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Automated Behavior Generation for Unmanned Ground Vehicles Using Virtual Environments

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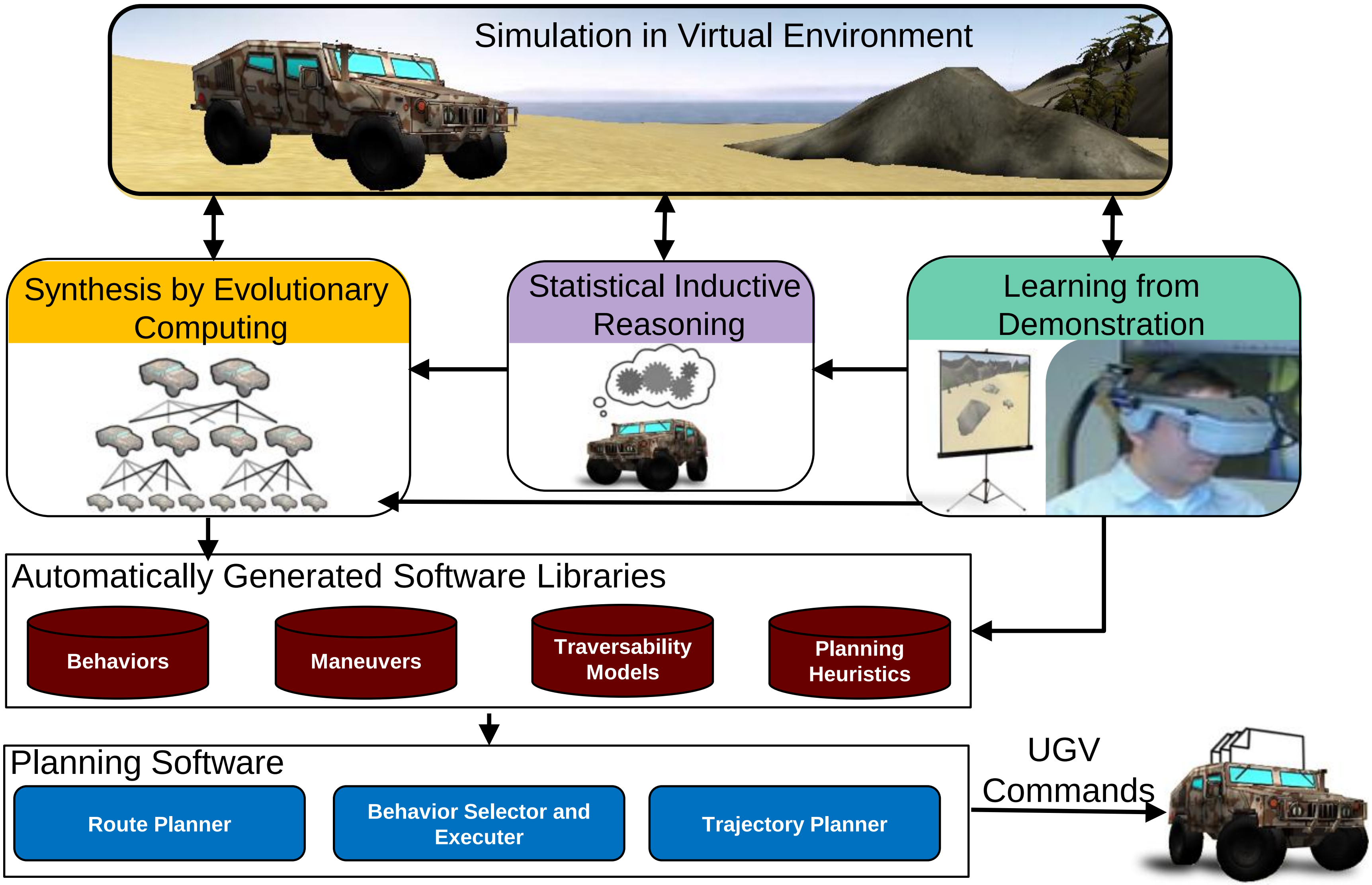
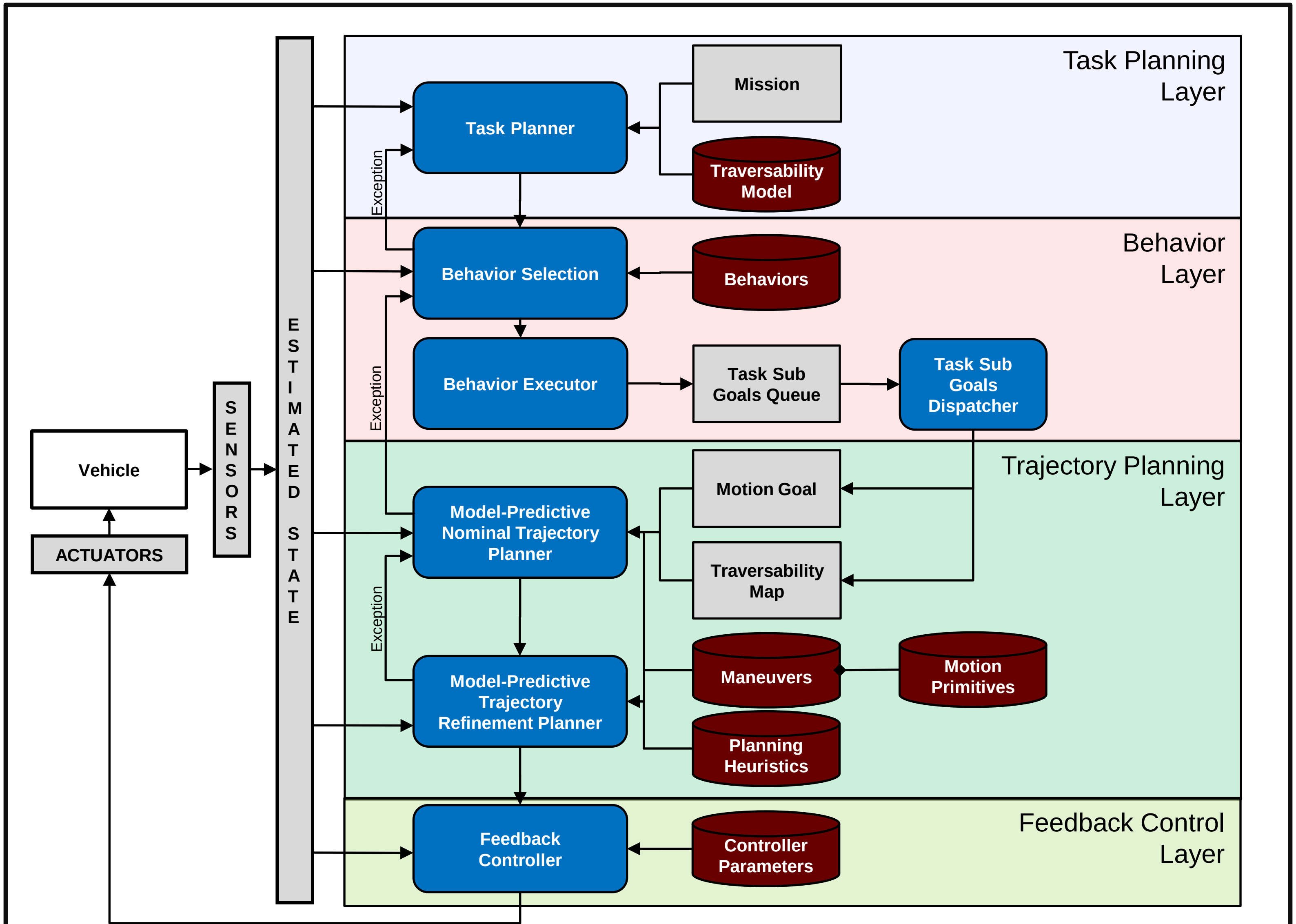
Objectives

