Computer Vision: Part 1 (2D CV)

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Lecture Content

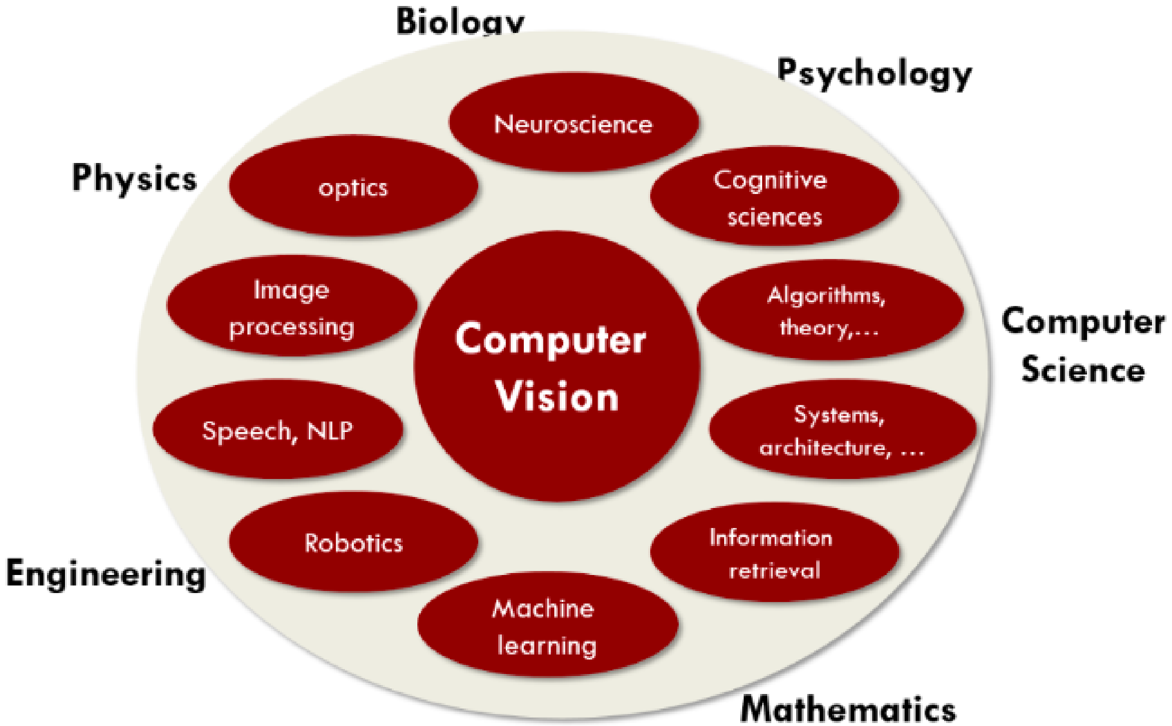
- What is Computer Vision?
- What is Image?
- Feature Detection and Matching
- Classification, Object Detection, Segmentation and Pose Estimation
- Visual Tracking
- Computer Vision Applications
- Conclusion
- References

Session Outcomes

- Acquire basic knowledge of computer vision as an interdisciplinary field.
- Understand feature detection and matching, and its applications.
- Gain basic understanding of Computer vision tasks.

What is Computer vision?

- **Computer vision** is an interdisciplinary field that deals with how computers can be made to gain high-level understanding from digital images or videos. It is a sub-field of AI.



What is image?

