Investigating Generalized Strategy for Single-Image Satellite Super-Resolution Using Deep Learning

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ESA - LIVING PLANET SYMPOSIUM

Why Super-Resolution?

- Enhances spatial resolution of satellite images
- Improves remote sensing applications (e.g., object detection, segmentation)
- Overcomes limitations of low-resolution sensors and environmental constraints

Challenges in Singe Image Satellite SR

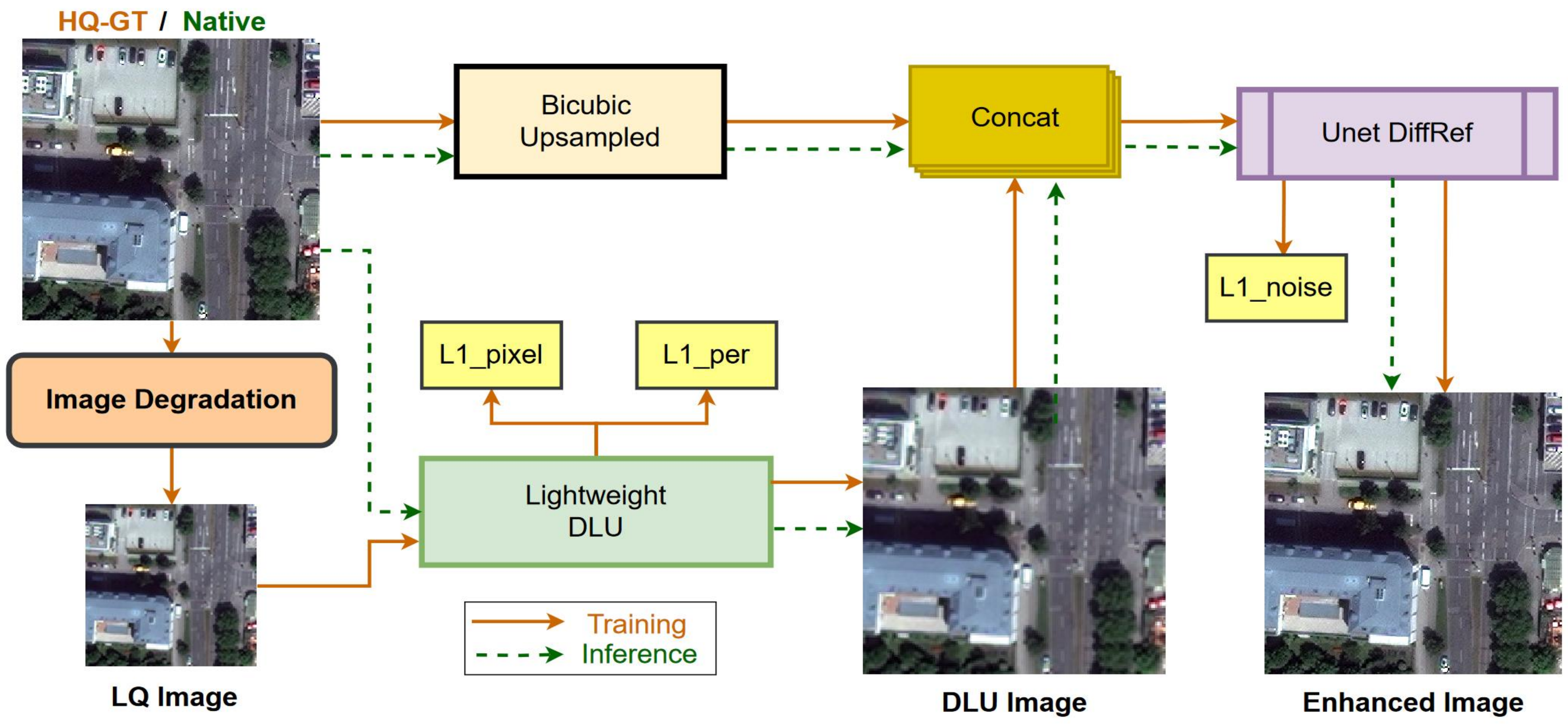
- Domain gaps between sensors and GSDs
- Traditional methods (interpolation, wavelet, sparse representation) lack robustness
- Deep learning needs LR/HR pairs for training and risks hallucinations
- Difficulty generalizing to unseen low-resolution satellite data

