Assignment 4:

Stereo Matching

Computer Vision

National Taiwan University

Spring 2024

Announced: 2024/05/10 (Fri.)

Due: 2024/05/30 (Thu.) 23:59

Introduction of Stereo Matching

- Q: How do human's eyes judge the distance between two objects or the depth of object?
- A: Two eyes perceive same object slightly differently and our brain can merge two images into a 3D image.
- That's Stereo Matching!!

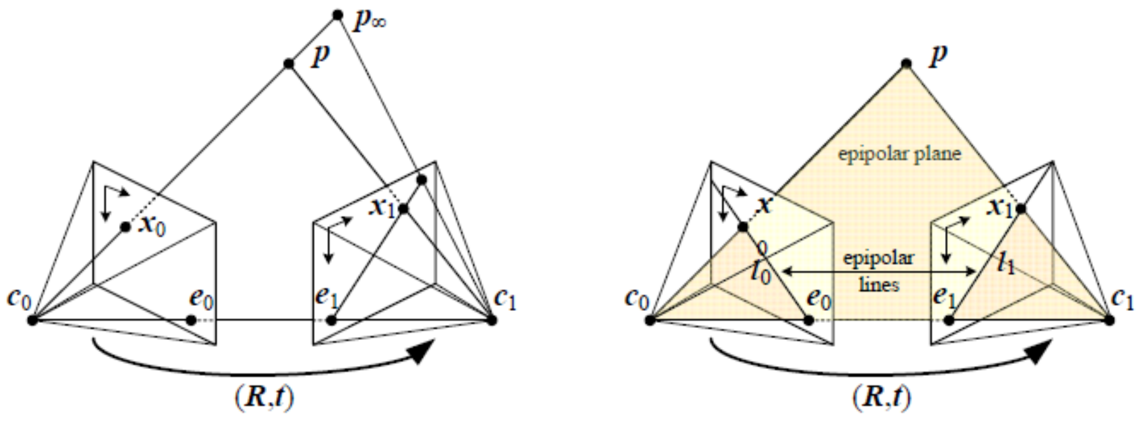
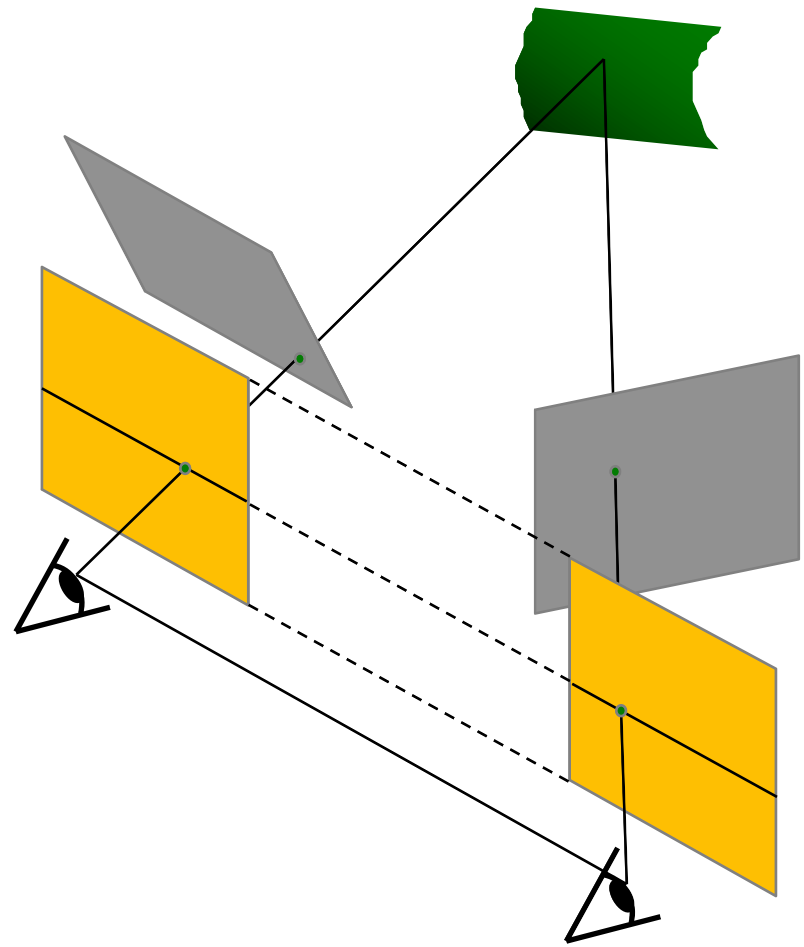