- Develop a computational framework for automated generation of behaviors and maneuvers using simulations for autonomous UGVs
  - Behaviors are automatically generated and verified through simulations
  - Symbolic representation facilitates human verification

Overview of Approach



UGV System Architecture



Anticipated Benefits of Our Approach

- Able to generate complex reactive behaviors
  - Handles fractured state space
  - Handles time-delayed action consequences
  - Offers flexibility in terms of function choices
- Works in conjunction with state of the art trajectory planners
  - Can cope up with dynamically moving objects in environment
  - Incorporates vehicle's dynamics constraints using simulations
- Cope with human-made rules
  - Introduces context dependent traversability constraints

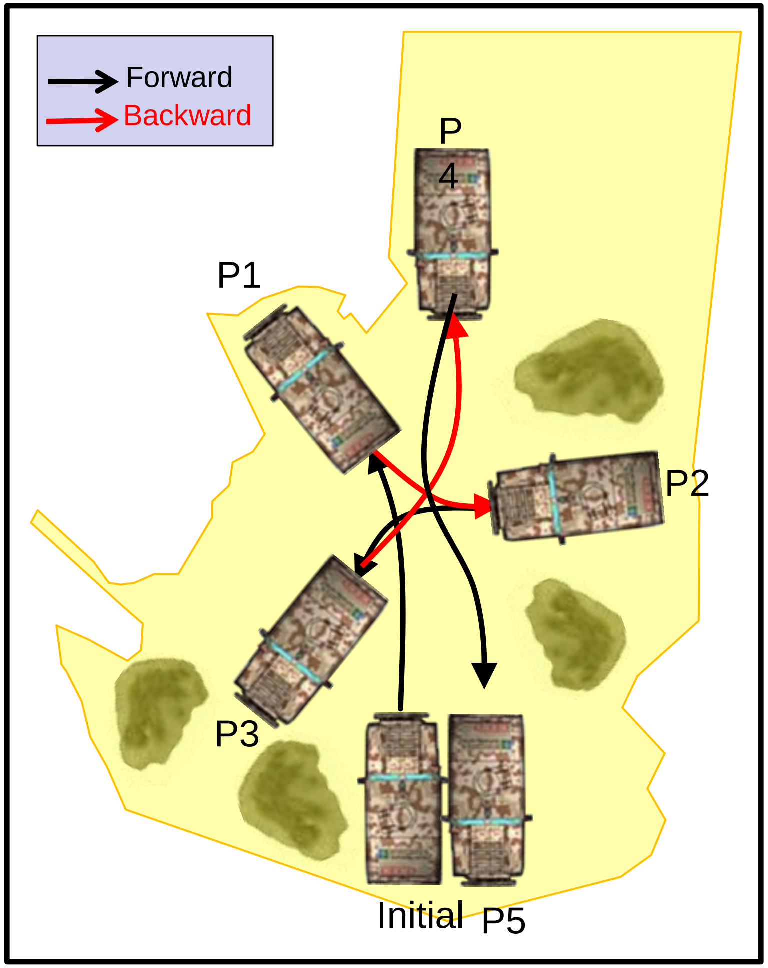
UGV Simulator

- Modular architecture allows physics engine, vehicle controller, and machine learning algorithms to be kept separate
  - Both Unreal engine and high-fidelity Vortex vehicle dynamics engine implemented
- Terrain modeled manually or imported from Digital Elevation Model files representing real-world locations
- Vehicles
  - Are modeled in CAD/3D programs and imported into simulator
  - Have dynamics models that can be tuned for realistic behavior
  - Can be controlled by a human, scripts, or machine-learning algorithms
  - Can have their movement recorded and played back
- Multiple types of sensors can be emulated
  - Vision, velocity, acceleration, wheel spin, rangefinders, etc. are all modeled
- Additional static and dynamic objects, each with their own physical properties, can be added to the environment and controlled for machine learning experiments

