## PROPOSAL SUMMARY

<table>
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<tr>
<th>Project Title: Six Dimensional Multi-Agent Path Planning</th>
<th>Problem Statement:</th>
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<td>Lead University: University of Denver</td>
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<td>Principal Investigator: Nathan Sturtevant</td>
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<td>Team Members: TBA</td>
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<td>Budget: $17.5k</td>
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<td>Schedule:</td>
<td>Build a multi-agent path planner (that avoids conflicts between agents) for agents that move in three spatial dimensions, with additional movement constraints. The general problem of multi-agent path planning is NP-Hard.</td>
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<td>Start date: Jan 1, 2016</td>
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<td>End date: Dec 31, 2016</td>
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<th>Objective(s):</th>
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<td>The resulting planner should be able to operate in real-time with limited on-board resource constraints.</td>
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<th>Deliverables:</th>
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<td>A set of C++ classes which implement the solver and that can provide conflict-free paths between multiple agents obeying the general movement constraints.</td>
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This research intersects several very large bodies of work. A few highly relevant publications include:

Time-bounded Lattice for Efficient Planning in Dynamic Environments  
Kushleyev & Likhachev
Planning Long Dynamically-Feasible Maneuvers For Autonomous Vehicles  
Likhachev & Ferguson
This work shows how to plan in complex environments using a lattice

Conflict-Based Search for Optimal Multi-agent Pathfinding,  
Sharon, Stern, Felner and Sturtevant
This work shows how to produce optimal multi-agent plans using a single-agent planner and location constraints

Optimizing motion-constrained pathfinding,  
Sturtevant
This work shows how to use heuristics and waypoints for real-time planning in high-dimensional constrained environments
We are combining work on (cooperative) multi-agent path planning with work on single-agent planning for dynamic worlds. Both of these areas have received significant work individually, but far less so together.

1. Our planner will initially be based on a lattice (voxel) discretization of the world. Other representations will be considered; this representation will simplify many aspects of the multi-agent planning.

2. Our planner will build a high-quality heuristic for the local movement constraints of the agents so that all unconstrained movement can be planned without significant cost.

3. Constraints in the environment, represented by x- y- and z-coordinates as well as time will be used to represent static obstacles as well as multiple agents in the world. Agent planning will never take place in a joint planning space; constraints will be passed between agent plans in a systematic way via the CBS algorithm to ensure correctness.
INNOVATION & UNIQUENESS

The core ideas have been explored previously; the uniqueness and innovation comes in putting them all together and a complete working system that is usable for partners in the IUCRC.

Examples from previous work are on following slides.
• Cooperative Pathfinding:
• With Agent Reservations:

Camera at (-0.0, -0.4, -12.5) looking at (-0.0, -0.0, 12.5) with 4.8 aperture
Simulation time elapsed: 2.11
Example video of vehicle model for Planning on a Lattice
Example video of vehicle model for Planning on a Lattice, *Detail View*
PROJECT PLAN: STATEMENT OF WORK & TIMELINES

- Task 1: Environment Implementation  
  Jan - Feb
- Task 2: Testing/tuning parameters and adding heuristics  
  March - April
- Task 3: Adding motion constraints  
  May - June
- Task 4: Add support for goal and waypoint constraints  
  July - August
- Task 5: Integrating high-level CBS planner  
- Task 6: Package and Document software  
  Nov - Dec