Impact

- Addresses domain gaps in SR
- X2 upscaling minimizes hallucination while improving clarity
- Enhances monitoring, planning, agriculture with minimal detail risks
- Provides robust, generalized SR for diverse low-resolution imagery

Our Approach: U2D2 Framework

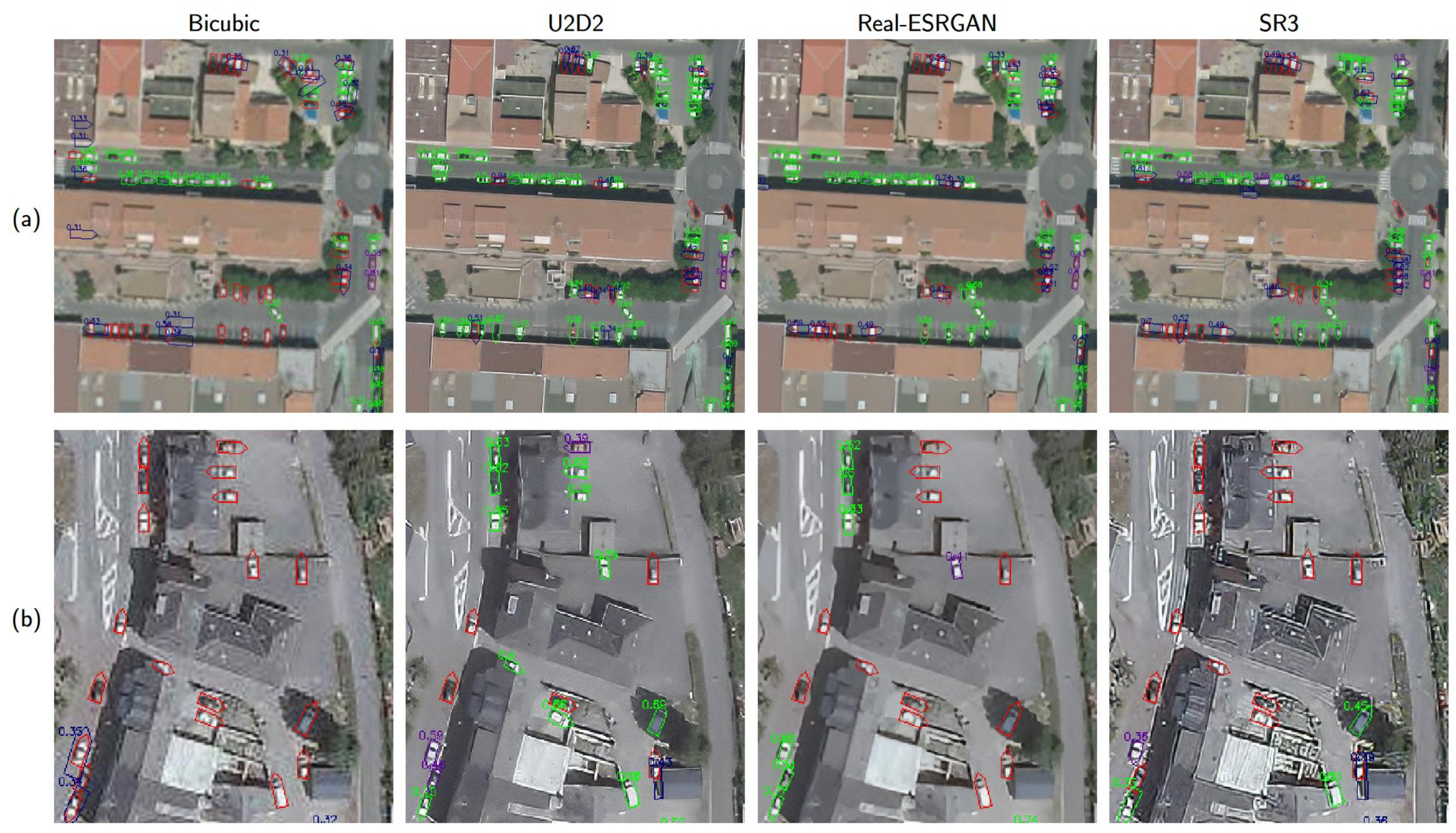
- Modular pipeline: Deep Learning Upsampler (DLU) + Diffusion-based Refinement
- Trained on high-resolution aerial/satellite images (GSD < 1 m) for X2 upscaling
- Generalizes to low-resolution Sentinel-2 and similar images