What we see

0	2	15	0	0	11	10	0	0	0	0	9	9	0	0	0
0	0	0	4	60	157	236	255	255	177	95	61	32	0	0	29
0	10	16	119	238	255	244	245	243	250	249	255	222	103	10	0
0	14	170	255	255	244	254	255	253	245	255	249	253	251	124	1
2	98	255	228	255	251	254	211	141	116	122	215	251	238	255	49
13	217	243	255	155	33	226	52	2	0	10	13	232	255	255	36
16	229	252	254	49	12	0	0	7	7	0	70	237	252	235	62
6	141	245	255	212	25	11	9	3	0	115	236	243	255	137	0
0	87	252	250	248	215	60	0	1	121	252	255	248	144	6	0
0	13	113	255	255	245	255	182	181	248	252	242	208	36	0	19
1	0	5	117	251	255	241	255	247	255	241	162	17	0	7	0
0	0	0	4	58	251	255	246	254	253	255	120	11	0	1	0
0	0	4	97	255	255	255	248	252	255	244	255	182	10	0	4
0	22	206	252	246	251	241	100	24	113	255	245	255	194	9	0
0	111	255	242	255	158	24	0	0	6	39	255	232	230	56	0
0	218	251	250	137	7	11	0	0	0	2	62	255	250	125	3
0	173	255	255	101	9	20	0	13	3	13	182	251	245	61	0
0	107	251	241	255	230	98	55	19	118	217	248	253	255	52	4
0	18	146	250	255	247	255	255	255	249	255	240	255	129	0	5
0	0	23	113	215	255	250	248	255	255	248	248	118	14	12	0
0	0	6	1	0	52	153	233	255	252	147	37	0	0	4	1
0	0	5	5	0	0	0	0	0	14	1	0	6	6	0	0

What a computer sees

What is image?

- Images are just numbers. i.e. a matrix of 2-dimensional numbers in this case (gray scale image).
- An image is made of pixels. Pixel value: 0 – 255.
- A video is a sequence of frames (images).

BW

Gray

RGB

What is image?

- RGB color image has 3 channels:

Red

Green

Blue

Feature Detection and Matching

- A pair of images to be matched. What kinds of features might one use to establish a set of correspondences between these images?

Feature Detection and Matching

- A pair of images to be matched. What kinds of features might one use to establish a set of correspondences between these images?

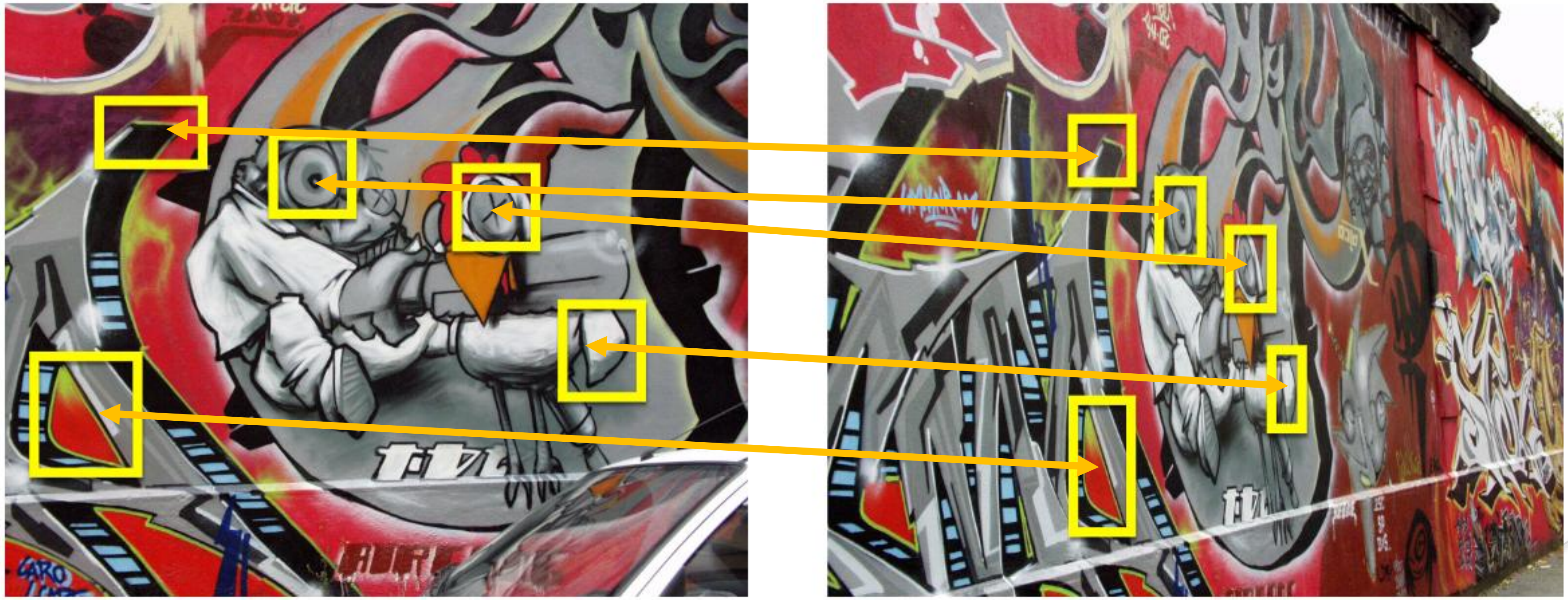
- The first kind of features that you may notice are specific locations in the images, such as building corners, doorways, etc.

