CS/EE/ME 75

Instructor: Joel W. Burdick
T.A.s: Daniel Naftalovich (nafty@caltech.edu)

Course Location/Time: 135 Gates-Thomas, TBD

- 1.5 hour/week class time
- 1-2 hour/week project meetings, plus prototyping as appropriate

Course Web Site:
http://robotics.caltech.edu/wiki/index.php/CS_EE_ME_75_2019-20

Units: See course web site for details

- First (3), 6, or 9 units:

CS/EE/ME 75

CS/EE/ME 75 abc. Multidisciplinary Systems Engineering. *3 units (2-0-1), 6 units (2-0-4), or 9 units (2-0-7) first term; 6 units (2-3-1), 9 units (2-6-1), or 12 units (2-9-1) second and third terms; units according to project selected.* This course presents the fundamentals of modern multidisciplinary systems engineering in the context of a substantial design project. Students from a variety of disciplines will conceive, design, implement, and operate a system involving electrical, information, and mechanical engineering components. Specific tools will be provided for setting project goals and objectives, managing interfaces between component subsystems, working in design teams, and tracking progress against tasks. Students will be expected to apply knowledge from other courses at Caltech in designing and implementing specific subsystems. During the first two terms of the course, students will attend project meetings and learn some basic tools for project design, while taking courses in CS, EE, and ME that are related to the course project. During the third term, the entire team will build, document, and demonstrate the course design project, which will differ from year to year. Freshmen must receive permission from the lead instructor to enroll. Instructor:

CS/EE/ME 75 Goals, Objectives, Schedule

Fall Goals:

- Build an integrated team that can win the next SubT Challenges
- Understand and complete system design and performance expectation
- Organize teams to prototype subsystems
- Explore options for providing technology sizzle in our system design
- **Advanced:** get ongoing

Objectives

- For subsystems (e.g., rollocoptor) with existing baseline designs:
  - Revalidate the baseline design; Agree on specifications/choices
  - Explore Design Options
  - Model-based analysis of system performance
  - Advance or develop new prototypes
- For subsystems without existing baseline designs
  - Analyze design options:
  - Establish baseline design to achieve max points
  - Build prototype. Evaluate for team integration.

The DARPA
“Grand Challenges”

The DARPA challenges

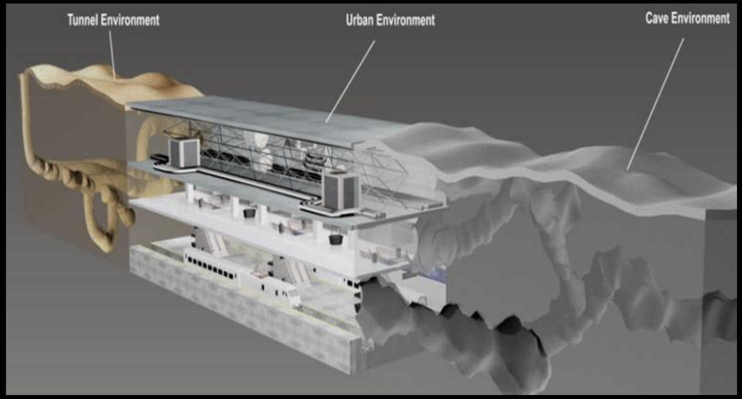
DARPA = Defense Advanced Research Project Agency

- Setting ambitious goals, making way for novel approaches that might otherwise seem too risky to pursue. [from DARPA website]
  - Realize advanced cutting-edge technologies
  - Address systems-level integration problems
- Have catalyzed advances in autonomy and changed the course of U.S. research/funding (for driving, robotics, manipulation).

