.9198	32.29 / 0.9007	32.84 / 0.9347	38.96 / 0.9776	35.21 / 0.9386
	EDSR [26]	×2	38.11 / 0.9602	33.92 / 0.9195	32.32 / 0.9013	32.93 / 0.9351	39.10 / 0.9773	35.27 / 0.9387
	RDN [51]	×2	**38.24 / 0.9614**	34.01 / 0.9212	32.34 / 0.9017	32.89 / 0.9353	39.18 / 0.9780	35.33 / 0.9395
	SRRFN (Ours)	×2	38.18 / 0.9612	33.97 / 0.9210	32.35 / 0.9018	33.04 / 0.9361	39.23 / 0.9781	35.35 / 0.9396
	SRRFN+ (Ours)	×2	**38.24 / 0.9614**	**34.13 / 0.9224**	**32.39 / 0.9023**	**33.24 / 0.9378**	**39.43 / 0.9786**	**33.49 / 0.9405**
	Bicubic	×3	30.39 / 0.8682	27.55 / 0.7742	27.21 / 0.7385	24.46 / 0.7349	26.95 / 0.8556	27.31 / 0.7943
	SRCNN [6]	×3	32.75 / 0.9090	29.30 / 0.8215	28.41 / 0.7863	26.24 / 0.7989	30.48 / 0.9117	29.44 / 0.8455
	VDSR [18]	×3	33.67 / 0.9210	29.78 / 0.8320	28.83 / 0.7990	27.14 / 0.8290	32.01 / 0.9340	30.29 / 0.8630
	LapSRN [21]	×3	33.82 / 0.9227	29.87 / 0.8320	28.82 / 0.7980	27.07 / 0.8280	32.21 / 0.9350	30.36 / 0.8631
	MemNet [37]	×3	34.09 / 0.9248	30.00 / 0.8350	28.96 / 0.8001	27.56 / 0.8376	32.51 / 0.9369	30.62 / 0.8669
	SRMDNF [47]	×3	34.12 / 0.9254	30.04 / 0.8382	28.97 / 0.8025	27.57 / 0.8398	33.00 / 0.9403	30.74 / 0.8692
	MSRN [24]	×3	34.48 / 0.9276	30.40 / 0.8436	29.13 / 0.8061	28.31 / 0.8560	33.56 / 0.9451	31.18 / 0.8757
	MDSR [26]	×3	34.66 / 0.9280	30.44 / 0.8452	29.25 / 0.8091	28.79 / 0.8655	34.17 / 0.9472	31.46 / 0.8790
	EDSR [26]	×3	34.65 / 0.9280	30.52 / 0.8462	29.25 / 0.8093	28.80 / 0.8653	34.17 / 0.9476	31.48 / 0.8793
	RDN [51]	×3	34.71 / 0.9296	30.57 / 0.8468	29.26 / 0.8093	28.80 / 0.8653	34.13 / 0.9484	31.49 / 0.8799
	SRRFN (Ours)	×3	34.74 / 0.9296	30.62 / 0.8478	29.29 / 0.8100	28.98 / 0.8689	34.36 / 0.9491	31.60 / 0.8811
	SRRFN+ (Ours)	×3	**34.84 / 0.9303**	**30.70 / 0.8490**	**29.35 / 0.8110**	**29.21 / 0.8721**	**34.66 / 0.9505**	**31.75 / 0.8826**
	Bicubic	×4	28.42 / 0.8104	26.00 / 0.7027	25.96 / 0.6675	23.14 / 0.6577	24.89 / 0.7866	25.62 / 0.7250
	SRCNN [6]	×4	30.48 / 0.8628	27.50 / 0.7513	26.90 / 0.7101	24.52 / 0.7221	27.58 / 0.8555	27.40 / 0.7804
	VDSR [18]	×4	31.35 / 0.8830	28.02 / 0.7680	27.29 / 0.7267	25.18 / 0.7540	28.83 / 0.8870	28.13 / 0.8037
	LapSRN [21]	×4	31.54 / 0.8850	28.19 / 0.7720	27.32 / 0.7270	25.21 / 0.7560	29.09 / 0.8900	28.27 / 0.8060
	MemNet [37]	×4	31.74 / 0.8893	28.26 / 0.7723	27.40 / 0.7281	25.50 / 0.7630	29.42 / 0.8942	28.46 / 0.8094
	SRMDNF [47]	×4	31.96 / 0.8925	28.35 / 0.7787	27.49 / 0.7337	25.68 / 0.7731	30.09 / 0.9024	28.71 / 0.8161
	MSRN [24]	×4	32.25 / 0.8958	28.63 / 0.7833	27.61 / 0.7377	26.20 / 0.7905	30.57 / 0.9103	29.05 / 0.8235
	D_DBPN [10]	×4	32.47 / 0.8980	28.82 / 0.7860	27.72 / 0.7400	26.38 / 0.7946	30.91 / 0.9137	29.26 / 0.8265
	RDN [51]	×4	32.47 / 0.8990	28.81 / 0.7871	27.72 / 0.7419	26.61 / 0.8028	31.00 / 0.9151	29.32 / 0.8292
	EDSR [26]	×4	32.46 / 0.8968	28.80 / 0.7876	27.71 / 0.7420	26.64 / 0.8033	31.02 / 0.9148	29.33 / 0.8289
	MDSR [26]	×4	32.50 / 0.8973	28.72 / 0.7857	27.72 / 0.7418	26.67 / 0.8041	31.11 / 0.9146	29.34 / 0.8287
	SRRFN (Ours)	×4	32.56 / 0.8993	28.86 / 0.7882	27.75 / 0.7424	26.78 / 0.8071	31.22 / 0.9159	29.43 / 0.8306
	SRRFN+ (Ours)	×4	**32.66 / 0.9006**	**28.95 / 0.7900**	**27.81 / 0.7437**	**26.98 / 0.8113**	**31.56 / 0.9190**	**29.59 / 0.8329**