Feature Detection and Matching

- These kinds of localized features are often called **keypoint features** or **interest points** (or even **corners**) and are often described by the appearance of pixel patches surrounding the point location.
- **Four** separate stages in keypoint detection and matching pipeline:
  - Feature detection (extraction) - each image is searched for locations that are likely to match well in other images.
  - Feature description - each region around detected keypoint locations is converted into a more compact and stable (invariant) descriptor that can be matched against other descriptors. There is a descriptor vector for each keypoint feature.
  - Feature matching - efficiently searching for likely matching candidates in other images.
  - Feature tracking – is more suitable for video processing i.e. for video tracking applications.

Feature Detection and Matching

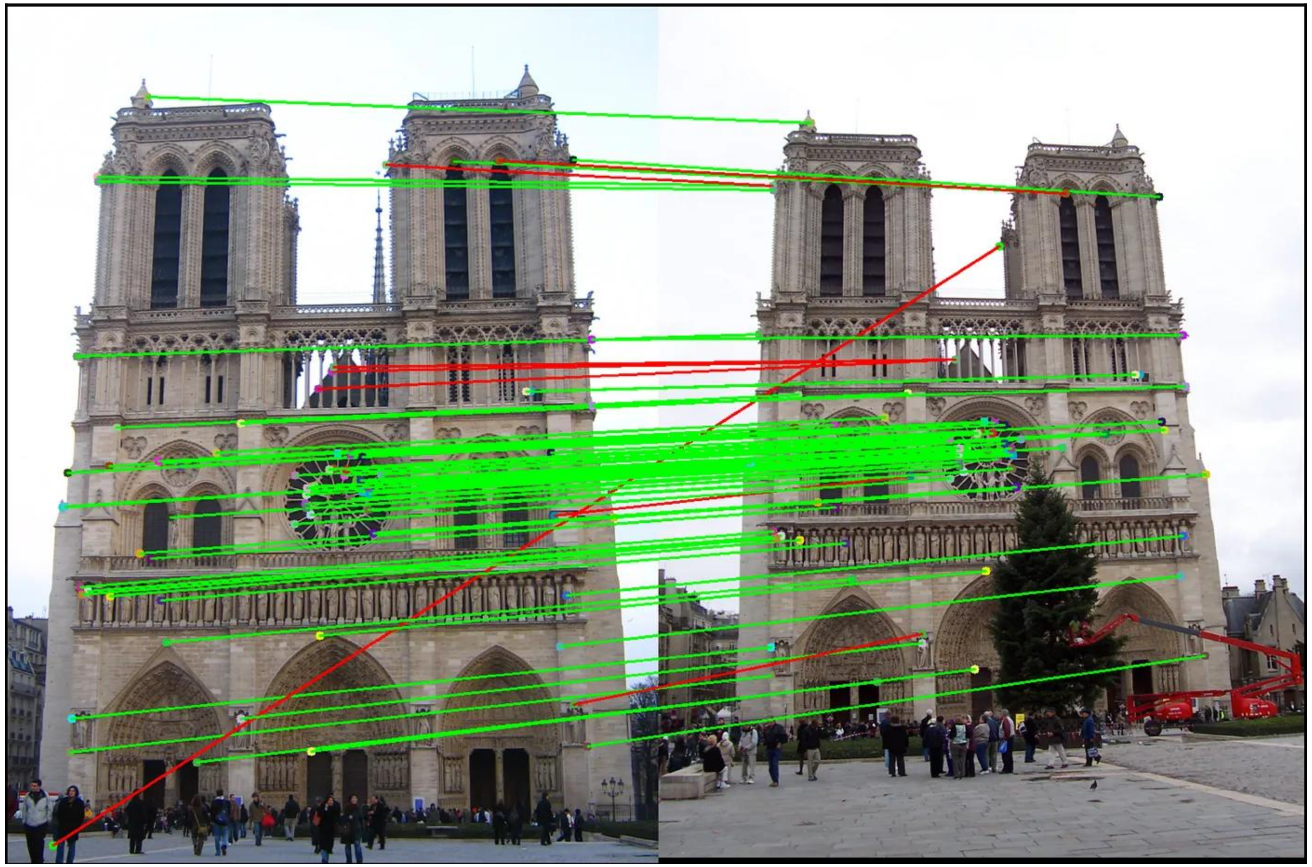
- Feature detection and matching example:



