Topic 2 - Face Detection

Group 57

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Overview

- Introduction to Face Detection
- Importance of Face Detection
- Applications of Face Detection
- Face Detection Techniques
- Project Goals

Introduction to Face Detection

- **Definition**: Technology to identify and locate human faces in images and videos.
- **Importance**:
  - Foundation for facial recognition, emotion detection, and security systems.
  - Crucial in various applications like surveillance, user authentication, and personalized marketing.
- **How it Works**:
  - Uses algorithms and machine learning techniques.
  - Detects facial features and distinguishes them from other objects.
- **Advancements**:
  - Deep learning has enhanced accuracy and efficiency.
  - Modern systems are more robust and reliable.

Proposed Solution

- **Model Selection**: Use YOLOv10-L, a state-of-the-art object detection model known for its speed and accuracy.
- **Data Collection**: Gather a dataset of diverse images containing faces, ensuring a balanced representation of different facial features.
- **Data Annotation**: Utilize the pre-labeled dataset downloaded from Kaggle, which includes about 32k images with clean labels in xywh (top-left x-coord, top-left y-coord, face-width, face-height) format for human face detection tasks.
- **Environment Setup**: Clone the YOLOv10-L repository and install dependencies in Google Colab for free GPU access.
- **Model Configuration**: Define the model architecture and configuration using a custom YAML file tailored for face detection.

Proposed Solution

- **Training**: Train the YOLOv10-L model on the annotated dataset, optimizing for accuracy and performance.
- **Evaluation**: Assess the model's performance using metrics such as mAP (mean Average Precision) and adjust parameters as needed.
- **Inference**: Test the trained model on new images to validate its face detection capabilities.
- **Deployment**: Export the trained model weights for use in real-world applications.

Architecture Model Evaluation

Model	Pros	Cons
VGG16	- Simplicity - Strong Feature Extraction	- Computationally Intensive - Not Specialized for Detectio
ResNet50	- Residual Connections - High Accuracy - Scalability	- Complexity - Resource Intensive
YOLO	- Real-Time Performance - High Accuracy - Unified Architecture	- Complexity - Resource Intensive

Architecture

- **YOLOv10 Detailed Structure**:
  - **Backbone**:
    - Uses CSPDarknet architecture for feature extraction.
    - Includes multiple convolutional layers and residual blocks.
  - **Neck**:
    - PANet structure for path aggregation.
    - Enhances feature pyramid for better detection at various scales.
  - **Head**:
    - Outputs bounding box coordinates, objectness scores, and class probabilities.
    - Utilizes anchor boxes for improved localization accuracy.
  - **Advantages**:
    - Superior performance on small and large objects.
    - Optimized for both accuracy and speed.

Data Processing

- **Preprocessing**:
  - **Normalization**: Adjust image pixel values to a common scale to improve model performance.
  - **Augmentation**: Apply techniques such as rotation, flipping, and scaling to increase dataset diversity.
  - **Annotation**: Utilize the pre-labeled dataset downloaded from Kaggle, which includes about 32k images with clean labels.
  - **Dataset Preparation**: Ensure balanced representation of various facial features and expressions.

Dataset

- **Source**:
  - We used the Face Detection Dataset from Kaggle.
  - This dataset is specifically curated for training and testing face detection models.
- **Dataset Composition**:
  - **Training Set**: 26,300 images with annotated face locations.
  - **Validation Set**: 6,500 images with similar annotations.
- **Annotations**:
  - Each image comes with corresponding labels indicating face positions using bounding boxes.

Dataset

- **Preparation**:
  - Downloaded and extracted the dataset using a simple helper script.
  - Ensured the removal of duplicate images and corresponding labels.
- **Directory Structure**:
  - Organized as follows:

```
train
    images
    labels
validation
    images
    labels
test
    images
face-detect-datase.yaml
```

- **YAML Configuration**:
  - Defined paths for training and validation data in a `face-detect-datase.yaml`.
  - Included class names and counts for model reference.
  - **Training Data Path**: `/content/drive/MyDrive/face-detection-project/merged/images/train`
  - **Validation Data Path**: `/content/drive/MyDrive/face-detection-project/merged/images/validation`
  - **Class Names**: `['face']`
  - **Number of Classes (nc)**: `1`

