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Automated Action Selection Policy Synthesis for Unmanned Surface Vehicles Using Virtual Environments

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Sponsor: Office of Naval Research

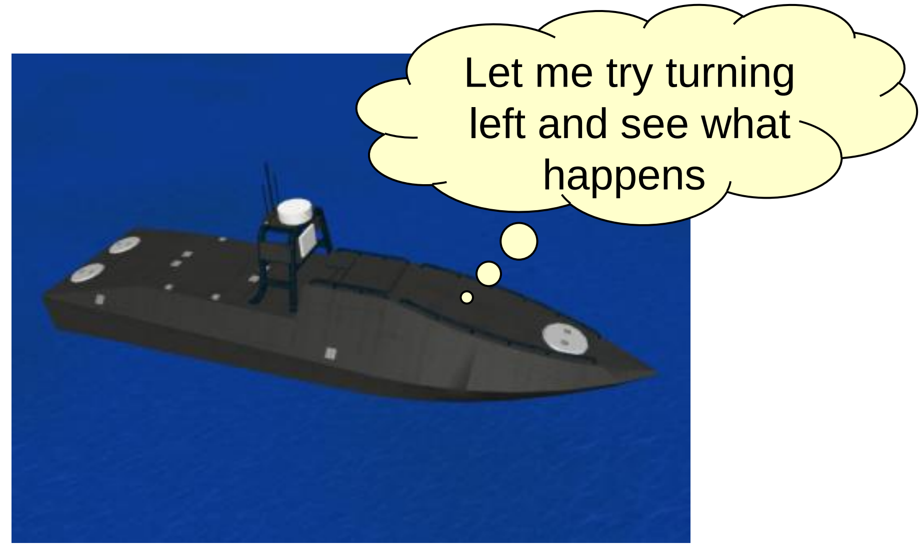
Achieving USV Autonomy

- USV will need to perform a large number of missions
  - Missions can be quite complex and may consist of many different tasks
  - Different tasks require different behaviors for achieving autonomy
  - Missions may involve intelligent adversaries
  - Handling contingencies requires additional behaviors
  - Ocean environment may impose significant motion uncertainty
- Manual development and tuning of behaviors for autonomous operations requires significant effort!

Unmanned Surface Vehicle (USV)

Project Goal

- *Automatically* generate behaviors and context dependent vehicle capability models for USV from a large number of simulations and demonstrations
  - Simulations are getting faster and more accurate with faster computers
  - Behaviors can be audited and edited to improve

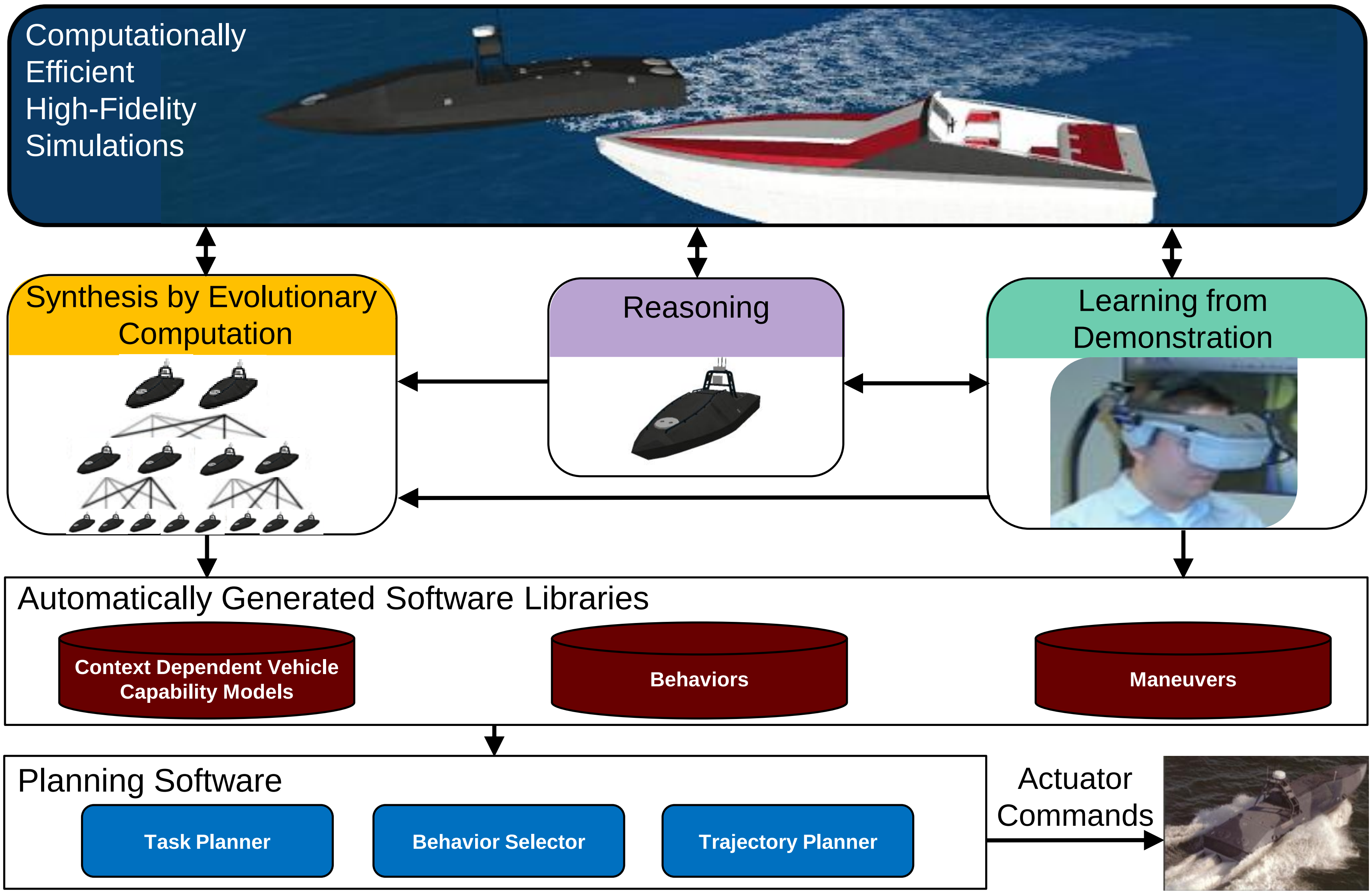


USV explores possible actions to limit the operation of an intruder in the virtual environment

