A Closed-form Solution to Photorealistic Image Stylization

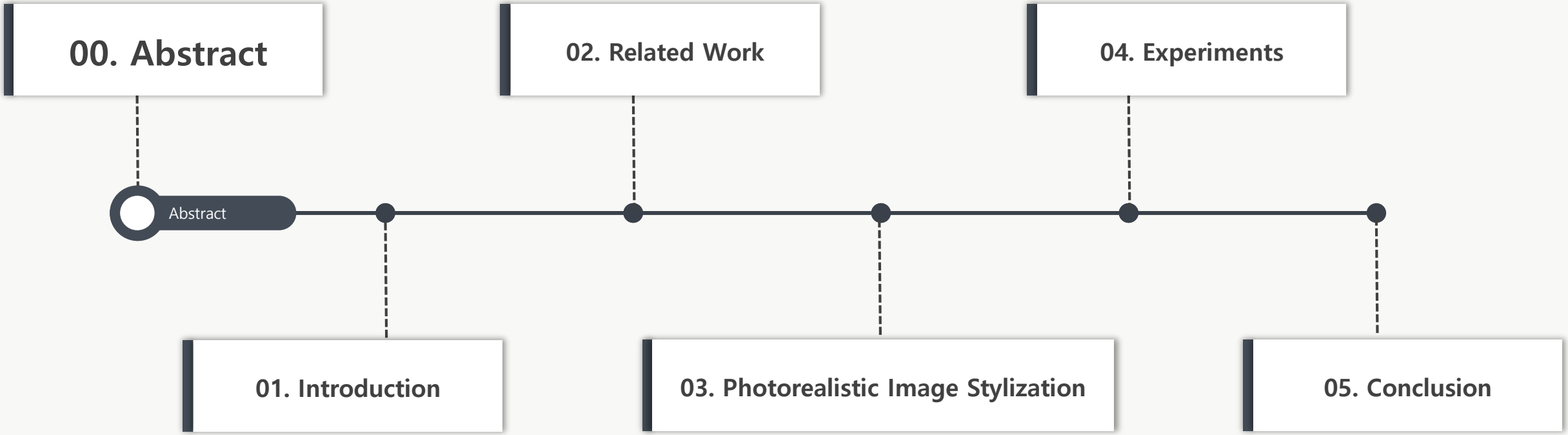
Search

컴퓨터과학과 202132033 염지현

Li, Yijun, et al. "A closed-form solution to photorealistic image stylization." *Proceedings of the European Conference on Computer Vision (ECCV)*. 2018.

목차

Search


00. Abstract
02. Related Work
04. Experiments
Abstract
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

00. Abstract – (1) 하고자 하는 것

Search

Style

Content

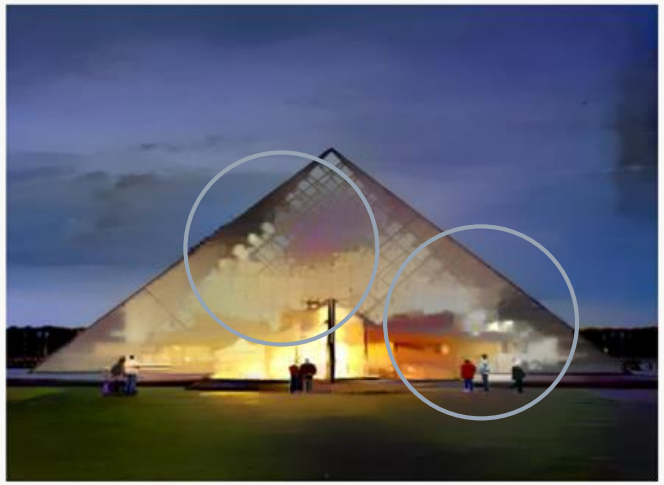
Output

00. Abstract – (2) 기존 연구의 한계점

Search

Output

Gatys et al. [8]



Luan et al. [9]