Environment Setup

- **GPU Status Check**:
  - Firstly we ensure the availability and readiness of the GPU for processing and running the YOLOv10 model.
  - Command:
    `!nvidia-smi`

```
[1]  !nvidia-smi

Sun Jun 30 15:33:10 2024
+---------------------------------------------------------------------------------------+
| NVIDIA-SMI 535.104.05             Driver Version: 535.104.05   CUDA Version: 12.2     |
|-----------------------------------------+----------------------+----------------------+
| GPU  Name                 Persistence-M | Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp   Perf          Pwr:Usage/Cap |         Memory-Usage | GPU-Util  Compute M. |
|                                         |                      |               MIG M. |
|=========================================+======================+======================|
|   0  NVIDIA L4                      Off | 00000000:00:03.0 Off |                    0 |
| N/A   44C    P8              12W /  72W |      1MiB / 23034MiB |      0%      Default |
|                                         |                      |                  N/A |
+-----------------------------------------+----------------------+----------------------+

+---------------------------------------------------------------------------------------+
| Processes:                                                                            |
|  GPU   GI   CI        PID   Type   Process name                            GPU Memory |
|        ID   ID                                                             Usage      |
|=======================================================================================|
|  No running processes found                                                           |
+---------------------------------------------------------------------------------------+
```

Figure 1: GPU Status

Environment Setup

- **Mounting Google Drive**:
  - Next, we need to navigate to folder where the dataset is stored
  - Command:

```
from google.colab import drive
drive.mount('/content/drive')
```

- **Display Current Directory**:
  - Store current working directory's path in the HOME variable for reference.
  - Command:

```
import os
HOME = os.getcwd()
print(HOME)
```

- **Install YOLOv10**:
  - To set up the environment for running the YOLOv10 model, we need to install and clone the YOLOv10 repository. These installations are crucial for ensuring that all necessary tools and libraries are available for the model to function correctly.

Environment Setup

- **Install YOLOv10**:
  - Command:
    `!pip install git+https://github.com/THU-MIG/yolov10.git`
- **Download YOLOv10-L Pre-trained Weights**:
  - This step involves creating a directory for storing the model weights and downloading the pre-trained weights for YOLOv10-L model. These weights are essential for initializing the model and can be used for both inference and fine-tuning.
  - Command:
    `!mkdir -p {HOME}/weights`
    `!wget -P {HOME}/weights -q https://github.com/jameslahm/yolov10/releases/download/v1.0/yolov10l.pt`

Evaluation Metrics

- **Average Precision (AP)**:
  - Measures precision and recall at various thresholds.
  - Calculates the weighted mean of precisions achieved at each threshold.
  - Provides a comprehensive view of model performance across different confidence levels.
- **AP@0.5**:
  - Measures precision and recall with a fixed Intersection over Union (IoU) threshold of 0.5.
  - Indicates how well the model distinguishes true positives from false positives.
  - Important for evaluating object detection models in real-world applications.

Evaluation Metrics

- **Mean Average Precision (mAP)**:
  - Combines AP scores over multiple IoU thresholds (e.g., 0.5 to 0.95).
  - Averages AP across all classes in the dataset.
  - Offers a comprehensive metric for overall model performance comparison.
- **Importance**:
  - These metrics provide insights into the trade-offs between precision and recall.
  - Essential for fine-tuning the model to achieve optimal detection accuracy.
  - Used to benchmark performance against other models and datasets.

Training Custom YOLOv10-L Detector

- **Model Summary**: YOLOv10-L with 628 layers, 25,766,870 parameters, and 127.2 GFLOPs.
- **Training**:
  - Total Epochs: 50
  - Batch Size: 8
  - Image Size: 640x640 pixels
  - Data Augmentation:
    - **Color Augmentation**: Adjustments in hue (hsv_h=0.02), saturation (hsv_s=0.8), and value (hsv_v=0.5).
    - **Geometric Transformations**: Includes rotation (degrees=5), translation (translate=0.2), scaling (scale=0.6), and shearing (shear=2).
    - **Perspective Transform**: Small adjustments with perspective (perspective=0.001).
    - **Flipping**: Both vertical flipping (flipud=0.1) and horizontal flipping (fliplr=0.6).