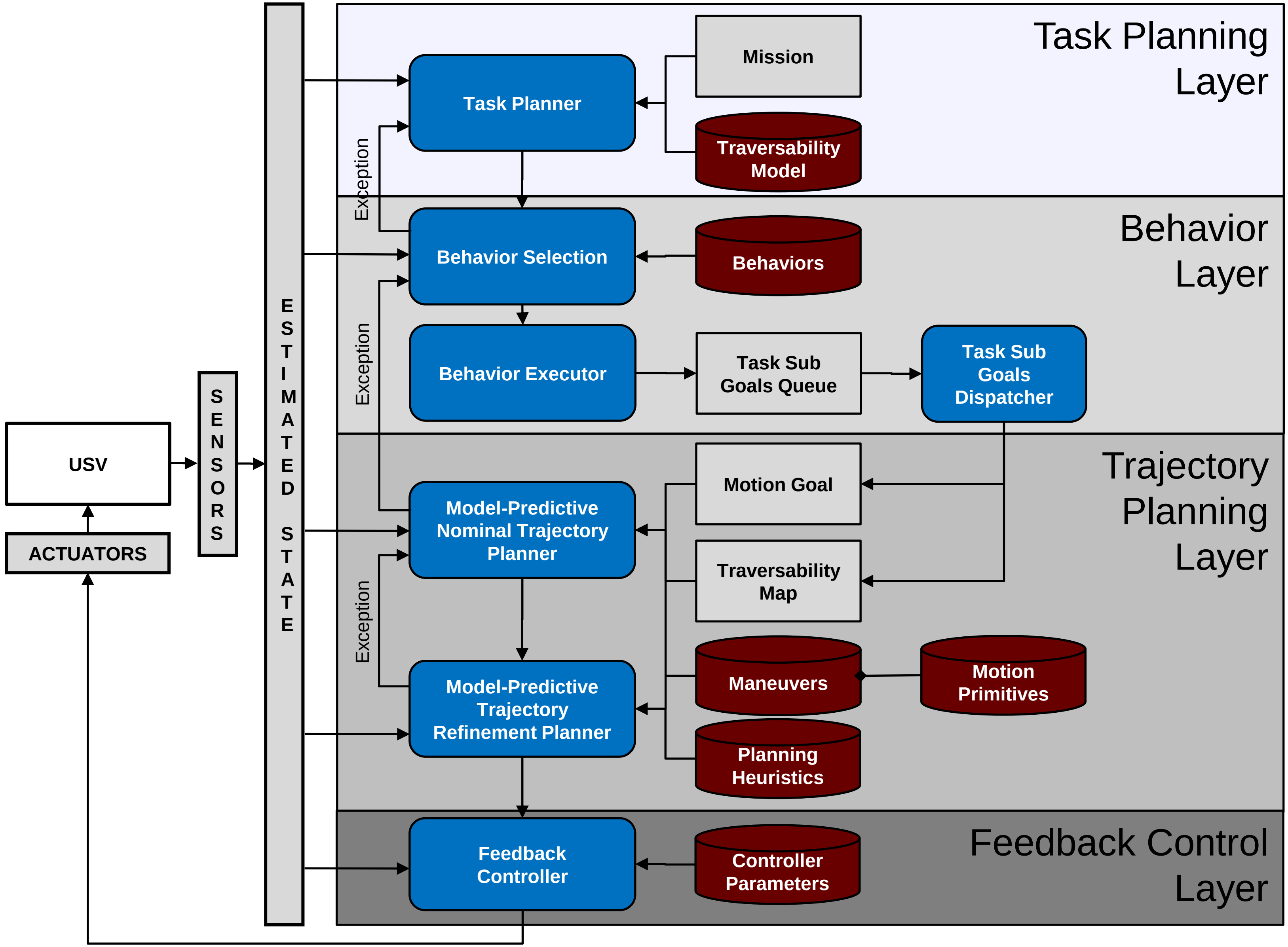
USV finds the right behavior

```
if distance < 20 then
  rudder angle = 30;
  throttle = 40;
  ...
  ...
```

Overview of Approach

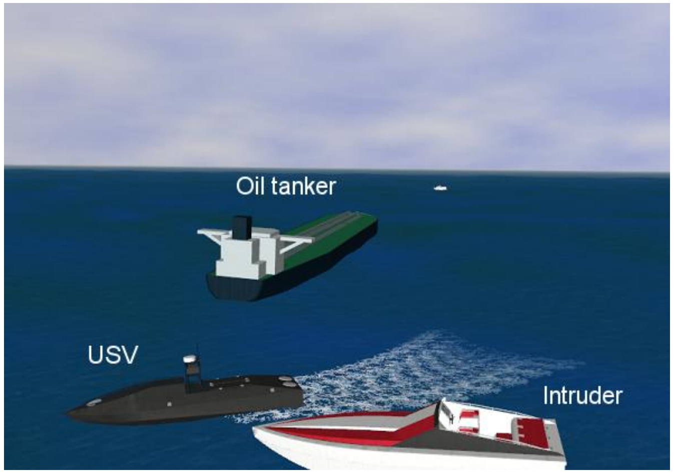


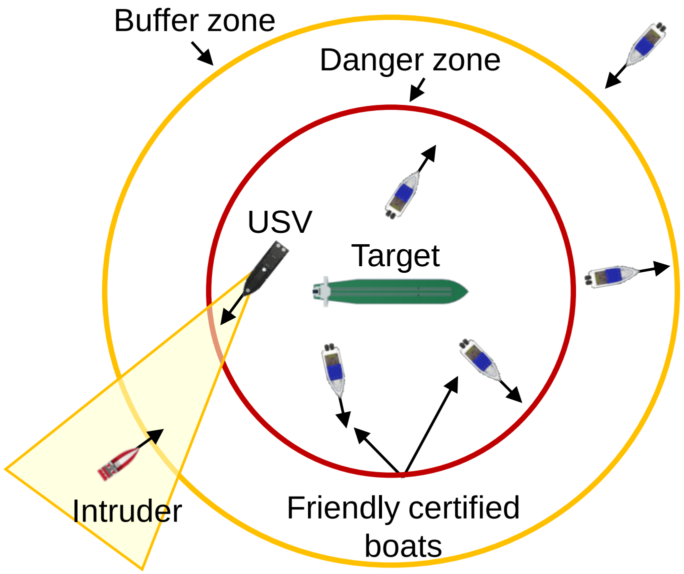
System Architecture



Summary of Accomplishments

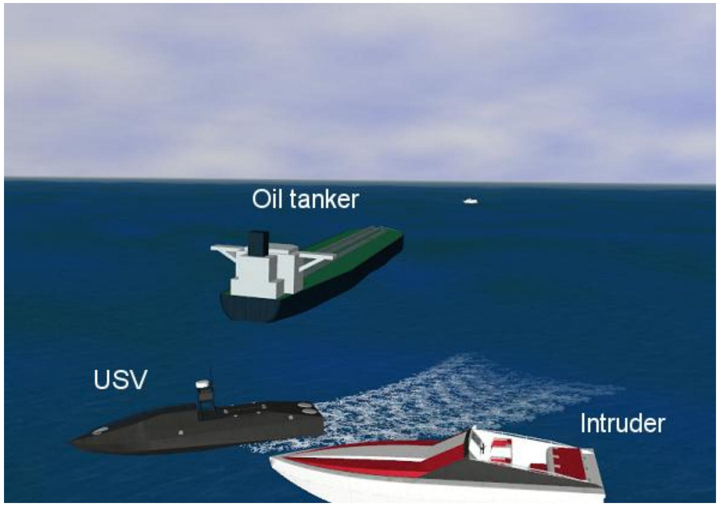
1) Developed a virtual environment
   - Stereo visualization
   - Human vs. human and human vs. autonomy
   - *Enables evaluation of behaviors*
2) Developed physics based meta-models
   - Six DOF dynamics model
   - *Geometric model simplification techniques to speed up computations by factor of 28*
3) Developed trajectory planners
   - *Safe, efficient, and dynamically feasible trajectory planning in high sea states*
4) Used evolutionary computation and statistical reasoning to automatically synthesize USV blocking behavior against a human-competitive intruder
   - Intruder with probabilistic actions
   - *Synthesized behavior was comparable to a hand-coded behavior*

