# UAV Traffic Management (UTM)

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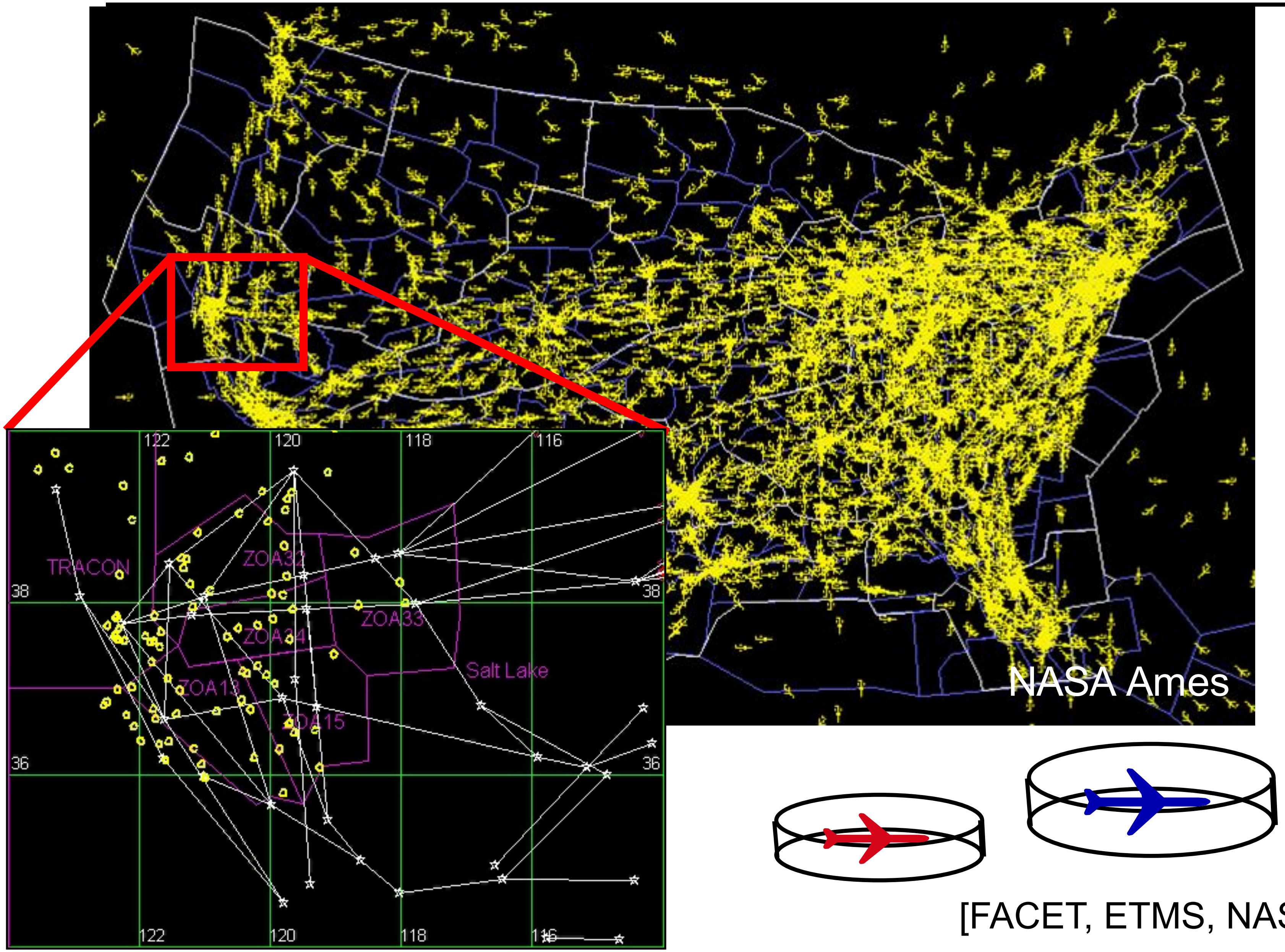
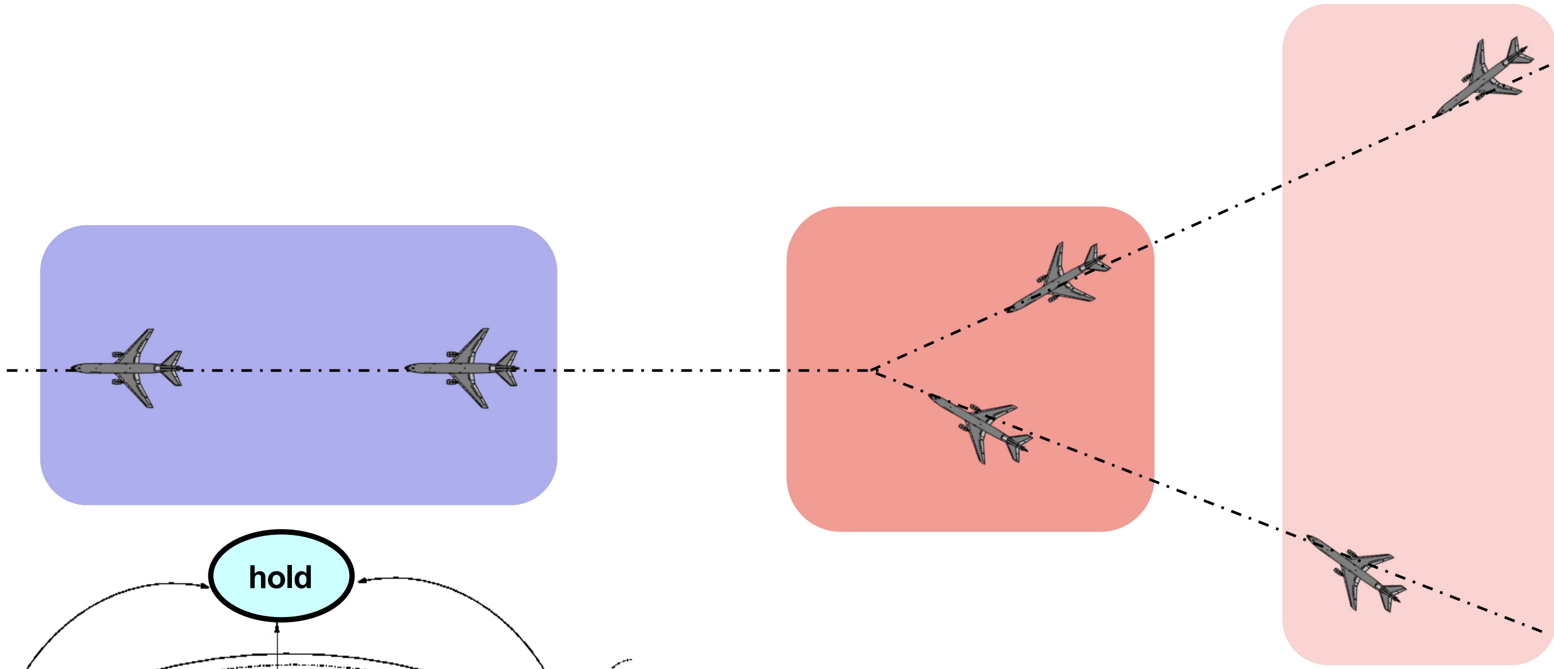
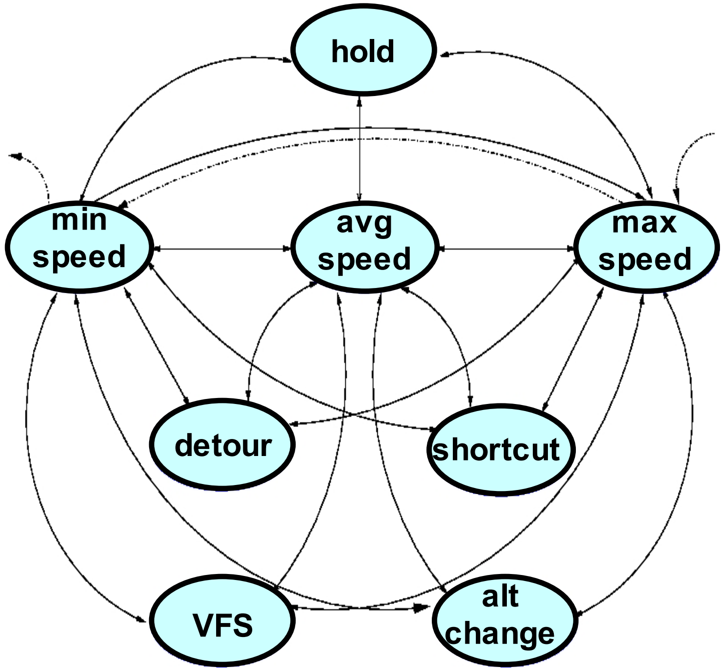
# Air Traffic Control