Training Custom YOLOv10-L Detector

- **Training**:
  - Data Augmentation:
    - **Mosaic**: Combines four images into one (mosaic=1.0).
    - **MixUp**: Merges two images into one (mixup=0.2).
    - **Copy-Paste**: Pastes objects from one image into another (copy_paste=0.1).
    - **Auto Augment**: Uses RandAugment strategy for automatic augmentation.
    - **Erasing**: Randomly erases parts of images (erasing=0.5).
    - **Cropping**: Applies cropping with a fraction of 1.0 (crop_fraction=1.0).

Benchmark

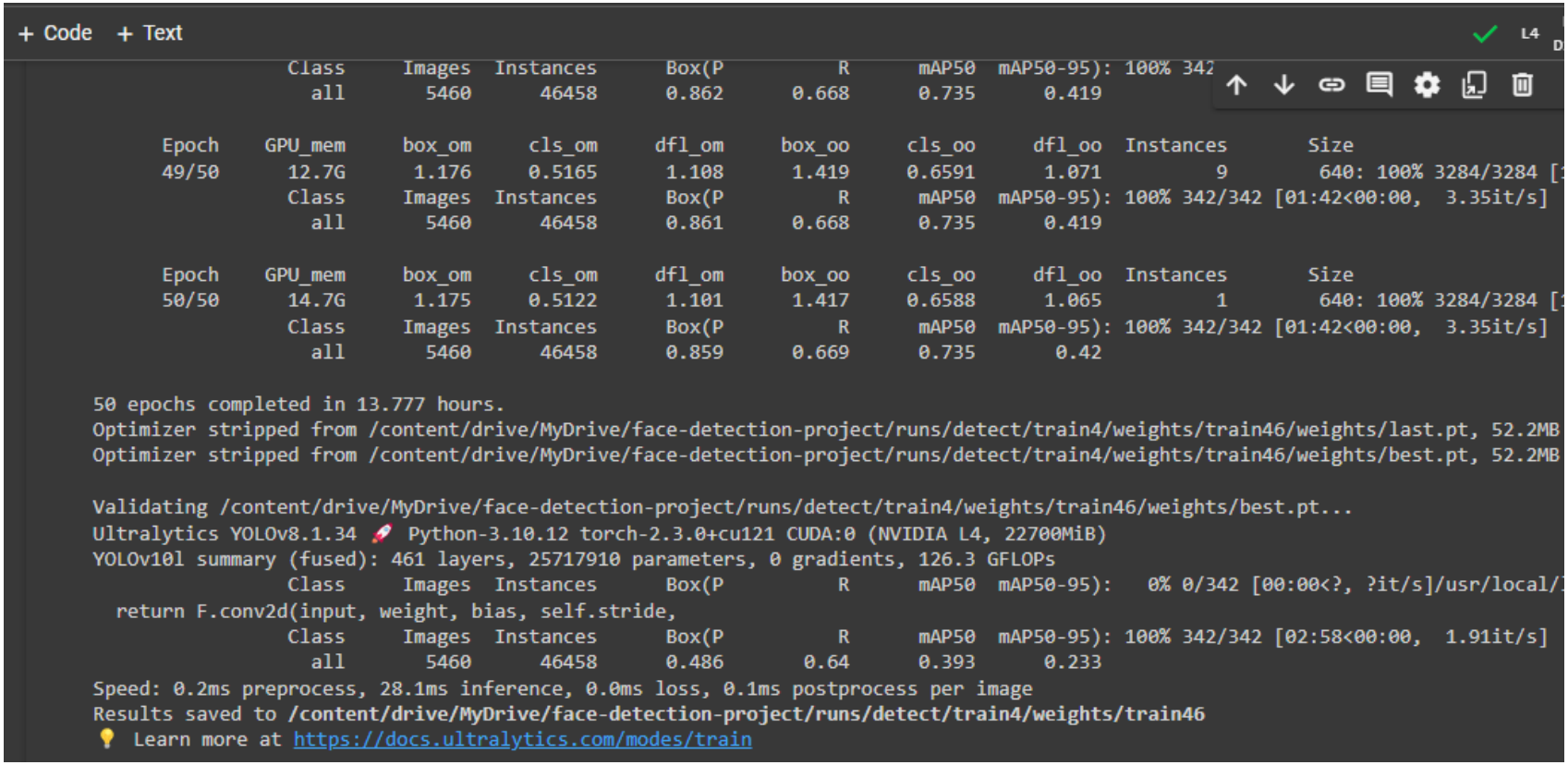
- **Training Results**:
  - Initial Epoch GPU Memory: 17.2G
  - Final Epoch GPU Memory: 14.7G
  - Total Training Time: 13.777 hours
- **Validation Results**:
  - Precision (P): 0.861
  - Recall (R): 0.669
  - mAP@0.5: 0.735
  - mAP@0.5:0.95: 0.42
- **Inference Speed**:
  - Preprocess: 0.2ms per image
  - Inference: 28.1ms per image
  - Postprocess: 0.1ms per image
- **Model Performance**: Efficient detection and robust accuracy, suitable for real-time face detection applications