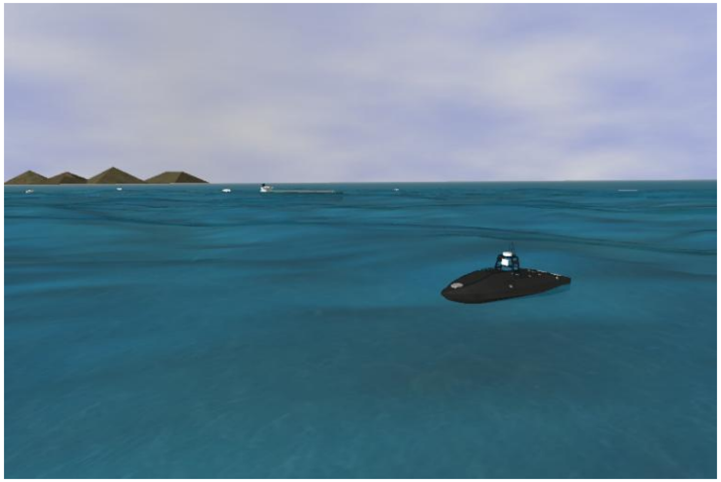




Accomplishment #1: Virtual Environment

- Developed interactive rate physics-based virtual simulation environment for USVs
  - Modeled interactions of waves and the vehicle
  - Real-time ocean rendering
  - Stereo visualization
  - Intuitive user interface
  - Modeling of boats, terrain, and shorelines
  - Modular software design
- Can be used for measuring performance of hand coded and computer synthesized behavior





P. Svec, A. Thakur, D.K. Anand, S.K. Gupta, and M. Schwartz. A simulation based framework for discovering planning logic for autonomous unmanned surface vehicles. *ASME Engineering Systems Design and Analysis Conference*, Istanbul, Turkey, July, 2010.

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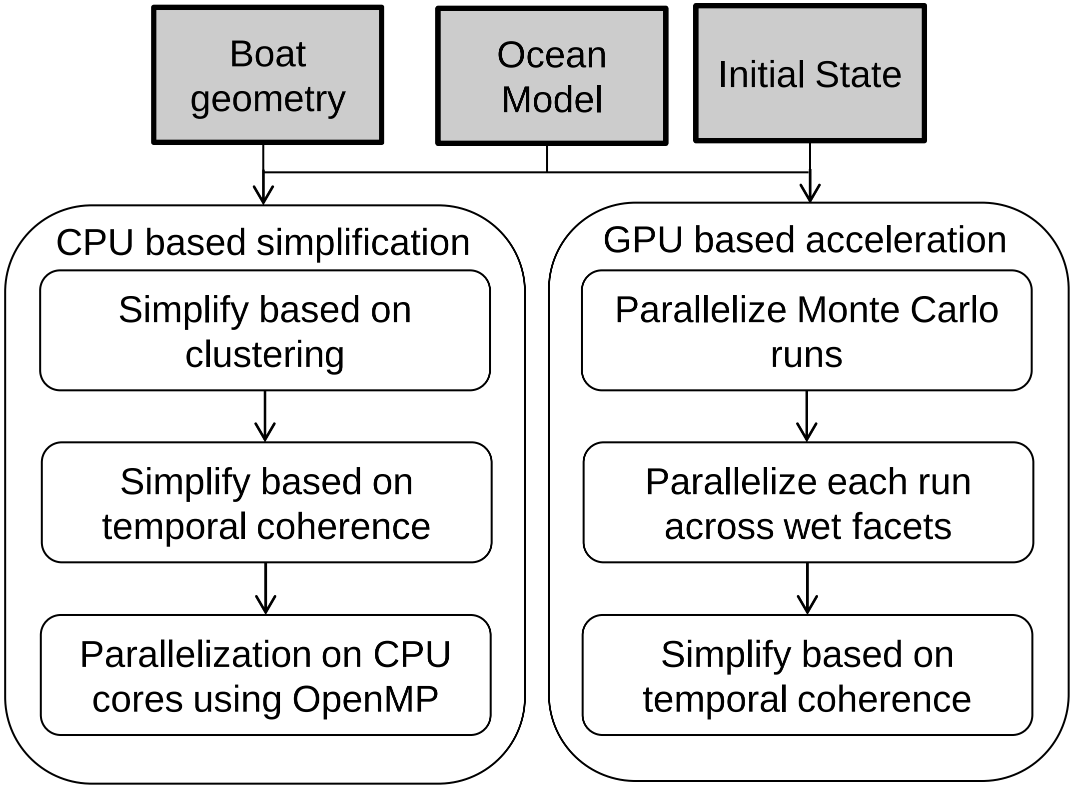
Accomplishment #2: Physics-Based Meta-Models

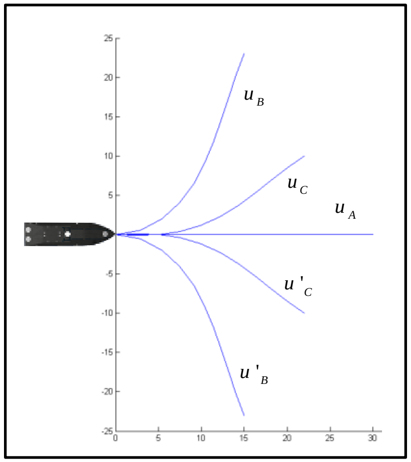
- Automated model simplification
- GPU computing



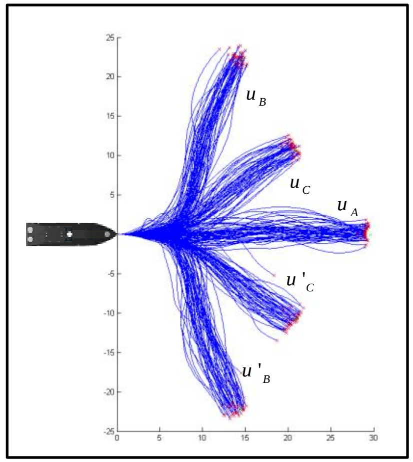
1) A. Thakur, and S.K. Gupta, Real-time dynamics simulation of unmanned sea surface vehicle for virtual environments. Journal of Computing and Information Science in Engineering, 11(3), 2011, 2-11.
2) A. Thakur, P. Svec, and S. K. Gupta. GPU based generation of state transition models using simulations for unmanned sea surface vehicle trajectory planning, *Robotics and Autonomous Systems*, In review.