Image Rectification

- Re-project image planes onto a common plane parallel to the line between optical centers.
- Pixel motion is horizontal after this transformation.



(The testing images in this assignment have been rectified.)

Disparity Estimation

- After rectification, stereo matching becomes the disparity estimation problem.
- Disparity = horizontal displacement of corresponding points in the two images
  - Disparity of ✕ = $x_L - x_R$

$Image_L$

$Image_R$

- You need to implement Disparity Estimation in hw4.

Disparity Estimation

- “Hello world” algorithm: block matching
  - Consider SSD (Sum of Squared Distance) as matching cost

d	0	1	2	3	…	33	…	59	60
SSD	100	90	88	88	…	$\boxed{12}$	…	77	85

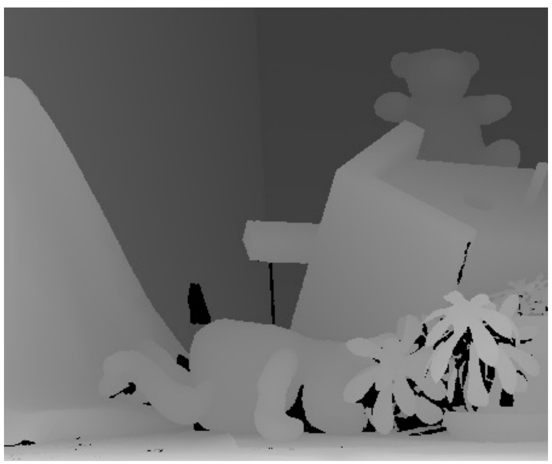
Minimal cost [Winner take all (WTA)]