Experimental Results

- Command:

```
!yolo task=detect mode=train epochs=50 batch=12
imgsz=640 plots=True model='/content/drive/MyDrive/
face-detection-project/yolov10/weights/yolov10l.pt'
data='/content/drive/MyDrive/face-detection-project/
merged/face-detect-datase.yaml' project='/content/
drive/MyDrive/face-detection-project/runs/detect/
train4/weights' name='train4' augment=True
hsv_h=0.02 hsv_s=0.8 hsv_v=0.5 degrees=5 translate=0.2
scale=0.6 shear=2 perspective=0.001 flipud=0.1
fliplr=0.6 mosaic=1.0 mixup=0.2 copy_paste=0.1
auto_augment=randaugment erasing=0.5 crop_fraction=1.0
```

Experimental Results



```
+ Code  + Text                                                                    L4
                  Class     Images  Instances      Box(P          R      mAP50  mAP50-95): 100% 342
                    all       5460      46458      0.862      0.668      0.735      0.419

      Epoch    GPU_mem     box_om     cls_om     dfl_om     box_oo     cls_oo     dfl_oo  Instances       Size
      49/50      12.7G      1.176     0.5165      1.108      1.419     0.6591      1.071          9        640: 100% 3284/3284 [1
                  Class     Images  Instances      Box(P          R      mAP50  mAP50-95): 100% 342/342 [01:42<00:00,  3.35it/s]
                    all       5460      46458      0.861      0.668      0.735      0.419

      Epoch    GPU_mem     box_om     cls_om     dfl_om     box_oo     cls_oo     dfl_oo  Instances       Size
      50/50      14.7G      1.175     0.5122      1.101      1.417     0.6588      1.065          1        640: 100% 3284/3284 [1
                  Class     Images  Instances      Box(P          R      mAP50  mAP50-95): 100% 342/342 [01:42<00:00,  3.35it/s]
                    all       5460      46458      0.859      0.669      0.735       0.42

50 epochs completed in 13.777 hours.
Optimizer stripped from /content/drive/MyDrive/face-detection-project/runs/detect/train4/weights/train46/weights/last.pt, 52.2MB
Optimizer stripped from /content/drive/MyDrive/face-detection-project/runs/detect/train4/weights/train46/weights/best.pt, 52.2MB

Validating /content/drive/MyDrive/face-detection-project/runs/detect/train4/weights/train46/weights/best.pt...
Ultralytics YOLOv8.1.34 🚀 Python-3.10.12 torch-2.3.0+cu121 CUDA:0 (NVIDIA L4, 22700MiB)
YOLOv10l summary (fused): 461 layers, 25717910 parameters, 0 gradients, 126.3 GFLOPs
                  Class     Images  Instances      Box(P          R      mAP50  mAP50-95):   0% 0/342 [00:00<?, ?it/s]/usr/local/l
  return F.conv2d(input, weight, bias, self.stride,
                  Class     Images  Instances      Box(P          R      mAP50  mAP50-95): 100% 342/342 [02:58<00:00,  1.91it/s]
                    all       5460      46458      0.486       0.64      0.393      0.233
Speed: 0.2ms preprocess, 28.1ms inference, 0.0ms loss, 0.1ms postprocess per image
Results saved to /content/drive/MyDrive/face-detection-project/runs/detect/train4/weights/train46
💡 Learn more at https://docs.ultralytics.com/modes/train
```