[FACET, ETMS, NASA Ames]

# Controller must keep aircraft separated



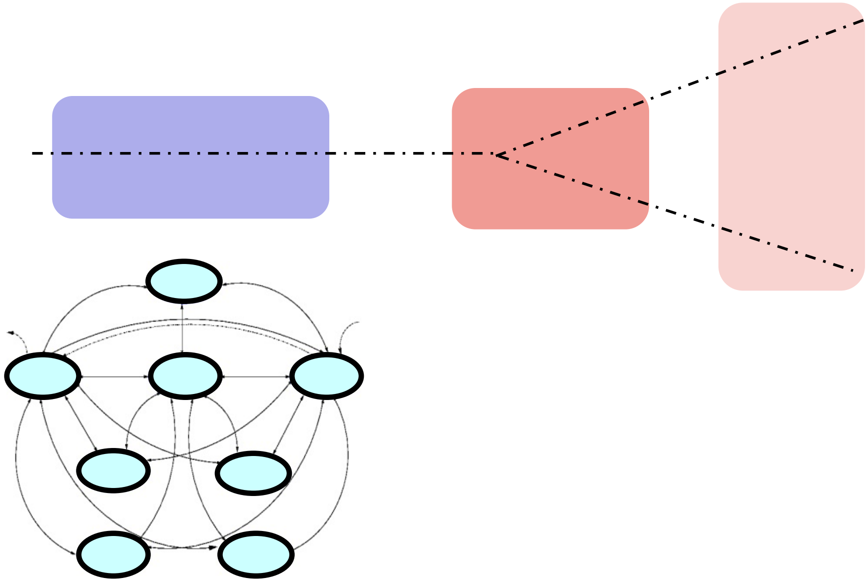



- Small set of control actions
- Infrequent deviations from nominal
- Grouping by potential conflict

# Growing numbers of UAV applications


[Amazon]

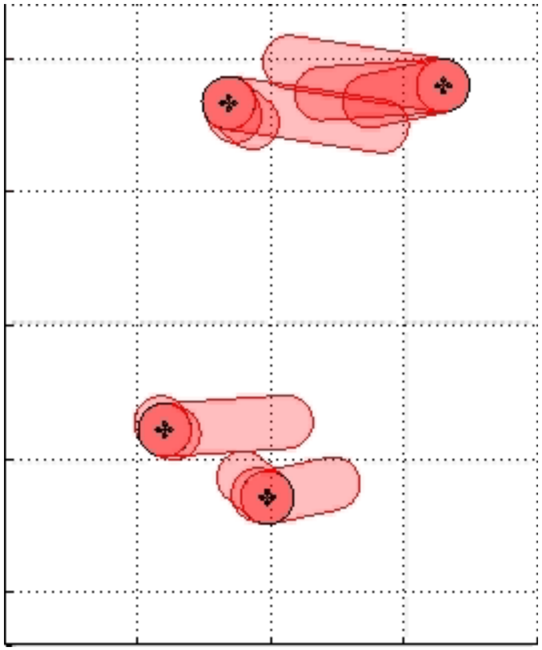
[Google]