공간과 상관없는 artifacts가 포함된 결과물 생성

00. Abstract – (3) 해결 방법

Search

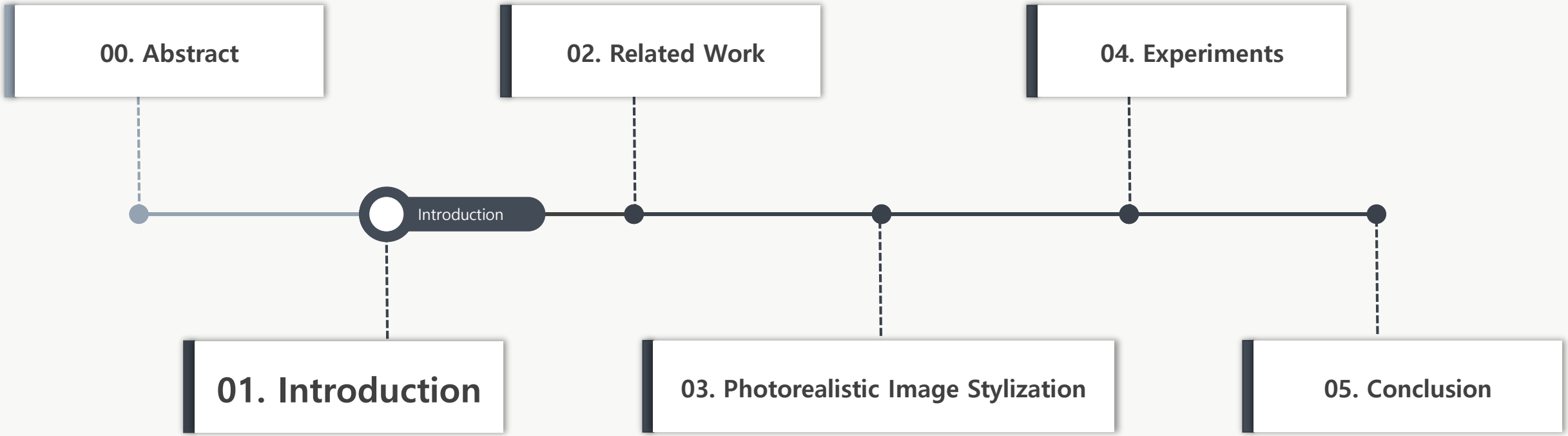
Stylization 단계

: style 변환 단계

+

Smoothing 단계

: 공간적으로 일관된 stylization 보장

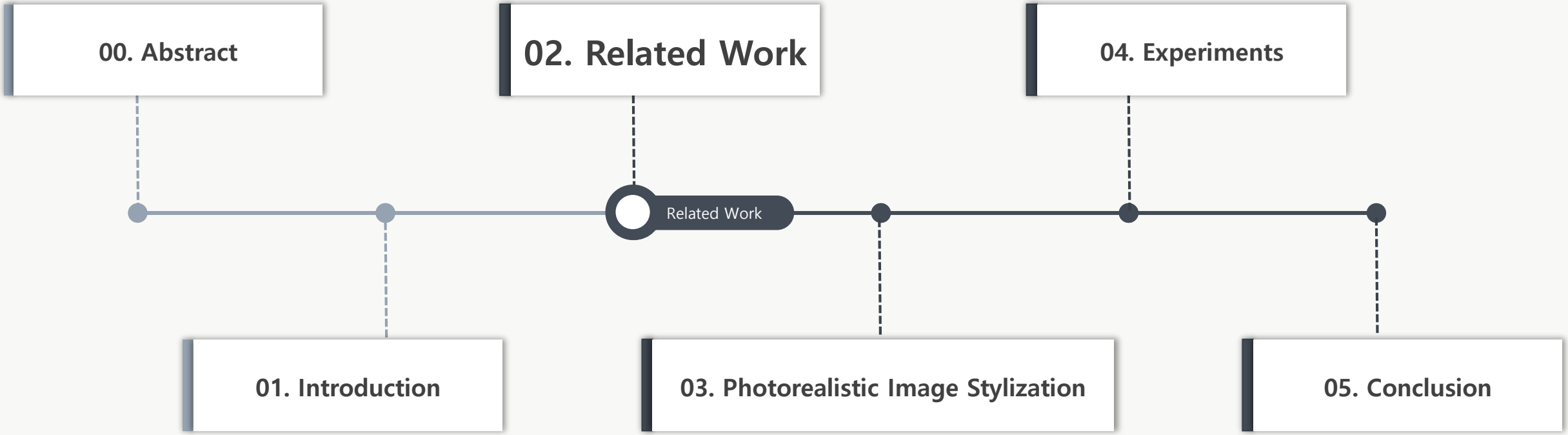

00. Abstract
02. Related Work
04. Experiments
Introduction
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

01. Introduction

Search

- 고정된 유한 수의 연산으로 해를 얻을 수 있음
- 문제에 대한 해답을 식으로 명확하게 제시할 수 있음

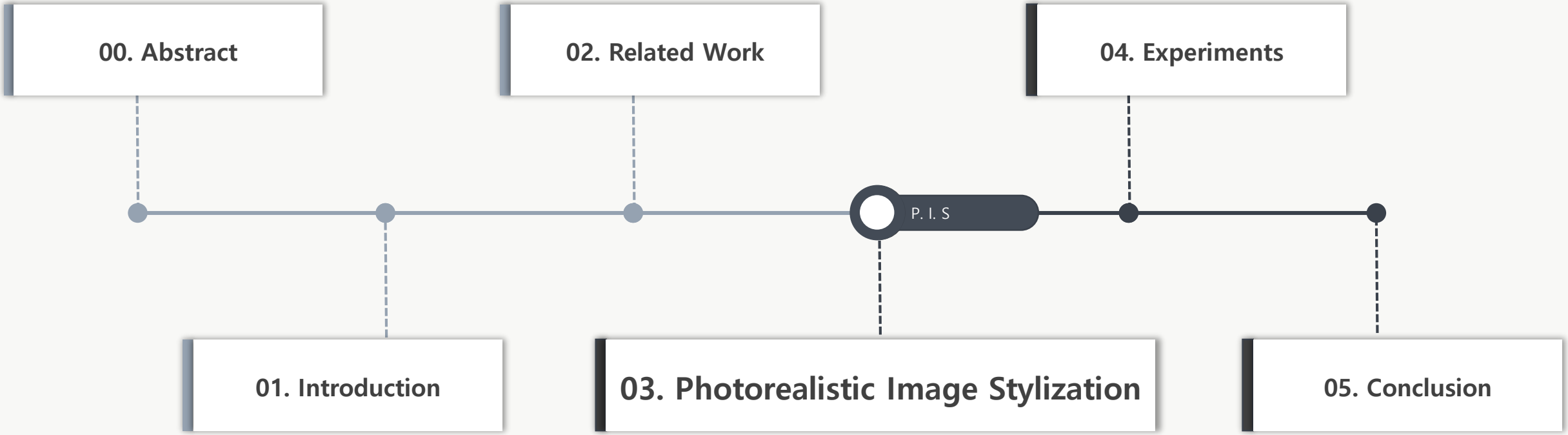
논문 제목	A Closed-form Solution to Photorealistic Image Stylization
목표	Content image를 photorealistic image style로 변환하기
기존 연구 한계	• Explicit method: 색상/톤 일치를 기반으로 하기 때문에 적용하는 데에 한계 존재 • Implicit method: 예술적 효과에 인상적인 성능을 보여주는 반면 photorealistic 변환 작업에서는 artifact 및 왜곡 발생
해결 방법	• Stylization 단계: WCT를 기반으로 하는 PhotoWCT 제안 • Smoothing 단계: 구조를 고려하여 유사한 artifact 감소
구조	Auto-Encoder


00. Abstract
02. Related Work
04. Experiments
Related Work
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

02. Related Work

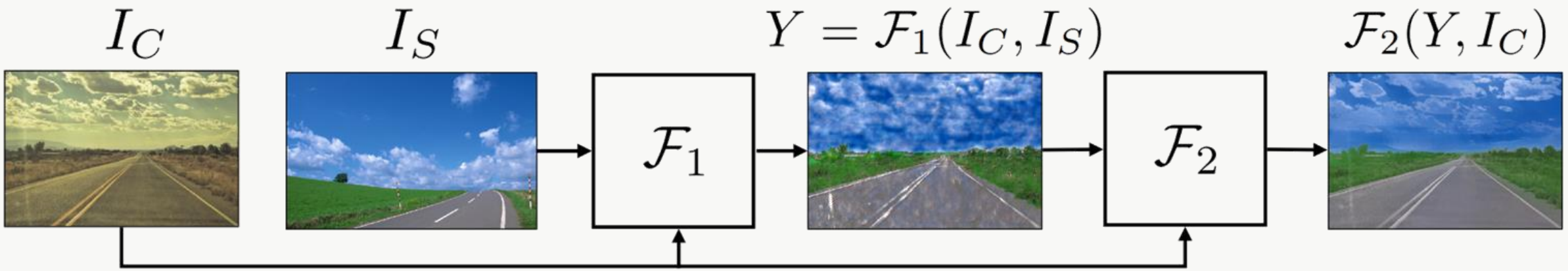
Search

method	설명	Reference
Global method	Pixel 색상 또는 히스토그램의 평균 및 분산 매칭	[1,2,11]
Local method	Low/high level feature 기반 content, style image 간의 조밀한 대응을 찾아 stylization 진행 (-) 속도 저하 및 특정 스타일을 목표로 진행	[12,6,13,5,14]
Neural style transfer algorithm	Content, style image에서 추출한 deep feature의 gram matrix 일치 (-) photorealism 보존 실패	[7,8] [15,16,17,18,19,20,21,22,10,23]
Image to image transfer	이미지를 한 도메인에서 다른 도메인으로 스타일 변환 (-) content, style train dataset 필요	[26,27,28,29,30,31,32,33]
Luan et al	새로운 loss term 도입 → 로컬 구조 보존 효과 상승 (-) 눈에 띄는 artifact가 있는 결과 생성	[9]