$Image_L$

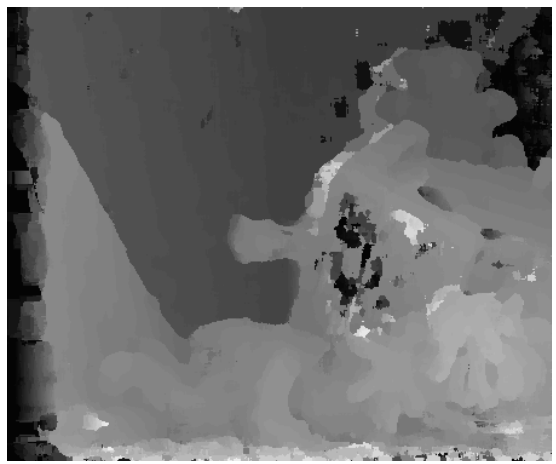
$Image_R$

Disparity Estimation

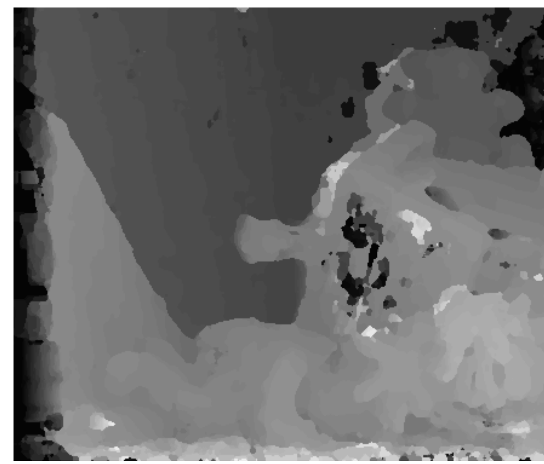
- Block matching result



Ground-truth



Window 5x5



After 3x3 median filter

Typical Improved Pipeline

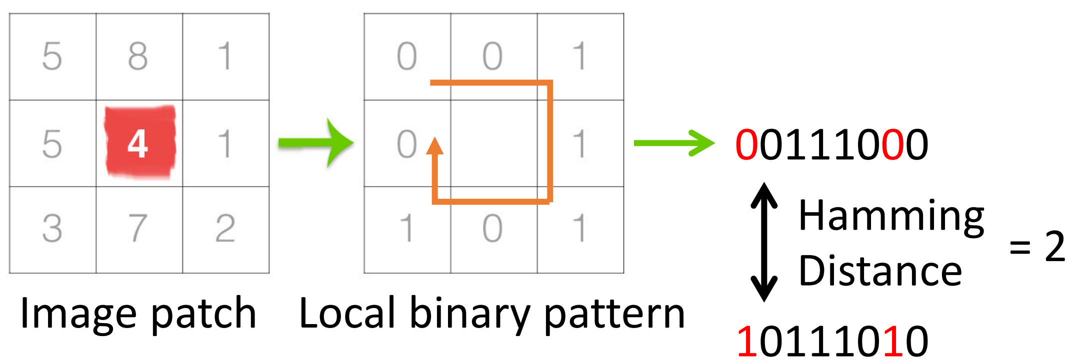
- It consists of 4 steps:
  - Cost computation
  - Cost aggregation
  - Disparity optimization
  - Disparity refinement

D. Scharstein and R. Szeliski. A taxonomy and evaluation of dense two-frame stereo correspondence algorithms. IJCV 2002.

Step 1: Cost Computation

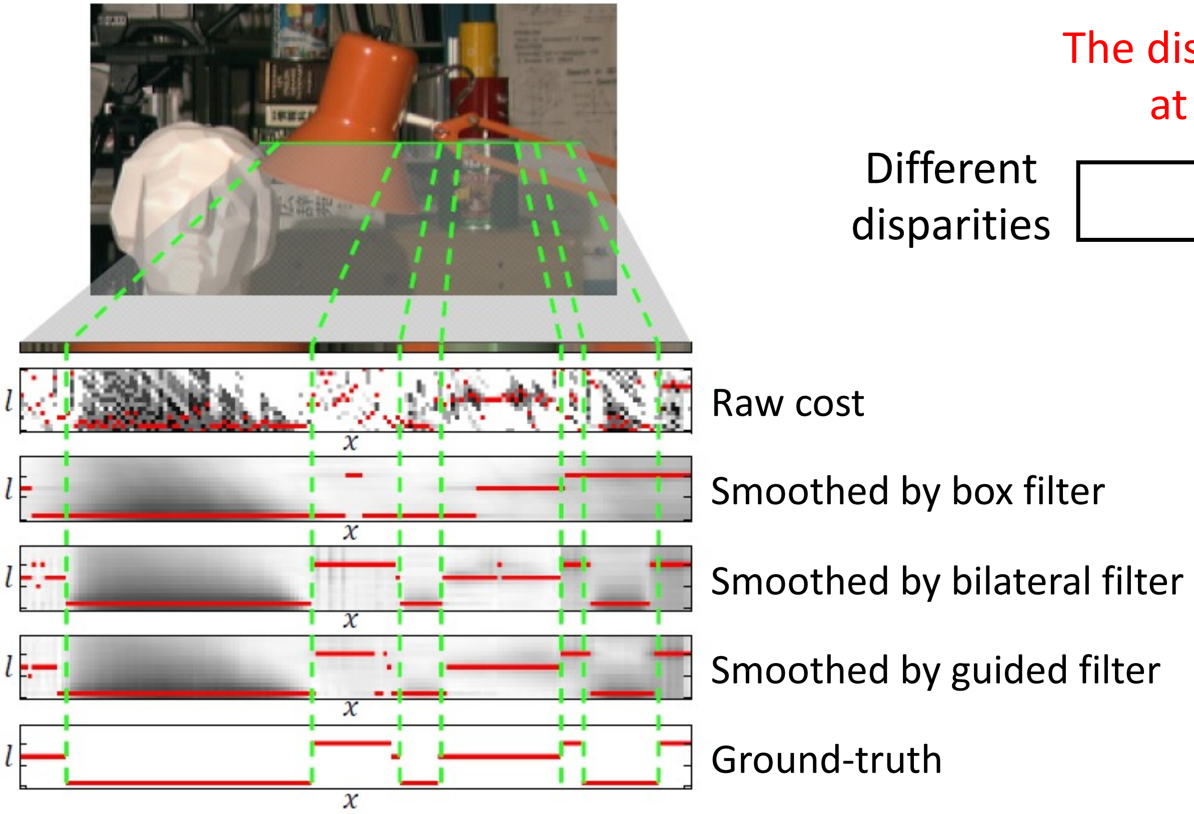
- Matching cost
  - Squared difference (SD): $(I_p - I_q)^2$
  - Absolute difference (AD): $|I_p - I_q|$
  - Census cost