2003-2007

2012-2015

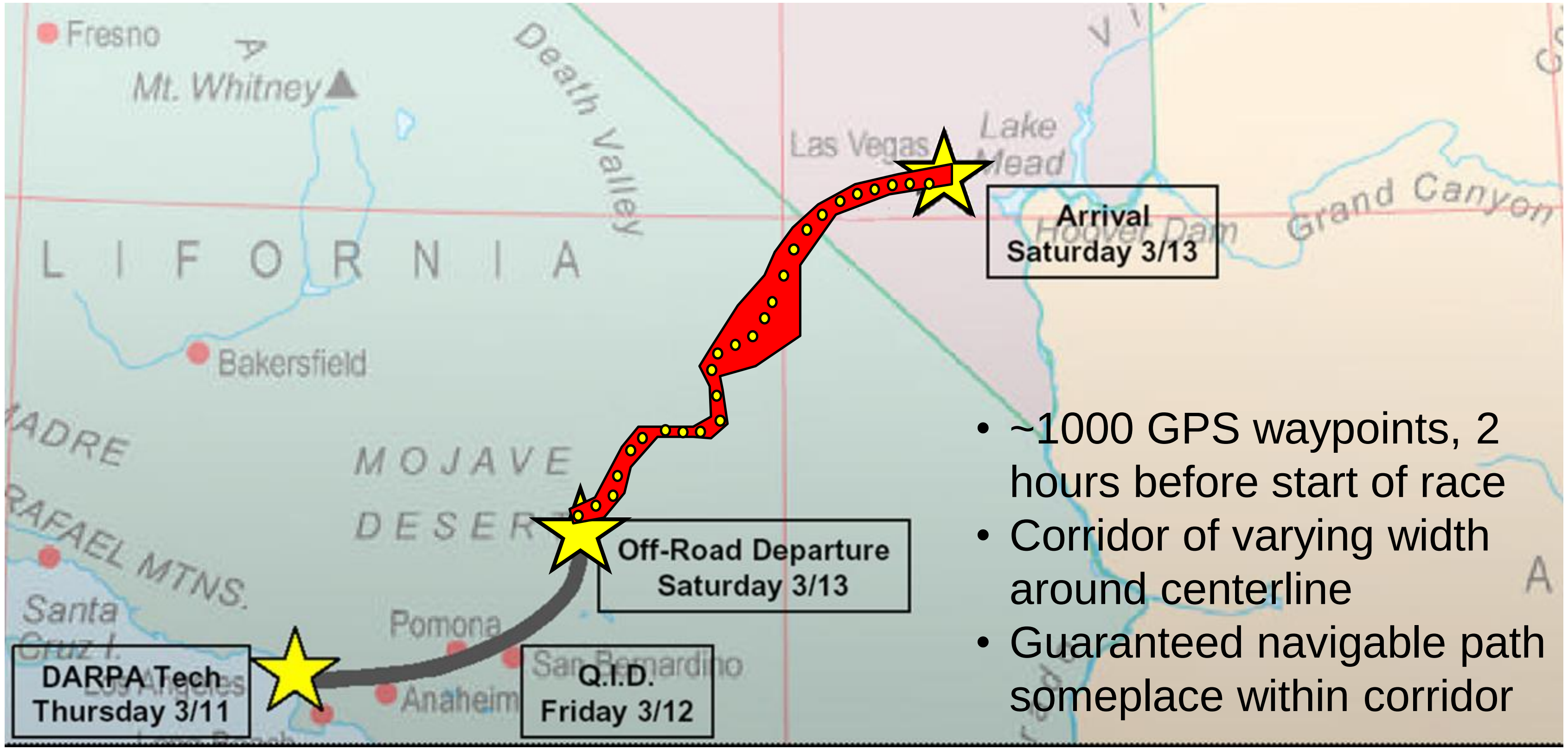
2019-2021



DARPA Grand Challenge #1:

