Assignment 1:

Scale Invariant Feature Detection and Image Filtering

Computer Vision

NTU, Spring 2025

Announced: 2025/03/07 (Fri.)

Due: 2025/03/27 (Thu.) 23:59

Outline

Part 1: Scale Invariant Feature Detection

- Implement Difference of Gaussian (DoG)

Part 2: Image Filtering

- Advanced color-to-gray conversion
- Implement bilateral filter

Rules

- Environment
- Report
- Submission
- Grading
- Late Policy

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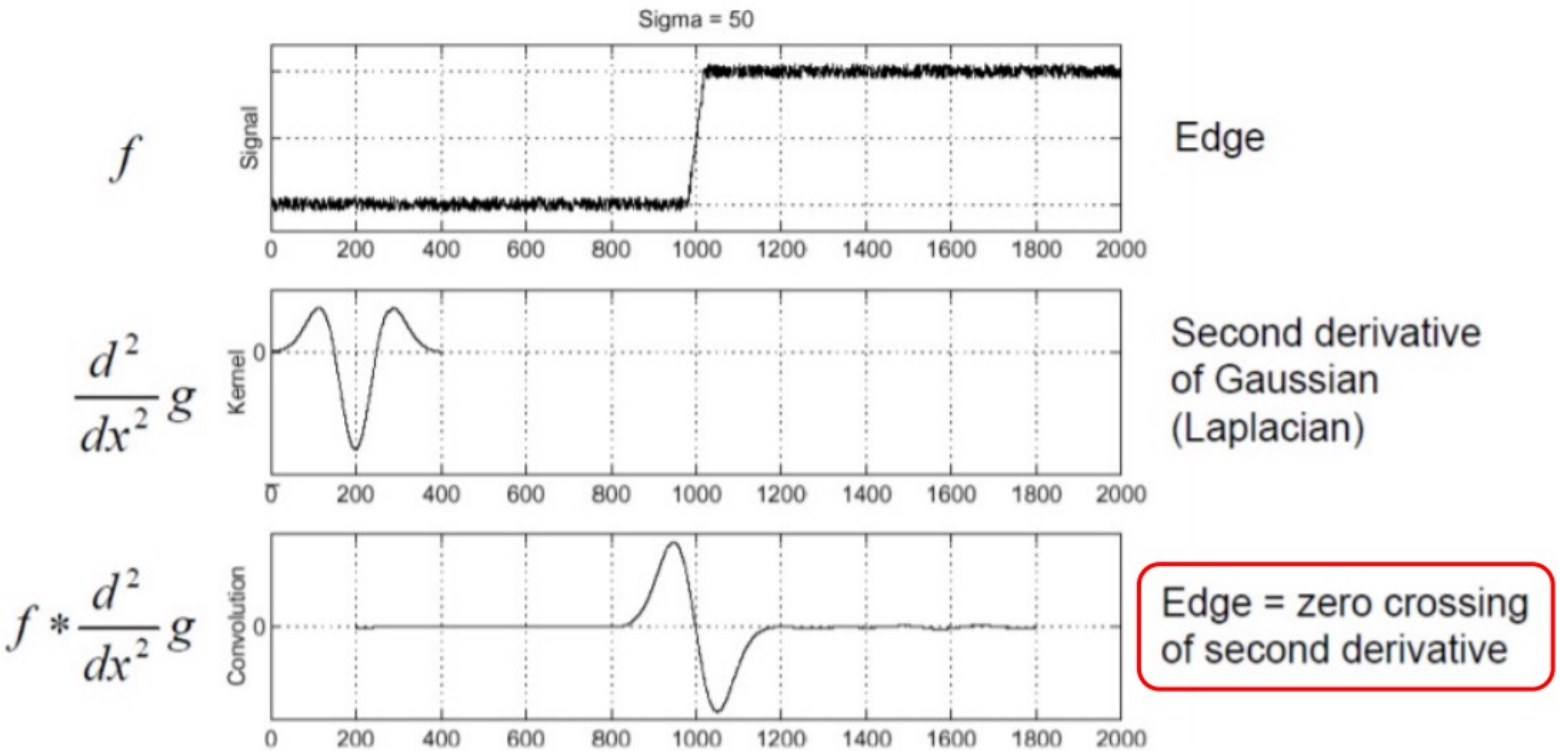
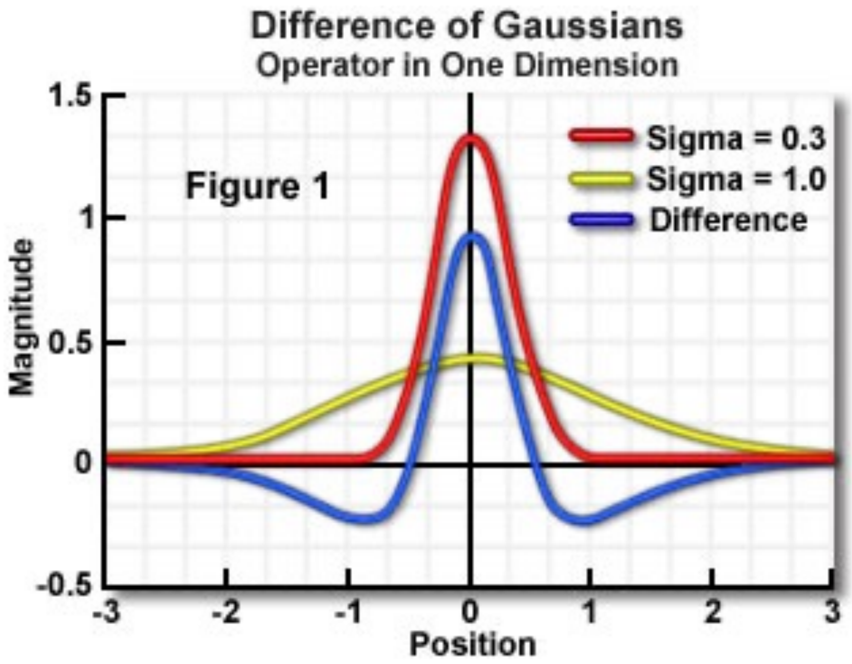
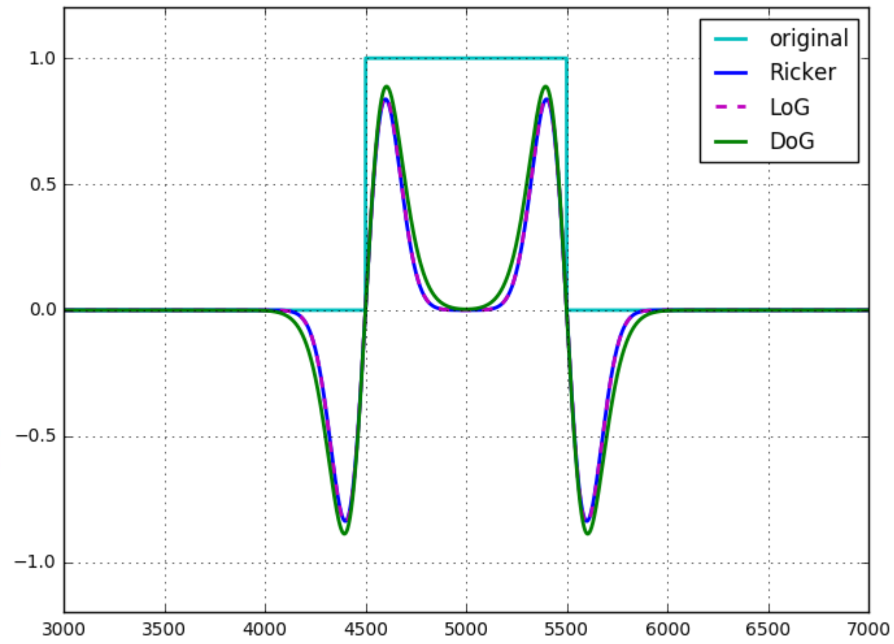
Laplacian of Gaussian