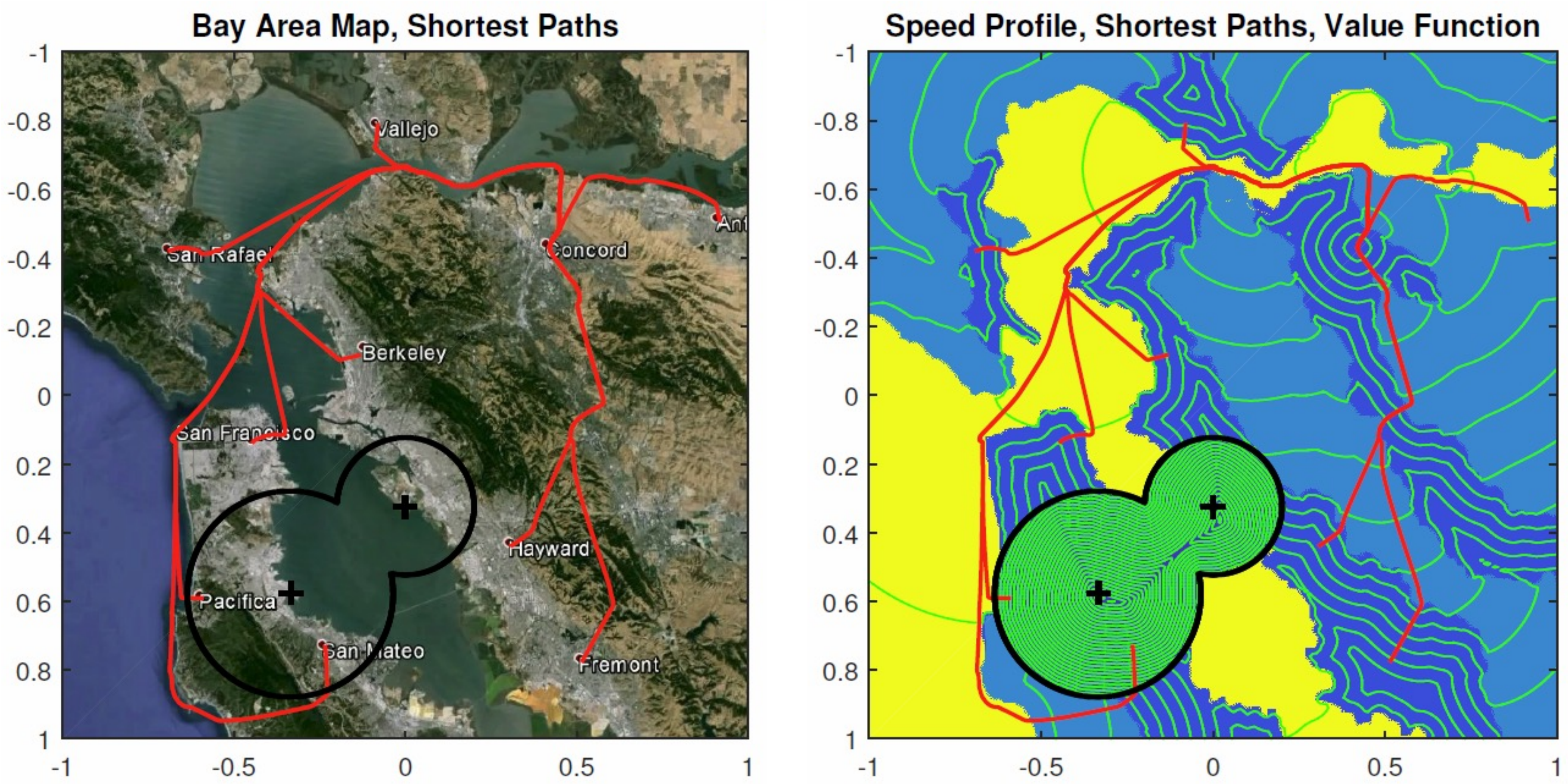
1. Safety
2. Simplicity
   [computation]
3. Ability to adapt to new information
   [data-driven]

# Example 1: Collision Avoidance

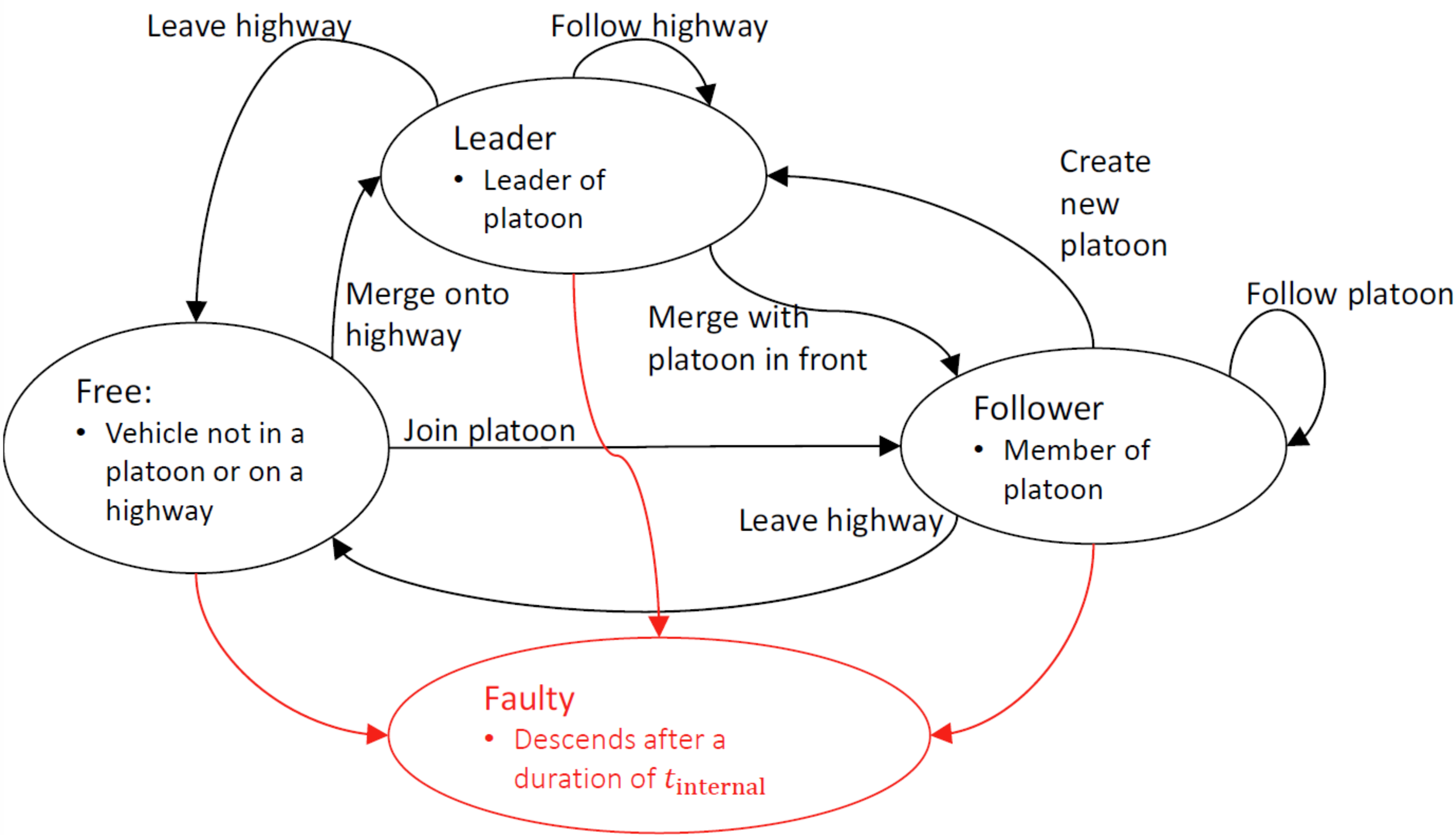
Pilots instructed to attempt to collide vehicles