Figure 2: Train model

Experimental Results

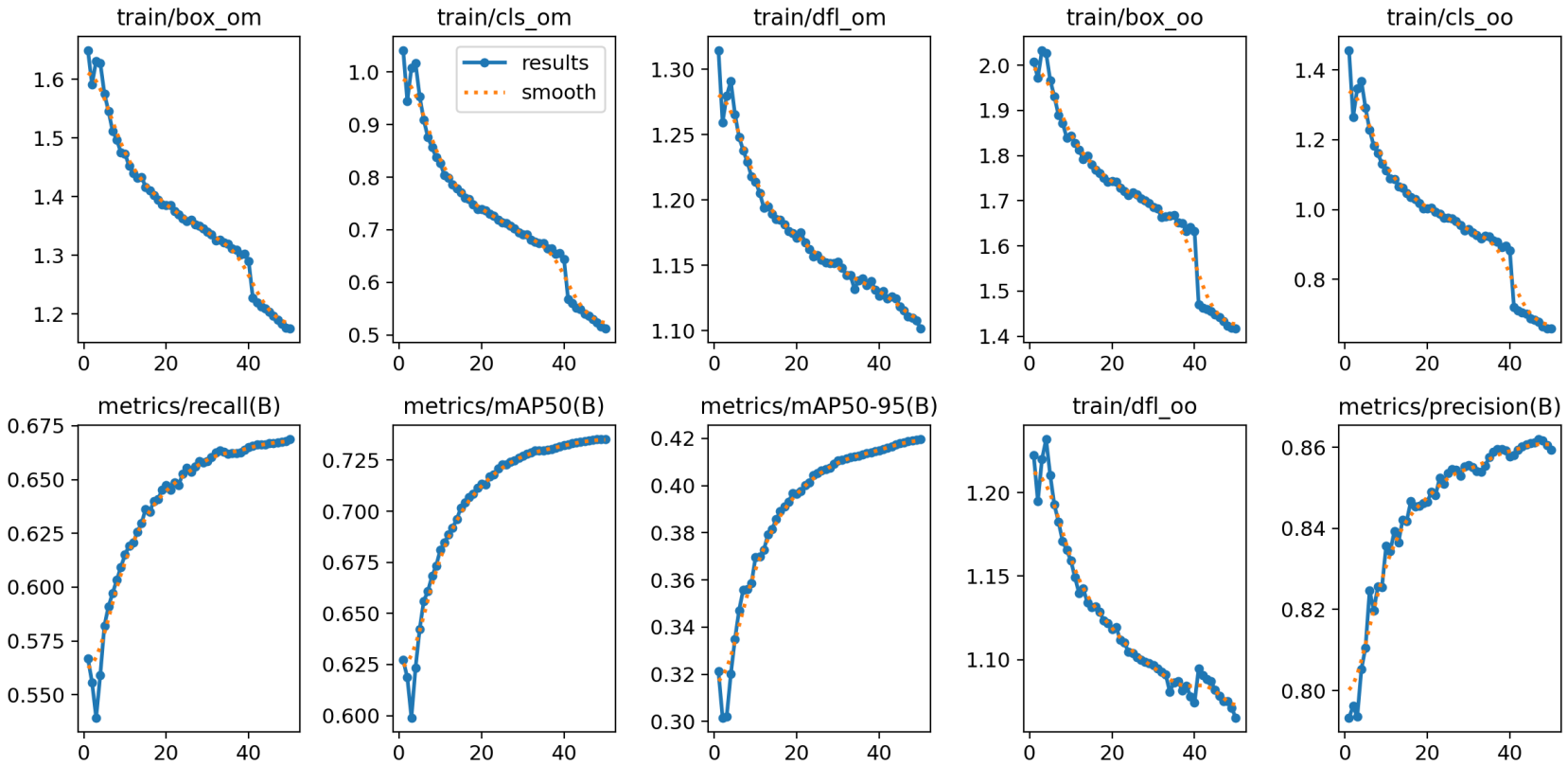


Figure 3: Train model result

Comparison with Other Models

- **Accuracy and Speed**:
  - Our model showed competitive precision and recall rates compared to other leading models.
  - The average precision (mAP@0.5) was 73.5%, while the mAP@0.5:0.95 reached 41.9%.
  - The inference speed was efficient, making our model suitable for real-time applications.
- **Resource Utilization**:
  - The model demonstrated efficient GPU memory usage, with a peak of 17.2G during training.
  - The combination of precision, speed, and resource efficiency highlights the robustness of our model for face detection tasks.

Test Environment

- **Hardware**: NVIDIA L4 GPU
- **Software**: Ultralytics YOLOv8.1.34, Python 3.10.12, Torch 2.3.0+cu121
- **Detection Performance**:
  - Generated images and screenshots demonstrate the detection performance on test data.
  - Model: YOLOv10
  - Confidence threshold: 0.25
  - Results show the model identifying multiple faces with high accuracy.

Test Results: Inference on Image

- **Inference Details**:
  - Model: YOLOv10l
  - Parameters: 46 layers, 25,717,910 parameters, 126.3 GFLOPs
  - Inference speed: 158.4ms per image
  - Command:
    ```
    !yolo task=detect mode=predict conf=0.25 save=True
    model="/content/drive/MyDrive/face-detection-project/
    runs/detect/train4/weights/train46/weights/best.pt"
    source="/content/drive/MyDrive/face-detection-project/
    test/12_Group_Group_12_Group_Group_12_2.jpg"
    project="/content/drive/MyDrive/face-detection-project/
    runs/detect/predict" name="prediction_results"
    ```
  - Results saved to:
    `/content/drive/MyDrive/face-detection-project/runs/detect/predict/prediction_results4`
  - Learn more at: Ultralytics Documentation