Los Angeles to Las Vegas

in 10 Hours or Less, No Humans (or govt. money) Allowed

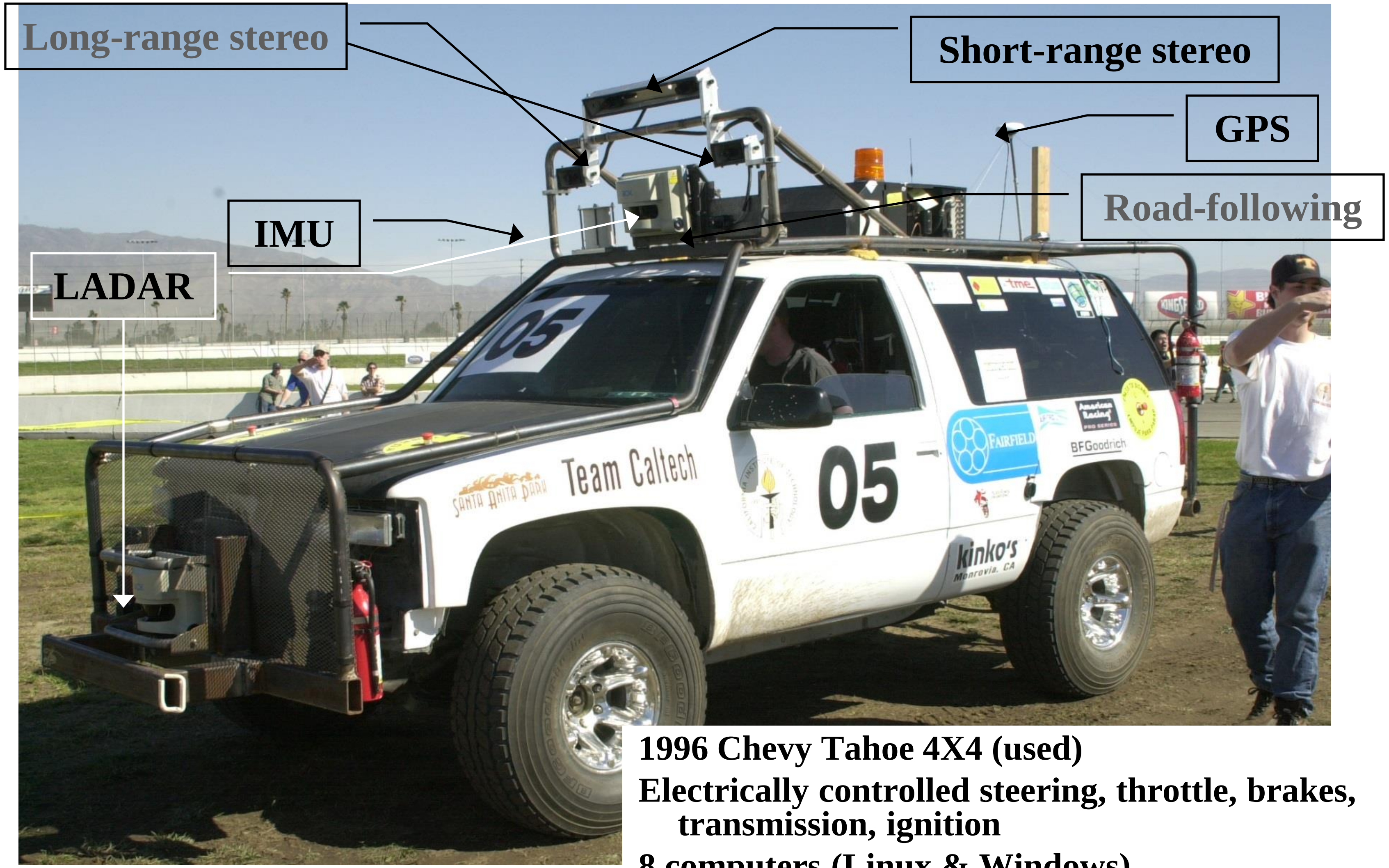


- ~1000 GPS waypoints, 2 hours before start of race
- Corridor of varying width around centerline
- Guaranteed navigable path someplace within corridor

- Vehicle must be completely autonomous; no remote control
- Vehicle avoid obstacles, including other vehicles.
- First vehicle to reach Las Vegas (~210 km) in <10 hours wins **$1M**

"Bob" & Team Caltech

(organized by Prof. Richard Murray)



1996 Chevy Tahoe 4X4 (used)

Electrically controlled steering, throttle, brakes, transmission, ignition

8 computers (Linux & Windows)

30 Sensors

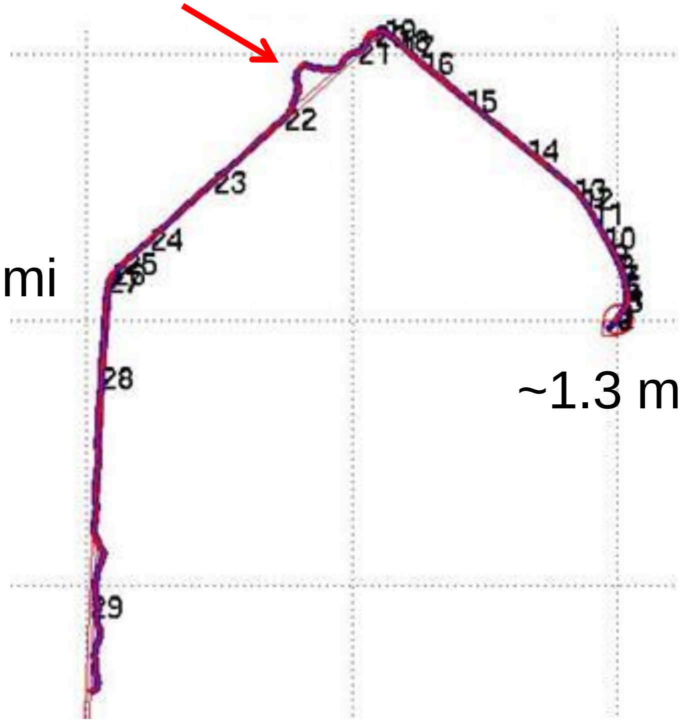
$500K, > 20,000 person-hours (25-55 undergrads)