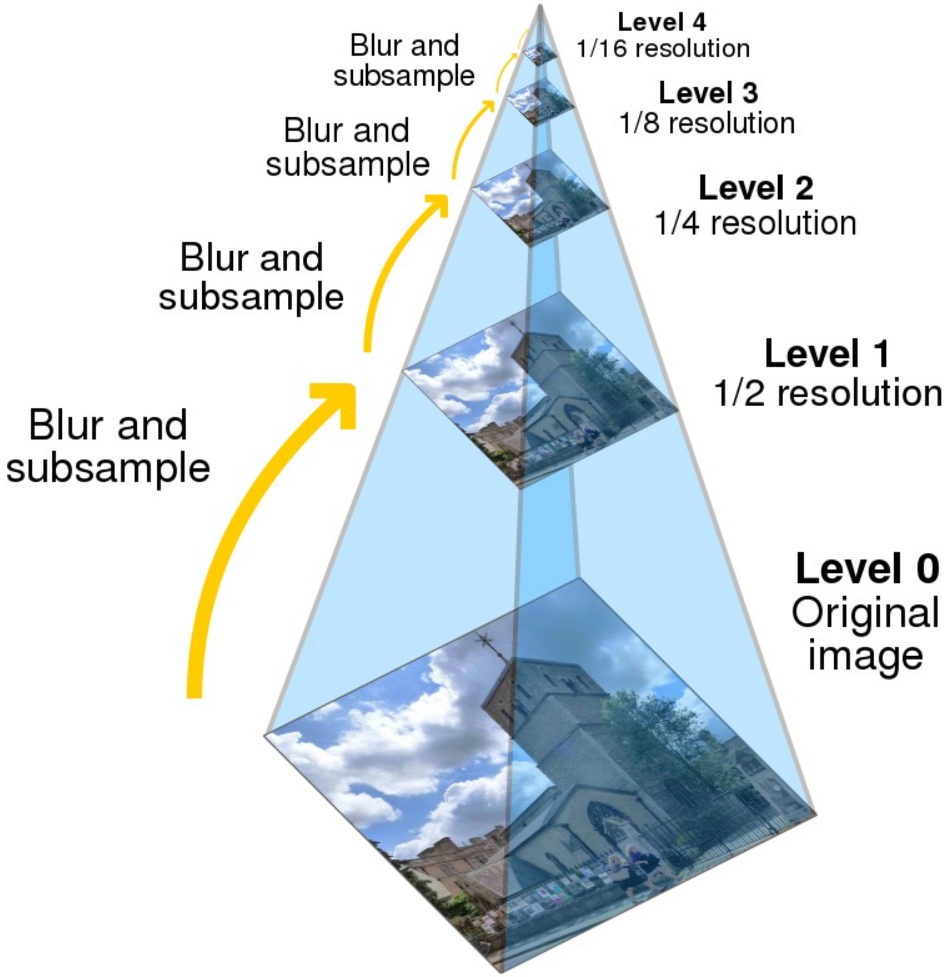


Difference of Gaussian Filter

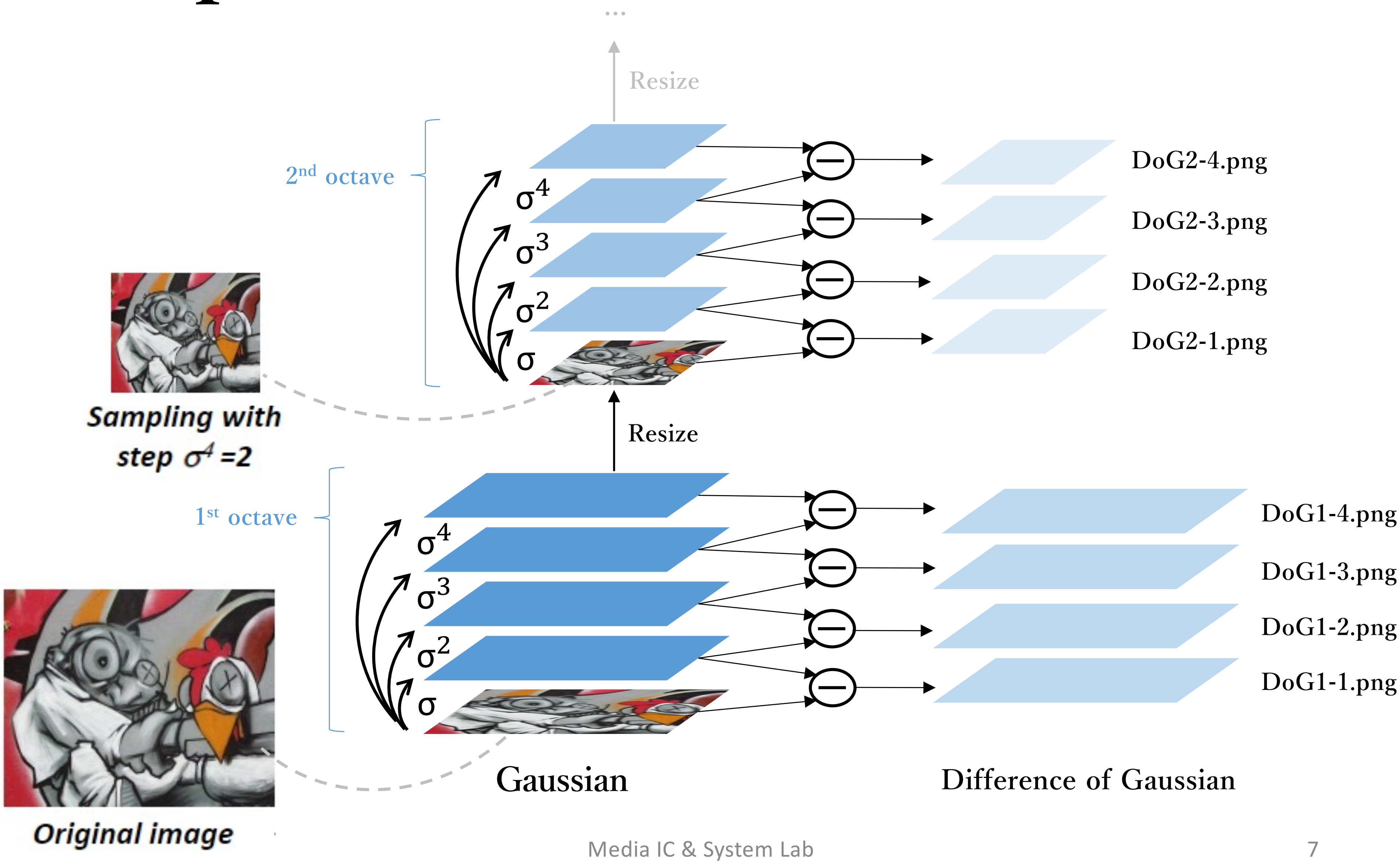




Gaussian Pyramid



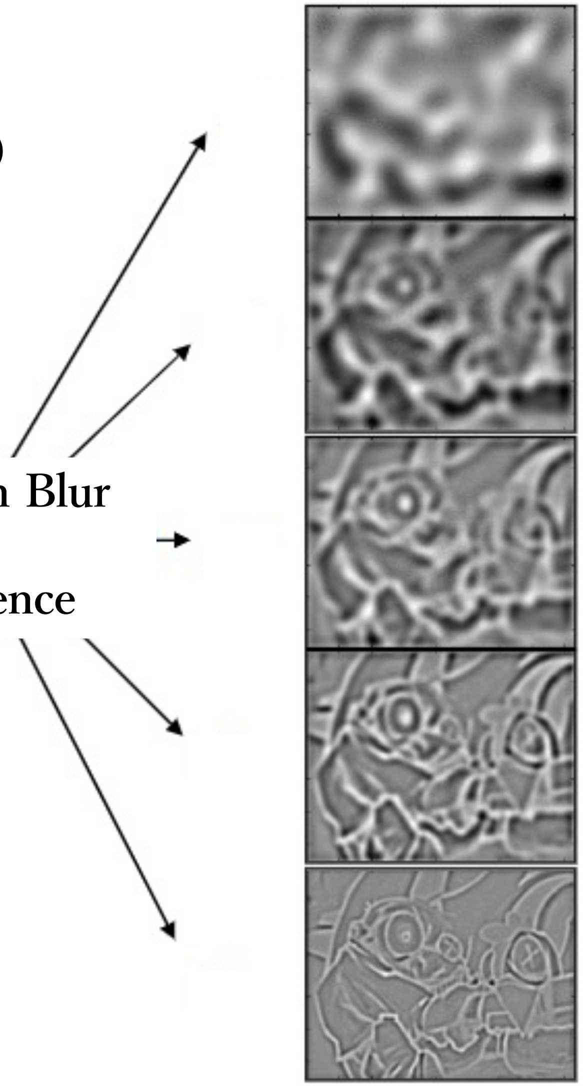
Implementation

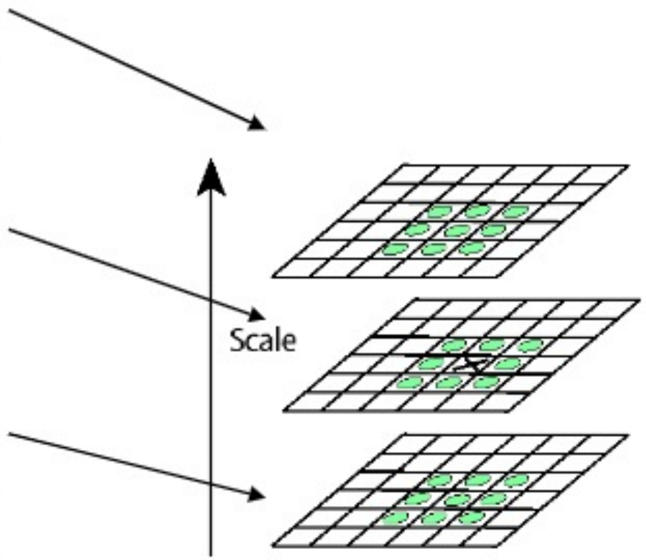


Implementation

- Find local extremum (maximum and minimum)
- Padding is not needed

Gaussian Blur
+
Difference





List of (x, y)
or
(2x, 2y) if resize to 1/2

Implementation

In DoG.py

```
# Step 1: Filter images with different sigma values (5 images per octave, 2 octave in total)
# - Function: cv2.GaussianBlur (kernel = (0, 0), sigma = self.sigma**___)
```

- Apply gaussian blur with corresponding sigma value on the input.
- The base image of the 1st octave is the input image.
- Down sample the last blurred image in the 1st octave as the base image of the 2nd octave.

```