00. Abstract
02. Related Work
04. Experiments
P. I. S
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

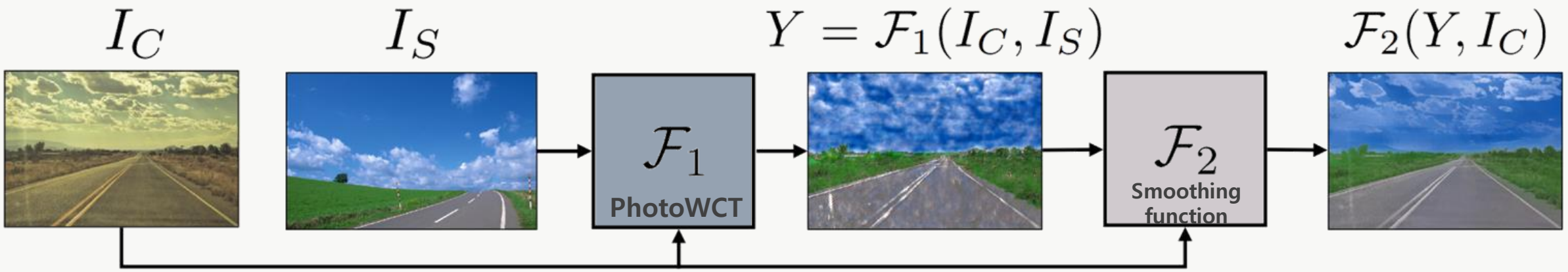
03. Photorealistic Image Stylization - overview

Search



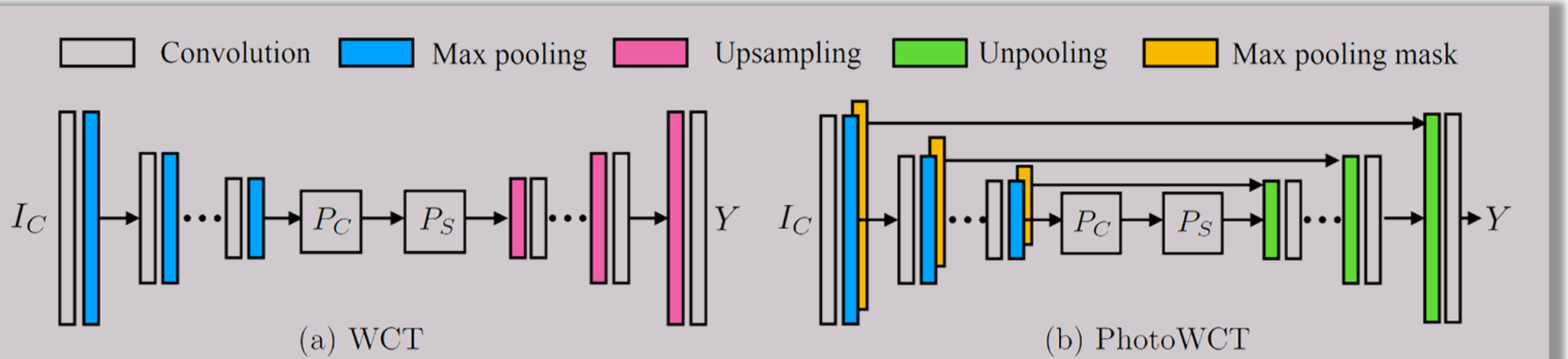
03. Photorealistic Image Stylization - overview

Search



03. Photorealistic Image Stylization - WCT

Search



WCT

- P_C(whitening): 전체 구조를 유지하면서 style과 관련된 정보 제거(correlation 감소) → Style 변환 준비
- P_S(coloring): P_C output(feature map)과 I_S correlation 일치시키도록 유도 → Style 변환

$$P_C = E_C \Lambda_C^{-\frac{1}{2}} E_C^\top$$

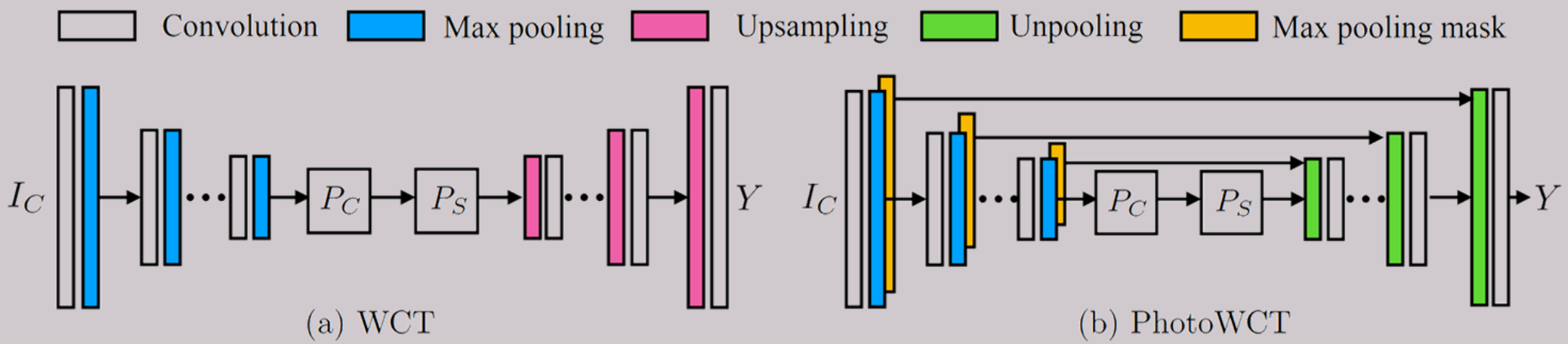
$$P_S = E_S \Lambda_S^{\frac{1}{2}} E_S^\top$$