Inside Bob

Team Caltech: Race Results

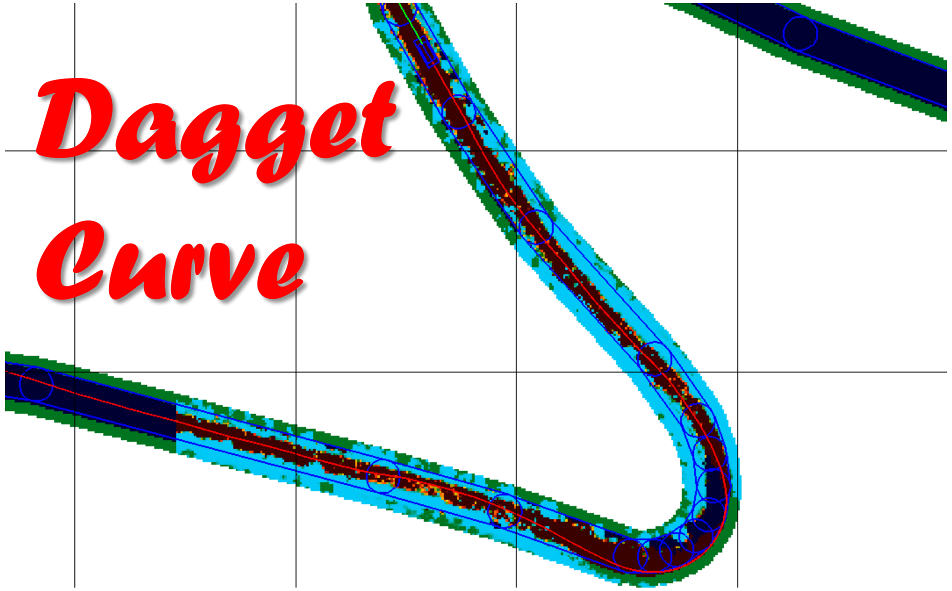
~1 mi: went off dirt road

~0.5 mi



~1.3 mi: Logical Error

Start



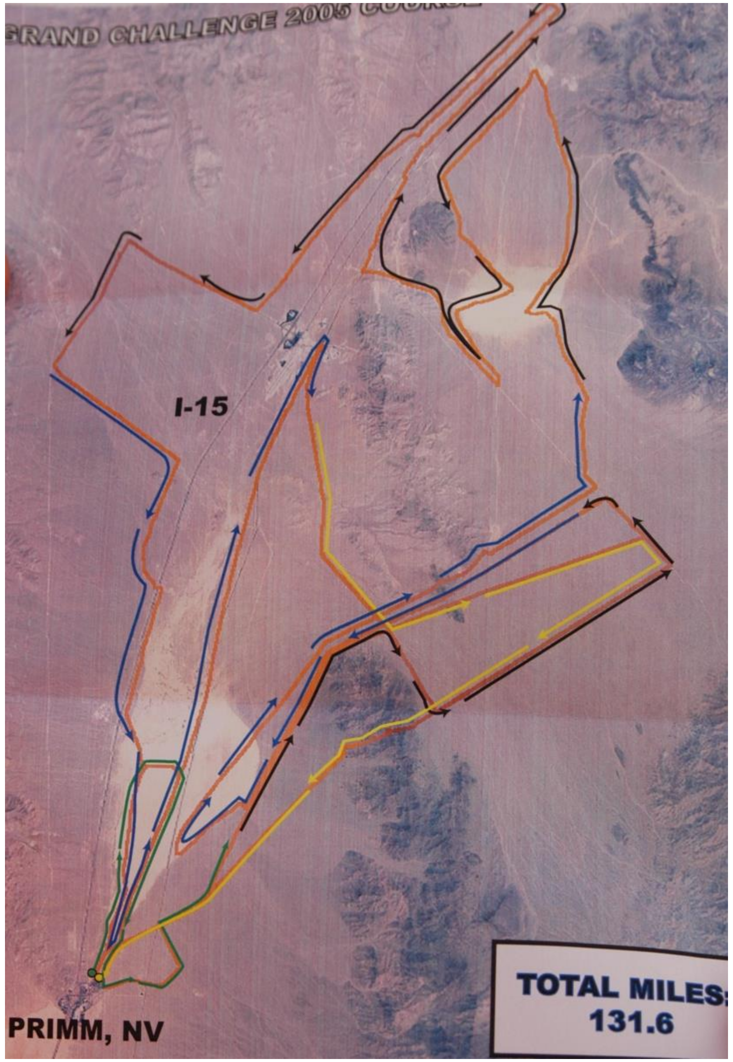
Results:

- 15 teams deemed “safe”
- Caltech placed 5th
- Caltech alums Golem Group placed 4th
- No team covered more than 5% of the distance
- Many important lessons

- A ***PR DISASTER*** for DARPA

DARPA Grand Challenge #2: The Mulligan

Race Day: 8 October 2005



- 10 teams funded at $1,000,000
- 198 teams submitted application video
- 118 teams selected for site visit
- 43 teams selected for qualifying event
- 21 qualified for final race
  - Team Caltech in 19th start
  - New Vehicle "Alice"

A **mulligan** is a second chance to perform an action, usually after the first chance went wrong through bad luck or a blunder.

Its best-known **meaning** is in **golf**, whereby a player is informally allowed to replay a stroke, even though this is against the formal rules of**golf**.