Accomplishment #3: Trajectory Planning

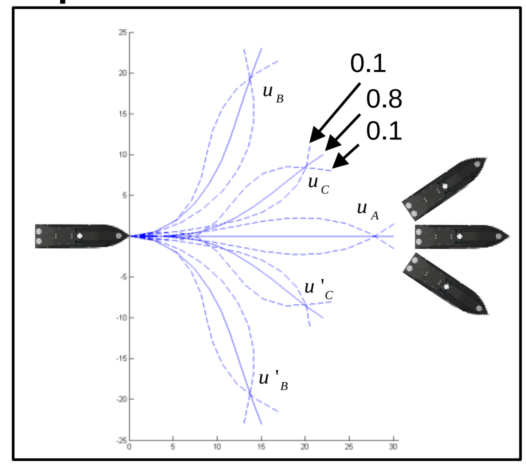
1.
Manually designed control actions



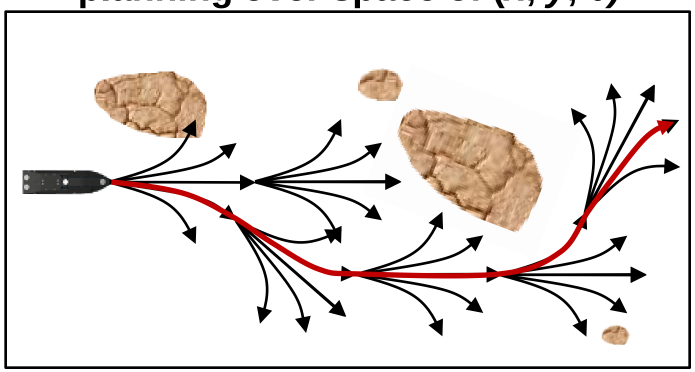
2.
Monte Carlo simulations of control actions



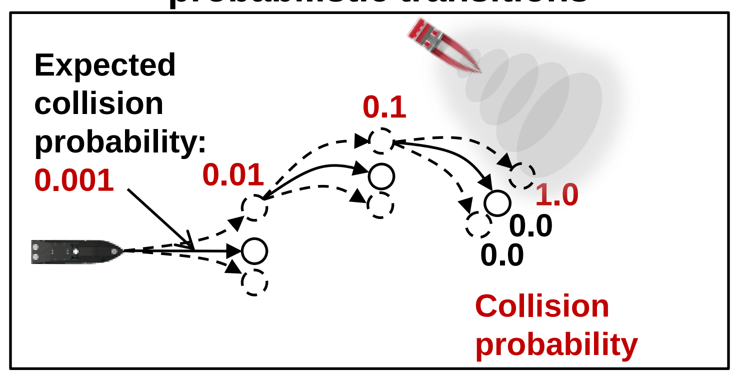
3.
Manually designed probabilistic transitions



4.
3D lattice based trajectory planning over space of (*x*, *y*, *θ*)

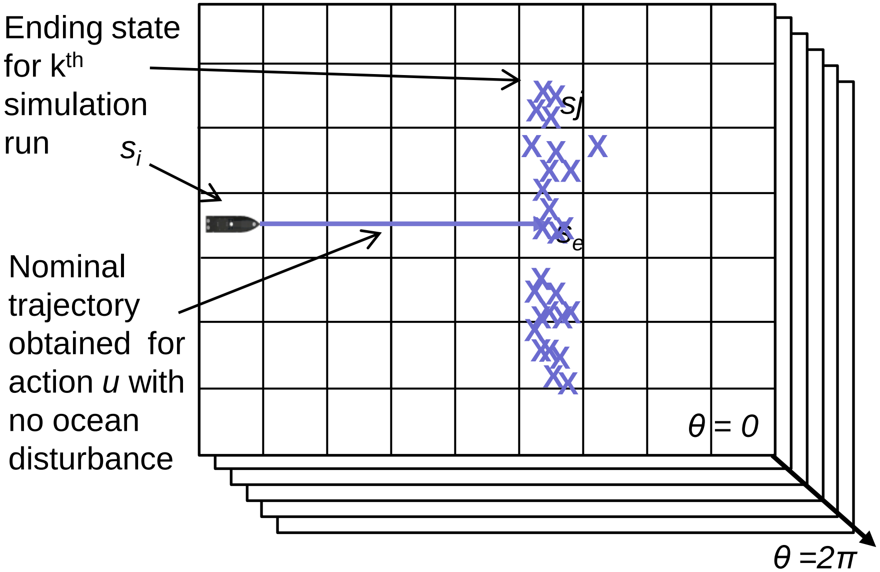


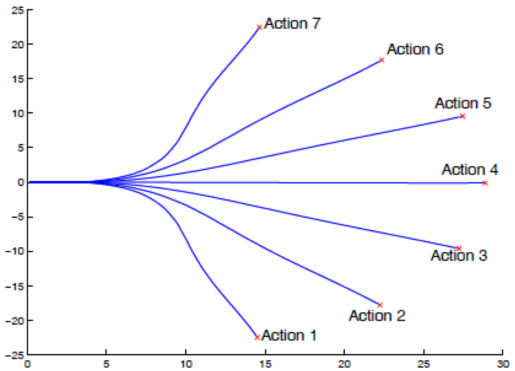
5.
Localized search in space of probabilistic transitions



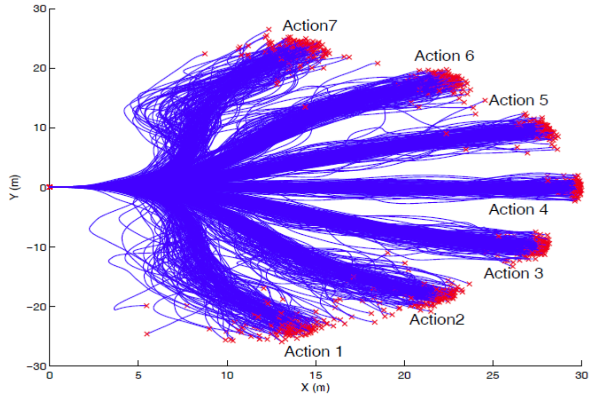
Accomplishment #3.1: Computing State Transition Probability Using High-Fidelity Simulations

- A state transition maps a given state and action combination to another state
- Motion commands are implemented as position tracking using PID controller
- Position uncertainty is captured by running *sufficient* number of simulation trials