$$H_{CS} = P_S P_C H_C$$

$$H_{CS} H_{CS}^\top = H_S H_S^\top$$

03. Photorealistic Image Stylization - PhotoWCT

Search



PhotoWCT

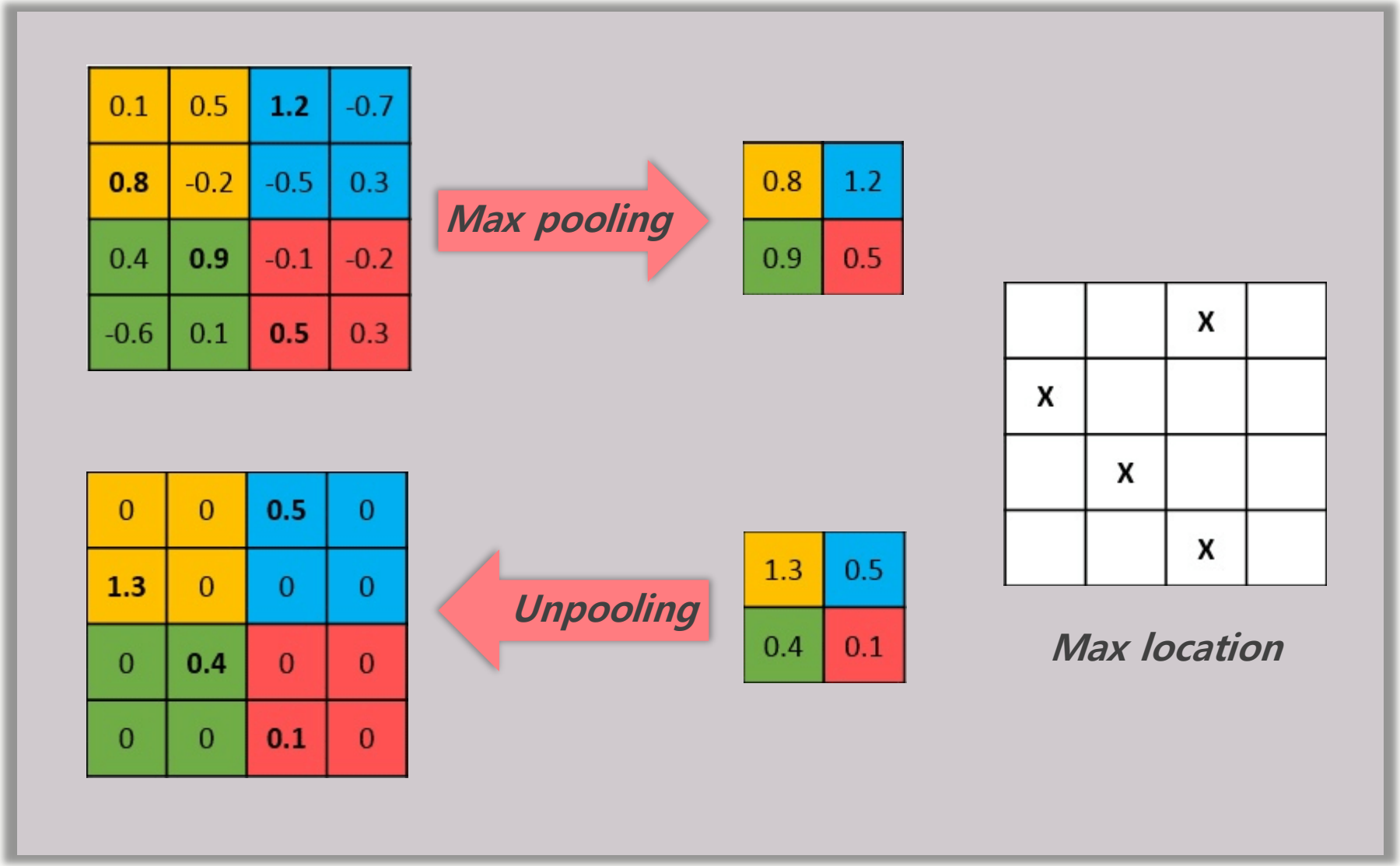
- WCT 에서 Upsampling layer를 Unpooling layer로 교체
- Max pooling mask 기반 Unpooling layer를 도입하여 위치 정보 파악 가능 → 세부 구조 복구 가능

* Unpooling layer란 Max pooling을 진행할 때 일정 영역에서 가장 큰 값을 가지고 있는 index를 저장한 mask를 기반으로 pooling 역연산을 진행하는 layer를 의미한다.

$$Y = \mathcal{F}_1(I_C, I_S) = \overline{\mathcal{D}}(P_S P_C H_C)$$

03. Photorealistic Image Stylization - Unpooling

Search



03. Photorealistic Image Stylization – Smoothing function

Search

$$R^* = \mathcal{F}_2(Y, I_C) = (1-\alpha)(I - \alpha S)^{-1} Y.$$

$$S = D^{-\frac{1}{2}} W D^{-\frac{1}{2}}$$

유사도 행렬을 사용하여 정규화된 라플라시안 행렬 출력
* 라플라시안 행렬: 그래프 내에 노드들을 비슷한 것끼리 클러스터링 할 때 활용

Smoothing function

- Content image의 pixel 유사도를 사용
- Local neighborhood에서 유사한 content를 가진 픽셀은 유사하게 stylization
- Global stylization 효과를 유지하기 위해 출력 PhotoWCT 결과에서 크게 벗어나지 않도록 유지

* PhotoWCT를 통해 Y에 대한 구조적인 정보를 WCT보다 정확하게 추출 → 유사도 행렬 기반 Smoothing function과 조화

r_i : smoothing function output pixel value
y_i : PhotoWCT output pixel value

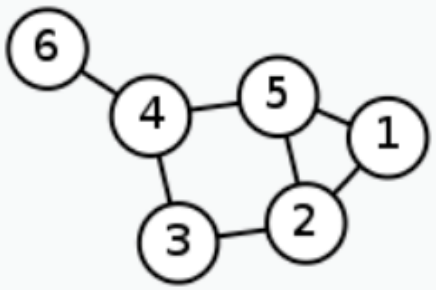
$$\underset{r}{\operatorname{argmin}} \frac{1}{2}\left(\sum_{i,j=1}^{N} w_{ij} \left\| \frac{r_i}{\sqrt{d_{ii}}} - \frac{r_j}{\sqrt{d_{jj}}} \right\|^2 + \lambda \sum_{i=1}^{N} \|r_i - y_i\|^2\right)$$

인접 픽셀 간 유사도

동일한 스타일 유지

03. Photorealistic Image Stylization – Symmetric normalized laplacian matrix

Search

Labelled graph	Degree matrix	Adjacency matrix	Laplacian matrix
	$\begin{pmatrix} 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 2 & -1 & 0 & 0 & -1 & 0 \\ -1 & 3 & -1 & 0 & -1 & 0 \\ 0 & -1 & 2 & -1 & 0 & 0 \\ 0 & 0 & -1 & 3 & -1 & -1 \\ -1 & -1 & 0 & -1 & 3 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 \end{pmatrix}$

The elements of L are given by

$$L_{i,j} := \begin{cases} \deg(v_i) & \text{if } i = j \\ -1 & \text{if } i \neq j \text{ and } v_i \text{ is adjacent to } v_j \\ 0 & \text{otherwise} \end{cases}$$

where $\deg(v_i)$ is the degree of the vertex i.