Test Results: Inference on Image

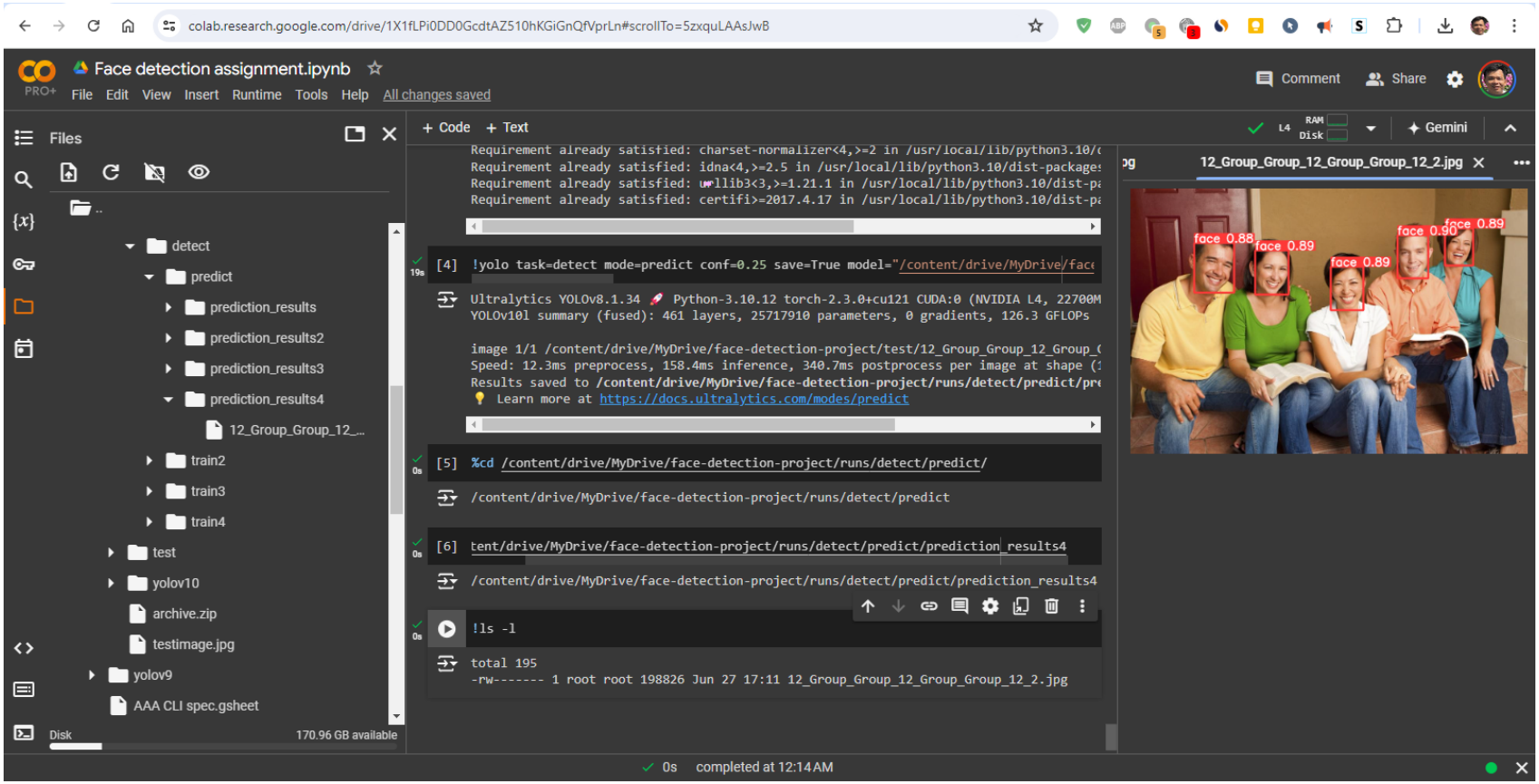


Figure 4: Google Colab workspace

Test Results: Inference on Image

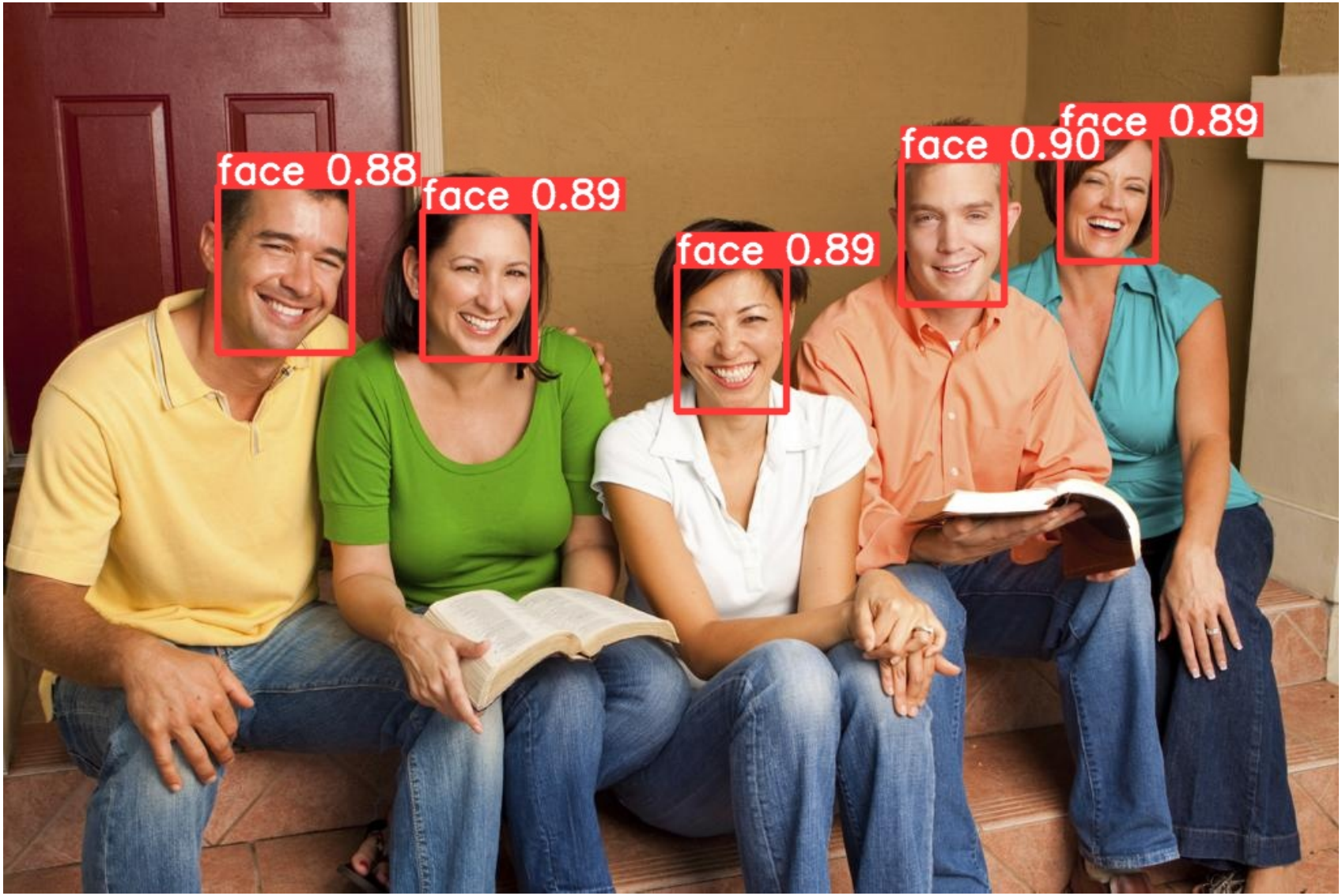


Figure 5: Test image 1

Test Results: Inference on Image

- **Inference Details**:
  - Model: YOLOv10l
  - Parameters: 461 layers, 25,717,910 parameters, 126.3 GFLOPs
  - Inference speed: 155.5ms per image
  - Command:
    ```
    !yolo task=detect mode=predict conf=0.25 save=True
    model="/content/drive/MyDrive/face-detection-project/
    runs/detect/train4/weights/train46/weights/best.pt"
    source="/content/drive/MyDrive/face-detection-project/
    test/runs/AOS-group.png"
    project="/content/drive/MyDrive/face-detection-project/
    runs/detect/predict" name="prediction_results"
    ```
  - Results saved to:
    `/content/drive/MyDrive/face-detection-project/runs/detect/predict/prediction_results5`