# Step 2: Subtract 2 neighbor images to get DoG images (4 images per octave, 2 octave in total)
# - Function: cv2.subtract(second_image, first_image)
```

- You should subtract the second image (more blurred one) to the first image (less blurred one) to get DoG.

```
# Step 3: Thresholding the value and Find local extremum (local maximun and local minimum)
#         Keep local extremum as a keypoint
```

- Find the local extremum and threshold the pixel value.

```
# Step 4: Delete duplicate keypoints
# - Function: np.unique
```

- Delete duplicate keypoints from 2 octaves.

Assignment Description

- part1/eval.py
  - TA will run this code to evaluation your result.
  - DO NOT Modify!
- part1/main.py
  - Execute DoG, visualize results for report, … etc.
- part1/DoG.py
  - Follow the instructions and implement Difference of Gaussian.
    - The output format should be a numpy array with shape (x, 2)
    - x is the number of feature points

Assignment Description

- Recommended steps
  1. Implement Difference of Gaussian in DoG.py
  2. Use eval.py to evaluate your DoG.py

```
$ python3 eval.py --threshold 3.0 --image_path ./testdata/1.png --gt_path ./testdata/1_gt.npy
```

     - Your Result needs to match Ground truth

```
[Info] All keypoints match.
```

  3. Finish remaining code in main.py if needed
     - e.g. visualize DoG, plot feature points

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Color Conversion

- RGB2YUV
  - Read https://en.wikipedia.org/wiki/YUV for more details

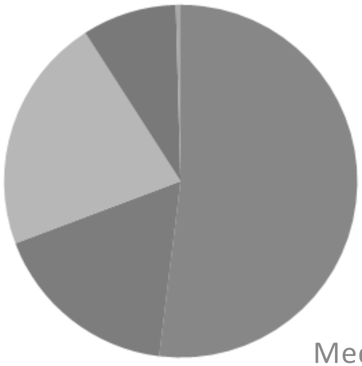
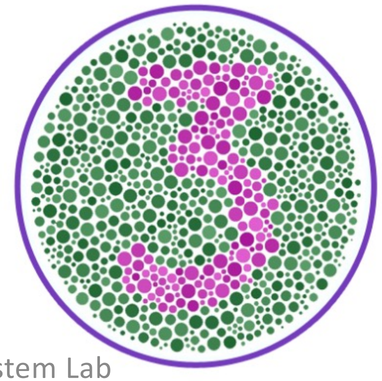
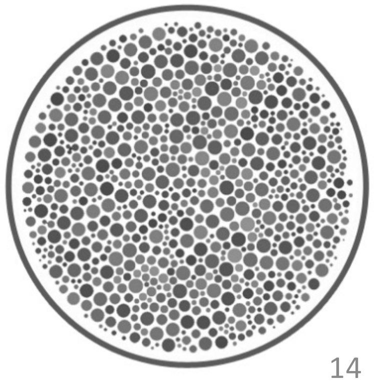
$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}.$$

- Many vision systems only take the Y channel (luminance) as input to reduce computations