The symmetric normalized Laplacian matrix is defined as:[1]

$$L^{\text{sym}} := D^{-\frac{1}{2}} L D^{-\frac{1}{2}} = I - D^{-\frac{1}{2}} A D^{-\frac{1}{2}},$$

The elements of L^{sym} are given by

$$L^{\text{sym}}_{i,j} := \begin{cases} 1 & \text{if } i = j \text{ and } \deg(v_i) \neq 0 \\ -\frac{1}{\sqrt{\deg(v_i)\deg(v_j)}} & \text{if } i \neq j \text{ and } v_i \text{ is adjacent to } v_j \\ 0 & \text{otherwise.} \end{cases}$$

03. Photorealistic Image Stylization – Output

Search

(a) Style

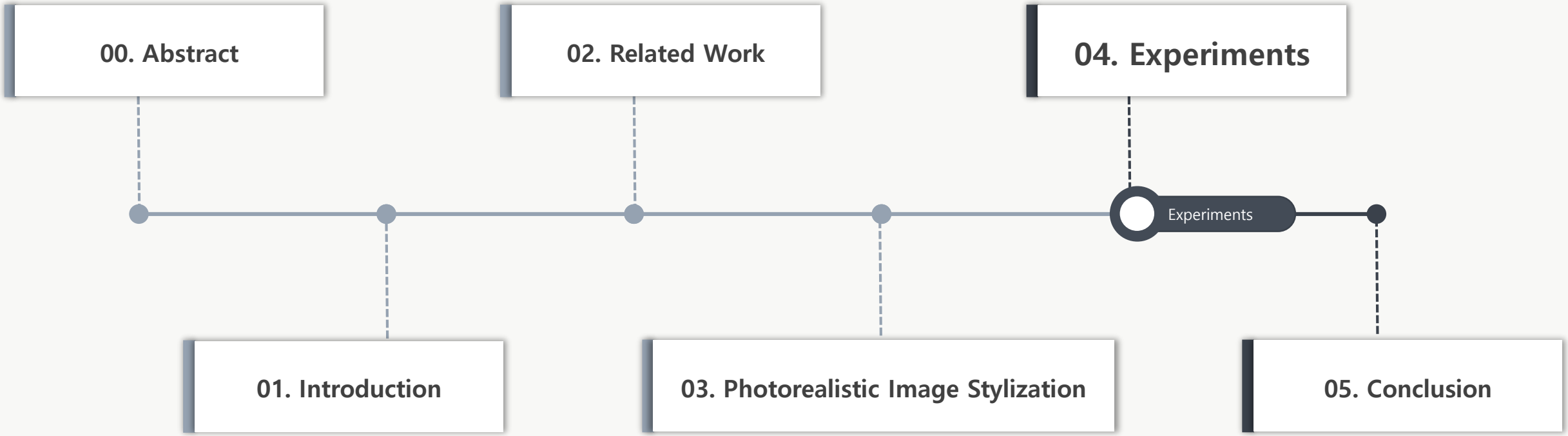
(b) Content

(c) WCT [10]

(d) PhotoWCT

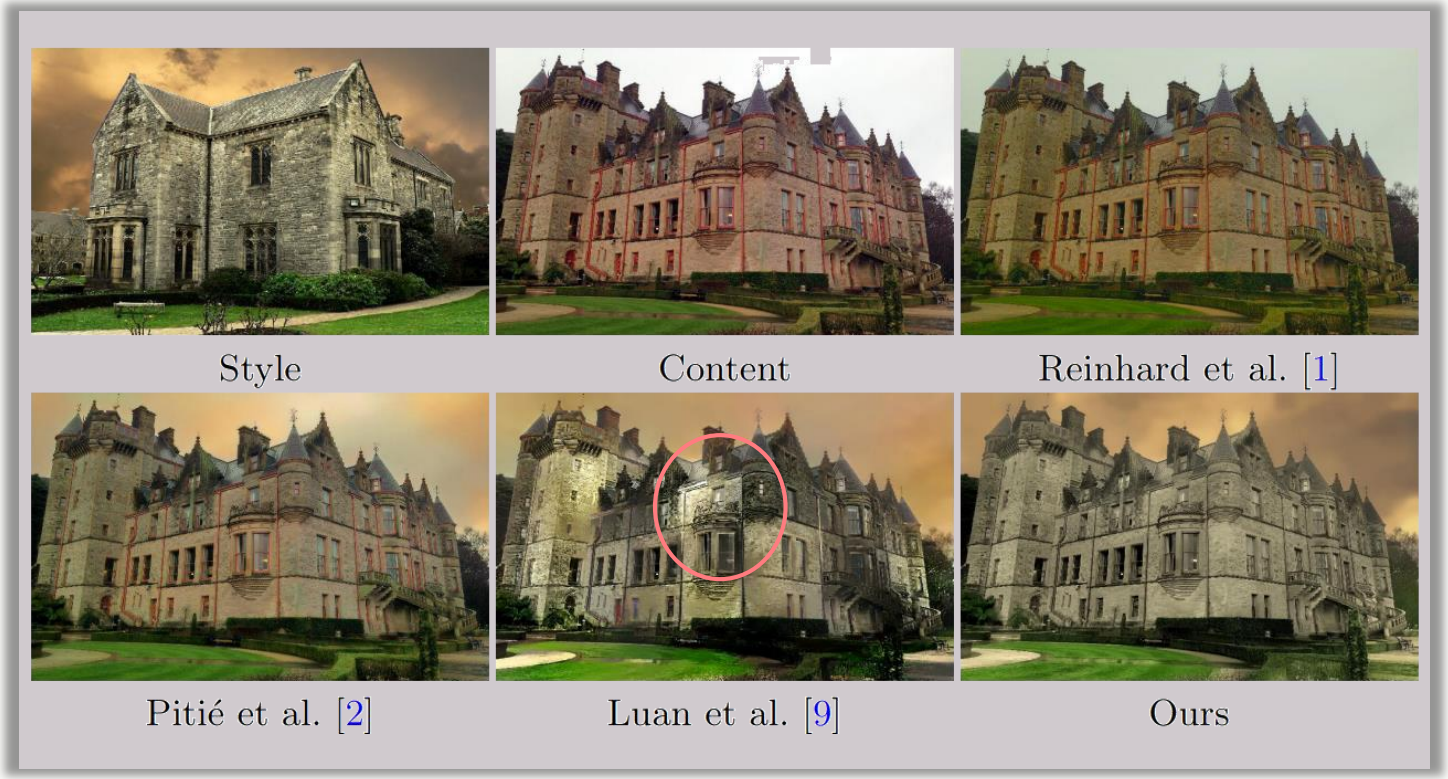
(e) WCT + smoothing

(f) PhotoWCT + smoothing


00. Abstract
02. Related Work
04. Experiments
Experiments
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

04. Experiments – Visual comparison(1)

Search



Classical Method	[1]	• Content image 색상을 변경하면 style transfer 작업이 제대로 수행되지 않음
	[2]	
Neural Style Transfer	[9]	• 불규칙적인 밝기를 포함 등의 artifact 발생
	Ours	• 색상 변환 뿐만 아니라 패턴을 합성