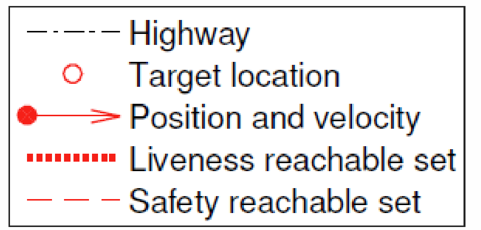
# Example 2:  Platooning UAVs



# Example 2: Platooning UAVs

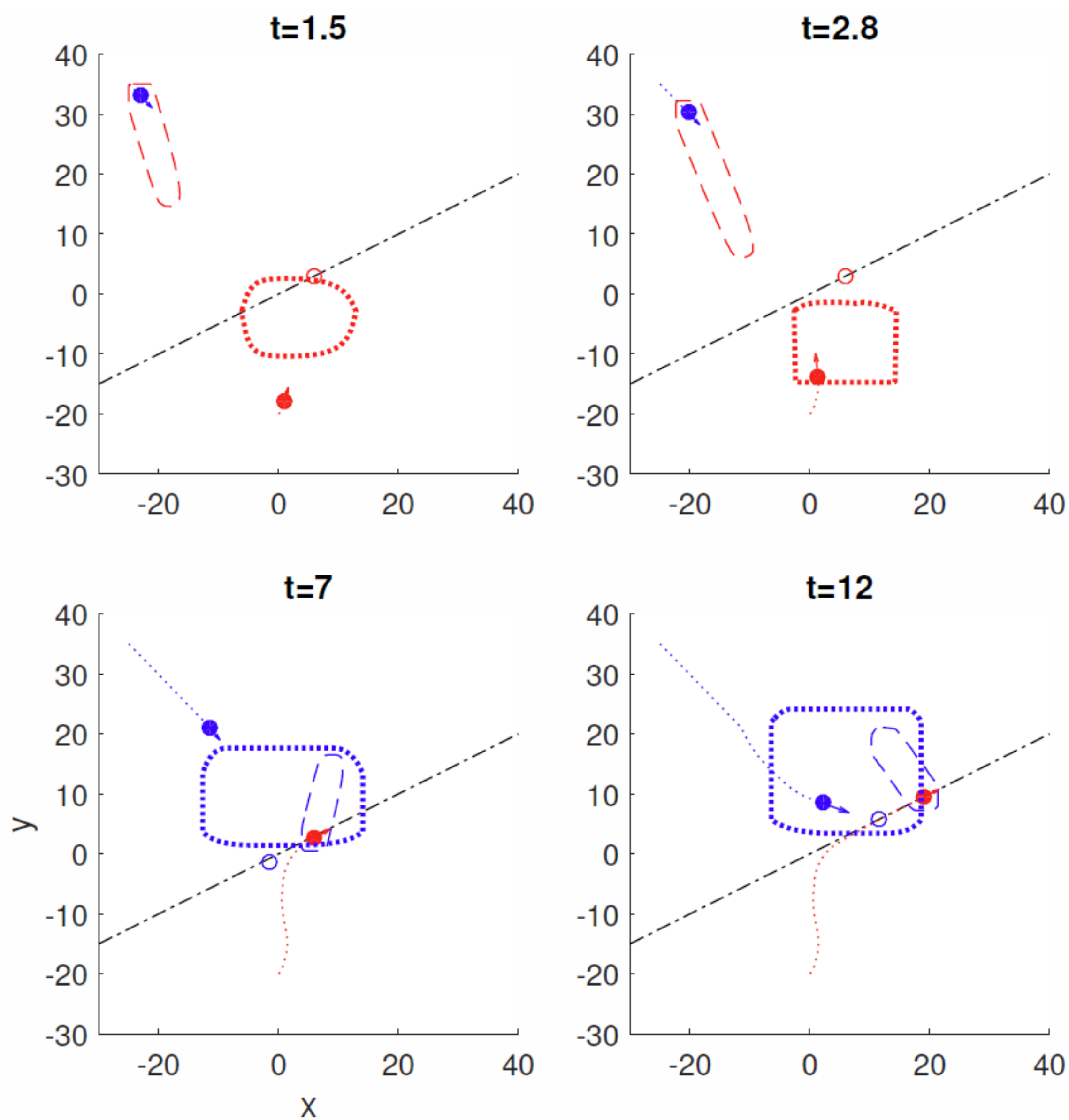


# Merge and join

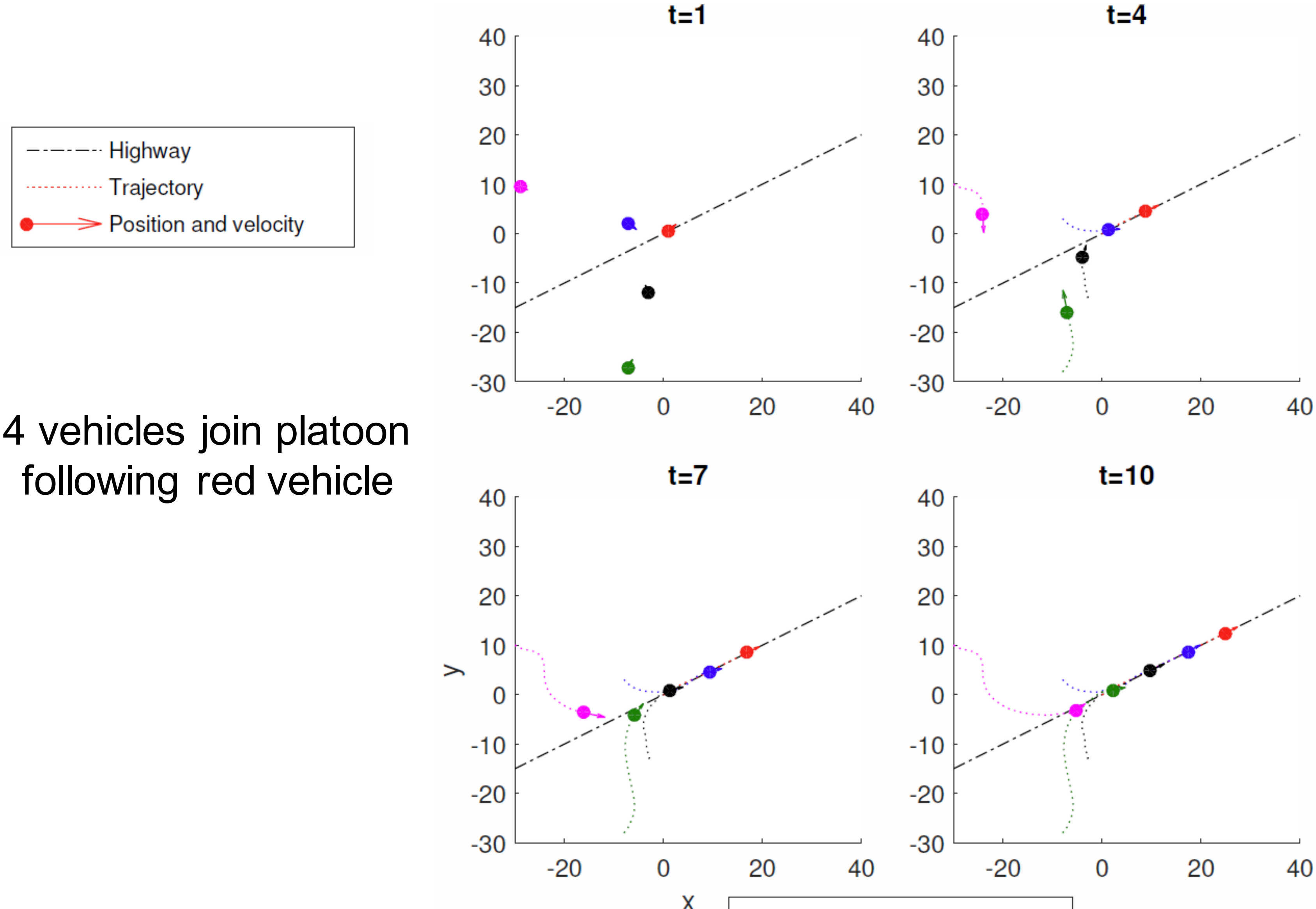