Problems



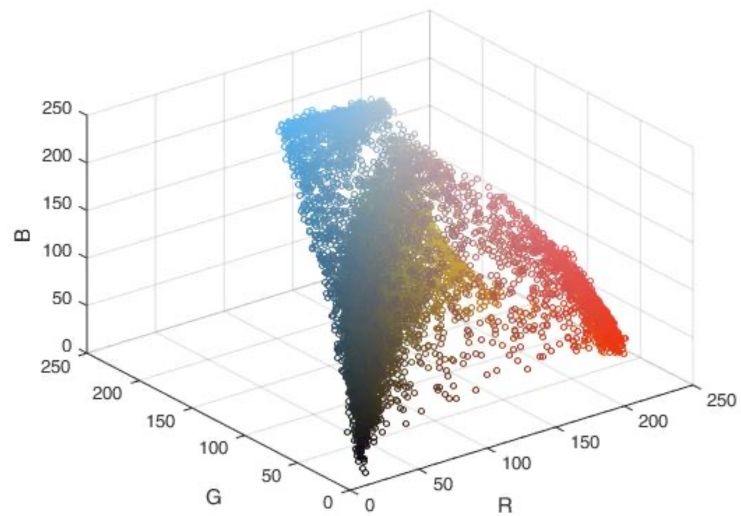





What happened?

- Dimensionality reduction

$$Y = 0.299R + 0.587G + 0.114B$$

- Another view:
  - The conversion is actually a plane equation! All colors on the same plane are converted to the same grayscale value.



Finding a better conversion

- The general form of linear conversion:

$$Y = w_r \cdot R + w_g \cdot G + w_b \cdot B$$

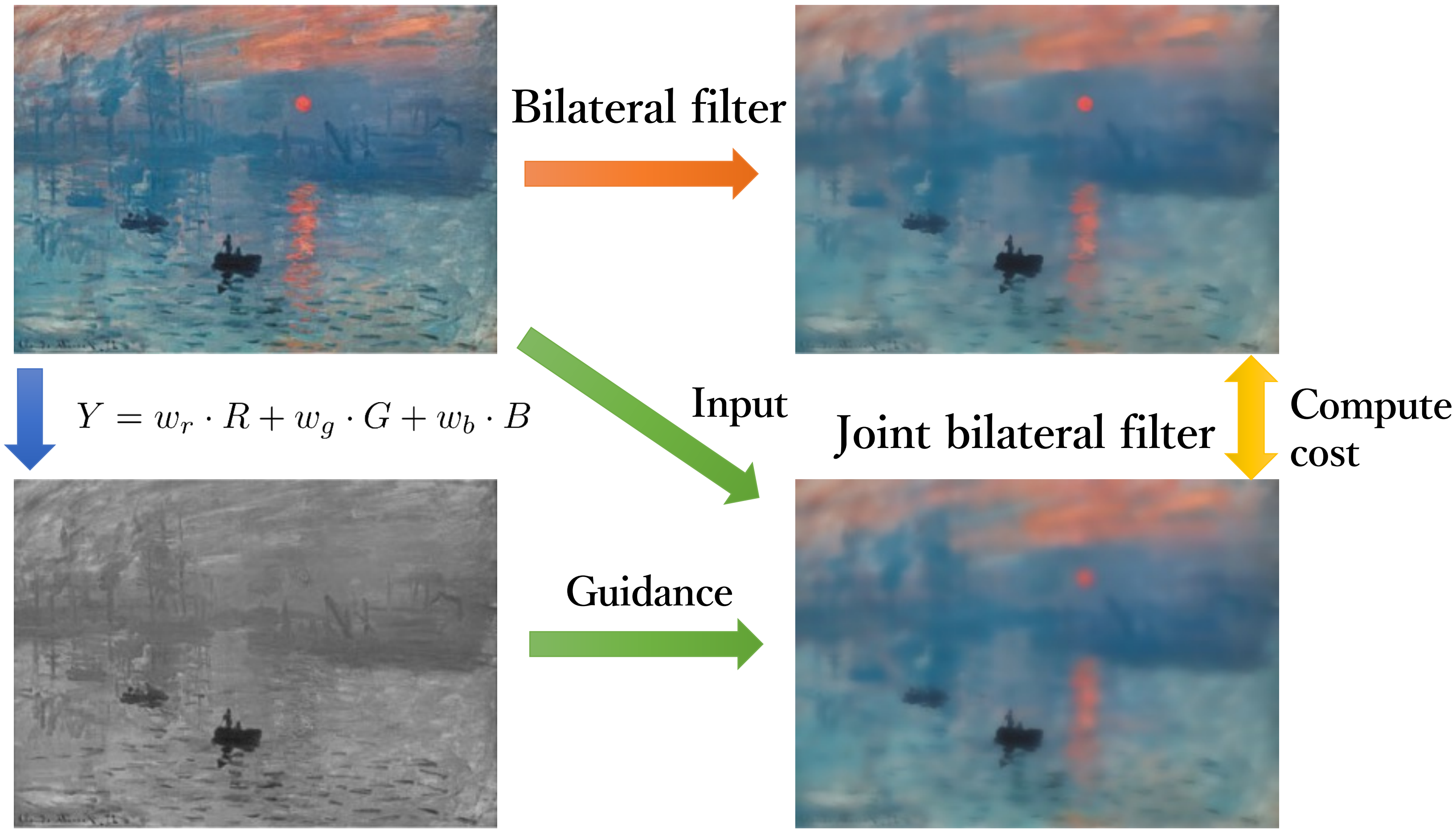
$$w_r, w_g, w_b >= 0$$

$$w_r + w_g + w_b = 1$$

- Let's consider the quantized weight space $w \in \{0, 0.1, 0.2, ..., 1\}$
  - For example: $(w_r, w_g, w_b) = (0, 0, 1)$
    $(w_r, w_g, w_b) = (0, 0.1, 0.9)$
  - Given a color image, a set of weight combination corresponds to a grayscale image candidate.
  - We are going to identify which candidate is better!