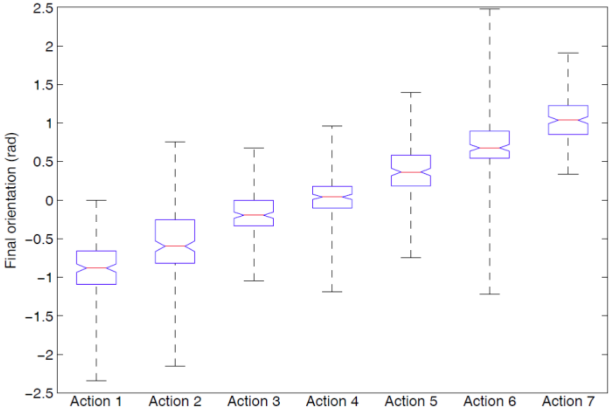




Motion Commands



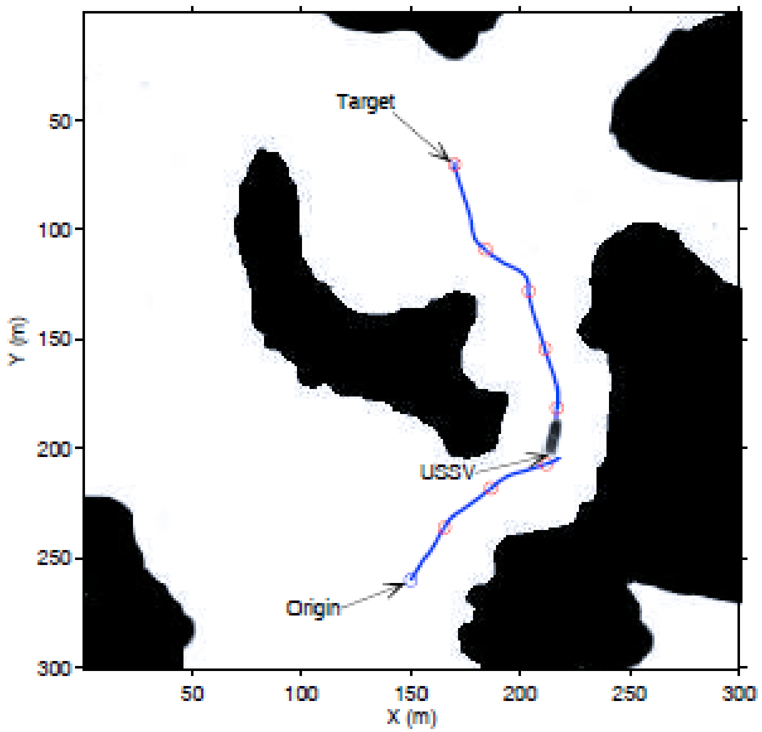
Computed Control Set



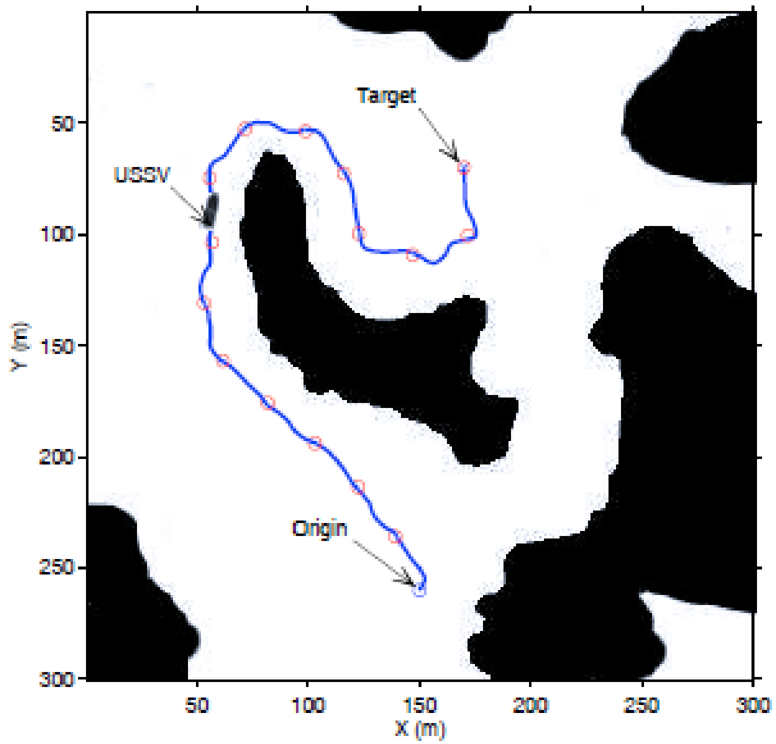
Variation in Final Orientation

A. Thakur, P. Svec, and S. K. Gupta. GPU Based Generation of State Transition Models Using Simulations for Unmanned Sea Surface Vehicle Trajectory Planning, *Robotics and Autonomous Systems*, In review.

Accomplishment #3.2: Computing Trajectories For Various Sea States



Trajectory for sea state 3
(avg. wave height 0.5 to 1.25 m)



Trajectory for sea state 4
(avg. wave height 1.25 to 2.5 m)

Value iteration used for obtaining optimal feedback plan

A. Thakur, P. Svec, and S.K. Gupta. Generation of State Transition Map Using Unmanned Sea Surface Vehicle (USSV) Simulation, *ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE '11)*, 2011.

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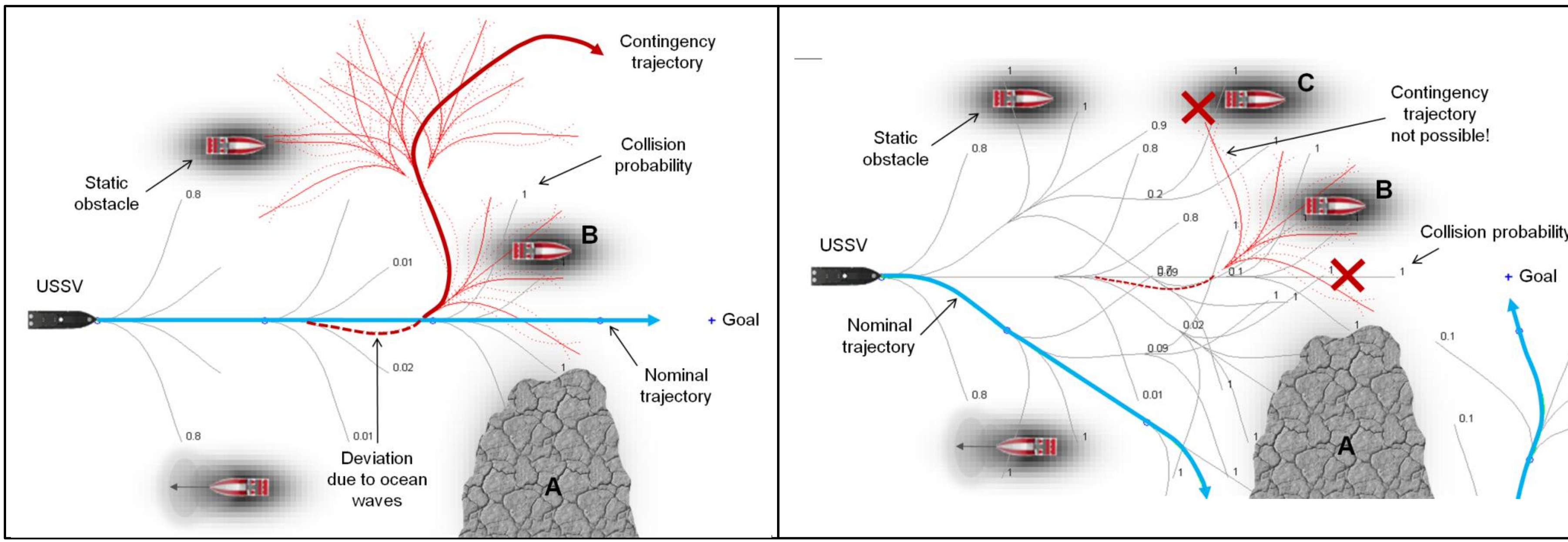
Accomplishment #3.3: Incorporating Look-Ahead Into Trajectory Planning