Red vehicle merges onto highway

Blue vehicle joins red vehicle's platoon

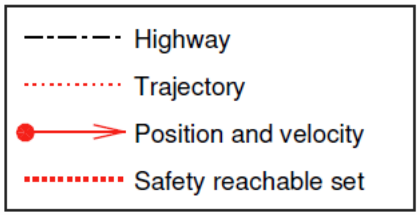


# Merge and join




4 vehicles join platoon following red vehicle

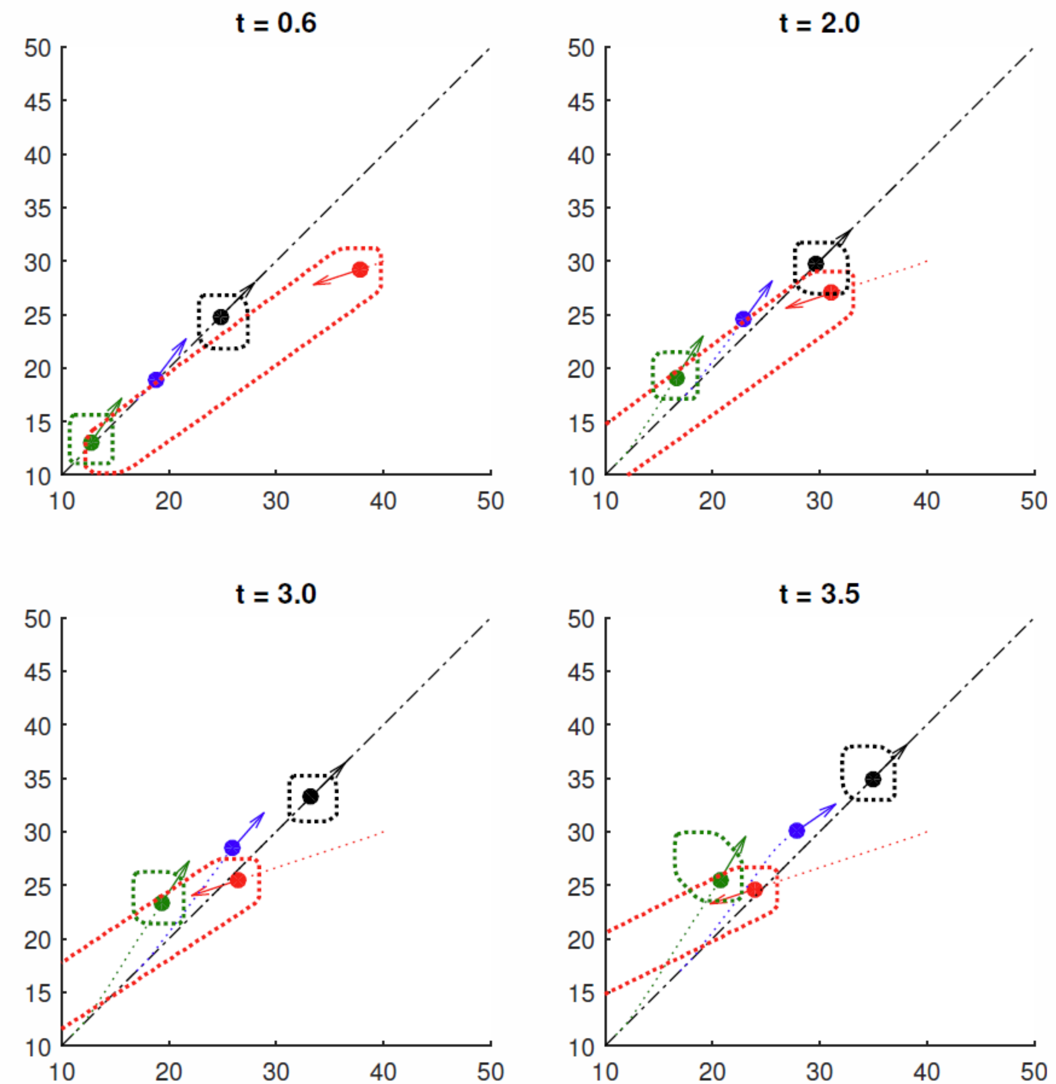
# Intruder




Platoon responding to intruder (red vehicle)

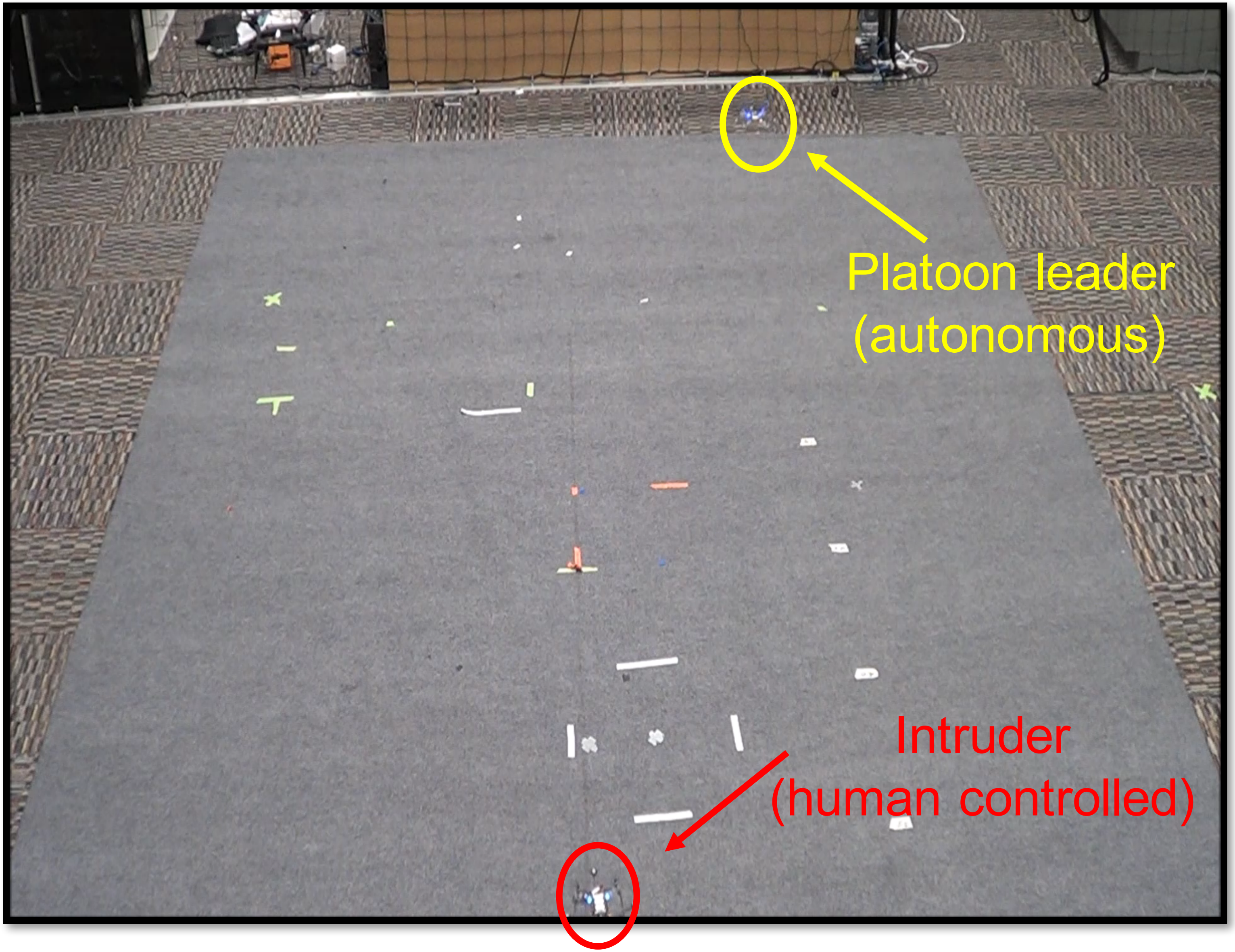
Reachable sets for blue vehicle are shown