N-Point Turn in Constrained Space Behavior

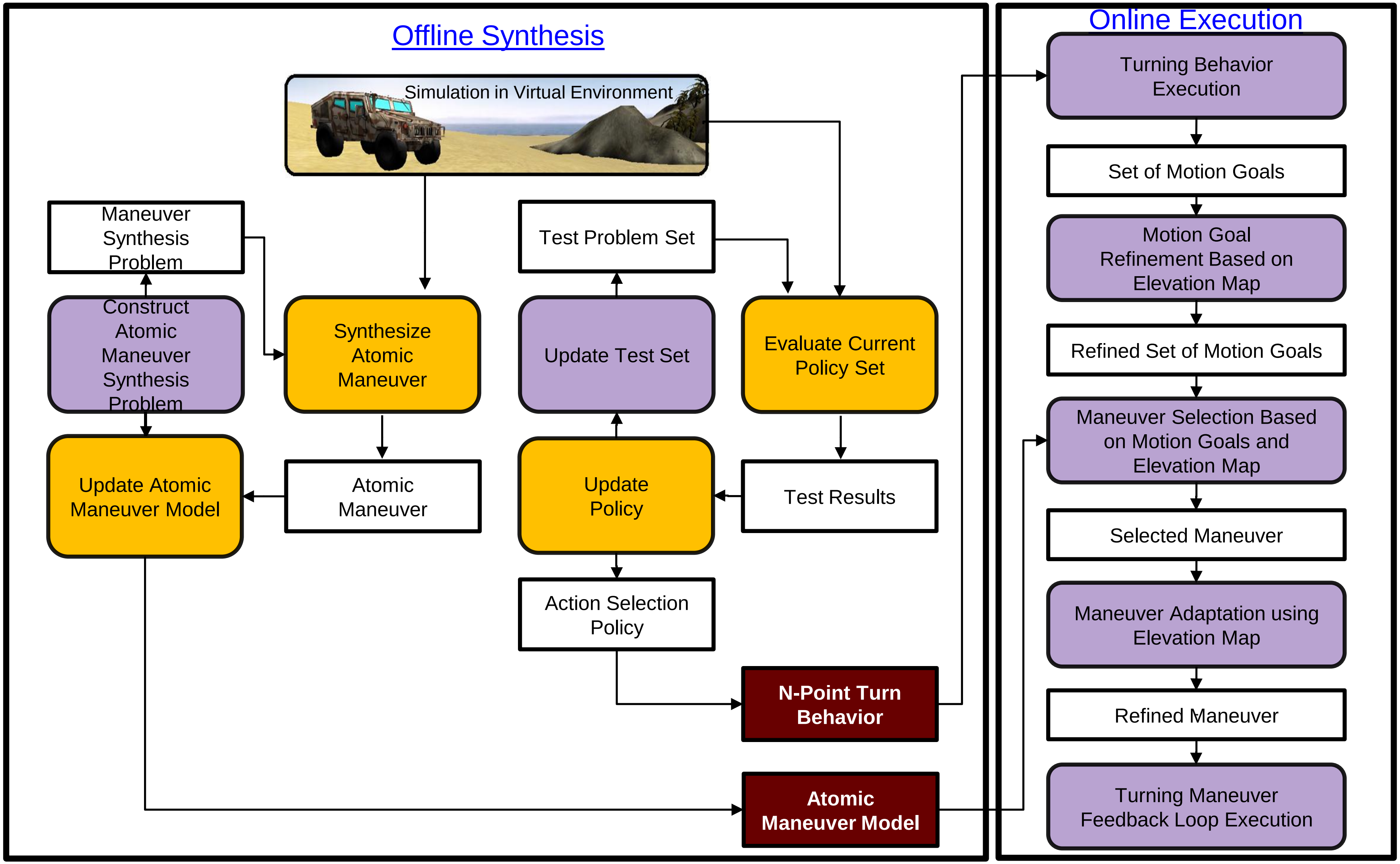
- Generate N-point turn maneuver between two arbitrary states $x_I = [x\ y\ \theta\ v]^T$ and $x_G = [x\ y\ \theta\ v]^T$, that satisfies the dynamics of the vehicle $f_M(x, u, t)$ and minimizes the execution time

- Generated maneuver should reliably be executed on a rugged, highly constrained terrain



5-point turn in a cluttered environment

Approach for Generating N-point Turn Behavior



Results

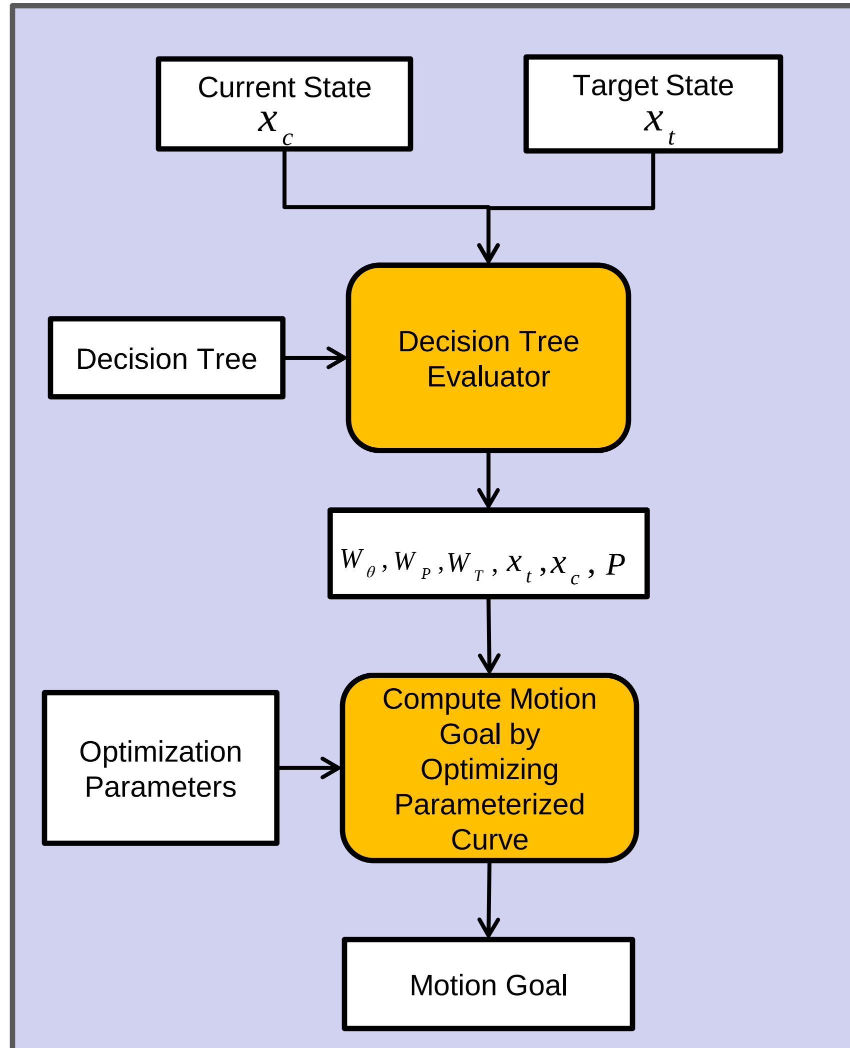
- Policy is represented as a decision tree
- Inputs:
  - Distance to target pose
  - Geometric configuration of obstacles
  - Maximum allowable clearances around the current and target poses
- Outputs:
  - Position error weight W_P
  - Orientation error weight W_θ
  - Terrain error weight W_T
  - Parameterized curve P
- It takes less that 16 seconds to compute motion goals for 13 point turns