Vehicle Detection

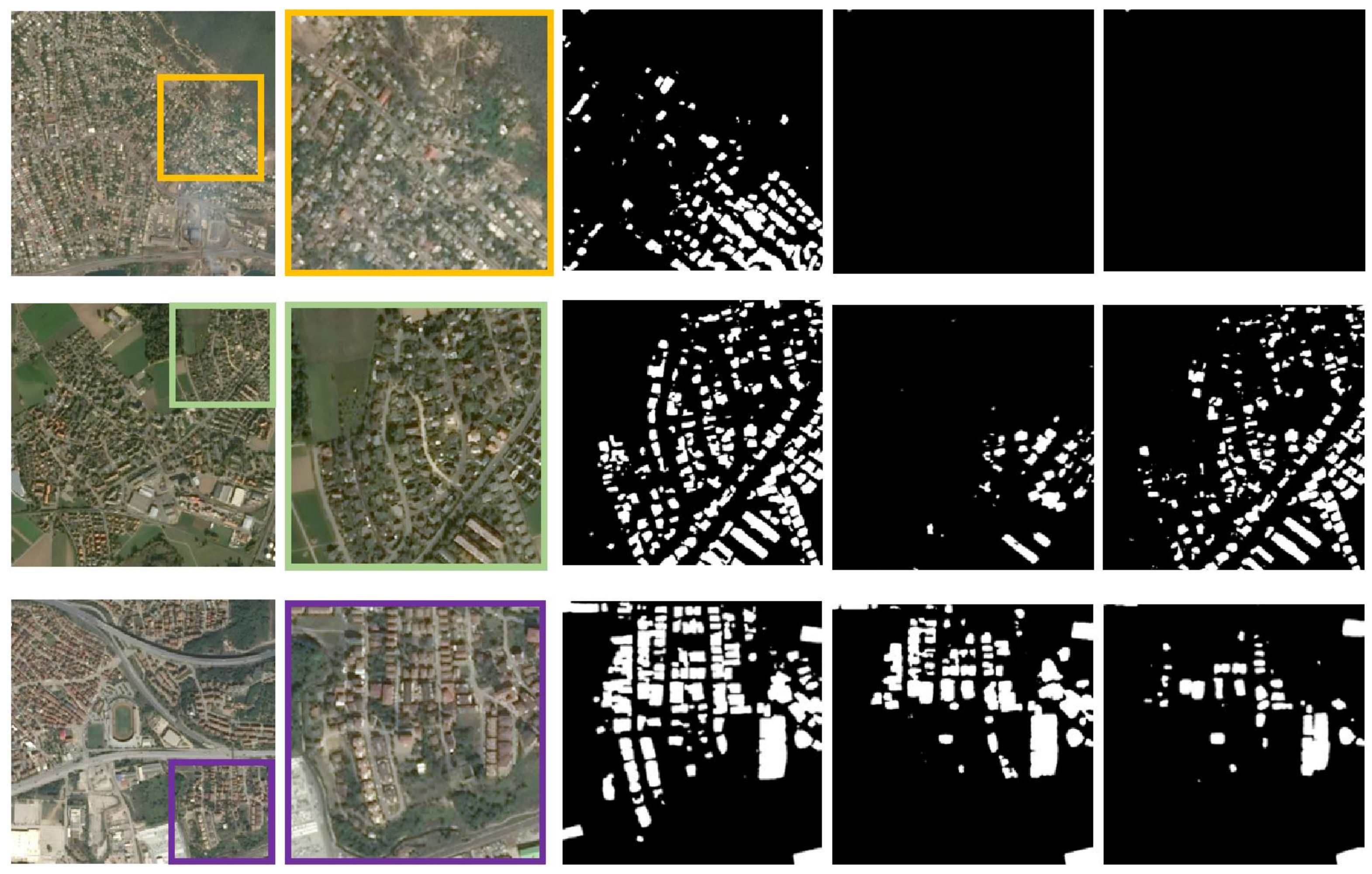
- Confusion plot of DINO-OBB comparing results from four SR methods, with a 0.3 confidence threshold and 50% IoU for TP detection.