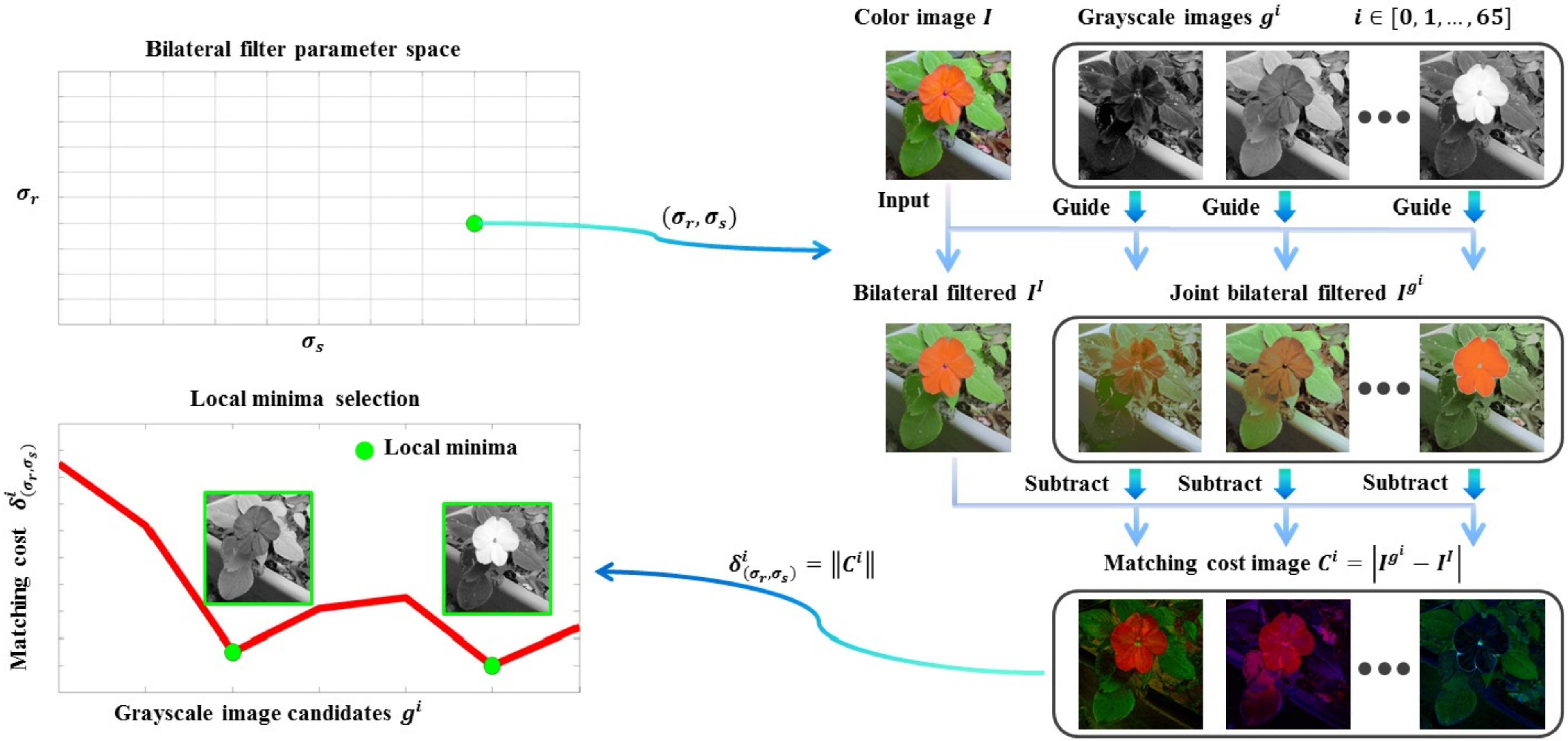
Measuring the perceptual similarity

- Joint bilateral filter (JBF) as the similarity measurement



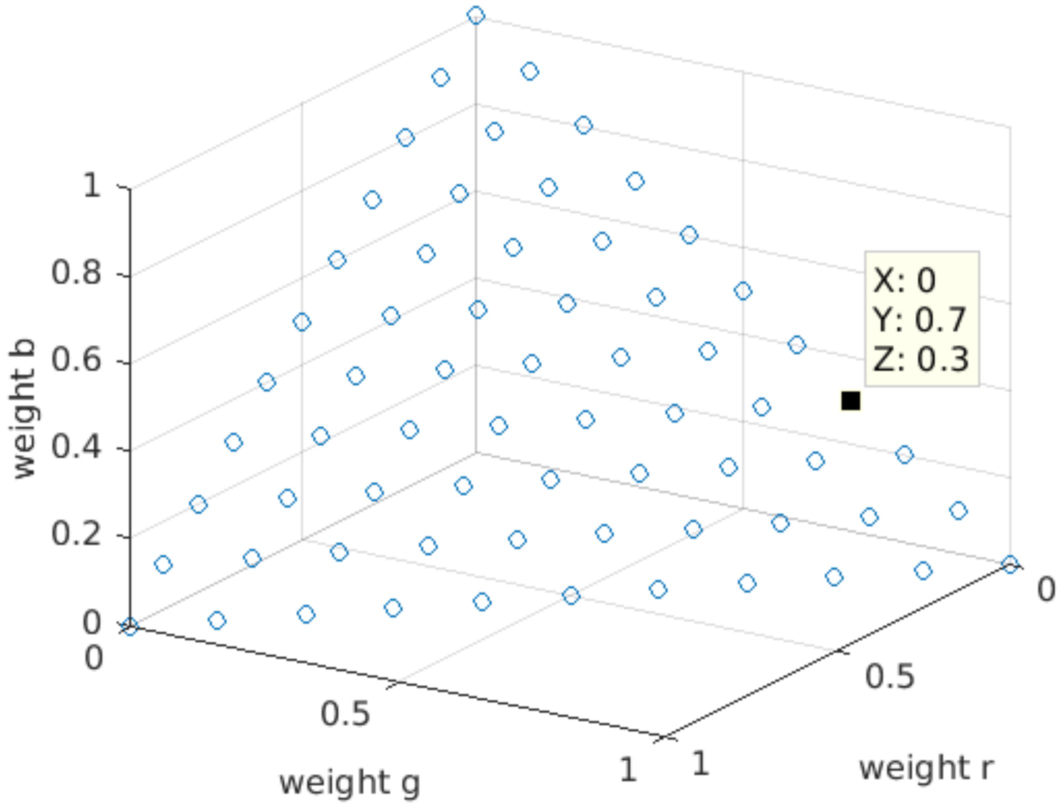
Measuring the perceptual similarity

- Joint bilateral filter (JBF) as the similarity measurement



Measuring the perceptual similarity

- Find local minimum
  - The actual weight space looks like this:



$$w_r, w_g, w_b >= 0$$

$$w_r + w_g + w_b = 1$$

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Bilateral Filter

- Given input image I and guidance T, the bilateral filter is written as:

$$I'_p = \frac{\sum_{q \in \Omega_p} G_s(p,q) \cdot G_r(T_p, T_q) \cdot I_q}{\sum_{q \in \Omega_p} G_s(p,q) \cdot G_r(T_p, T_q)}$$

  - I_p: Intensity of pixel p of original image I
  - I'_p: Intensity of pixel p of filtered image I'
  - T_p: Intensity of pixel p of guidance image T
  - Ω_p: Window centered in pixel p
  - G_s: Spatial kernel
  - G_r: Range kernel

Bilateral Filter

- For the spatial kernel G_s:

$$G_s(p,q) = e^{-\frac{(x_p - x_q)^2 + (y_p - y_q)^2}{2\sigma_s^2}}$$

- For the range kernel G_r:
  - If T is a single-channel image:

$$G_r(T_p, T_q) = e^{-\frac{(T_p - T_q)^2}{2\sigma_r^2}}$$

  - If T is a color image:

$$G_r(T_p, T_q) = e^{-\frac{(T_p^r - T_q^r)^2 + (T_p^g - T_q^g)^2 + (T_p^b - T_q^b)^2}{2\sigma_r^2}}$$

  - Pixel values should be normalized to [0, 1] (divided by 255) to construct range kernel.

Assignment Description

- part2/main.py
  - Read image, execute joint bilateral filter, read setting file, select the best grayscale conversion… etc.
- part2/JBF.py
  - Implement joint bilateral filter

```python
class Joint_bilateral_filter(object):
    def __init__(self, sigma_s, sigma_r):
        self.sigma_r = sigma_r
        self.sigma_s = sigma_s
        self.wndw_size = 6*sigma_s+1
        self.pad_w = 3*sigma_s