Alice Overview

Team Caltech

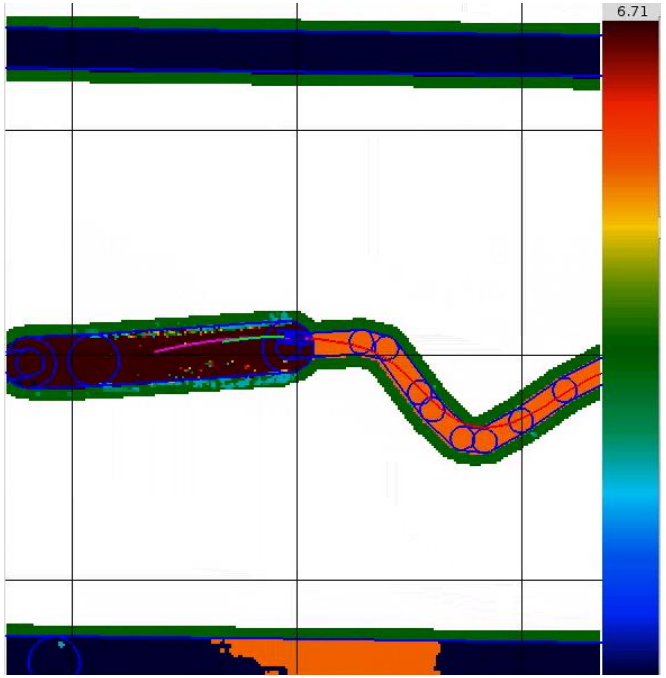
- 50 students worked on Alice over 1 year
- Course credit through CS/EE/ME 75
- Summer team: 20 SURFs + 10 others

Alice

- 2005 Ford E-350 Van
- Sportsmobile 4x4 offroad package
- 5 cameras: 2 stereo pairs + roadfinding
- 5 LADAR : long, medium*2, short, bumper
- 2 GPS units + 1 IMU (LN 200)
- 6 Dell 750 PowerEdge Servers
- 1 IBM Quad Core AMD64
- 1 Gb/s switched ethernet

Software

- 15 programs with ~50 execution threads
- FusionMapper: integrate all sensor data into a speed map for planning
- PlannerModule: optimization-based planning over a 10-20 second horizon