Blue vehicle must stay outside of all dotted boundaries



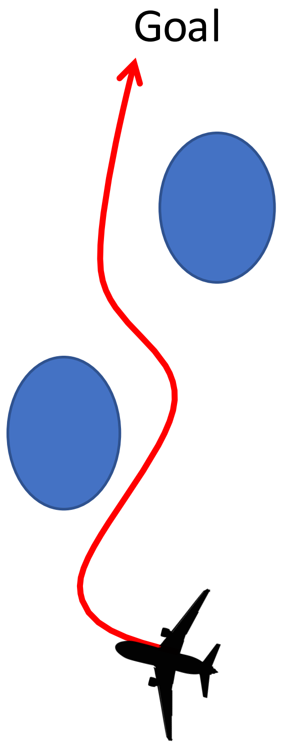
# Experiments: Form Platoon

# Experiments: Intruder Avoidance



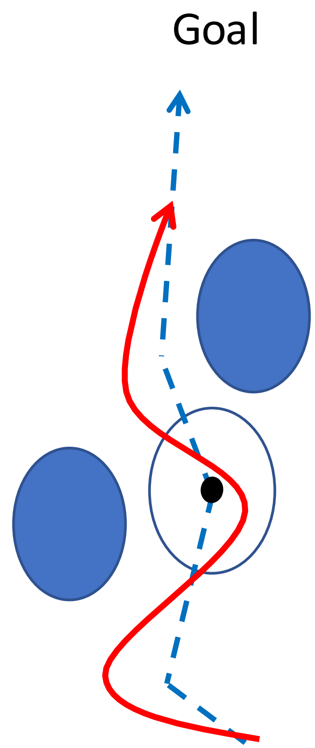
# Experiments: Change Highways

## Slow and Accurate Planning




- Optimal control
- Guarantees on safety and goals
- Handles external disturbances (e.g. wind)
- Slow to compute

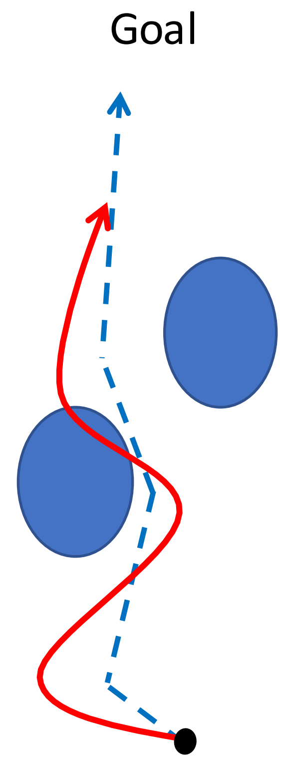
## The Proposal




- Precompute a tracking error bound around the simple planning model

- Usable with lots of path/trajectory planners

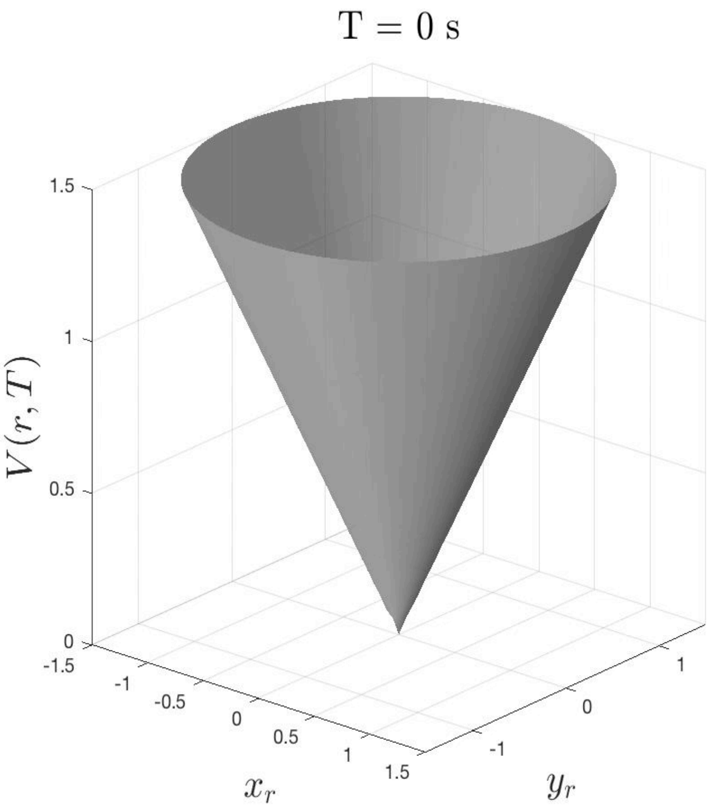
## Fast (but less accurate) Planning




- Very fast with simple dynamics
- May not capture all system behavior
- Not necessarily robust to disturbances