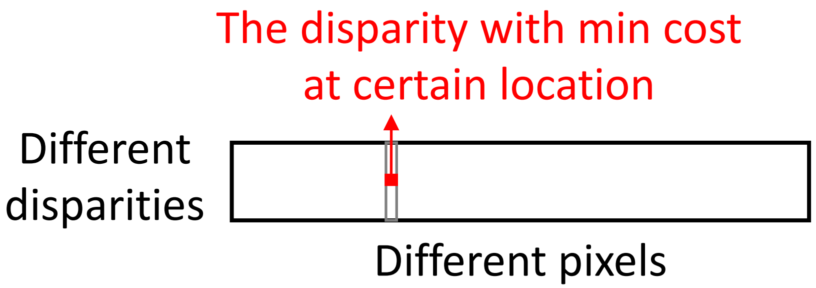
如果比中間小label成1
比中間大label成0



Step 2: Cost Aggregation

- Illustration of the matching cost

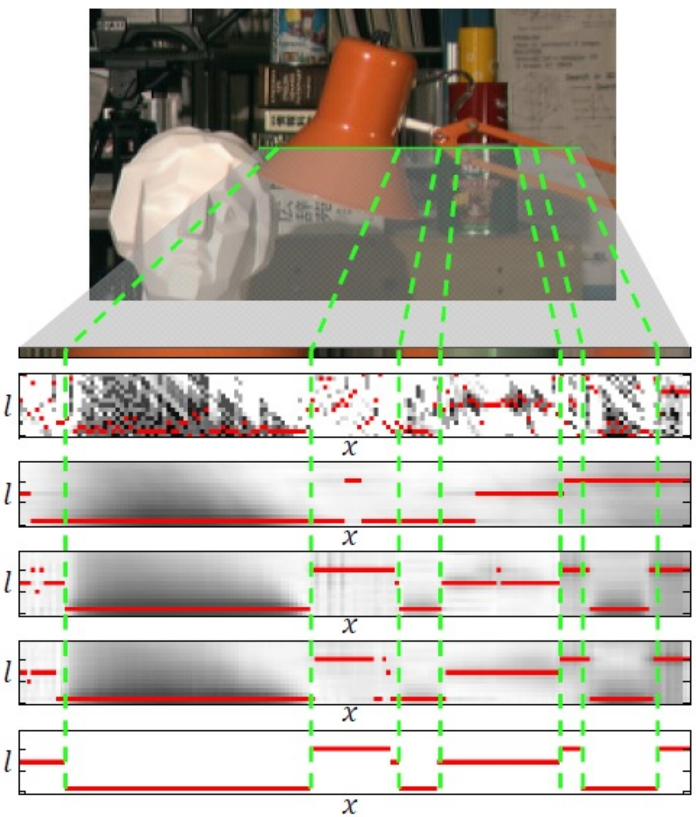




Rhemann et al. Fast cost-volume filtering for visual correspondence and beyond. In CVPR 2011.