  - Learn more at: Ultralytics Documentation

Test Results: Inference on Image

Test Results: Inference on Video

- Command:

```
!yolo task=detect mode=predict conf=0.25 save=True
model="/content/drive/MyDrive/face-detection-project
/runs/detect/train4/weights/train46/weights/best.pt"
source="/content/drive/MyDrive/face-detection-project
/test/WALK-NEW-YORK-City-USA-vlog.mp4" project="/conter
drive/MyDrive/face-detection-project/runs/detect/predic
name="prediction_results"
```

- Log:

```
Streaming output truncated to the last 5000 lines.
video 1/1 (frame 76799/81795) /content/drive/MyDrive/
face-detection-project/test/WALK-NEW-YORK-City-USA-vlog
 384x640 1 face, 16.6ms
```

Test Results: Inference on Video

- Log:

```
video 1/1 (frame 76800/81795) /content/drive/MyDrive/
face-detection-project/test/WALK-NEW-YORK-City-USA-vlog
 384x640 2 faces, 16.8ms
video 1/1 (frame 77973/81795) /content/drive/MyDrive/
face-detection-project/test/WALK-NEW-YORK-City-USA-vlog
384x640 (no detections), 16.7ms
...
Speed: 2.3ms preprocess, 17.3ms inference, 1.1ms
postprocess per image at shape (1, 3, 384, 640)
Results saved to /content/drive/MyDrive/face-detection-
project/runs/detect/predict/prediction_results6
```

- Play the inference result video:
https://www.youtube.com/watch?v=HwbmiKk6k3I

Test Results: Inference on Video

Figure 7: inference result video

Conclusion

- Face detection is a vital technology
- Wide range of applications
- Project aims to contribute to this field

Questions?

- Open for any questions or discussions

References

- Dataset: Face Detection Dataset
- Information: Train set - 26,300 images, Test set - 6,500 images
- Evaluation Metric: AP, AP@0.5