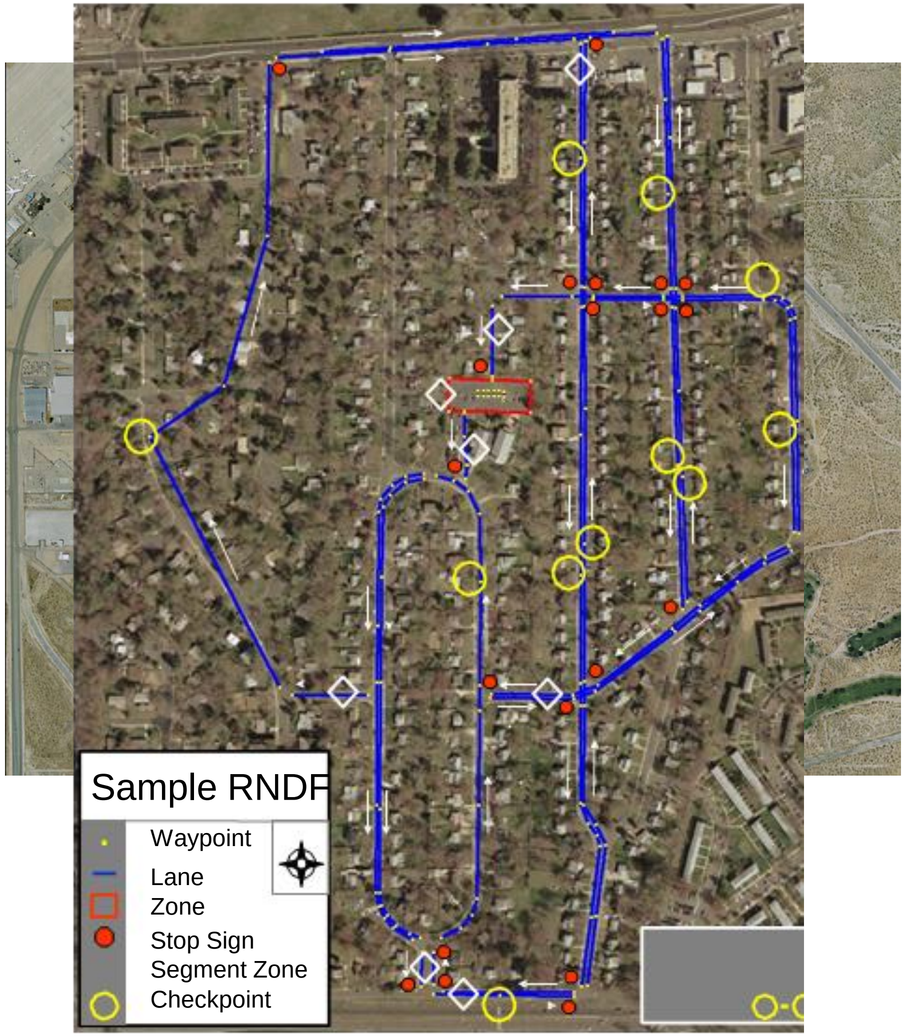
Alice's Media Debut

Alice’s Media Debut

Slashdot | DARPA GC Updates, 8 Oct 05. 2:45 pm

Most interesting one so far is … Caltech's Alice

DARPA Grand Challenge #3:
The Urban Challenge

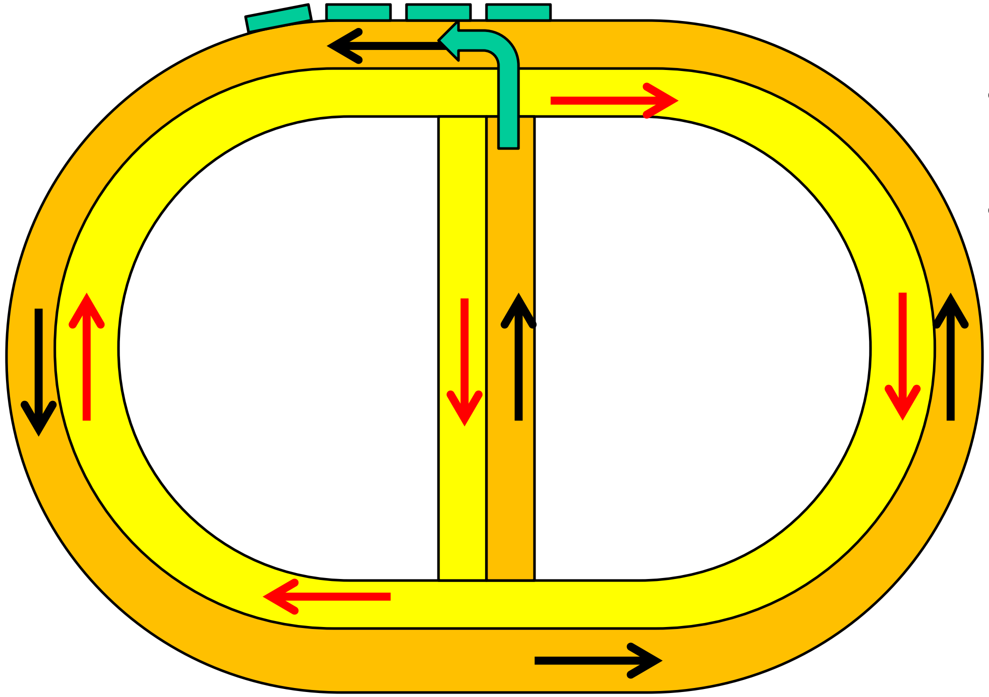


Autonomous Urban Driving

- Mock “city” in old air base
- 60 mile course in < 6 hours
- City streets, intersections
- Obey traffic rules with other robot cars and human operated cars)
- Pull around stopped vehicles
- Navigate in parking lots (with cars)
- U-turns, traffic merges, replanning
- **Prizes: $2M, $1M, $500K**

- 12 Teams given $1M budget

DARPA Grand Challenge #3: The Urban Challenge



Qualifying Round Necessary

- **Test A:** CIT does well
  - Open lane speed/safety
- **Test B:** CIT does well
  - Replanning and navigation
- **Test C:** Driving/merging in cross traffic
  - Human Driven Cars
  - "Safely" merge into traffic

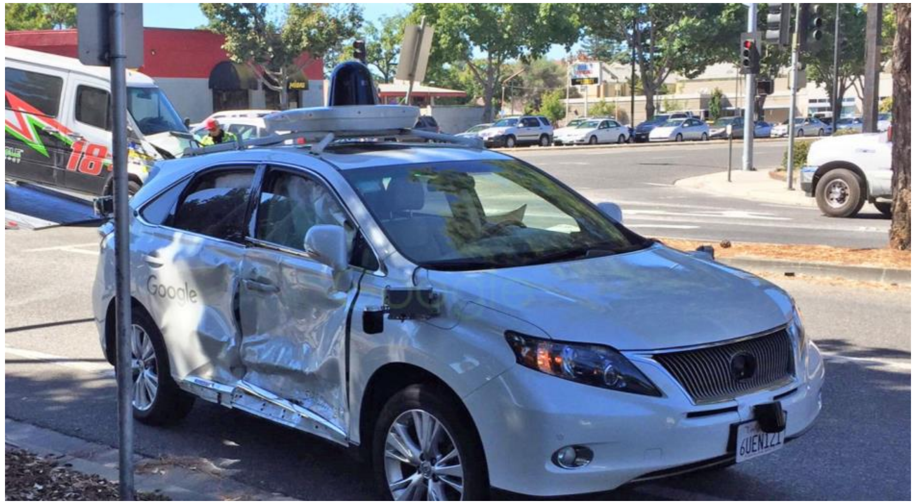
Alice's Waterloo

- Couldn't make sharp turn onto course (course didn't meet spec.s)
- Backed up into oncoming traffic
  - It was the right move
  - DARPA didn't like it ☹