04. Experiments – Visual comparison(1)

Search

Classical Method	[1]	• Content image 색상을 변경하면 style transfer 작업이 제대로 수행되지 않음
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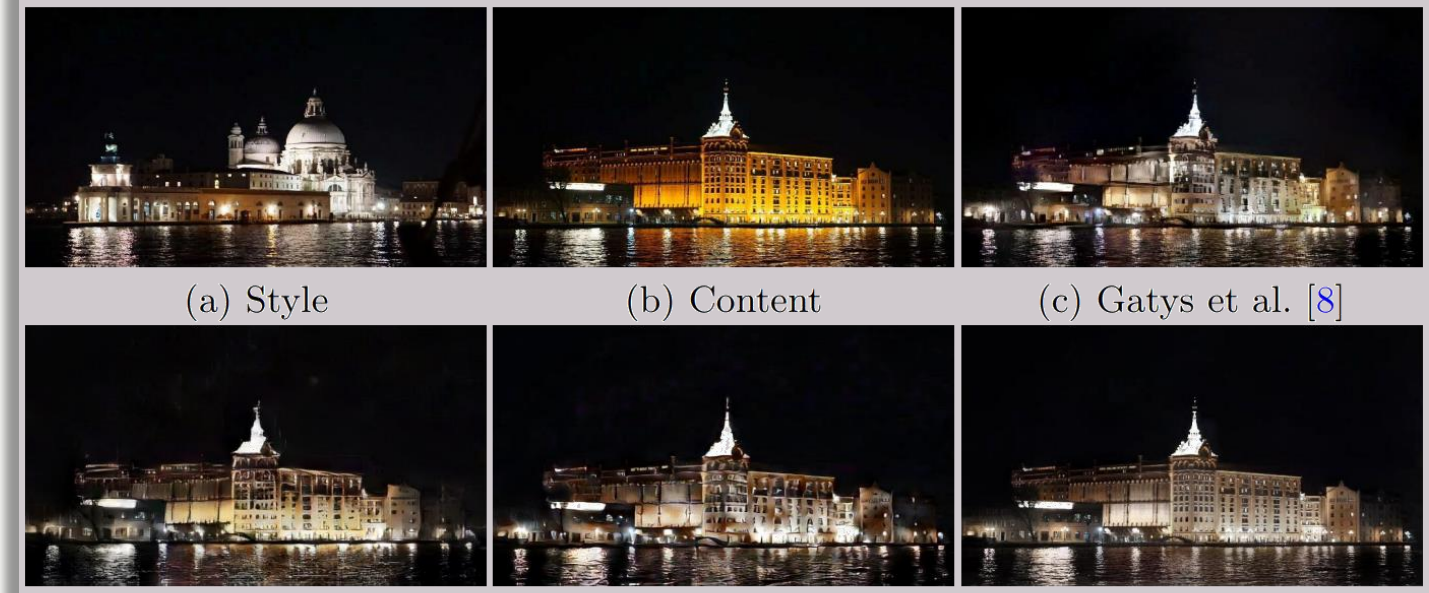
Neural Style Transfer	[9]	• 불규칙적인 밝기를 포함 등의 artifact 발생
	Ours	• 색상 변환 뿐만 아니라 패턴을 합성

04. Experiments – Visual comparison(2)

Search



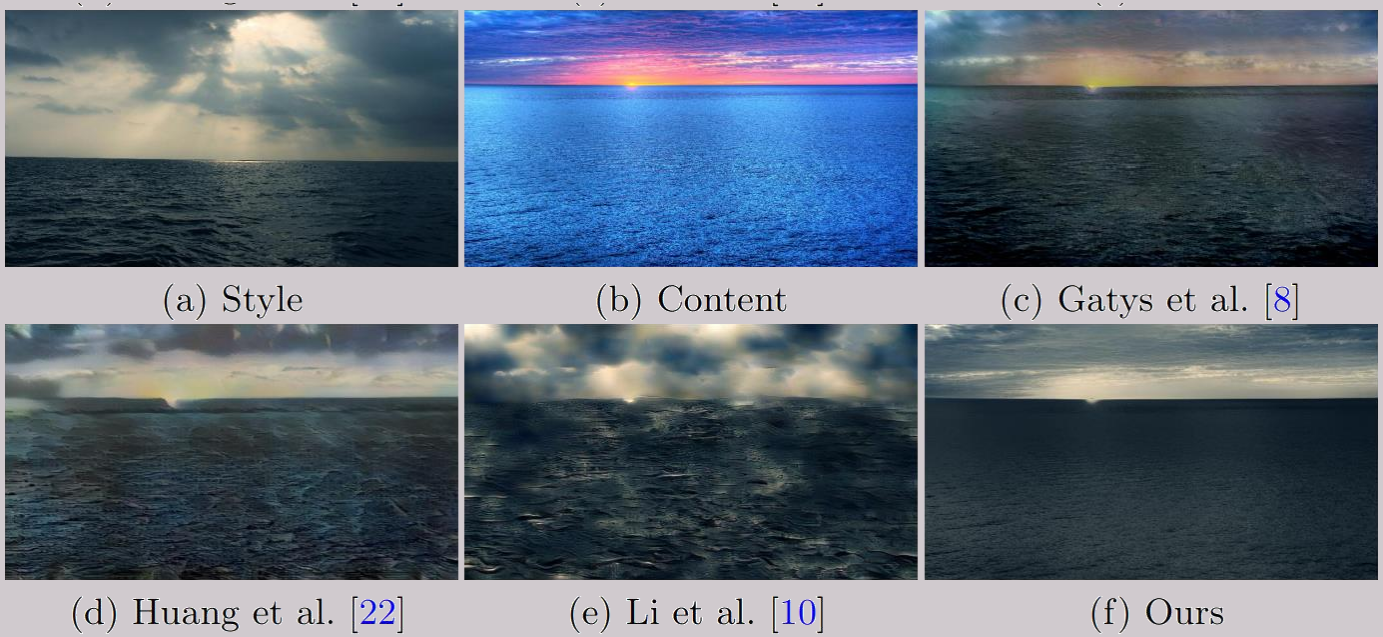
(a) Style (b) Content (c) Gatys et al. [8]

(d) Huang et al. [22] (e) Li et al. [10] (f) Ours

Neural Style Transfer	[8]	• 대상 경계(건물)의 구조적 왜곡 발생
	[22]	
	[10]	
	Ours	• 대상 경계(건물)의 구조적 왜곡 발생 X

04. Experiments – Visual comparison(2)

Search



(a) Style (b) Content (c) Gatys et al. [8]

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Neural Style Transfer	[8]	• Detailed 가장자리(바다, 구름) 구조적 왜곡 발생
	[22]	
	[10]	
	Ours	• Detailed 가장자리(바다, 구름) 구조적 왜곡 발생 X

04. Experiments – User studies

Search

Table 1: User preference: proposed vs. Luan et al. and proposed vs. Pitié et al.

