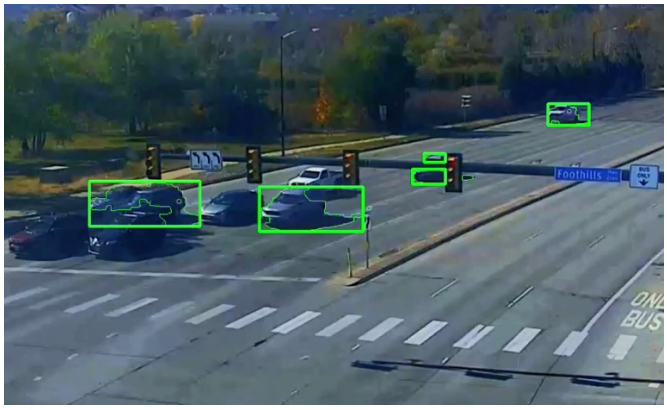
Autonomous Detection, Tracking, & Interception

CS@Mines Field Session, Summer 2025

Sponsor: Northrop Grumman

In compliance with legal and security requirements, **all team members must be US citizens.**



Company Background:

Northrop Grumman is a global aerospace, defense, and security company. The majority of our business is with the U.S. government, principally the Department of Defense and intelligence community. In addition, we deliver solutions to global and commercial customers. NG Boulder develops software in the areas of advanced sensor fusion and processing, providing accurate tracking, state estimation, and prediction of high-priority threats.

Problem Statement:

Multiple Object Tracking (MOT) is the practice of identifying multiple targets from incoming data and recording trajectories for each. MOT is an increasingly interesting topic in computer vision, AI/ML, optimization and control theory. Possible applications include pose estimation, action recognition, surveillance, as well as probability-based prediction and decision-making under uncertainty.

In this project you'll utilize pre-trained object detectors and create tracks for ground targets. You'll incorporate emerging AI/ML technologies to plan and execute intercepts, and you'll create stunning visualizations, simulations, and demonstrations with Unity. Some of the concepts and considerations include:

- Detection: How would you detect vehicles and determine which are hostile?
- Tracking: How could you efficiently form tracks from these detections, or perhaps track unknown objects and do the detection later? ("track before detect")
- Prediction: Where will the vehicles be in N seconds? What's their destination(s)? Where did they come from? How precisely can these questions be answered in a timely manner?
- Scheduling: How can you identify optimal mobile sensor trajectories and search patterns for multi-target tracking?
- Planning: Use AI/ML as well as classical techniques to identify the best policies for all the above.
- Synthetic Data: How can you utilize simulations to test scenarios you've not yet seen in real life? How can you handle differences between reality and simulation?
- Data collection: is it more important to train on sparse real-world data or lots of synthetic data?
- Sensor cost vs. quality: just a few high-quality sensors vs. many low-quality sensors… or a mix?
- Interceptors: agile or fast?

Recommended Skills:

Note: Any level of experience (including none) with any of the following is completely acceptable. Our sponsors have experience in all of these areas and are happy to help you.

- Unity, C# (visualization environment: ex: polycity)
- OpenCV, Python or C++ (detection, tracking, planning/intercept, etc.)
- Basic networking
- Basic multiprocessing/threading
- Basic/low-poly 3D Modelling

Project Requirements:

- **All team members must be US citizens.**
- 5-7 team members
- All software utilized in this project will be freely available and/or open source.
- Simulation & Visualization:
    - Utilize Unity to visualize an urban environment and ground targets.
        - Ground targets should include civilian vehicles, robber vehicles, and police interceptors.
    - Place ground vehicles at various locations and orientations within your simulated environment.
    - Move vehicles around the scene using a pre-made traffic simulation or by specifying your own trajectories for each object type.
        - Dynamically generated trajectories are preferable, but not required for civilian vehicles.
    - Include variety in the environment: high-density residential zones, businesses, parking lots, low-density suburbia.
    - Include high value locations and escape points for hostile vehicles.
        - Robber vehicles should periodically complete heists on high value locations.
        - Robber vehicles should attempt to escape to the designated points.
        - Interceptor vehicles should attempt to capture robbers before reaching the designated escape points.
- Sensors:
    - Use virtual cameras to simulate optical sensors.
    - Simulate viewpoints from traffic lights and buildings.
        - Strech goal: include mobile sensors like helicopters or drones.
    - Sensors should be customizable: frame-rate, field of view, focal length, resolution, etc.
- Detection & Tracking:
    - Utilize sockets, shared memory, or other inter-process communication methods to enable two-way communication with the sensors.
        - Send commands to the sensors to zoom in or rotate.
        - Receive incoming sensor data.
        - Efficiently transfer data structure content and objects between components.
    - Write software that utilizes OpenCV to process sensor data in real time.
        - Recommended: Utilize multiple threads/processes to handle incoming data from multiple sensors
    - Detect robber vehicles in the presence of non-target vehicles and buildings.
    - Utilize pre-trained AI/ML/RL models and refine those models using simulated data.

    - Utilize cameras' intrinsic and extrinsic parameters or fuse data from multiple cameras to convert detections from camera-local coordinates to world coordinates.
    - Track robber vehicles in the presence of simulated non-target objects.
- Prediction, Planning, and Intercept:
    - Predict travel routes and possible destinations for the hostile vehicles.
    - Generate probability-related maps, showing the most likely routes and destinations.
    - Plan when and where to intercept.
    - Develop cost functions that appropriately weight positive and negative considerations.
    - Avoid pursuing non-robber civilian vehicles. How can you use the simulated behaviors you defined to separate friend from foe?
    - Protect the city against a single wave of multiple enemy vehicles (i.e. when the sensors have unobstructed views of all targets at once)
    - Stretch goals: modify your plans & system to defend against ongoing, continuous robberies. How many waves can you withstand before a single failure? Before N failures?

Milestones:

- In-person initial meeting at NG Boulder office. (Nice-to-have, not required)
- Virtual twice-weekly updates: 2-way Q&A/feedback with your technical sponsors.
- Weekly feature deliveries including short demo videos from Unity, code pushed to GitHub or similar.
- In-class final presentation.
- Final on-site presentation (NG Boulder).

Available Resources:

- Twice-weekly interaction and guidance with multiple Northrop Grumman engineers specializing in AI/ML, Software, Aerospace, Tracking, and Systems Engineering.
- Unity and OpenCV (Python or C++)
- A set of assets you can use in your environment: SimplePoly City and a traffic sim from the Unity Store.
- 3D modeling software to create assets not included in SimplyPoly City pack.
- AI/ML and classical methods including but not limited to YOLO, Grounding Dino, particle filtering, etc.
    - If a library already exists, use it!

Possible Job Opportunities:

- As fall approaches the NG sponsors are willing to review resumes (for use anywhere, but we hope you apply with Northrop Grumman!). We'll also give our recommendations for high-performing students to our local hiring managers and help you foster connections with NG sites outside of Boulder.
- Throughout the capstone project we are also happy to answer any career-related questions.