# Precomputed Tracking Bound

Goal: Map initial relative state to worst possible tracking error over time

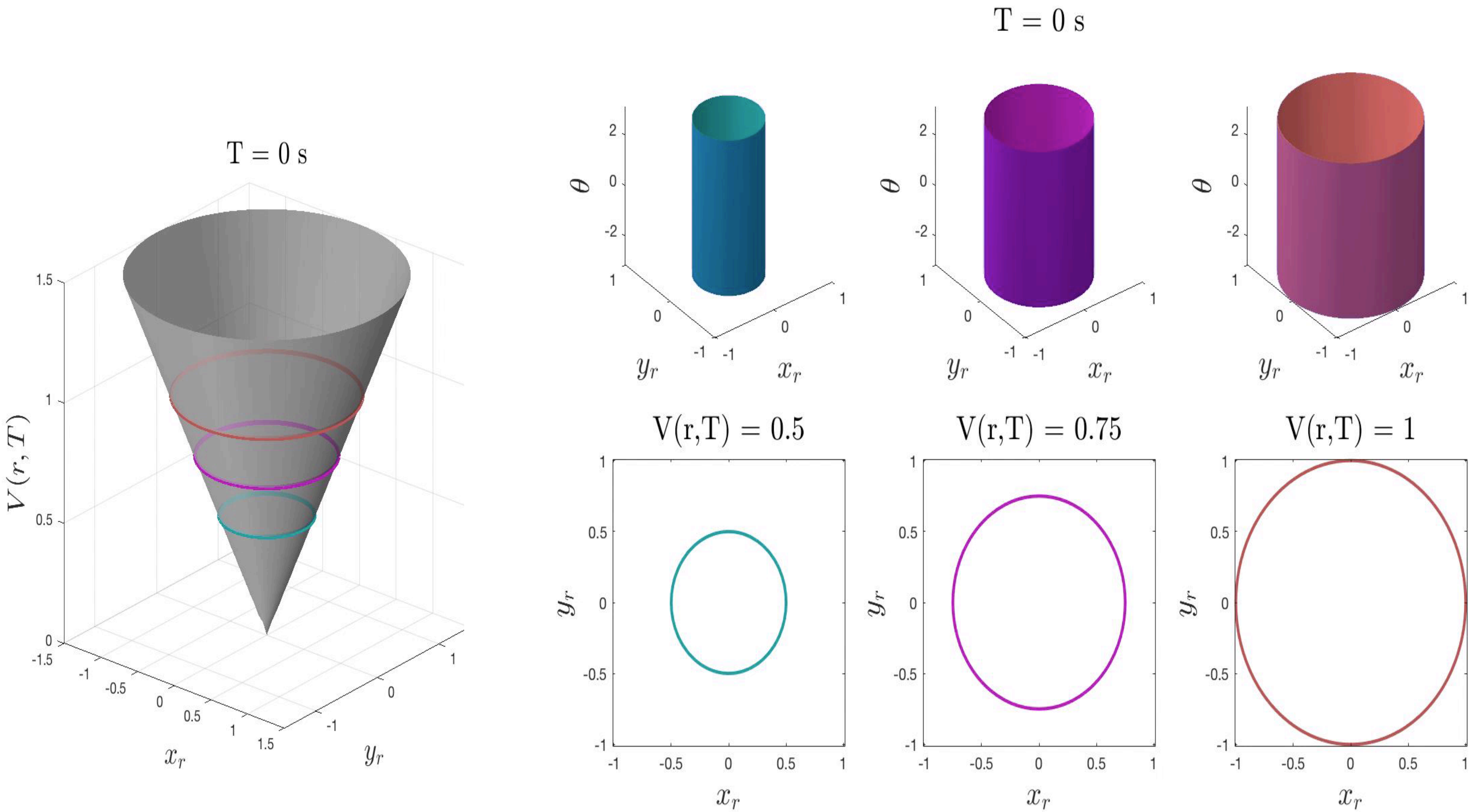



Planning system tries to maximize cost

Tracking system tries to minimize cost

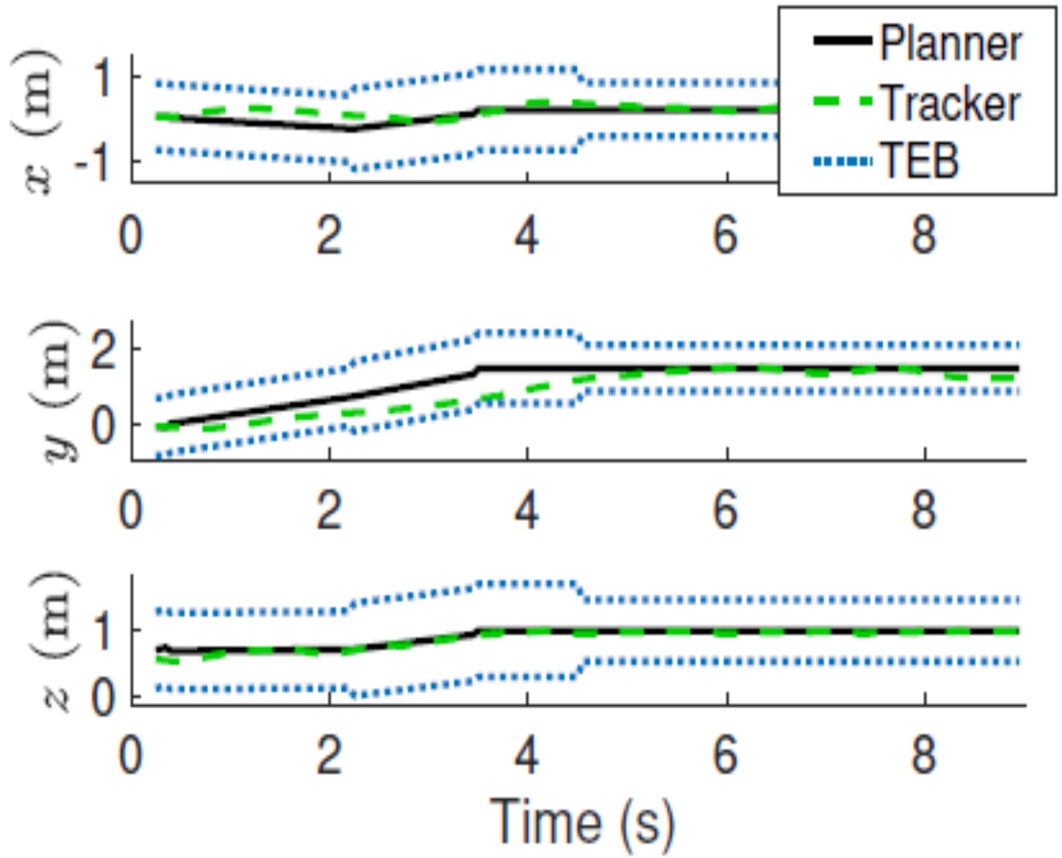
Capture maximum cost over time

# Precomputed Tracking Bound




Smallest Invariant Level Set = Tracking Error Bound

# Fast and Slow Planning




D. Fridovich-Keil*, S. Herbert*, J. Fisac, S. Deglurkar, and C. J. Tomlin, "Goal-Driven Dynamics Learning via Bayesian Optimization," 56th IEEE Conference on Decision and Control, Dec 2017.

# Learn models from data…

… but stay safe while learning

- **Safety:**
  - A nominal model with error bounds
  - Reachable sets computed to ensure safety in worst case
- **Performance:**
  - Use online learning to update model
  - Cost function used to generate control action within the safe set

# Safe Learning

with online model validation

Berkeley
University of California

# New Vistas: Personal Air Mobility





[AeroVelo, Aurora, Vahana, Terrafugia…]

# Thanks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**NSF PIRE**