- False positive (outlier) matches can be detected and then removed using RANSAC.

Feature Detection and Matching

- Feature detection and matching example:



What are the **red** matches?
How do you remove them?

Feature Detection and Matching

- Most descriptors are computed in a local manner, hence a description is obtained for every interest point or keypoint identified. These descriptors are (ideally) invariant under changes in illumination, translation, scale, and in-plane rotation, such that they can be reliably computed with a high degree of repeatability.

- Common feature descriptor algorithms:
  - Scale Invariant Feature Transform (SIFT) – length of each descriptor vector is 128 (128-D).
  - Speeded up robust features (SURF) – length of each descriptor is 64.
  - Features from Accelerated Segment Test (FAST).
  - Binary Robust Independent Elementary Features (BRIEF).
  - Oriented FAST and Rotated BRIEF (ORB).

Feature Detection and Matching

- Common feature matching algorithms:
  - Brute-Force Matcher.
  - Fast Library for Approximate Nearest Neighbors (FLANN) Matcher.
- Applications of feature matching or image matching include:
  - Image registration
  - image mosaic or image stitching
  - Object recognition
  - Image retrieval
  - Camera calibration
  - 3D reconstruction
  - Visual SLAM e.g. https://www.youtube.com/watch?v=G-5jesjNfLc
  - Vision-based robot localization and navigation, etc.

