TOWARDS A UNIVERSAL IMAGE DEGRADATION MODEL VIA CONTENT-DEGRADATION DISENTANGLEMENT

Wenbo (Paul) Yang[1], Zhongling Wang[2], Zhou Wang[1]
[1] University of Waterloo, Canada; [2] AI Center-Toronto, Samsung Electronics, Canada

Webpage, Code, Paper, Videos, & Supplementary

ICCV OCT 19-23, 2025 HONOLULU HAWAII

MOTIVATION

✅ **Image degradation modeling** and **synthesis** have wide range of applications: 🖌 Image restoration, 📝 Data augmentation, and 🎬 Simulating artistic effects

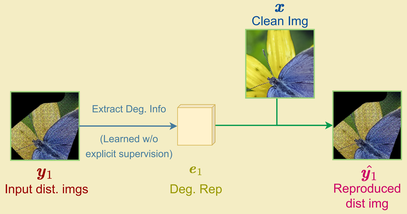
❗ **Existing methods** –
- are **labor consuming**: each model is designed *for each downstream application*, which requires strong domain knowledge.
- have difficulties modeling **localized degradations**
- require **supervised degradation parameters**

CONTRIBUTIONS

- First **universal degradation model**: **one architecture for all types** of **global and localized** degradations
- **Disentangle-by-compression** method: learning disentangled degradation representation **without explicit supervision**
- **Plug-and-play**: enabling **blind image restoration** for inversion-based methods for the first time

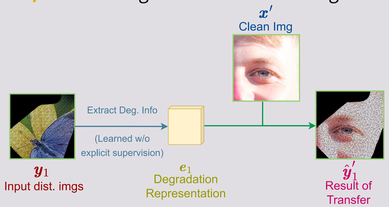
USE CASES (U-n) AND POTENTIAL APPLICATIONS (P-n)

(U-1) Encode & reproduce degradations from input

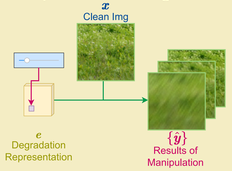


(P-2) Simulate real-world degradations for visual effects
(P-3) Dataset augmentation
(P-4) Blind image restoration

(U-2) Transfer degradations to new images



(U-3) Direct manipulation of degradation features



(P-1) Transmission of artistic effects (e.g., film grain)

(P-5) More flexible and controllable dataset augmentation

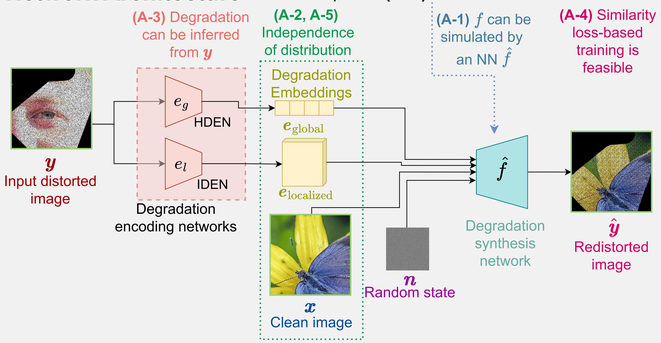
References:
RSG Y. Poirier-Ginter and J.-F. Lalonde, "Robust Unsupervised StyleGAN Image Restoration," in CVPR, 2023.
DPS Hyungjin Chung et al., "Diffusion Posterior Sampling for General Noisy Inverse Problems," in ICLR, 2023.
StyTr Y. Deng et al., "StyTr2: Image Style Transfer With Transformers," in CVPR, 2022.
GoPro S. Nah et al., "Deep Multi-scale Convolutional Neural Network for Dynamic Scene Deblurring," in CVPR, 2017.
FilmGrainStyle Z. Ameur et al., "Style-based film grain analysis and synthesis," in MMSys, 2023.

PROPOSED METHOD

Theoretical Modeling

$$\underbrace{\boldsymbol{y}}_{\text{Distorted Image}} = \underbrace{f}_{\text{Distortion Operator}}\Big(\underbrace{\boldsymbol{x}}_{\text{Clean Image}}, \underbrace{\boldsymbol{d}}_{\text{Distortion Info.}}, \underbrace{\boldsymbol{n}}_{\text{Random State}}\Big)$$

Network Architecture and assumptions (A-n)



Highlight: **Disentangle-by-Compression** – Killing Three Birds with One Stone

$$\mathcal{L}_{\text{comp}} := \sum_i \underbrace{H(e^{(i)})}_{\text{Entry in Degradation Embedding}} = \sum_i \mathbb{E}\ \underbrace{-\log_2 p(e^{(i)})}_{\text{(Empirically estimated entropy)}}$$

$$= \underbrace{H(\boldsymbol{e})}_{\text{Entropy of Degradation Embedding}} + D_{\text{KL}}(p(\boldsymbol{e}) \,\|\, q(\boldsymbol{e}))$$

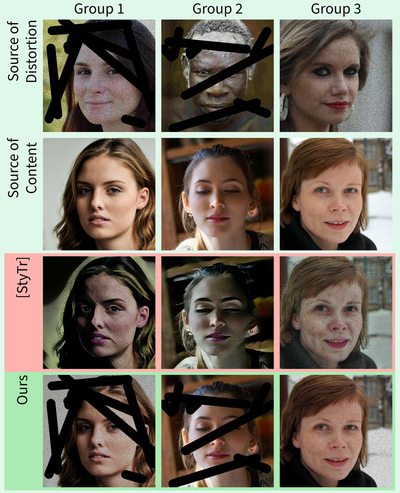
$$= H(\boldsymbol{d}) + I(\boldsymbol{e};\boldsymbol{x}) + D_{\text{KL}}(p(\boldsymbol{e}) \,\|\, q(\boldsymbol{e})), \quad \text{where } q(\boldsymbol{e}) := \prod_i p(e^{(i)})$$

Term	Meaning	Effect (E-n)
$H(\boldsymbol{d})$	Degradation's entropy (unknown & fixed constant)	–
$I(\boldsymbol{e};\boldsymbol{x})$	Mutual information between $\boldsymbol{e}$ and $\boldsymbol{x}$	**(E-1) Disentangle degradation ($\boldsymbol{e}$) from content ($\boldsymbol{x}$)**
$D_{\text{KL}}(p(\boldsymbol{e}) \,\|\, q(\boldsymbol{e}))$	"Independentness" of components in $\boldsymbol{e}$	**(E-2) Disentangle entries in $\boldsymbol{e}$ from each other**

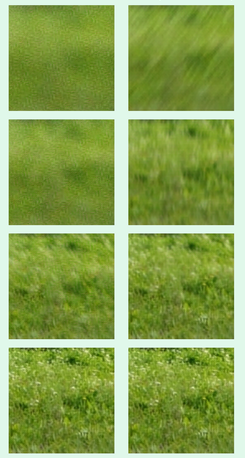
In addition, our method in the paper can **(E-3) separate homogeneous and inhomogeneous degradations**. (Details and proof can be found in the supplementary material.)

EFFECTS OF DISENTANGLEMENT

(E-1) Disentangle Degradation from Content



(E-2) Disentangle Entries in Degradation Embedding



(E-3) Homo. and Inhomo. Degradations

APPLICATIONS

(P-2) Simulating **real-world degradation** for visual effects

(P-4) Converting non-blind image restoration methods to **blind image restoration**: