Segment Anything Model (SAM2) Integration with 3D Dataset for Object Tracking and Evaluation

1. Repository Cloning and Setup:

```
# Clone the SAM repository
!git clone https://github.com/facebookresearch/segment-anything-2.git
%cd segment-anything-2
!pip install -e .
```

This section begins by cloning the SAM2 repository from GitHub, installing the required dependencies, and setting up the environment for running the code.

2. Download and Extract Checkpoints:

```
# Download the all 4 checkpoints
%cd checkpoints
!./download_ckpts.sh
```

SAM2 checkpoints are necessary for initializing and running the model. The script download_ckpts.sh downloads all four model checkpoints.

3. Installing Libraries:

```
!pip install torch torchvision
!pip install Pillow
```

We install torch and torchvision for PyTorch support, and Pillow for image processing.

4. Download and Extract the CMU 3D Dataset:

```
# Download CMU 3D dataset
!wget http://www.cs.cmu.edu/~ehsiao/3drecognition/CMU10_3D.zip -O CMU10_3D.zip

# Extract the dataset
import zipfile
with zipfile.ZipFile("CMU10_3D.zip", 'r') as zip_ref:
    zip_ref.extractall("CMU10_3D")
```

The CMU 3D dataset is downloaded to test object tracking capabilities. The dataset contains 3D object recognition data and The dataset is extracted for further usage.

5. Importing Required Libraries and Functions:

```python
# Now importing the necessary functions
import torch
from PIL import Image, ImageOps
import numpy as np
import matplotlib.pyplot as plt
import os, glob, shutil
import matplotlib.patches as patches
from sam2.build_sam import build_sam2
from sam2.automatic_mask_generator import SAM2AutomaticMaskGenerator
from sam2.sam2_image_predictor import SAM2ImagePredictor
from sam2.build_sam import build_sam2_video_predictor
from pycocotools import mask as mask_utils
```

6. Model Initialization:

```python
device = 'cuda' if torch.cuda.is_available() else 'cpu'
print(f"Using device: {device}")
```

```
Using device: cuda
```

```python
# Path to the model checkpoint and config file
checkpoint = "./sam2_hiera_tiny.pt"
model_cfg = "./sam2_hiera_t.yaml"
```

```python
# Initialize the model
predictor_prompt = SAM2ImagePredictor(build_sam2(model_cfg, checkpoint))
sam2 = build_sam2(model_cfg, checkpoint, device=device, apply_postprocessing=False)
mask_generator = SAM2AutomaticMaskGenerator(sam2)
predictor_vid = build_sam2_video_predictor(model_cfg, checkpoint, device=device)
```

The SAM2 model is initialized with the necessary configuration and checkpoint files. The device is automatically set to cuda if available for faster computations.

7. Helper Functions

7.1 Directory Management:

```python
# Helper function to create directory
def create_if_not_exists(dirname):
    if not os.path.exists(dirname):
        os.mkdir(dirname)

# Helper function to clear temporary directory
def cleardir(tempfolder):
    filepaths = glob.glob(tempfolder + "/*")
    for filepath in filepaths:
        os.unlink(filepath)
```

These functions help manage directories by creating new ones or clearing temporary folders during image processing.

7.2 Display Mask and Bounding Boxes:

```python
# Show mask on the plot
def show_mask(mask, ax, obj_id=None, random_color=False):
    if random_color:
        color = np.concatenate([np.random.random(3), np.array([0.6])], axis=0)
    else:
        cmap = plt.get_cmap("tab10")
        cmap_idx = 0 if obj_id is None else obj_id
        color = np.array([*cmap(cmap_idx)[:3], 0.6])

        h, w = mask.shape[-2:]
        mask_image = mask.reshape(h, w, 1) * color.reshape(1, 1, -1)
        ax.imshow(mask_image)

# Show bounding box on the plot
def show_box(box, ax):
    x0, y0 = box[0], box[1]
    w, h = box[2] - box[0], box[3] - box[1]
    ax.add_patch(plt.Rectangle((x0, y0), w, h, edgecolor='green', facecolor='none', lw=2))
```

These functions visualize masks and bounding boxes on images, providing helpful visual representations of the tracking process.

8. Processing Image and Mask:

```python
# Process image and its corresponding mask to get bounding box
def process_img_png_mask(imgpath, maskpath):
    img = Image.open(imgpath)
    mask = Image.open(maskpath).convert("L")  # Convert to grayscale

    mask_np = np.array(mask)
    indices = np.where(mask_np > 0)
    ymin, ymax = indices[0].min(), indices[0].max()
    xmin, xmax = indices[1].min(), indices[1].max()

    return [xmin, xmax, ymin, ymax]
```

This function processes the input image and mask, converting the mask to grayscale and extracting bounding box coordinates for further use.

9. Object Tracking in Videos:

```
def track_item_boxes(imgpath1, imgpath2, img1boxclasslist, visualize=True):
    tempfolder = "./tempdir"
    create_if_not_exists(tempfolder)
    cleardir(tempfolder)

    shutil.copy(imgpath1, tempfolder + "/00000.jpg")
    shutil.copy(imgpath2, tempfolder + "/00001.jpg")

    inference_state = predictor_vid.init_state(video_path="./tempdir")
    predictor_vid.reset_state(inference_state)

    ann_frame_idx = 0
    for img1boxclass in img1boxclasslist:
        ([xmin, xmax, ymin, ymax], objectnumint) = img1boxclass
        box = np.array([xmin, ymin, xmax, ymax], dtype=np.float32)

        _, out_obj_ids, out_mask_logits = predictor_vid.add_new_points_or_box(
            inference_state=inference_state,
            frame_idx=ann_frame_idx,
            obj_id=objectnumint,
            box=box
        )

    video_segments = {}
    for out_frame_idx, out_obj_ids, out_mask_logits in predictor_vid.propagate_in_video(inference_state):
        video_segments[out_frame_idx] = {
            out_obj_id: (out_mask_logits[i] > 0.0).cpu().numpy()
            for i, out_obj_id in enumerate(out_obj_ids)
        }

    if visualize:
        fig, ax = plt.subplots()
        plt.title(f"Original Image object::")
        ax.imshow(Image.open(tempfolder + "/00000.jpg"))
        rect = patches.Rectangle((xmin, ymin), xmax - xmin, ymax - ymin, linewidth=1, edgecolor='green', facecolor='none')
        ax.add_patch(rect)
        plt.show()

        out_frame_idx = 1
        plt.figure(figsize=(6, 4))
        plt.title(f"Detected Object in Test Image:")
        plt.imshow(Image.open(tempfolder + "/00001.jpg"))
        for out_obj_id, out_mask in video_segments[out_frame_idx].items():
            show_mask(out_mask, plt.gca(), obj_id=out_obj_id)

    return video_segments
```

This core function tracks objects in two consecutive frames (images) and predicts the mask for objects based on bounding boxes. It also visualizes the predicted object in the second image using the model.

10. Bounding Box to Mask Conversion and IoU Calculation

10.1 Bounding Box to Mask:

```python
def bbox_to_mask(box, img_shape):
    """Convert a bounding box to a binary mask."""
    mask = np.zeros(img_shape, dtype=np.uint8)
    xmin, xmax, ymin, ymax = box
    mask[ymin:ymax, xmin:xmax] = 1
    return mask
```

This function converts the bounding box into a binary mask, which is essential for calculating the Intersection over Union (IoU).

10.2 IoU Calculation:

```python
def calculate_iou(pred_box, gt_box, img_shape):
    # Convert bounding boxes to binary masks
    pred_mask = bbox_to_mask(pred_box, img_shape)
    gt_mask = bbox_to_mask(gt_box, img_shape)

    # Encode masks into COCO RLE format using pycocotools
    pred_rle = mask_utils.encode(np.asfortranarray(pred_mask))
    gt_rle = mask_utils.encode(np.asfortranarray(gt_mask))

    # Calculate IoU
    iou = mask_utils.iou([pred_rle], [gt_rle], [0])[0][0]
    return iou
```

IoU is computed using the predicted and ground truth bounding boxes. The pycocotools is utilized to encode masks and calculate IoU, a metric to evaluate model performance.

11. Evaluating Model Performance:

```python
# Evaluate performance by calculating IoU between predicted and ground truth masks

def evaluate_performance(imgpath1, imgpath2, gt_maskpath, img1boxclasslist):
    video_segments = track_item_boxes(imgpath1, imgpath2, img1boxclasslist)

    # Assuming out_frame_idx=1 and single object detection
    pred_mask = video_segments[1][1]

    # Squeeze the predicted mask to remove any extra dimensions
    pred_mask = np.squeeze(pred_mask)

    # Visualize the predicted and ground truth masks
    plt.figure(figsize=(10, 5))

    plt.subplot(1, 2, 1)
    plt.title("Ground Truth Mask")
    plt.imshow(Image.open(gt_maskpath), cmap='gray')

    plt.subplot(1, 2, 2)
    plt.title("Predicted Mask")
    plt.imshow(pred_mask, cmap='gray')

    plt.show()
```

```python
# Get ground truth bounding box
[xmin_gt, xmax_gt, ymin_gt, ymax_gt] = process_img_png_mask(imgpath2, gt_maskpath)
gt_box = [xmin_gt, xmax_gt, ymin_gt, ymax_gt]

# Convert predicted mask to bounding box
indices = np.where(pred_mask > 0)
ymin_pred, ymax_pred = indices[0].min(), indices[0].max()
xmin_pred, xmax_pred = indices[1].min(), indices[1].max()
pred_box = [xmin_pred, xmax_pred, ymin_pred, ymax_pred]

# Debug: Print bounding box coordinates
print(f"Predicted Bounding Box: {pred_box}")
print(f"Ground Truth Bounding Box: {gt_box}")

# Get image shape
img = Image.open(imgpath2)
img_shape = img.size[::-1]  # Height, Width

# Calculate IoU
iou = calculate_iou(pred_box, gt_box, img_shape)
print(f"IoU for {imgpath2}: {iou}")
return iou
```