Classification, Object Detection, Segmentation and Pose Estimation

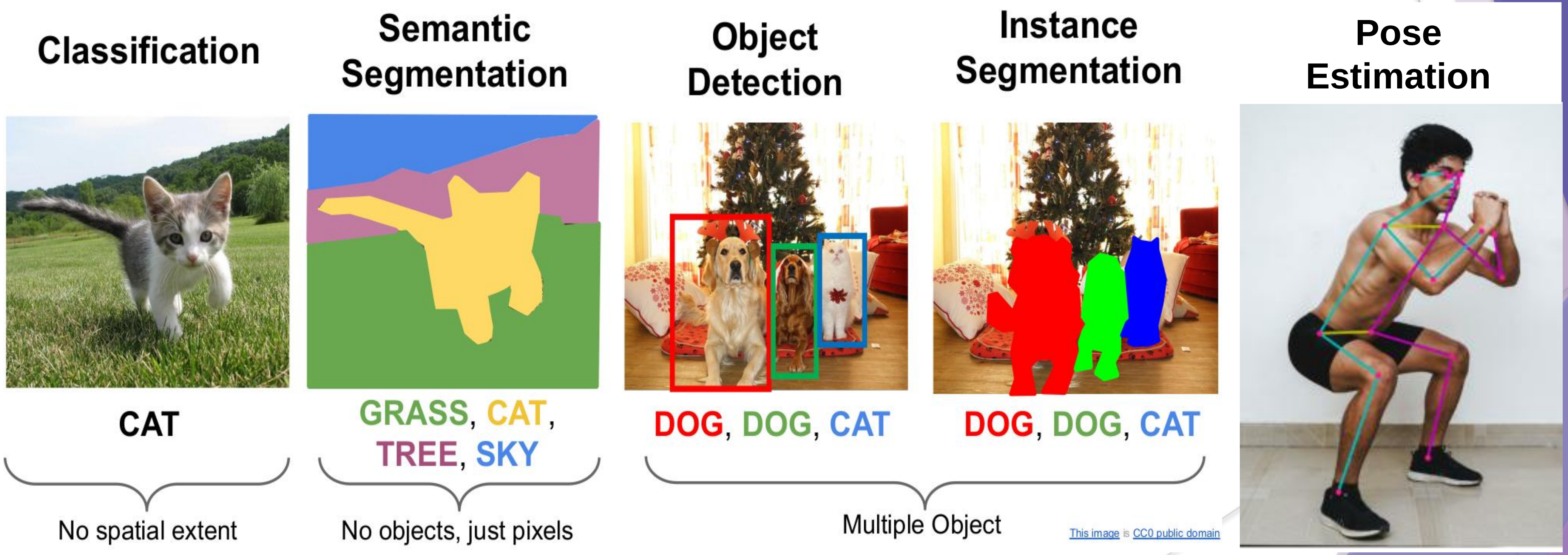
- **Image Classification:** A core task in Computer Vision.

(assume given a set of possible labels)
{dog, cat, truck, plane, ...}

→ cat

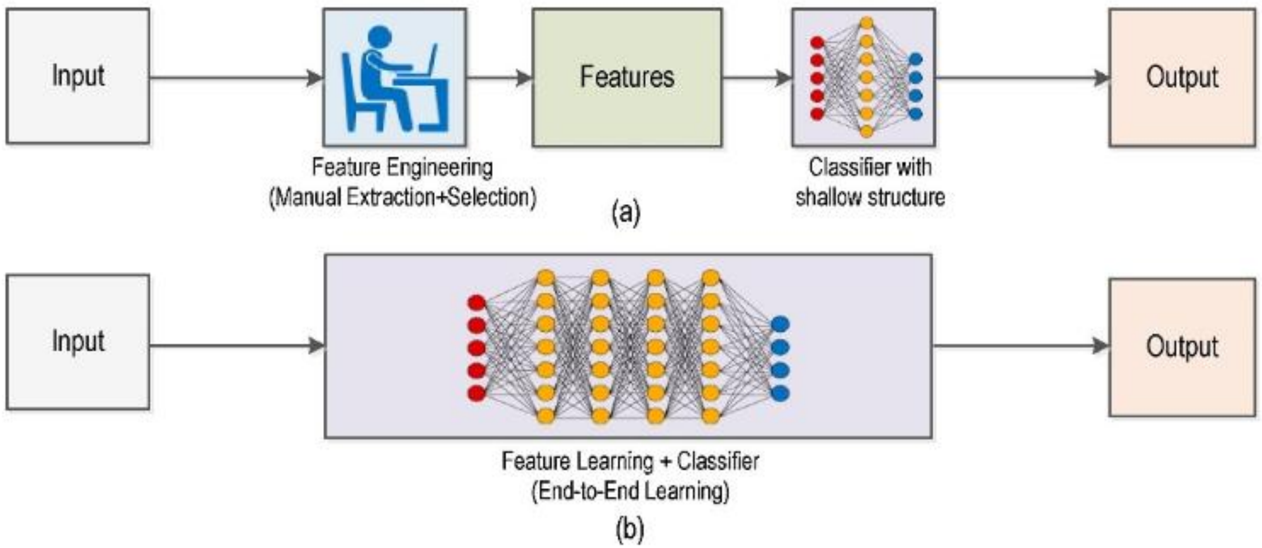
Classification, Object Detection, Segmentation and Pose Estimation