Model	Methods	Set5 PSNR / SSIM	Set14 PSNR / SSIM	BSDS100 PSNR / SSIM	Urban100 PSNR / SSIM	Manga109 PSNR / SSIM	Average PSNR / SSIM
BD	Bicubic	28.34 / 0.8161	26.12 / 0.7106	26.02 / 0.6733	23.20 / 0.6601	25.03 / 0.7987	25.74 / 0.7318
	SRCNN [6]	31.63 / 0.8888	28.52 / 0.7924	27.76 / 0.7526	25.31 / 0.7612	28.79 / 0.8851	28.40 / 0.8159
	VDSR [18]	33.30 / 0.9159	29.67 / 0.8269	28.63 / 0.7903	26.75 / 0.8145	31.66 / 0.9260	30.00 / 0.8547
	SRMD(NF) [47]	34.09 / 0.9242	30.11 / 0.8364	28.98 / 0.8009	27.50 / 0.8370	32.97 / 0.9391	30.73 / 0.8675
	RDN [51]	34.57 / 0.9280	30.53 / 0.8447	29.23 / 0.8079	28.46 / 0.8581	33.97 / 0.9465	31.35 / 0.8770
	SRFBN [25]	34.66 / 0.9283	30.48 / 0.8439	29.21 / 0.8069	28.48 / 0.8581	34.07 / 0.9466	31.38 / 0.8768
	RCAN [50]	34.70 / 0.9288	30.63 / 0.8462	29.32 / 0.8093	28.81 / 0.8647	34.38 / 0.9483	31.57 / 0.8795
	SRRFN (Ours)	34.77 / 0.9293	30.67 / 0.8469	29.31 / 0.8096	28.85 / 0.8653	34.51 / 0.9489	31.62 / 0.8800
	SRRFN+ (Ours)	**34.86 / 0.9299**	**30.76 / 0.8479**	**29.36 / 0.8105**	**29.06 / 0.8682**	**34.80 / 0.9502**	**31.77 / 0.8813**
DN	Bicubic	24.14 / 0.5445	23.14 / 0.4828	22.94 / 0.4461	21.63 / 0.4701	23.08 / 0.5448	22.99 / 0.4977
	SRCNN [6]	27.16 / 0.7672	25.49 / 0.6580	25.11 / 0.6151	23.32 / 0.6500	25.78 / 0.7889	25.37 / 0.6958
	VDSR [18]	27.72 / 0.7872	25.92 / 0.6786	25.52 / 0.6345	23.83 / 0.6797	26.41 / 0.8130	25.88 / 0.7186
	SRMD(NF) [47]	27.74 / 0.8026	26.13 / 0.6974	25.64 / 0.6495	24.28 / 0.7092	26.72 / 0.8424	26.10 / 0.7402
	RDN [51]	28.46 / 0.8151	26.60 / 0.7101	25.93 / 0.6573	24.92 / 0.7362	28.00 / 0.8590	26.78 / 0.7555
	SRFBN [25]	28.53 / 0.8182	26.60 / 0.7144	25.95 / 0.6625	24.99 / 0.7424	28.02 / 0.8618	26.82 / 0.7599
	SRRFN (Ours)	28.57 / 0.8194	26.69 / 0.7155	25.98 / 0.6630	25.21 / 0.7506	28.21 / 0.8646	26.93 / 0.7626
	SRRFN+ (Ours)	**28.66 / 0.8211**	**26.75 / 0.7169**	**26.02 / 0.6639**	**25.34 / 0.7538**	**28.37 / 0.8672**	**27.03 / 0.7646**

Visual Comparison


×2
21.40/0.6094
22.90/0.7197
24.08/0.7693
24.50/0.7866
24.42/0.7827
PSNR/SSIM
×3
17.32/0.5169
18.70/0.6358
20.58/0.7440
21.30/0.7708
21.49/0.7726
PSNR/SSIM
×4
20.45/0.6560
21.03/0.6989
22.37/0.7780
22.72/0.7954
23.10/0.8023
PSNR/SSIM
Method
Bicubic
SRCNN [6]
MSRN [24]
RCAN [50]
SRRFN (Ours)
Orignal (HR)

MIVRC: https://github.com/MIVRC SRRFN: https://github.com/MIVRC/SRRFN-PyTorch Homepage: https://junchenglee.com