$$C = W_\theta C_\theta + W_P C_p + W_T C_T$$

$$C_\theta = \frac{-dot(\vec{v}.\vec{v}')}{2} + \frac{1}{2} \longrightarrow \textit{Orientation}$$

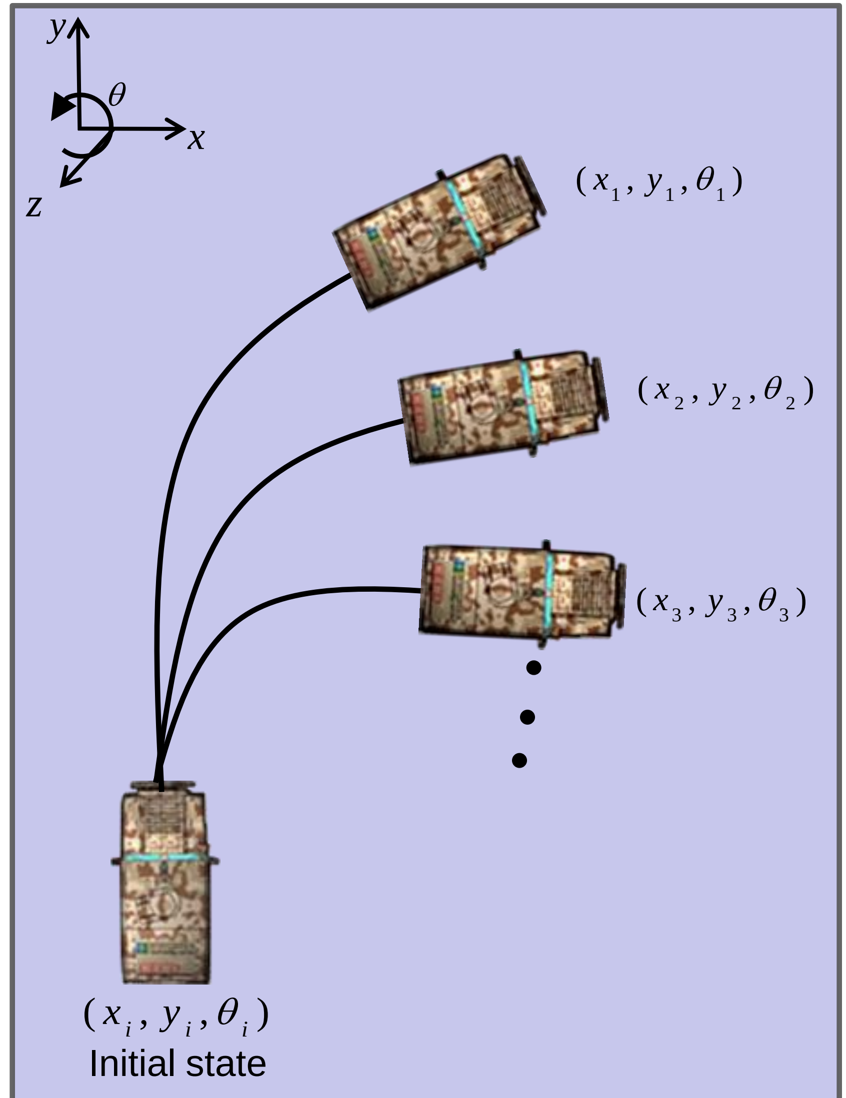
$$C_P = \|x_t - x_c\| \longrightarrow \textit{Position}$$

$$C_T = \begin{cases} 1 & \textit{if collision} \\ 0 & \textit{otherwise} \end{cases} \longrightarrow \textit{Collision}$$



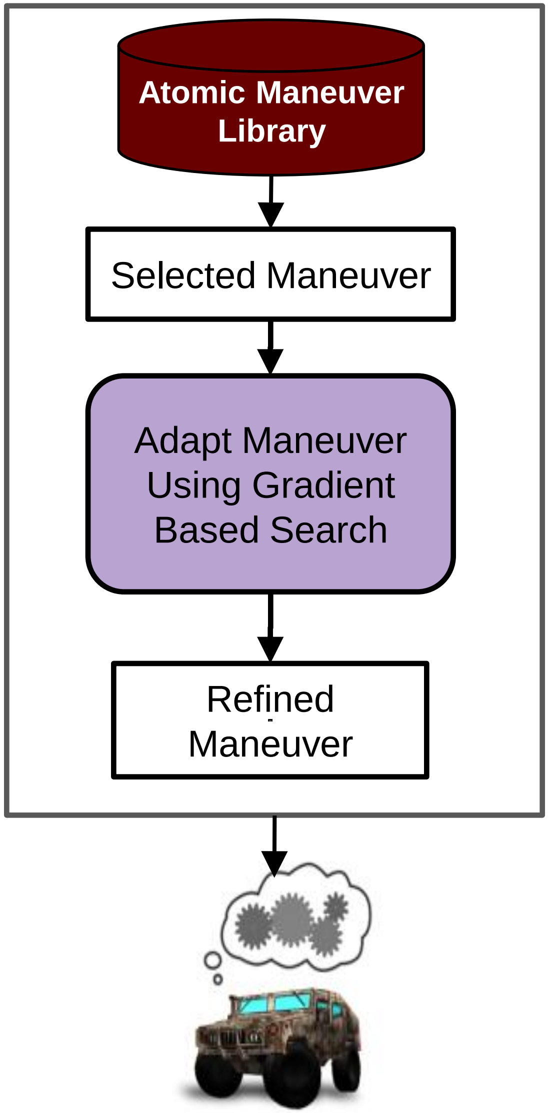
Results (Cont.)