Step 3: Disparity optimization

- Winner-take-all 選cost最小的當結果



Step 4: Disparity Refinement

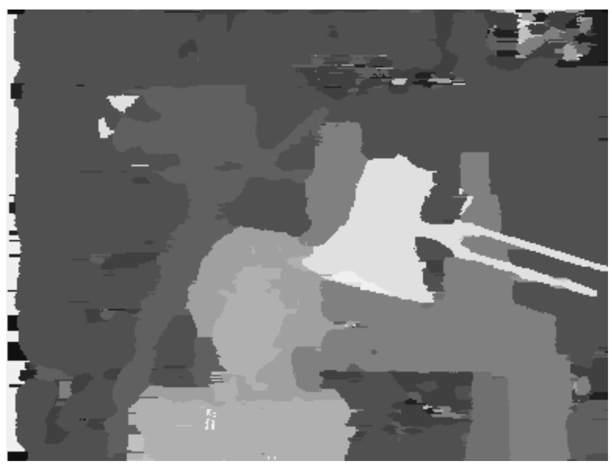
- Left-right consistency check
  - Compute disparity map D_L for left image
  - Compute disparity map D_R for right image
  - Check if $D_L(x, y) = D_R(x - D_L(x, y), y)$
    - If Yes, keep the computed disparity
    - If No, mark hole (invalid disparity)

Note: D_R are only used in this step!!
Only need to keep D_L for the next step.

Two corresponding positions in images

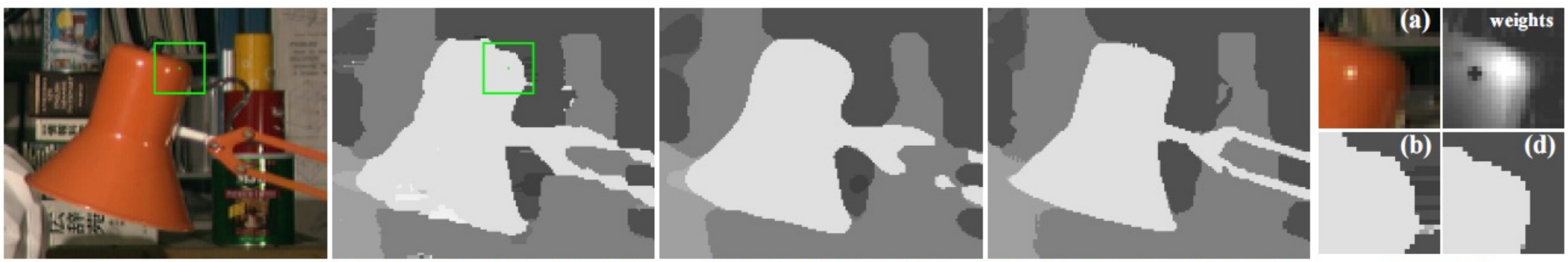
Step 4: Disparity Refinement

- Hole filling
  - F_L, the disparity map filled by closest valid disparity from left
  - F_R, the disparity map filled by closest valid disparity from right
  - Final filled disparity map $D = \min(F_L, F_R)$ (pixel-wise minimum)
  - Tips: pad maximum for the holes in boundary (start point)



Step 4: Disparity Refinement

- Weighted median filtering



(a) left image (b) box agg.+LR check+hole-filling (c) median filtering of (b) (d) weighted median filtering of (b) (e) zoom-in

Ma et al. Constant time weighted median filtering for stereo matching and beyond. In ICCV 2013.