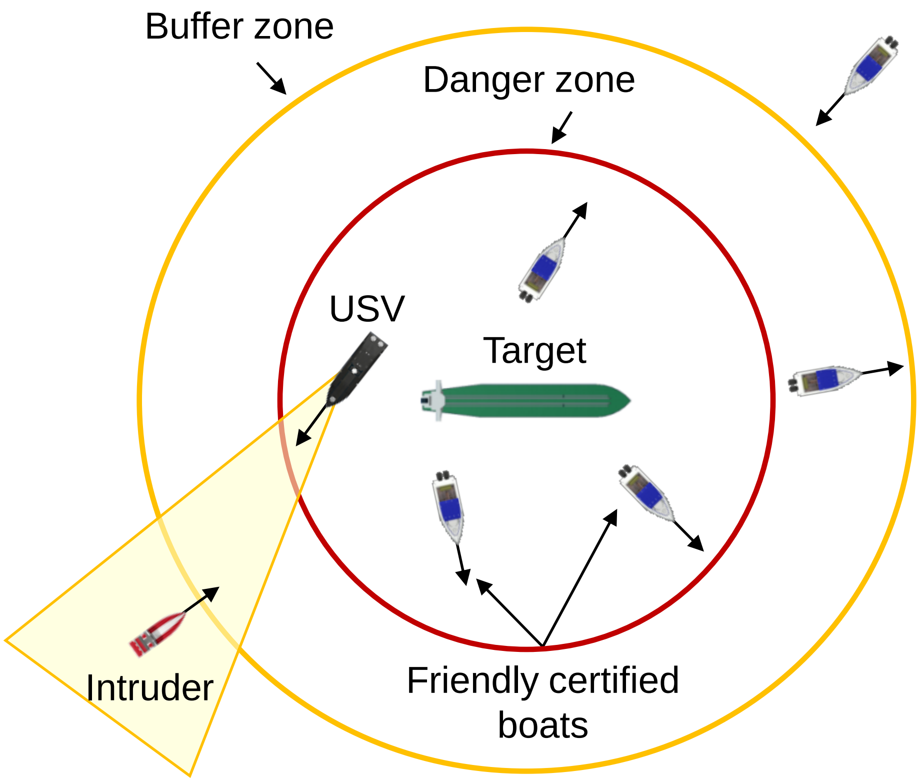
- Standard stochastic dynamic programming algorithms too slow to handle motion uncertainty for non-holonomic vehicles
- A* or D* based heuristic search alone does not handle motion uncertainty
- Developed a look-ahead based algorithm for trajectory planning under motion uncertainty for USVs
- Motion uncertainty is modeled and explicitly used during the computation of the trajectory
- Contingency plan is generated to efficiently handle sudden large deviations from the intended trajectory



P. Svec, M. Schwartz, A. Thakur, and S.K. Gupta. Trajectory Planning with Look-Ahead for Unmanned Sea Surface Vehicles to Handle Environmental Uncertainties, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS '11)*, San Francisco, September 25-30, 2011.

Accomplishment #4: Action Selection Policy Synthesis For Blocking Task

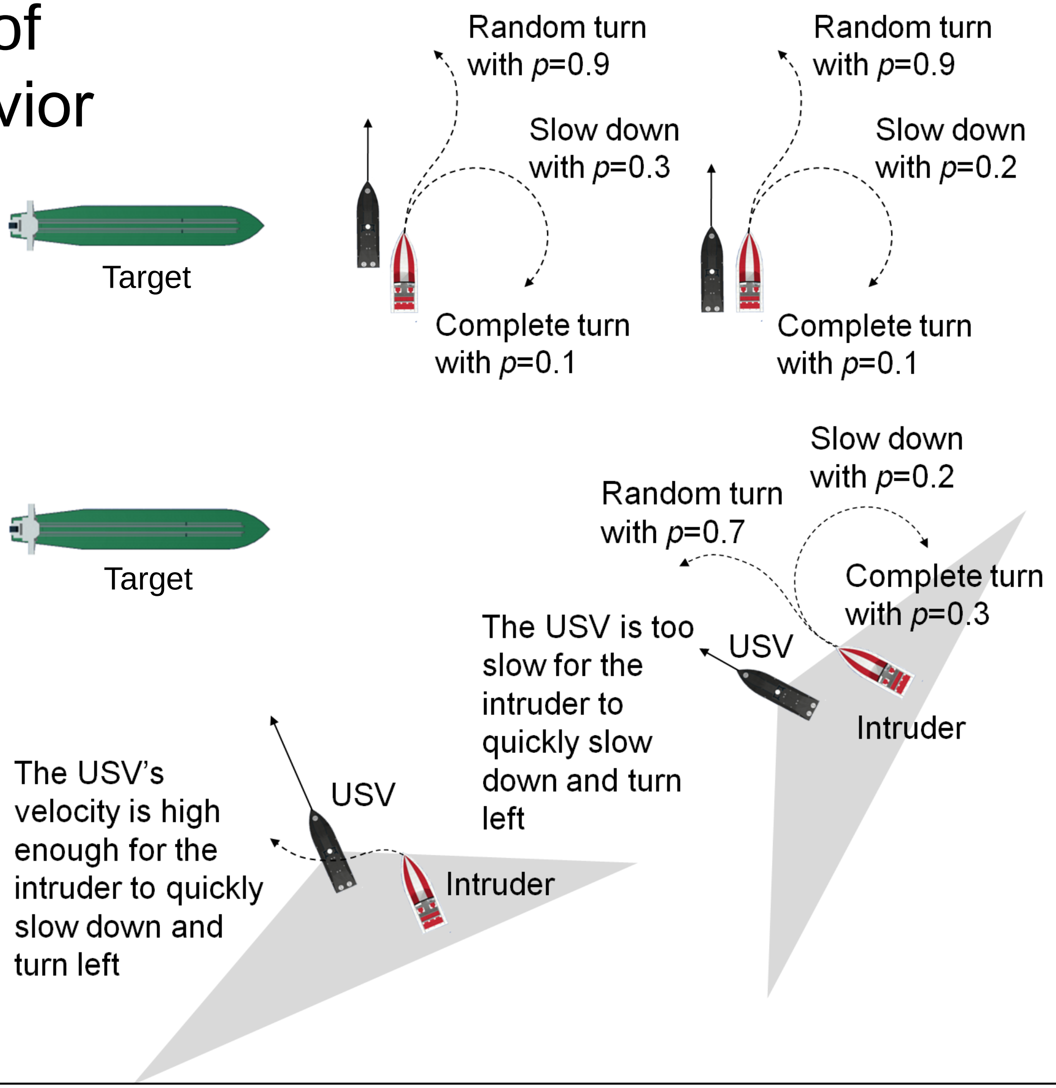
- Case study: USV supposed to block the advancement of an intruder boat
  - Needs a reactive action selection policy to compute motion goals
- Intruder exhibits a human-competitive, deceptive attacking behavior
  - USV cannot exploit regularity in the intruder's behavior due to its probabilistic actions



P. Svec and S.K. Gupta. Automated Synthesis of Action Selection Policies for Unmanned Vehicles Operating in Adverse Environments. *Autonomous Robots*, Accepted for publication.