- Automatically synthesized atomic maneuvers using a combination of evolutionary and local search and adaption of nearest neighbor
  - Represented using two 5-point B-splines
    - Force profile (throttle and brake)
    - Steering angle profile
  - Computed over 5 dimensional space
    - Δx Δy and $\Delta \theta$ are the position and orientation differences of the vehicle in the initial and final states
    - α and β are slopes of the terrain
    - Initial and final velocities are considered zero for each atomic maneuver
- Maneuvers are robust with respect to small perturbations in the terrains
  - Tested by introducing waviness in terrain

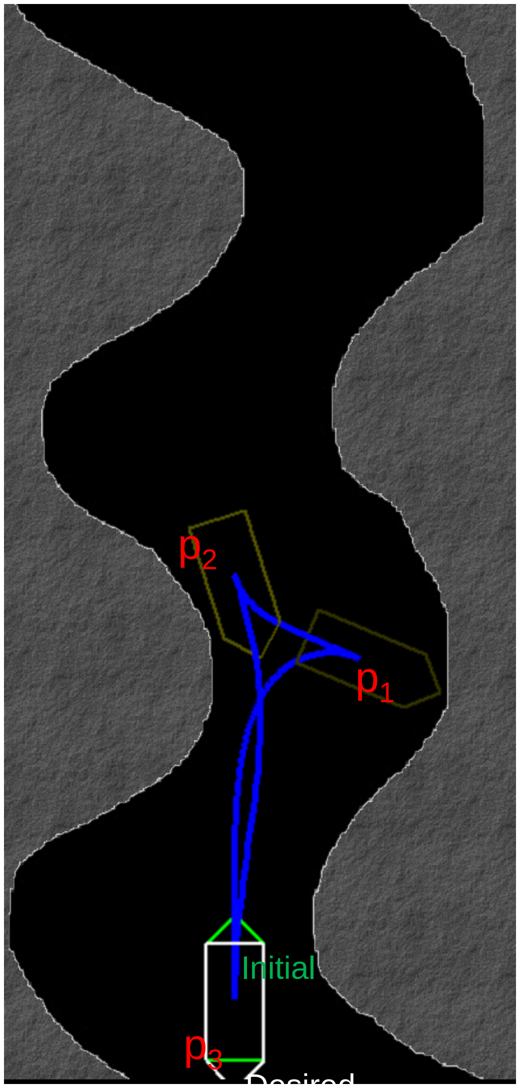


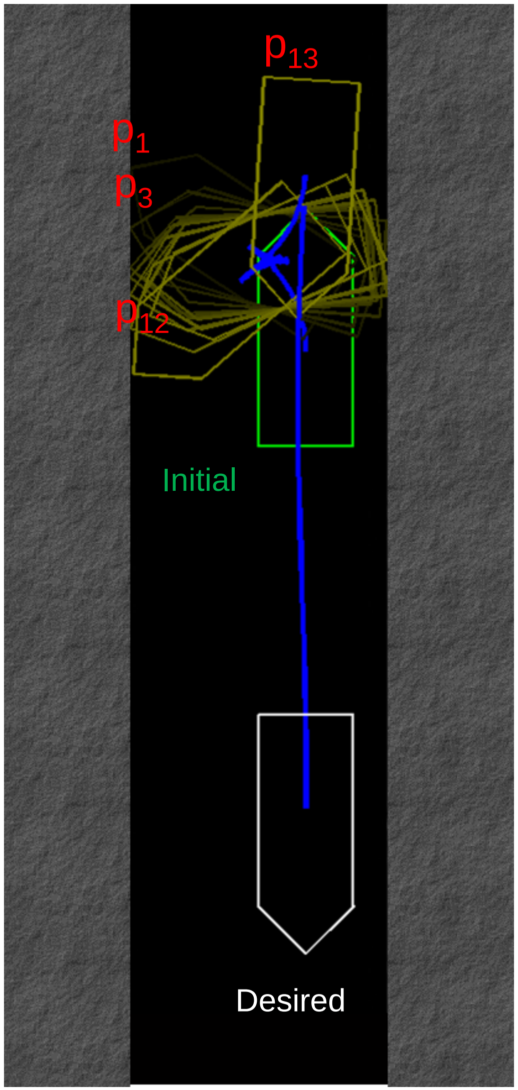
Results (Cont.)