Assignment Description(1/2)

- computeDisp.py (TODO)

```python
import numpy as np
import cv2.ximgproc as xip


def computeDisp(Il, Ir, max_disp):
    h, w, ch = Il.shape
    labels = np.zeros((h, w), dtype=np.float32)
    Il = Il.astype(np.float32)
    Ir = Ir.astype(np.float32)

    # >>> Cost Computation
    # TODO: Compute matching cost
    # [Tips] Census cost = Local binary pattern -> Hamming distance
    # [Tips] Set costs of out-of-bound pixels = cost of closest valid pixel
    # [Tips] Compute cost both Il to Ir and Ir to Il for later left-right consistency


    # >>> Cost Aggregation
    # TODO: Refine the cost according to nearby costs
    # [Tips] Joint bilateral filter (for the cost of each disparty)


    # >>> Disparity Optimization
    # TODO: Determine disparity based on estimated cost.
    # [Tips] Winner-take-all


    # >>> Disparity Refinement
    # TODO: Do whatever to enhance the disparity map
    # [Tips] Left-right consistency check -> Hole filling -> Weighted median filtering


    return labels.astype(np.uint8)
```

Good News:
you CAN use cv2.ximgproc package with plenty of filtering operations

Maximum possible disparity (do not need to search the disparity larger than it)

You are not forced or limited to those tips. *But, they are good for you to improve your algorithm.*

CANNOT use deep learning based methods.

Assignment Description(2/2)

- main.py (completed)
  - Read image, execute stereo matching, and visualize disparity map.
  - Usage: python3 main.py --image {input_image}
- eval.py (DO NOT EDIT this file)
  - Compute disparity maps of the **left image** for the four standard test pairs from Middlebury v2

Tsukuba

with gt

Venus

without gt

Teddy

with gt

Cones

without gt

  - Evaluation metric: bad pixel ratio (error threshold = 1)

Environment

- Python 3.6+
- Package
    - (optional)conda create –n <env name> python=3.6
    - pip3 install –r requirement.txt

Report

- Your student ID, name
- Visualize the disparity map for all 4 testing images.
- Report the bad pixel ratio for 2 testing images with given gt.
- Explain your algorithm in terms of the standard 4-step pipeline.

Submission(1/2)

- Directory architecture:

    + R12345678_hw4/

        - computeDisp.py

- Put all the files in a directory named StudentID_hw4 and compress the directory into zip file (named StudentID_hw4.zip)
- After TAs run “unzip R12345678_hw4.zip”, it should generate one directory named “R12345678_hw4”.
- Do NOT copy homeworks (including code and report) from others

Submission(2/3)

- Please submit those two files, i.e. your StudentID_hw4.zip and report.pdf, separately to NTU COOL
- Deadline: 5/30 11:59 pm
  - Late policy: refer to hw1

Submission(3/3)

- If we can not execute your code, you'll get 0 points. But you'll have a chance to modify your code.

- Your code has to be finished in 10 mins.
  - Otherwise, you'll only get 70% points.
  - Intel Core i7-6800K CPU + 128GB RAM

- We will execute your code on Linux system, so make sure your code can be executed on Linux system before submitting homework.

Grading (Total 15%)

- Code: 60% (15% for each testing image)

Score	Tsukuba	Venus	Teddy	Cones
15	< 8	< 5	< 18	< 15
12	>= 8	>= 5	>= 18	>= 15
5	>= 9	>= 7	>= 24	>= 20
0	>= 10	>= 10	>= 30	>= 25

- Report : 30%
- Ranking: 10% (on average score of all testing images)
    - 10%, Top ~30%
    - 7%, Top ~60%
    - 5%, Top ~80%
    - 0%, others
- If runs longer than 10 minutes on any image will only get 70% score

TA information

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  Location: BL-421

- Yu-Kai Hsieh(謝郁楷)
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