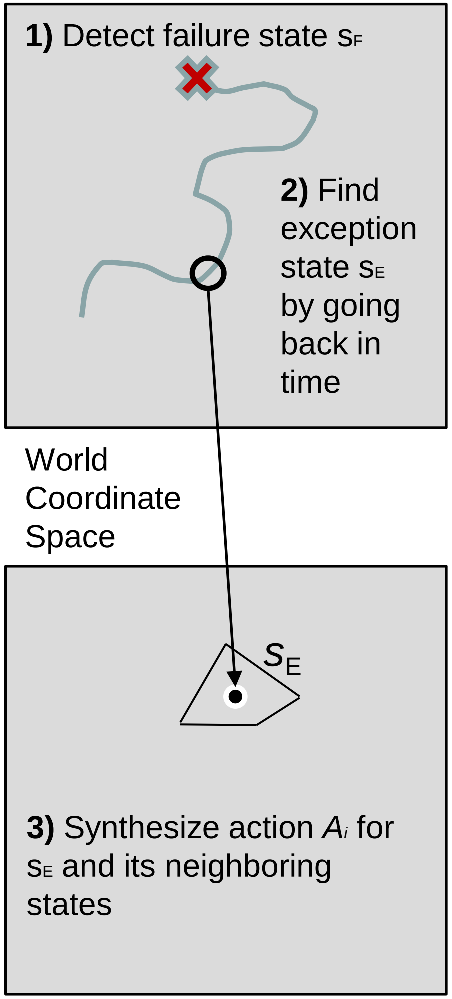
Accomplishment #4: Action Selection Policy Synthesis For Blocking Task (Cont.)

- Representative portions of intruder's attacking behavior

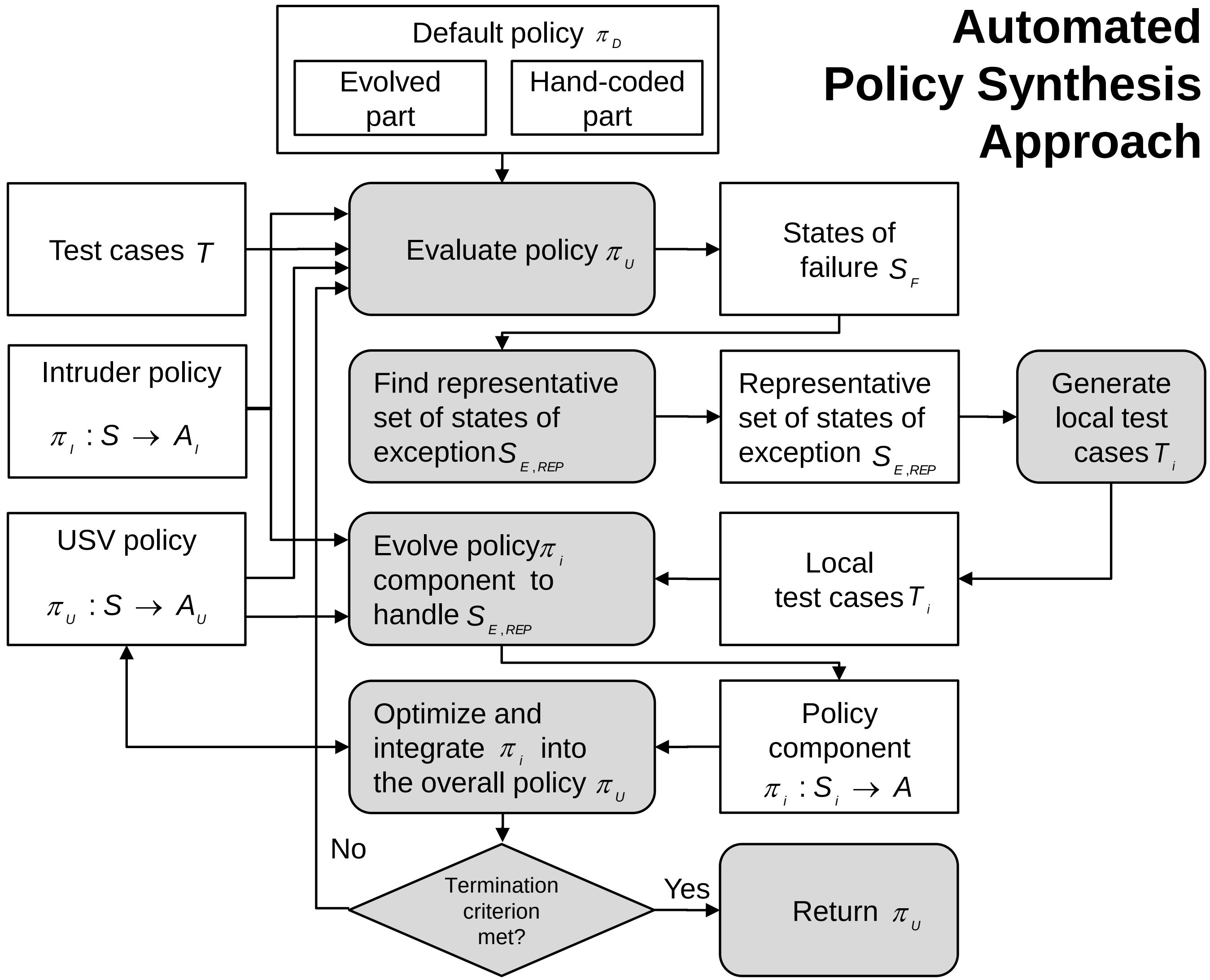


P. Svec and S.K. Gupta. Automated Synthesis of Action Selection Policies for Unmanned Vehicles Operating in Adverse Environments. *Autonomous Robots*, Accepted for publication.

Accomplishment #4: Action Selection Policy Synthesis For Blocking Task (Cont.)