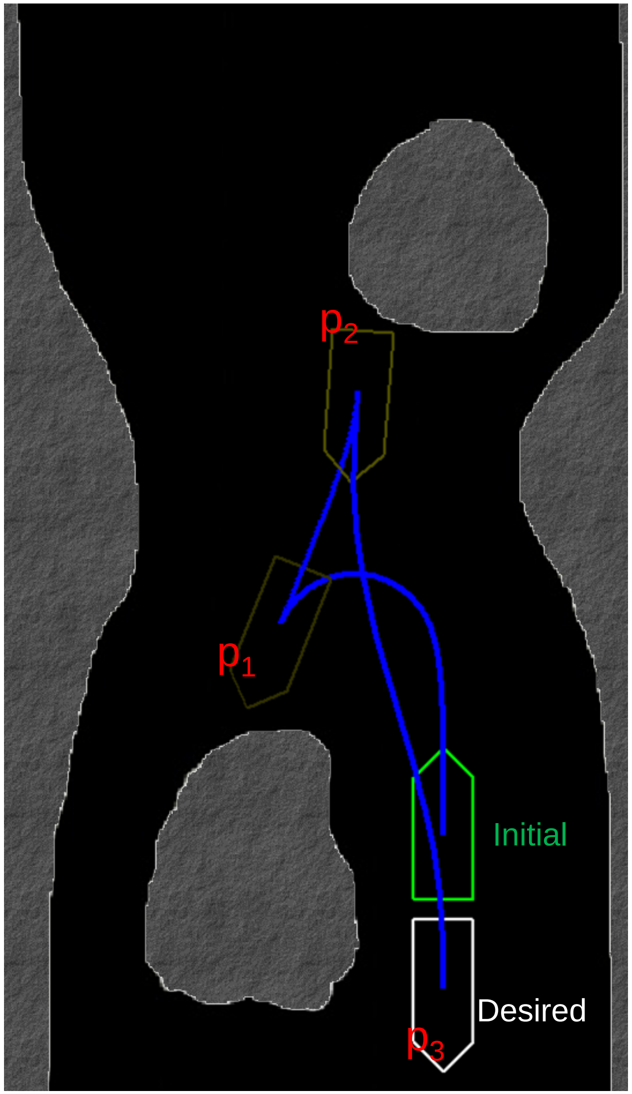
- Identified rules for selecting a reference maneuver from the atomic maneuver library
  - Evaluated several different interpolation strategies
  - Nearest neighbor produced the best results
  - Decided on appropriate grid resolution to allow fast adaptation
- Developed adaptation algorithm for adapting the reference maneuver
  - Reference maneuver adapted using gradient based search methods
  - To improve the faster convergence we used adaptive step-size searching techniques where the step-size is decided based on the information acquired from previous iterations
  - Average time for adaptation: 2 sec



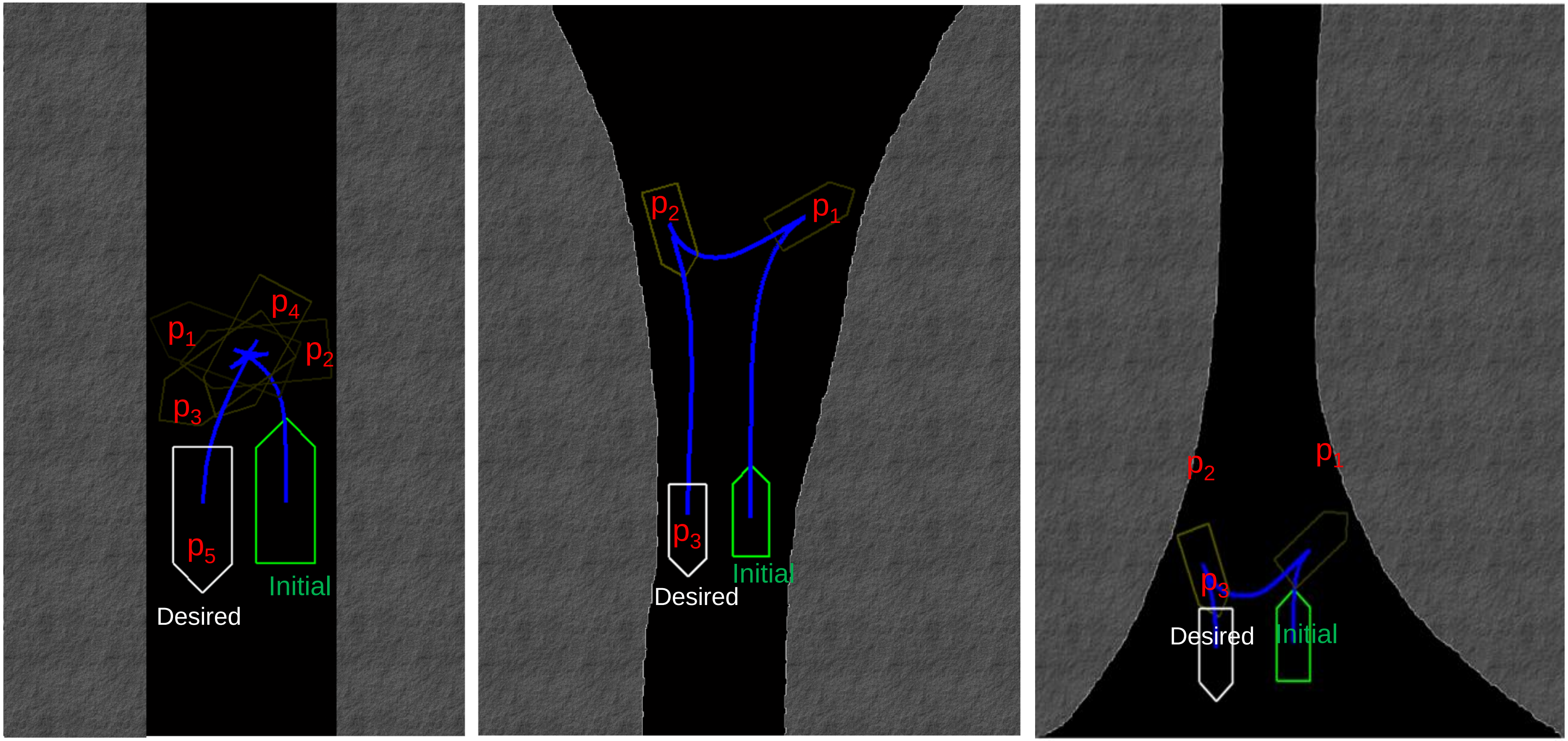
Examples


p_2
p_1
Initial
p_3


p_{13}
p_1
p_3
p_{12}
Initial
Desired


p_2
p_1
Initial
Desired
p_3

Examples (Cont.)