    def joint_bilateral_filter(self, img, guidance):
        BORDER_TYPE = cv2.BORDER_REFLECT
        padded_img = cv2.copyMakeBorder(img, self.pad_w, self.pad_w, self.pad_w, self.pad_w, BORDER_TYPE)
        padded_guidance = cv2.copyMakeBorder(guidance, self.pad_w, self.pad_w, self.pad_w, self.pad_w, BORDER_TYPE)

        ### TODO ###

        return np.clip(output, 0, 255).astype(np.uint8)
```

Define window size

Pad the input and guidance image

Output image should be in format of uint8

Assignment Description

- part2/eval.py (DO NOT Modify!)
  - Evaluate the correctness of the output of joint bilateral filter

```
def main():
    parser = argparse.ArgumentParser(description='evaluation function of joint bilateral filter')
    parser.add_argument('--sigma_s', default=3, type=int, help='sigma of spatial kernel')
    parser.add_argument('--sigma_r', default=0.1, type=float, help='sigma of range kernel')
    parser.add_argument('--image_path', default='./testdata/ex.png', help='path to input image')
    parser.add_argument('--gt_bf_path', default='./testdata/ex_gt_bf.png', help='path to ground truth bf image')
    parser.add_argument('--gt_jbf_path', default='./testdata/ex_gt_jbf.png', help='path to ground trut jbf image')
    args = parser.parse_args()

    img = cv2.imread(args.image_path)
    img_rgb = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
    img_gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

    # create JBF class
    JBF = Joint_bilateral_filter(args.sigma_s, args.sigma_r)

    bf_out = JBF.joint_bilateral_filter(img_rgb, img_rgb).astype(np.uint8)
    t0 = time.time()
    jbf_out = JBF.joint_bilateral_filter(img_rgb, img_gray).astype(np.uint8)
    print('[Time] %.4f sec'%(time.time()-t0))
```

We will test your inference duration of joint bilateral filter.