Metrics	Bicubic	EDSR	ESRGAN	RealESRGAN	SR3	U2D2
AP_{50} ↑	25.4508	22.5152	26.8578	**62.2921**	50.4800	**68.6954**
TP / TP_{OBB} (+-10°) ↑	73.5007	74.5914	73.6375	**78.2391**	71.5581	**80.2761**



Building Segmentation

- Building segmentation results from HRNet applied to three SR SPOT scenes, upsampled from 1.2 m to 60 cm GSD using Real-ESRGAN, SR3, and our U2D2 method.



(a) RGB image (b) Zoomed RGB (c) U2D2 (d) Real-ESRGAN (e) SR3

Road Segmentation on Sentinel-2

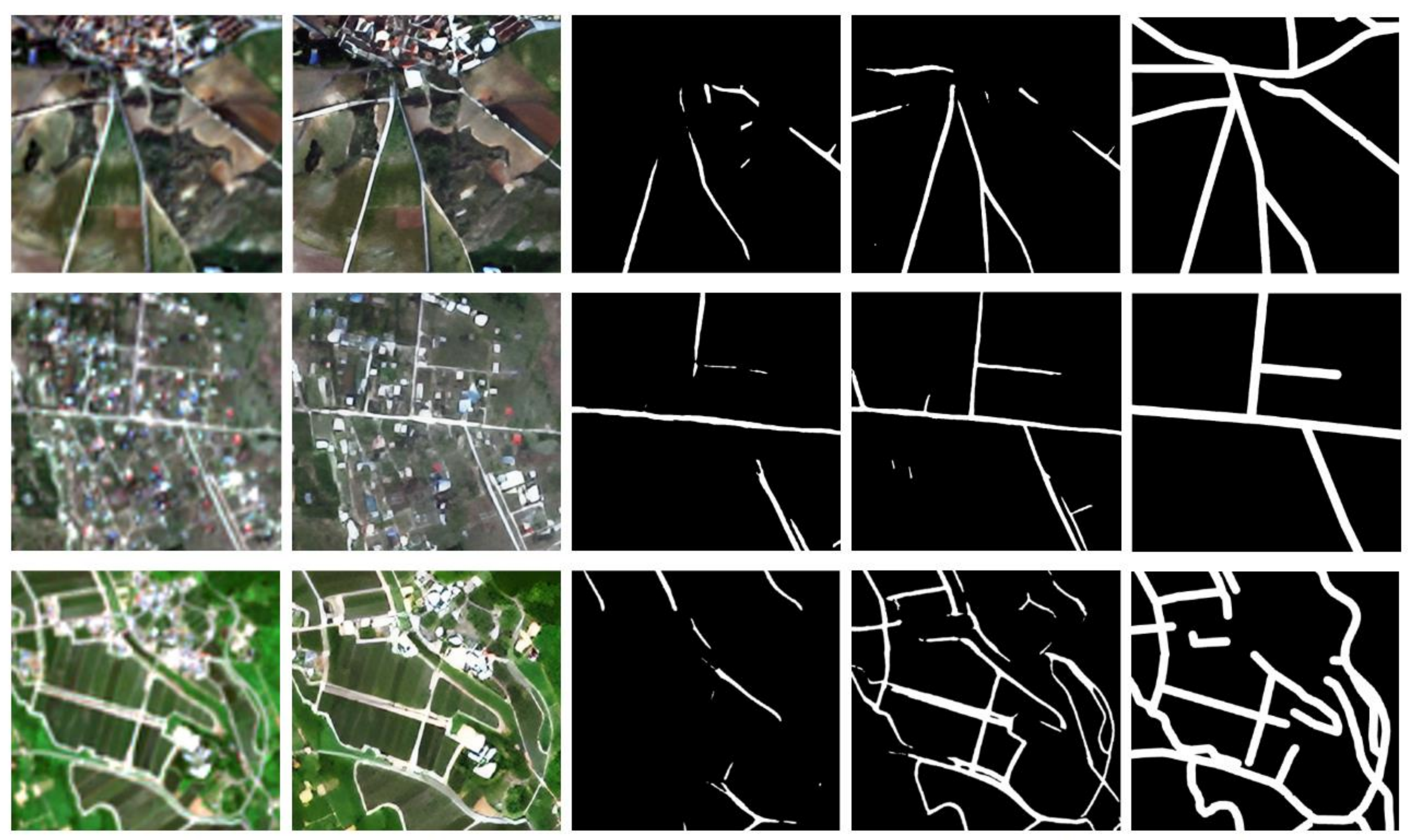
- **Objective:** Evaluate SR to enhance Sentinel-2 RGB imagery from 10 m to 1.25 m GSD for improved road segmentation at 62.5 cm GSD.
- **Approach:**
  - Applied U2D2 framework for SR
  - Testing SR and bicubic upsampling strategies.