	Luan et al. [9] / proposed	Pitié et al. [2] / proposed
Better stylization	36.9% / **63.1%**	44.8% / **55.2%**
Fewer artifacts	26.5% / **73.5%**	48.8% / **51.2%**

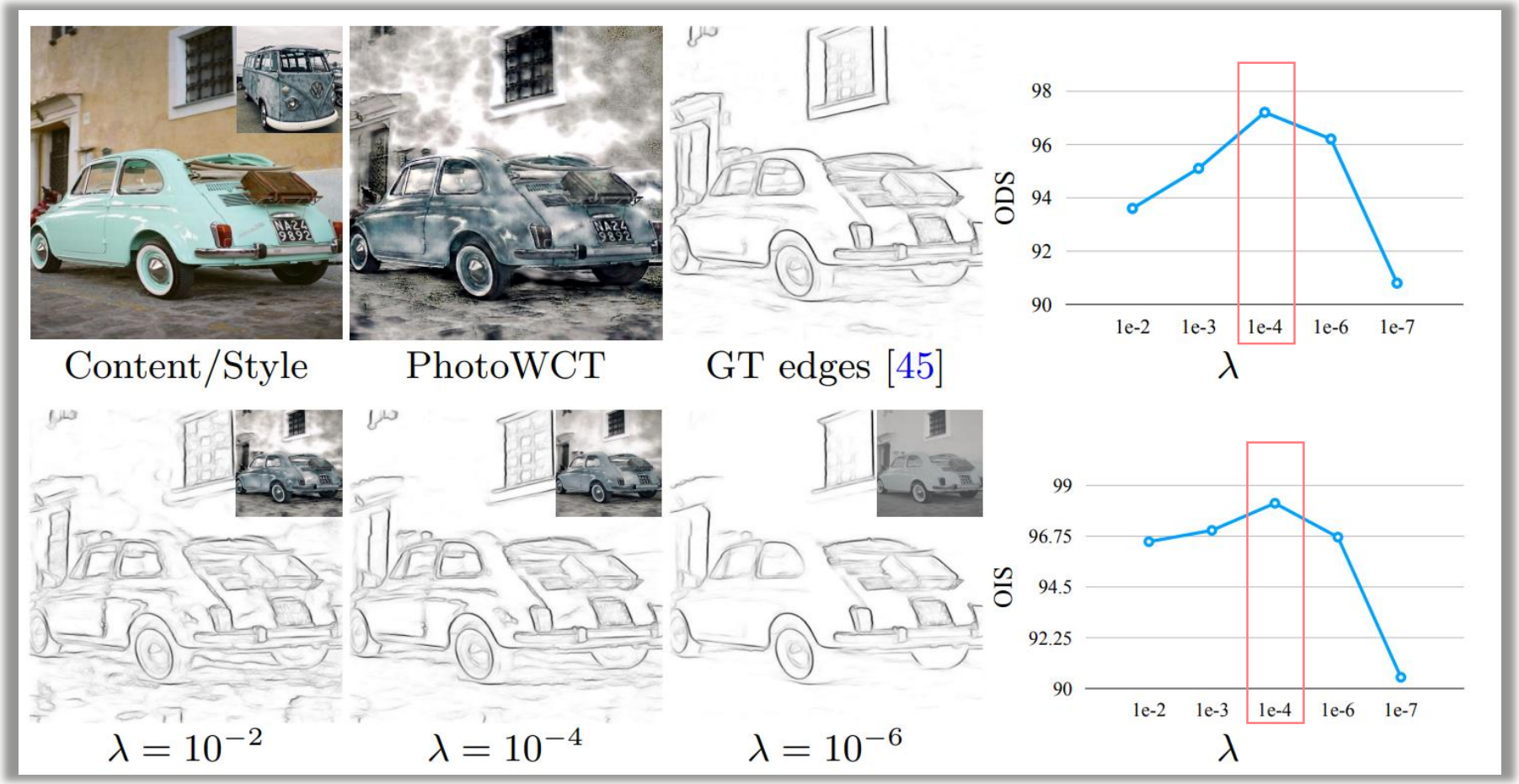
Table 2: User preference: proposed versus *artistic* stylization algorithms.

	Gatys et al. [8]	Huang et al. [22]	Li et al. [10]	proposed
Better stylization	19.2%	8.4%	16.0%	**56.4%**
Fewer artifacts	21.6%	6.0%	6.8%	**65.6%**

추가적으로 WCT, PhotoWCT output 을 기반으로 동일한 설문(Better stylization, Fewer artifacts) 진행 결과,
PhotoWCT가 각각에 문항에 대해 83.6%, 83.2% 결과

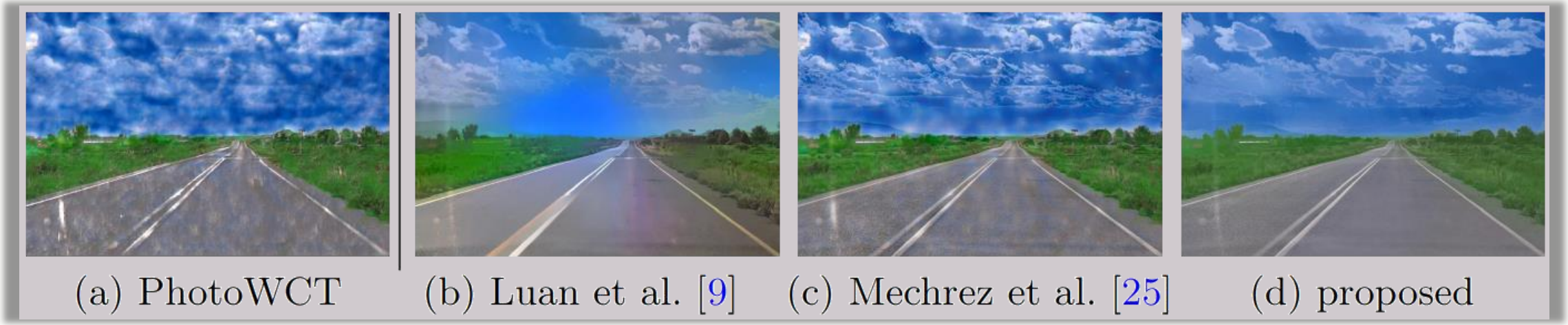
04. Experiments – λ 영향 파악하기

Search



04. Experiments – Alternative smoothing techniques

Search



(a) PhotoWCT (b) Luan et al. [9] (c) Mechrez et al. [25] (d) proposed

• input	• 도로 색상에서 왜곡 발생	• Output gradient와 content image gradient 를 일치시켜 최종 결과 이미지 개선 • 구조적 왜곡 제거 성공 • 시각적 artifact 제거 실패	• Luan et al., Mechrez et al 방법보다 photorealism한 결과 생성

04. Experiments – Runtime

Search

- NVIDIA Titan X Pascal GPU 환경에서 수행

Table 3: Run-time comparison. We compute the average run time (in seconds) of the evaluated algorithms across various image resolutions.