  - TAs will run this file to score your code.
  - When testing your code, different arguments, e.g. σ_s and σ_r, and corresponding ground truth file will be applied.

Assignment Description

- part2/testdata/
  - One example image with bf and jbf ground truth
  - Two images with respective setting files

1.png

1_setting.txt

```
R,G,B
0.0,0.0,1.0
0.0,1.0,0.0
0.1,0.0,0.9
0.1,0.4,0.5
0.8,0.2,0.0
sigma_s,2,sigma_r,0.1
```

  - There are σ_s, σ_r and 5 groups of gray-conversion parameters in the setting files. Generate 6 gray-scale images by those parameters and cv2.cvtColor().
  - Use those gray-scale images as guidance to run joint bilateral filter and compute the perceptual similarity.
    - Refer p.21 and p.22 for details (use L1-norm as our cost function).
    - Note: casting the image into np.int32 is needed to avoid overflow when subtraction.

Assignment Description

Recommended steps:

1. Implement joint bilateral filter in JBF.py
2. Use eval.py to evaluate your JBF.py

```
$ python3 eval.py --image_path ./testdata/ex.png --gt_bf_path ./testdata/ex_gt_bf.png --gt_jbf_path ./testdata/ex_gt_jbf.png
```

   - The error of bilateral and joint bilateral filter should be both 0

```
[Error] Bilateral: 0
[Error] Joint bilateral: 0
```

3. Finish remaining code in main.py if needed
4. Improve the inference speed of joint bilateral filter

Assignment Description

- About the speed test of JBF…
  - Some useful tips
    - Build look-up-table for both spatial and range gaussian kernels
    - Reduce the usage of for-loop to enhance parallel processing
  - Reference time of TA code on ex.png
    - MacBook Pro 2019 (Intel Core i5 CPU) + 8 GB RAM ⇒ ~1.09 sec
    - Intel Core i7-9700K CPU + 8 GB RAM ⇒ ~0.93 sec
    - Intel Core i9-9900K CPU + 128 GB RAM ⇒ ~0.57 sec
  - For fair comparison, you can only use basic functions (e.g. cannot use cv2.filter2D, cv2.GaussianBlur) in JBF.py
  - Cython, multi-thread and GPU acceleration is forbidden.

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Environment

- Package
  - Python == 3.10
  - Numpy == 1.21.6
  - Opencv-python == 4.6.0.66
  - Python standard library
- You can refer to this link for environment setup.
- The following APIs are forbidden in part2/JBF.py
  - OpenCV: cv2.filter2D, cv2.GaussianBlur
  - Cython, multi-thread and GPU acceleration
- You will NOT get corresponding points if you violate rules above.

Report (30%)

- Follow the template we provide and submit pdf file

- Part1: Difference of Gaussian (9%)
  - Plot 8 DoG images descripted in page.7 with threshold 5.0 on 1.png (4%)
  - Use three thresholds (2.0, 5.0, 7.0) on 2.png, plot DoG feature, and describe the difference. (5%)

Report (30%)

- Part2: Joint bilateral filter (21%)
  - For 1.png and 2.png:
    - Report the cost for each filtered image (by using 6 grayscale images as guidance) (1%+1%)
    - Show original RGB image, two filtered RGB images and two grayscale images with highest and lowest cost (five images in total for each input image) (2%+2%)
    - Describe the difference between those two grayscale images. (5%+5%)
  - Describe how you speed up the implementation of bilateral filter. (5%)

Submission

- Directory architecture:

  + R12345678/

    - DoG.py

    - JBF.py

- Put above files in a directory (named StudentID) and compress the directory into zip file (named StudentID.zip)
  - e.g. After TAs run "unzip R12345678.zip", it should create one directory named "R12345678"
- Do NOT copy homework (code and report) from others
- Do NOT show or write images in files you hand in.

Submission

- Please submit those two files, i.e. your StudentID.zip and report.pdf, separately to NTU COOL
- Deadline: 2025/03/27 (Thu.) 23:59

Grading (Total 15%)

- Part 1 Code: 30%
  - 30%, runs within 5 mins and no error (TA will check your answer on 2.png)
  - 0%, others
- Part 2 Code: 30%
  - 30%, runs within 5 mins and no error (both bf and jbf error == 0)
  - 0%, others
- Report : 30%
- Part 2 Inference time: 10%
  - 10%, Top ~ 20%
  - 6%, 20% ~ 50%
  - 3%, 50% ~ 80%
  - 0%, 80% ~

Late Policy

- Each student has in total 3 days delay quota.
  - Specifically, we take 12 hr. (half day) as one unit.
  - Each student has 6 units.
- All four homework assignments share the same 3-day delay.
  - For example, if you delay 1 day in HW1, then you will have 2 day delay quota left for HW2, HW3 and HW4.
- If you have spent all 6 delay units, your late submission will not be accepted.
  - That is, you are required to submit your homework in time to get points.
- If you have questions about the policy, you can contact TAs.

TA information

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  Location: 博理 421

- Yu-Ching Fan (范宇清)
  E-mail: jackmafan@media.ee.ntu.edu.tw
  Location: 博理 421