Exp.	10→ 5 m	5→ 2.5 m	2.5→ 1.25 m	1.25→ 0.625 m
#1	Bicubic	Bicubic	Bicubic	Bicubic
#2	Bicubic	Bicubic	SR	Bicubic
#3	Bicubic	SR	Bicubic	Bicubic
#4	Bicubic	SR	SR	Bicubic
#5	SR	SR	Bicubic	Bicubic
#6	SR	SR	SR	Bicubic

  - Used OneFormer (Swin-Transformer) for road segmentation, trained on high-resolution data (30–67 cm GSD).
  - Tested on Sentinel-2 patches (Spain, Germany, Kenya, Japan) with manual road annotations.
- **Results:**
  - Best SR strategy (SR-SR-Bicubic-Bicubic): 61% quality, 76% completeness, 75% correctness.
  - Bicubic-only: 46% quality, 51% completeness, 87% correctness.
  - Excessive SR caused artifacts, lowering quality to 55%.
  - SR outperformed bicubic, improving road clarity and detection
- **Impact:** SR enables road segmentation in low-resolution Sentinel-2 data, supporting humanitarian and infrastructure applications despite minor color loss.

Effect of upsampling strategies on road extraction results

Exp.	Ups. Strategy	Quality ↑	Completeness ↑	Correctness ↑
#1	B-B-B-B	46.53 %	51.45 %	**86.94 %**
#2	B-B-SR-B	53.30 %	67.89 %	71.84 %
#3	B-SR-B-B	59.91 %	**77.45 %**	72.77 %
#4	B-SR-SR-B	56.30 %	69.15 %	76.20 %
#5	SR-SR-B-B	**60.97 %**	76.46 %	75.48 %
#6	SR-SR-SR-B	55.12 %	69.38 %	73.26 %



(a) Sentinel-2 (b) enhanced Sentinel-2 (c) pred. on Sen2 (d) pred. on enhanced Sen2 (e) road buffer labels

- Visual comparison of bicubic upsampling (a) vs. super-resolution (b) on Sentinel-2 RGB images, showing road segmentation results (c-d) and ground truth labels (e) at 62.5 cm GSD for patches from Spain (row 1), Kenya (row 2), and Japan (row 3).

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