- **Computer Vision Tasks:**



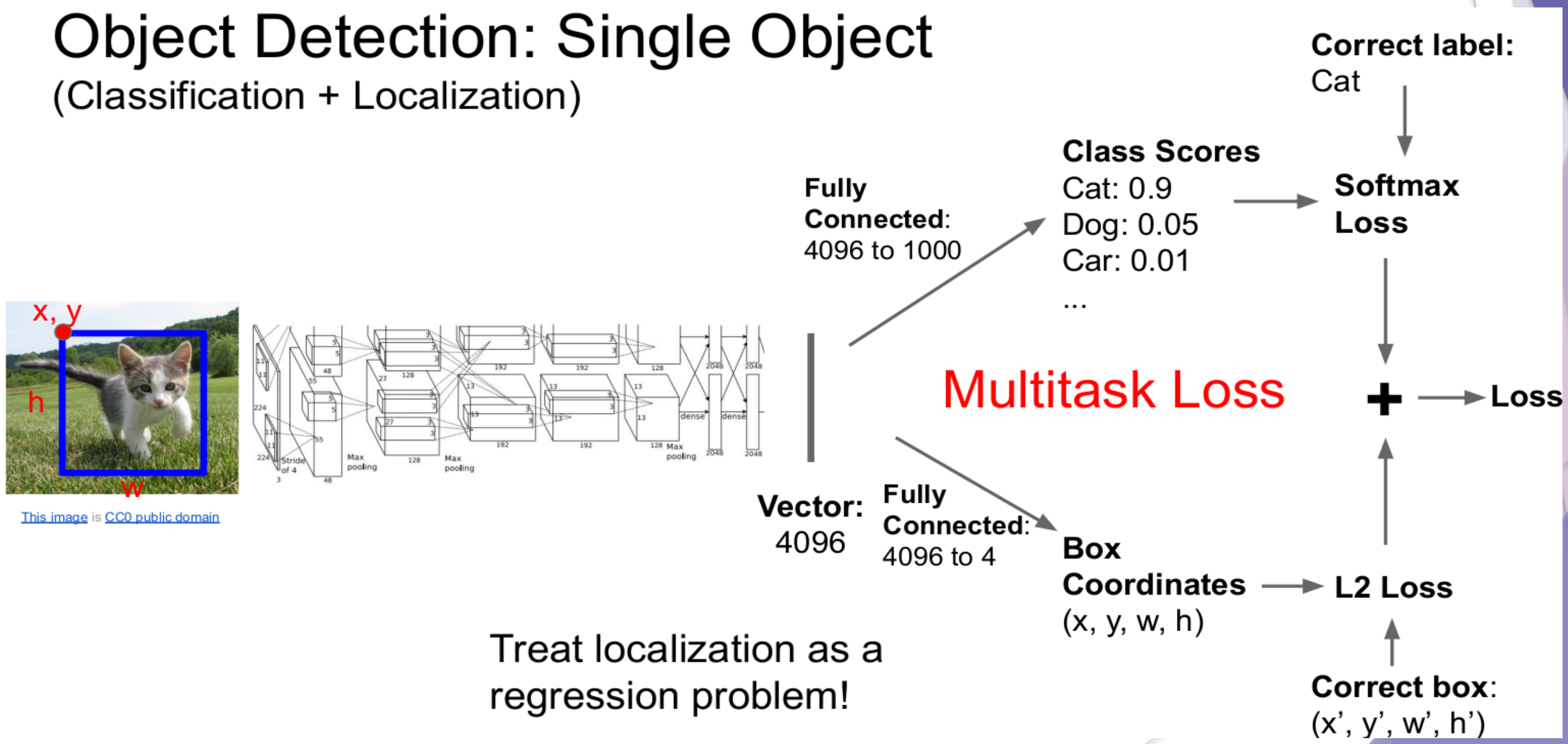
Classification, Object Detection, Segmentation and Pose Estimation