Summary: DARPA “Grand” Challenges

Proved robots can operate in real world

- Origin of ***key*** driverless car efforts

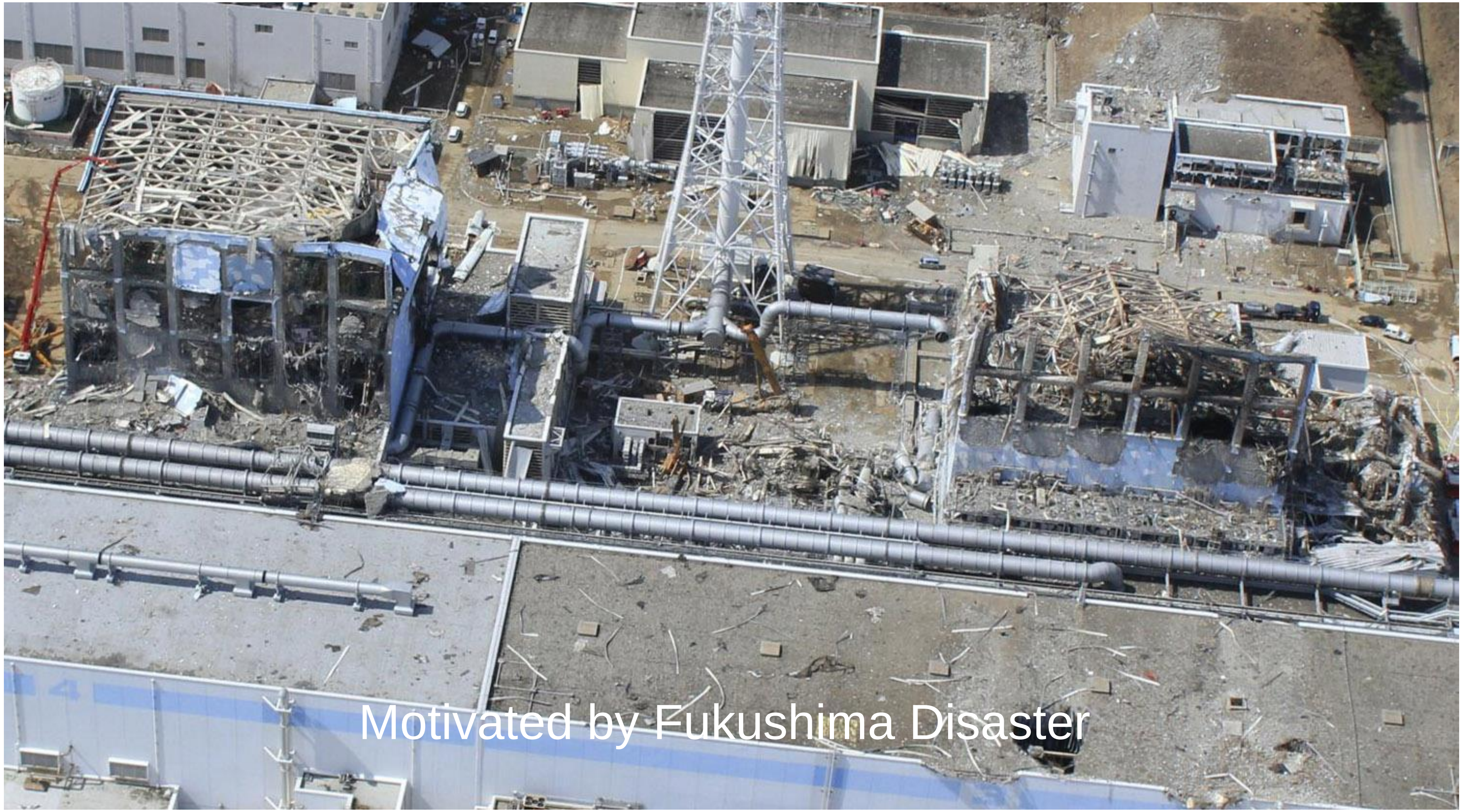


GREAT **application for autonomy**

- Required *system level* approach
- *Feedback* is everywhere
- Required new levels of autonomy: perception, decision making

GREAT **educational project**

The DARPA Robotics Challenge (DRC)
(www.theroboticschallenge.org)



WHY THE DARPA ROBOTICS CHALLENGE TASKS?

The story of the DARPA Robotics Challenge (DRC) begins on March 12, 2011, the day after the Tohoku, Japan earthquake and tsunami struck the Fukushima-Daiichi nuclear power plant. On that day, a team of plant workers set out to enter the darkened reactor buildings and manually vent accumulated hydrogen to the atmosphere. Unfortunately, the vent team soon encountered the maximum level of radiation allowed for humans and had to turn back. In the days that followed, with the vents still closed, hydrogen built up in each of three reactor buildings, fueling explosions that extensively damaged the facility, contaminated the environment and drastically complicated stabilization and remediation of the site.