Image resolution	Luan et al.[9]	proposed	PhotoWCT	smoothing	approx
256×128	79.61	0.96	0.40	0.56	0.41
512×256	186.52	2.95	0.42	2.53	0.47
768×384	380.82	7.05	0.53	6.52	0.55
1024×512	650.45	13.16	0.56	12.60	0.64

04. Experiments – Runtime

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49배 감소

04. Experiments – Runtime

Search

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768×384	380.82	7.05	0.53	6.52	0.55
1024×512	650.45	13.16	0.56	12.60	0.64

희소행렬 W를 transpose 하는 데에 대부분의 시간 소요

04. Experiments – Runtime

Search

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768×384	380.82	7.05	0.53	6.52	0.55
1024×512	650.45	[illegible]	[illegible]	[illegible]	0.64

1016배 감소

04. Experiments – Runtime

Search

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1024×512	650.45	[illegible]	[illegible]	[illegible]	0.64

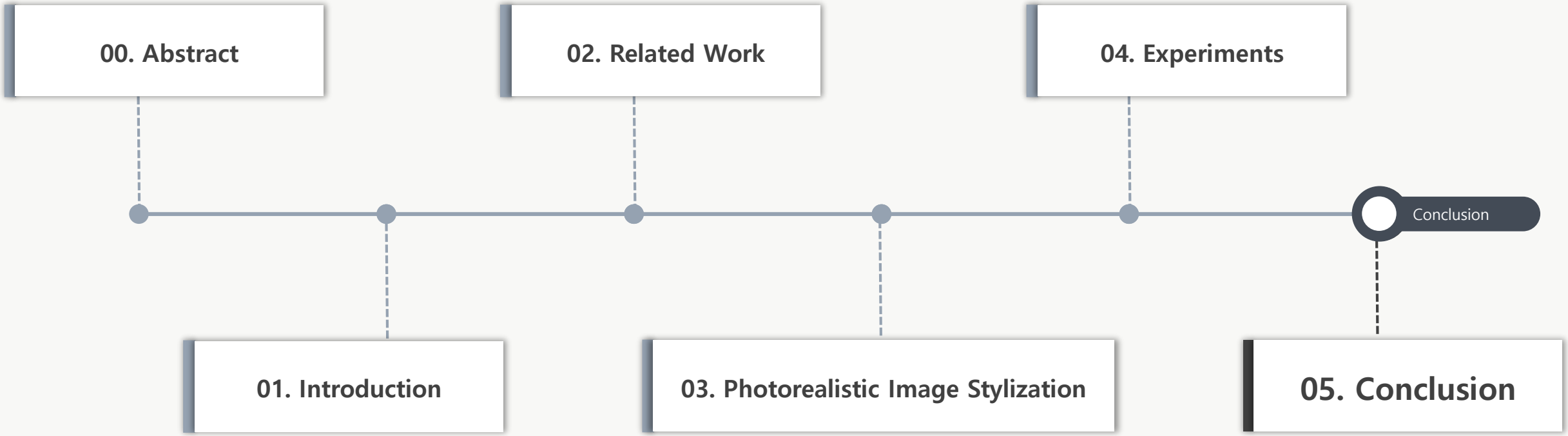
1016배 감소

	proposed/approx	Luan et al. [9]/approx	Pitié et al. [2]/approx
Better stylization	**59.6%** / 40.4	36.4 / **63.6%**	46.0 / **54.0%**
Fewer artifacts	**52.8%** / 47.2	20.8 / **79.2%**	46.8 / **53.2%**

04. Experiments – Failure case

Search

픽셀 유사도 사용 → 냄비 표면에서 부드러운 색상 전환을 목표로 stylization 진행


00. Abstract
02. Related Work
04. Experiments
Conclusion
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

05. Conclusion

Search

1

빠르고
사실적인
stylization
method
제안

2

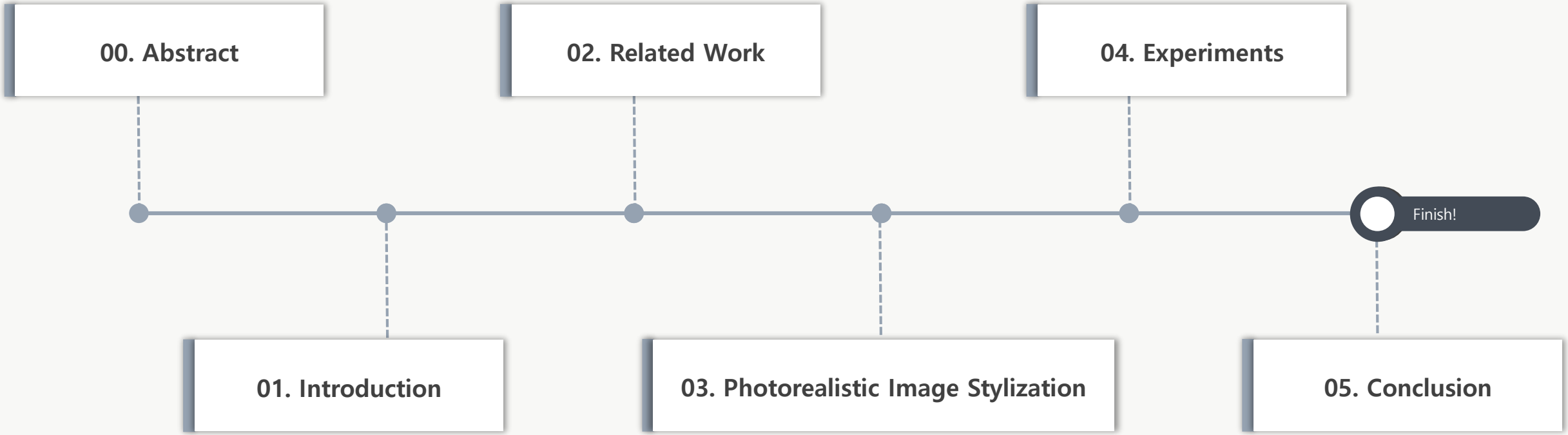
Stylization
+
Smoothing
단계로 구성

3

효율적인
closed-form
Solution
제공

4

SOTA 기술에
비해
선호도 높은
이미지 생성


00. Abstract
02. Related Work
04. Experiments
Finish!
01. Introduction
03. Photorealistic Image Stylization
05. Conclusion

감사합니다

Search