- Traditional computer vision workflow (a) vs deep learning computer vision workflow (b):



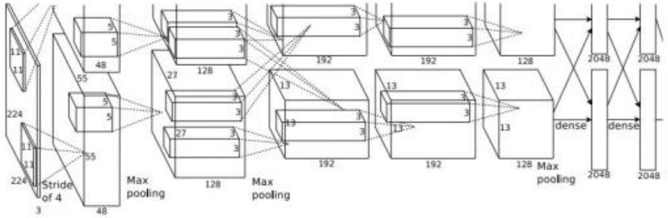
- Read more on: https://arxiv.org/abs/1910.13796

Classification, Object Detection, Segmentation and Pose Estimation

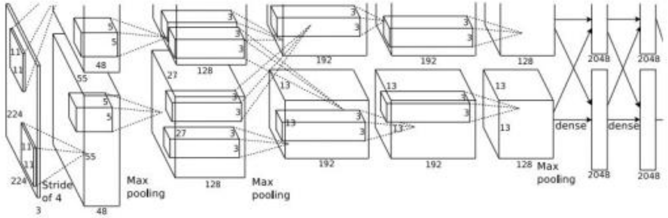


Classification, Object Detection, Segmentation and Pose Estimation

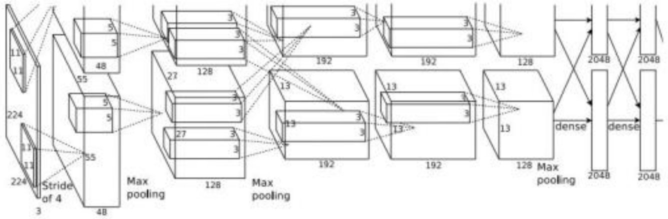
- Object Detection: Multiple Objects

CAT: (x, y, w, h)

DOG: (x, y, w, h)
DOG: (x, y, w, h)
CAT: (x, y, w, h)

DUCK: (x, y, w, h)
DUCK: (x, y, w, h)
….

Classification, Object Detection, Segmentation and Pose Estimation

- Types of object detectors:
  - Two-stage object detectors
    - Region proposals generation + object classification and bounding box prediction.
    - E.g. Faster RCNN
  - Single-stage object detectors
    - Removes the region proposals generation stage.
    - E.g. YOLO family (YOLOv1, …, YOLOv8, …)