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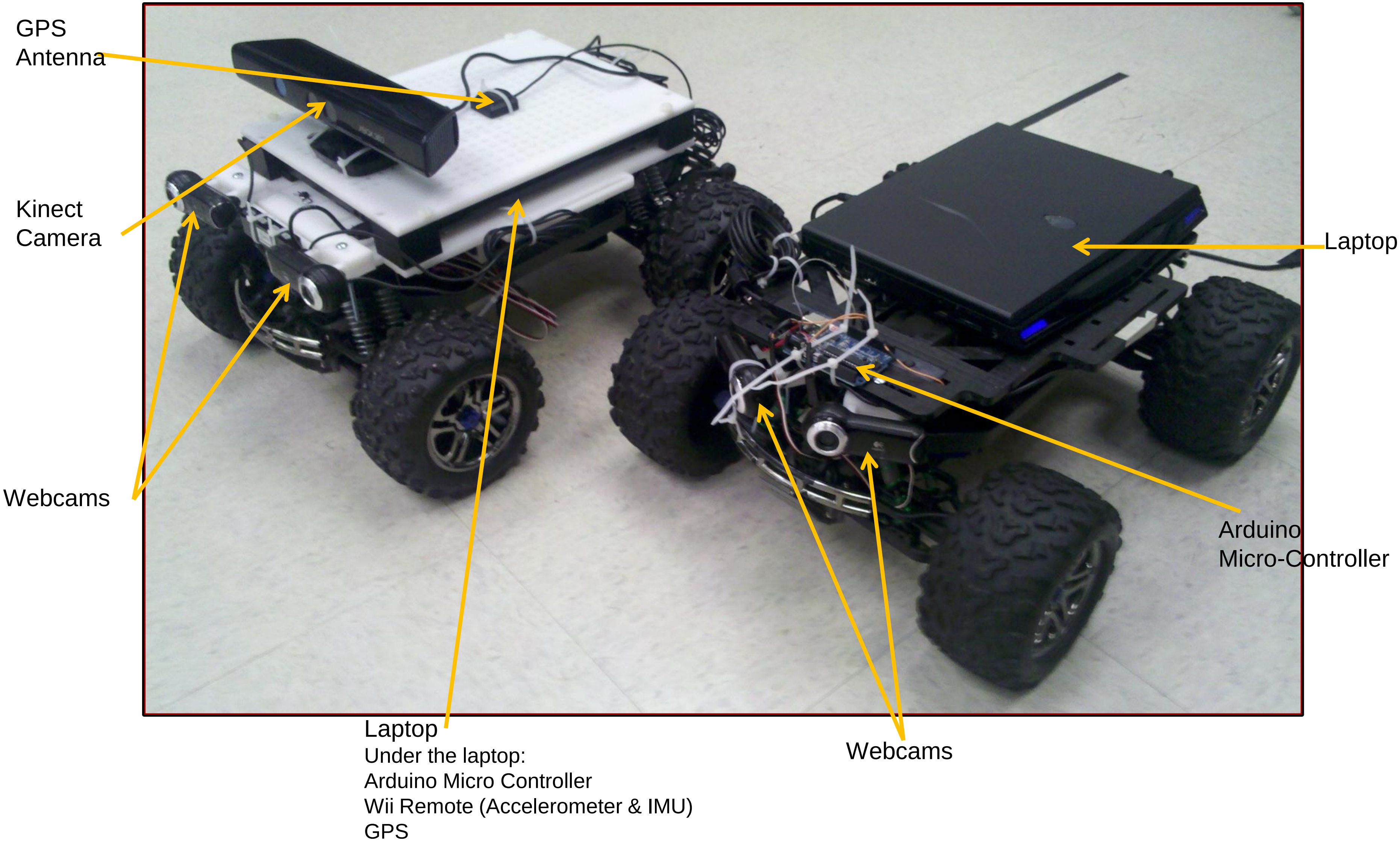
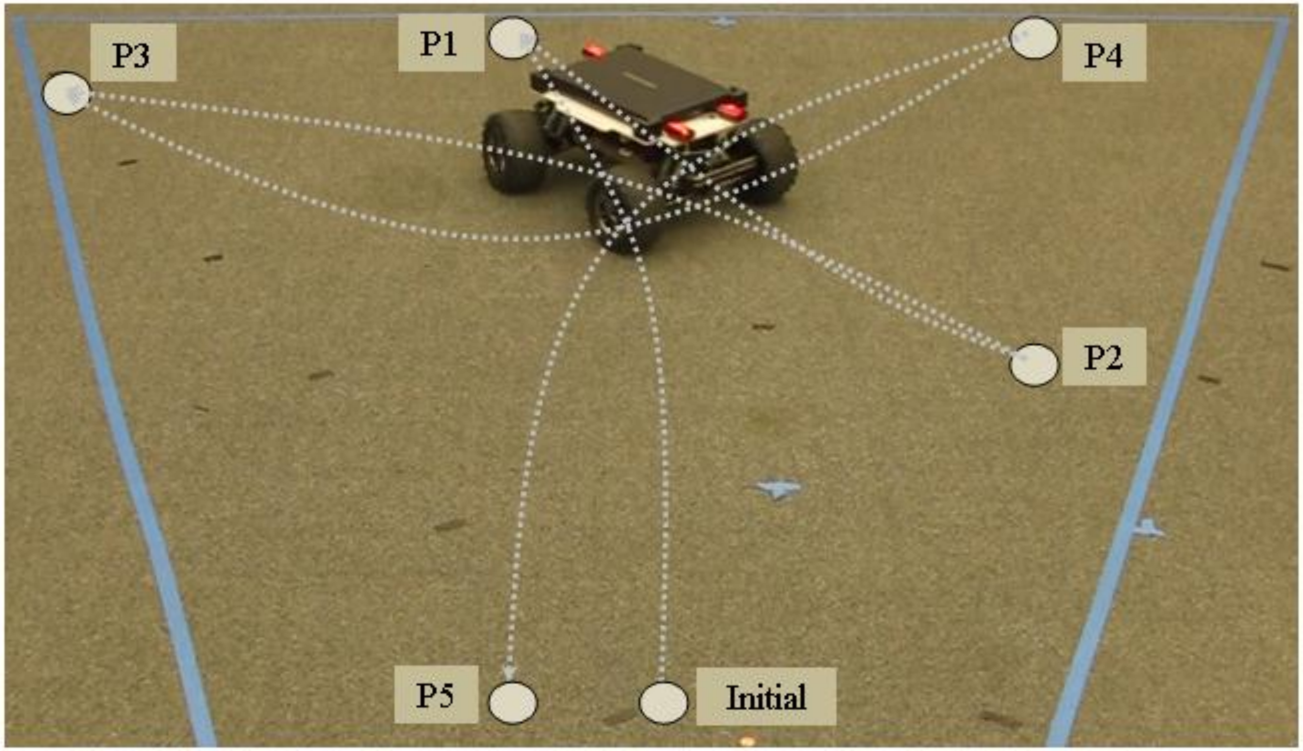
Physical Test Platform