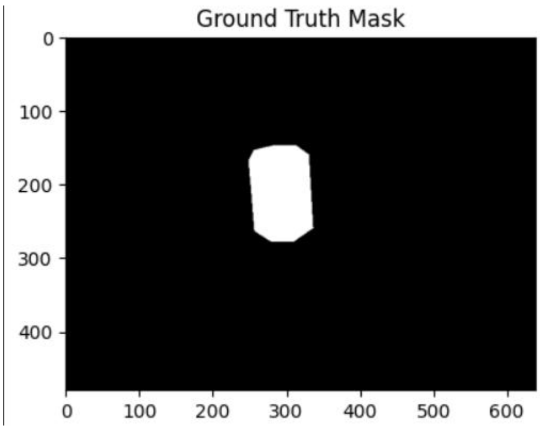
This function evaluates the model by calculating the IoU between the predicted and ground truth masks. It also displays both masks for visual comparison.

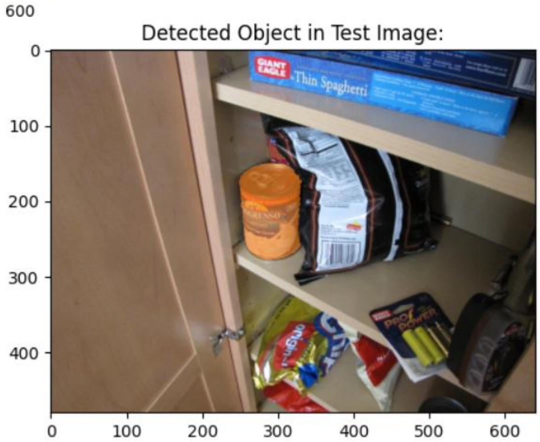
12. Running the Full Workflow:

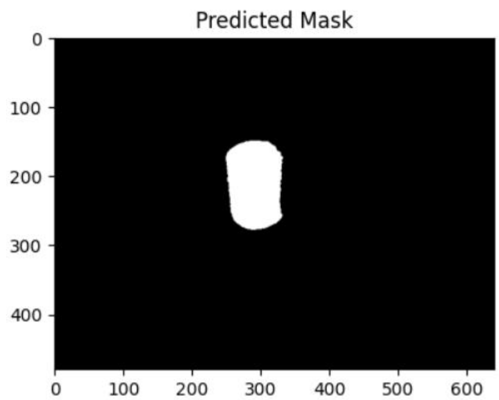
```
# Paths to the first image, its mask, and the second image
firstimgpath = './CMU10_3D/CMU10_3D/data_2D/can_chowder_000001.jpg'
firstimgmaskpath = './CMU10_3D/CMU10_3D/data_2D/can_chowder_000001_1_gt.png'
secondimgpath = './CMU10_3D/CMU10_3D/data_2D/can_chowder_000002.jpg'
secondimgmaskpath = './CMU10_3D/CMU10_3D/data_2D/can_chowder_000002_1_gt.png'

# Get bounding box from first image and mask
[xmin, xmax, ymin, ymax] = process_img_png_mask(firstimgpath, firstimgmaskpath)
img1boxclasslist = [([xmin, xmax, ymin, ymax], 1)]  # Object 1 with ID = 1

# Track objects in other images and evaluate performance
iou = evaluate_performance(firstimgpath, secondimgpath, secondimgmaskpath, img1boxclasslist)
print(f"Final IoU: {iou}")
```








```
Predicted Bounding Box: [249, 331, 150, 278]
Ground Truth Bounding Box: [249, 336, 148, 278]
IoU for ./CMU10_3D/CMU10_3D/data_2D/can_chowder_000002.jpg: 0.928028293545535
Final IoU: 0.928028293545535
```

The first image and its corresponding mask are used to obtain bounding boxes, which are then tracked in the second image. The IoU between the ground truth and predicted mask is computed to assess the accuracy of the object tracking.