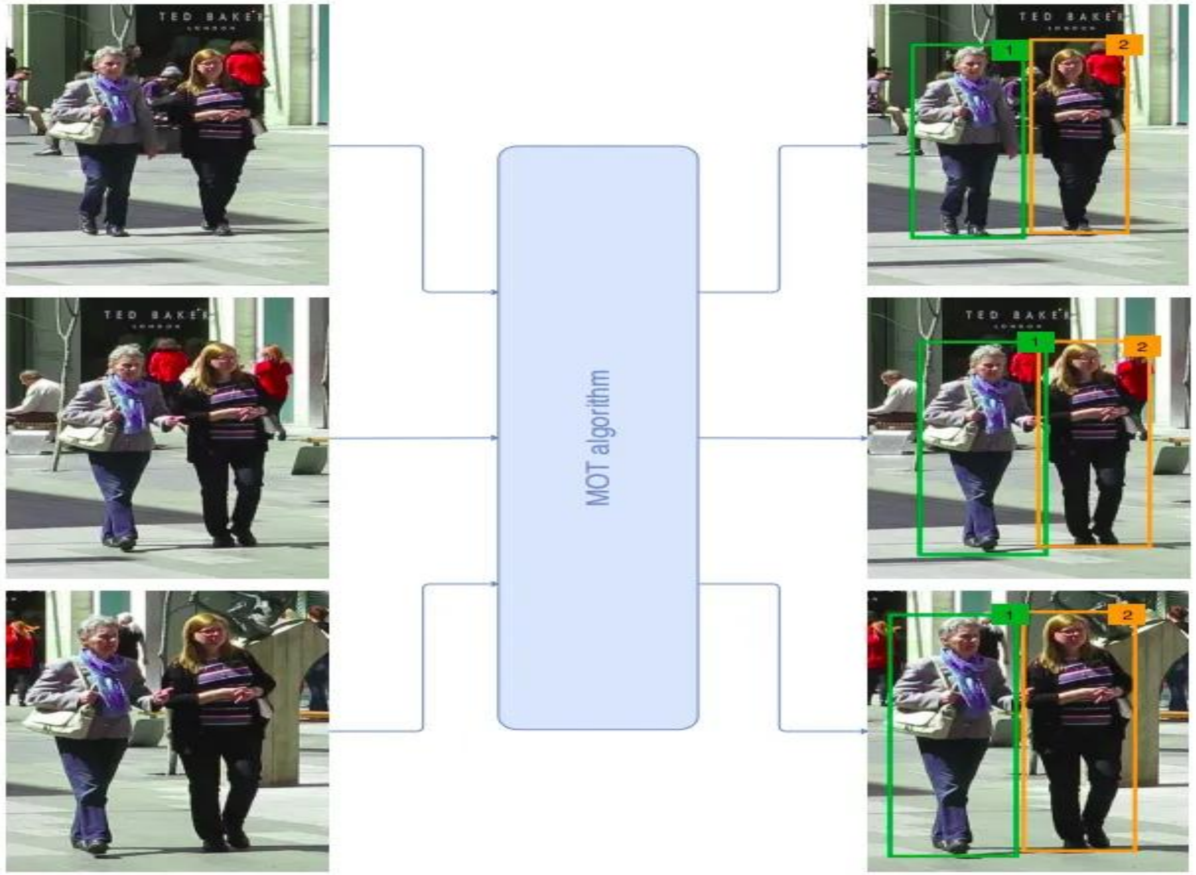
Visual Tracking

- Multi-Object Tracking (MOT):

frame k =1

frame k = 5

frame k = 10



Adapted from:
https://arxiv.org/pdf/1907.12740

Visual Tracking

- Key components of MOT:
  - Object detection
    - YOLO family, FRCNN, etc.
  - Motion prediction
    - Kalman filter
    - GM-PHD filter
  - Data association
    - Hungarian algorithm using:
      - Motion information i.e. Intersection over Union (IoU), Mahalanobis distance, etc. and/or
      - Appearance information

Visual Tracking

- Example of MOT:

- Figure from: Nathanael L. Baisa, "Occlusion-robust online multi-object visual tracking using a GM-PHD filter with CNN-based re-identification," Journal of Visual Communication and Image Representation, 2021.

Computer Vision Applications

- **Security** e.g. Face Recognition:
  - How does facial recognition work? (youtube.com)
- **Security** e.g. Surveillance:
  - How China is building an all-seeing surveillance state (youtube.com)
- **Computer Vision (CV) in Robotics:**
  - Computer vision applications in robotics (youtube.com)
- **Computer Vision in Self Driving Cars and Autonomous Vehicles:**
  - Self Driving Cars and Autonomous Vehicles Technology (youtube.com)
- **Computer Vision in HealthCare:**
  - What is Computer Vision in Healthcare Education (youtube.com)

Conclusion

- Image classification is a core task in computer vision.
- Feature detection and matching plays a crucial role in vision-based robot mapping, localization and visual SLAM.
- Understanding computer vision tasks is important to apply them to intelligent robot-based applications, security, healthcare, etc.

References

- R. Szeliski, 'Computer Vision: Algorithms and Applications', Springer, 2021. [https://szeliski.org/Book/]
- https://medium.com/data-breach/introduction-to-feature-detection-and-matching-65e27179885d
- Image Matching Comparison: https://arxiv.org/pdf/1710.02726
- OpenCV: https://opencv.org/
- Open3D: http://www.open3d.org/
- https://huggingface.co/learn/computer-vision-course/en/unit0/welcome/welcome
- https://github.com/polygon-software/python-visual-odometry
- https://github.com/luigifreda/pyslam