Executing 5-point Turn Behavior at Maryland Robotics Realization Laboratory



Executing 5-point turn behavior without crossing the blue border lines

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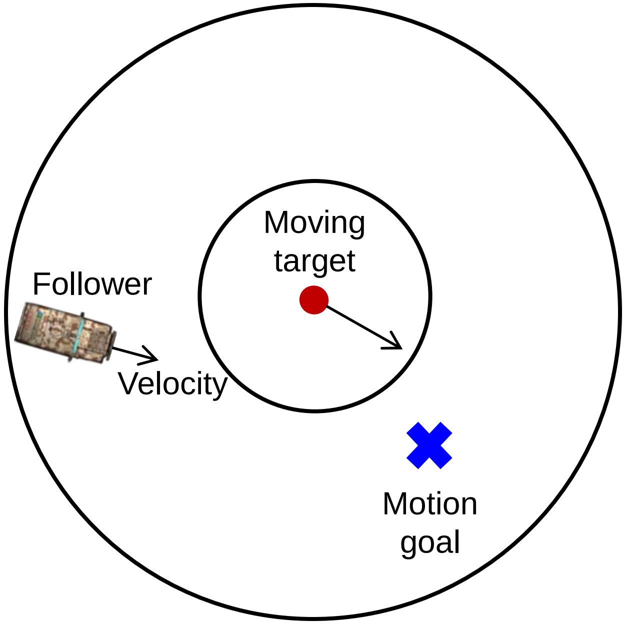
Follow Target Behavior

- Generate a behavior for robust and efficient following of a moving target on a rugged terrain
  - Follower should stay within given minimum a maximum distance from the target
  - Follower should anticipate the next most probable movement of the target given its behavioral model
  - Target may have fundamentally different motion characteristics compared to the vehicle
  - Target exhibits a behavior similar to a human scouting a complex terrain



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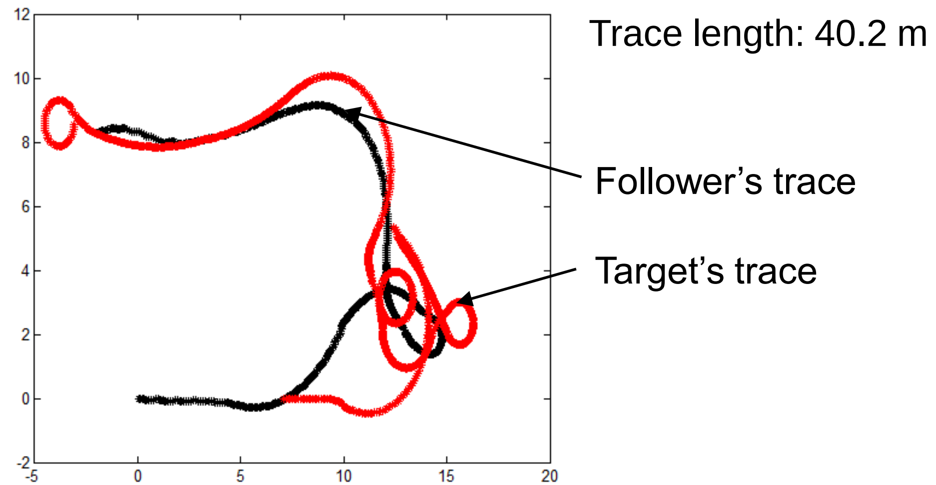
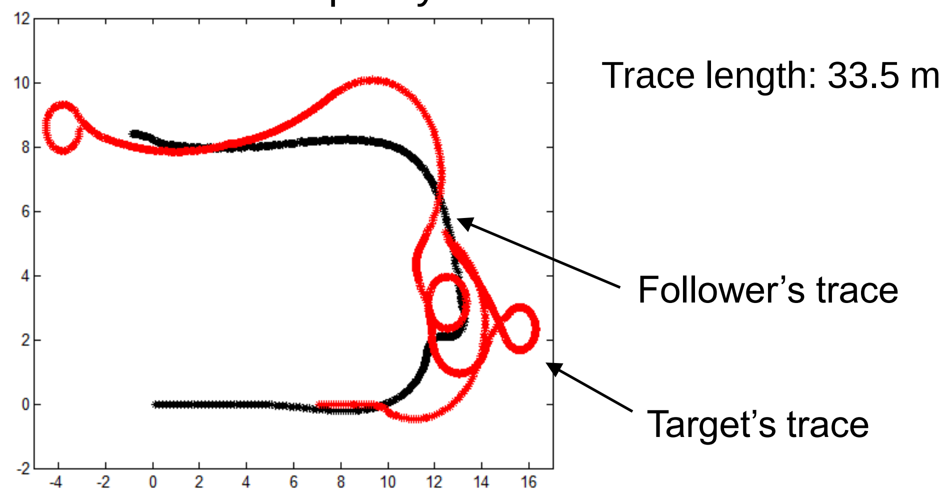
Initial Results

- Evolved a policy for placing motion goal and controlling velocity with respect to the moving target
- Performance of evolved policy exceeds the performance of manually coded rules for following a moving target
  - Target exhibits a scouting behavior

Simple hand-coded policy



Evolved policy



Summary

- We are developing a new approach for automated behavior synthesis for UGVs
- We have shown that useful behaviors can be synthesized using simulations
  - N-Point Turn behavior
  - Follow Target behavior
- The next steps would be
  - Demonstrate that the behavior generation system can be easily reconfigured to generate new behaviors
  - Demonstrate that the synthesized behaviors can be executed on a physical platform without deterioration in performance
  - Demonstrate that the useful complex behaviors can be synthesized automatically

For more information please contact:

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