Iterative State Space Partitioning



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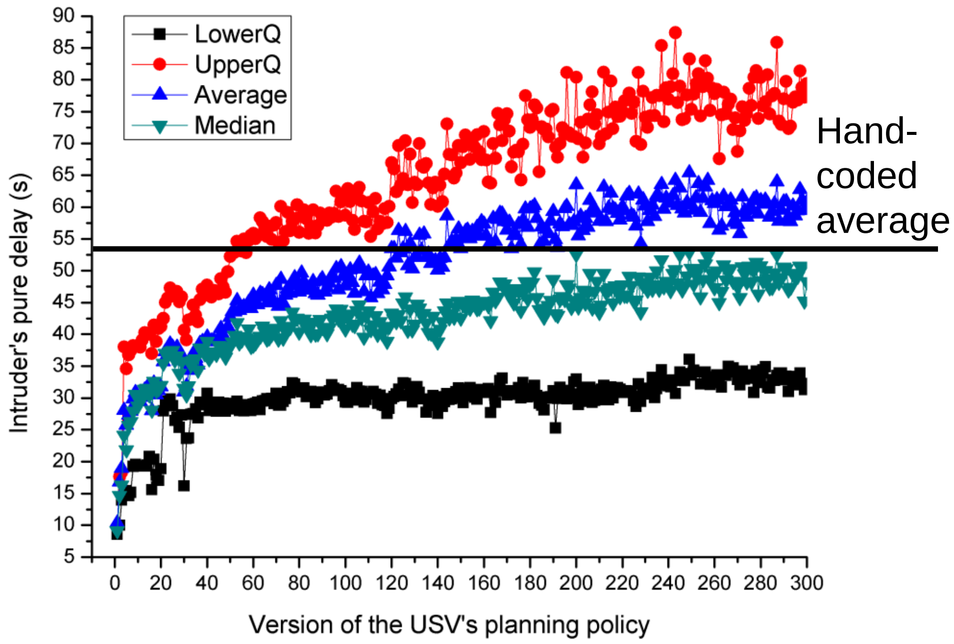
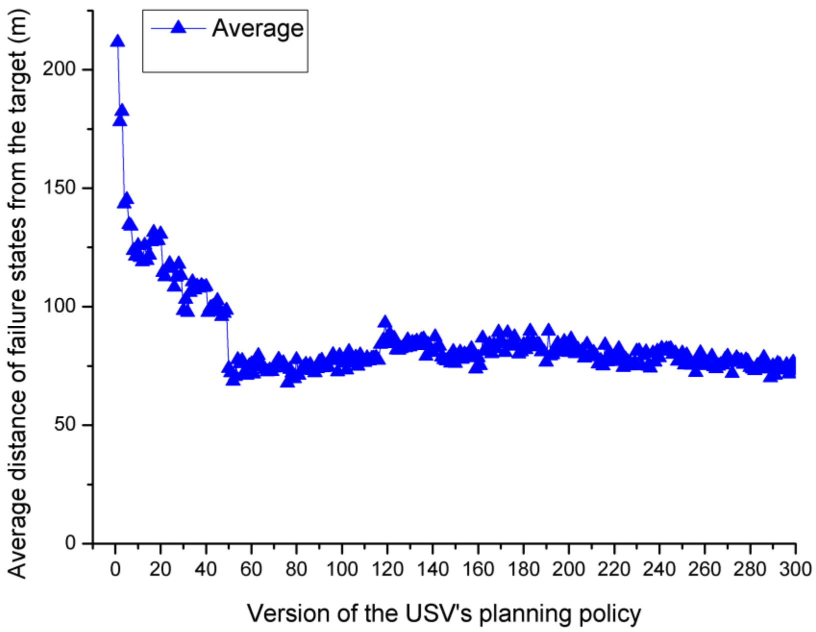
Accomplishment #4: Action Selection Policy Synthesis For Blocking Task (Cont.)





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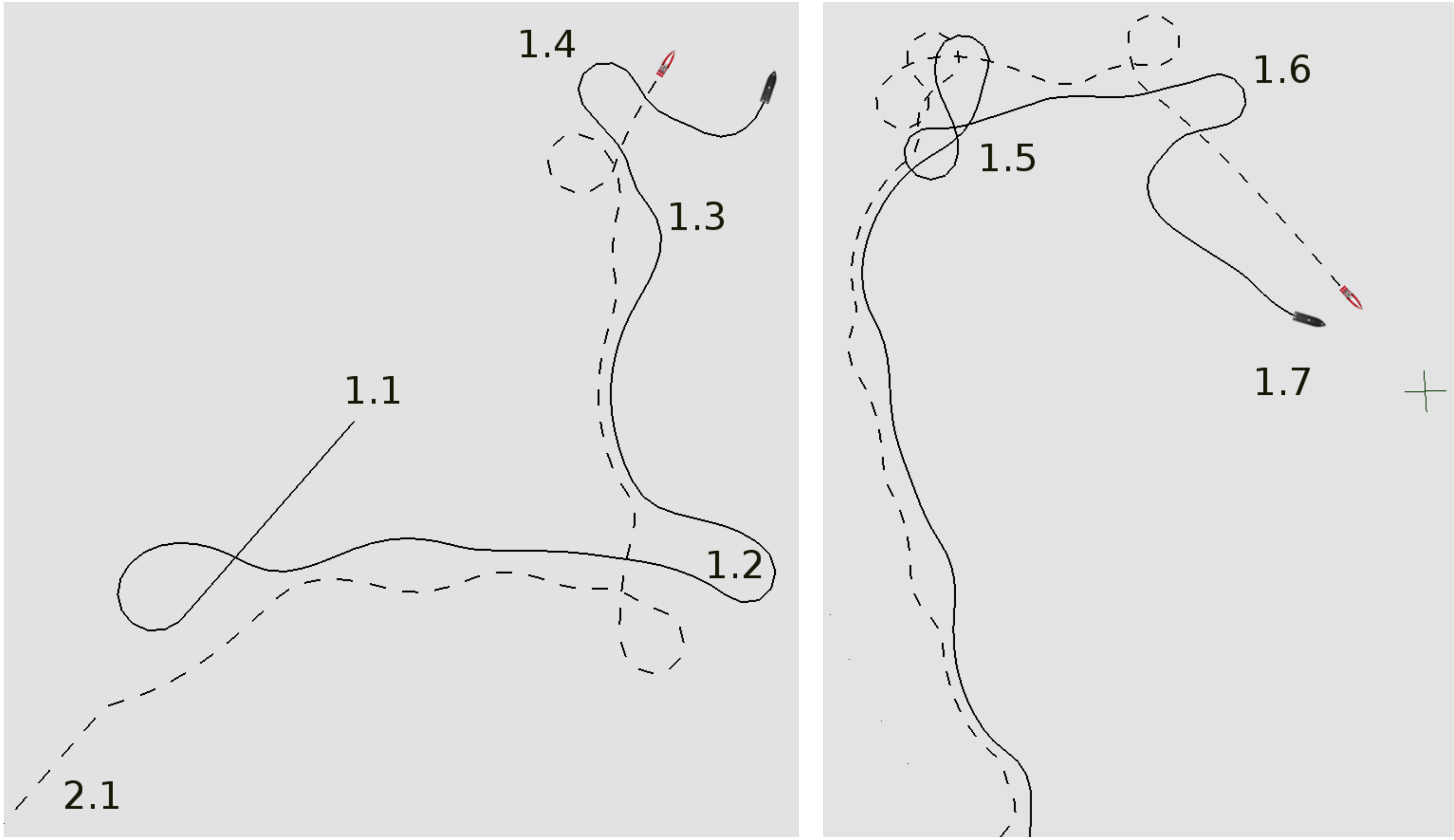
Accomplishment #4: Action Selection Policy Synthesis For Blocking Task (Cont.)



Example of a run in which the USV managed to block the intruder for additional 45 seconds. The start position of the USV is marked as 1.1 while the start position of the intruder is marked as 2.1.

P. Svec and S.K. Gupta. Automated Synthesis of Action Selection Policies for Unmanned Vehicles Operating in Adverse Environments. *Autonomous Robots*, Accepted for publication.

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