At Fukushima, having a robot with the ability to open valves to vent the reactor buildings might have made all the difference. But to open a valve, a robot first has to be able to get to it. The DRC tasks test some of the mobility, dexterity, manipulation and perception skills a robot needs to be effective in disaster response.

DARPA

ROBOTICS CHALLENGE 2013 TRIALS

#DARPADRC

The DARPA Robotics Challenge (DRC)
(www.theroboticschallenge.org)

JPL-Caltech
DARPA-ARM
Team +
dozens of
others

Top 6
teams

$

Prelim
12/2013

Top 8
get $1M

Finals
06/2015

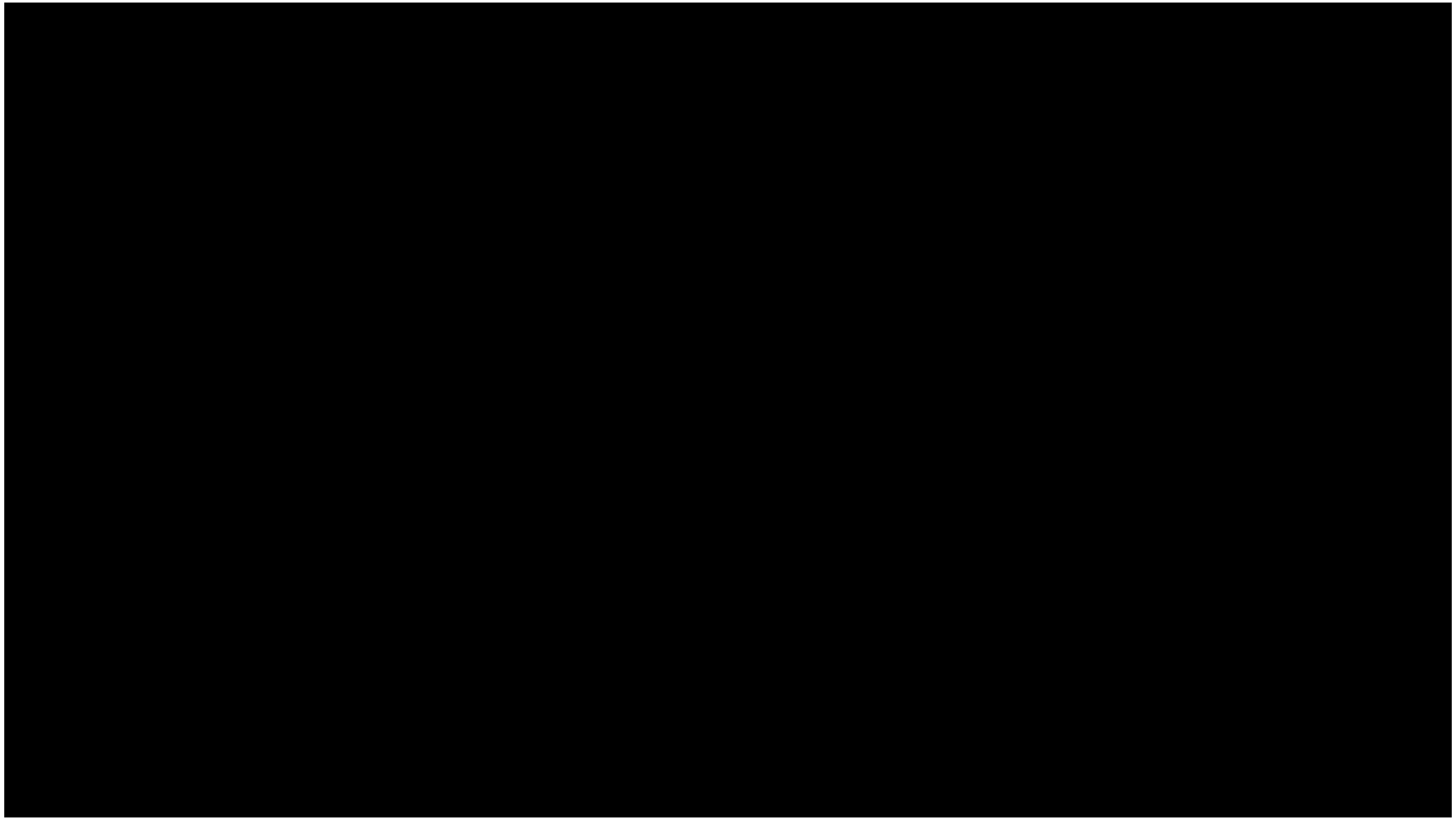
(Pomona
Fairgrounds)

JPL (B. Kennedy)
+ 9 others

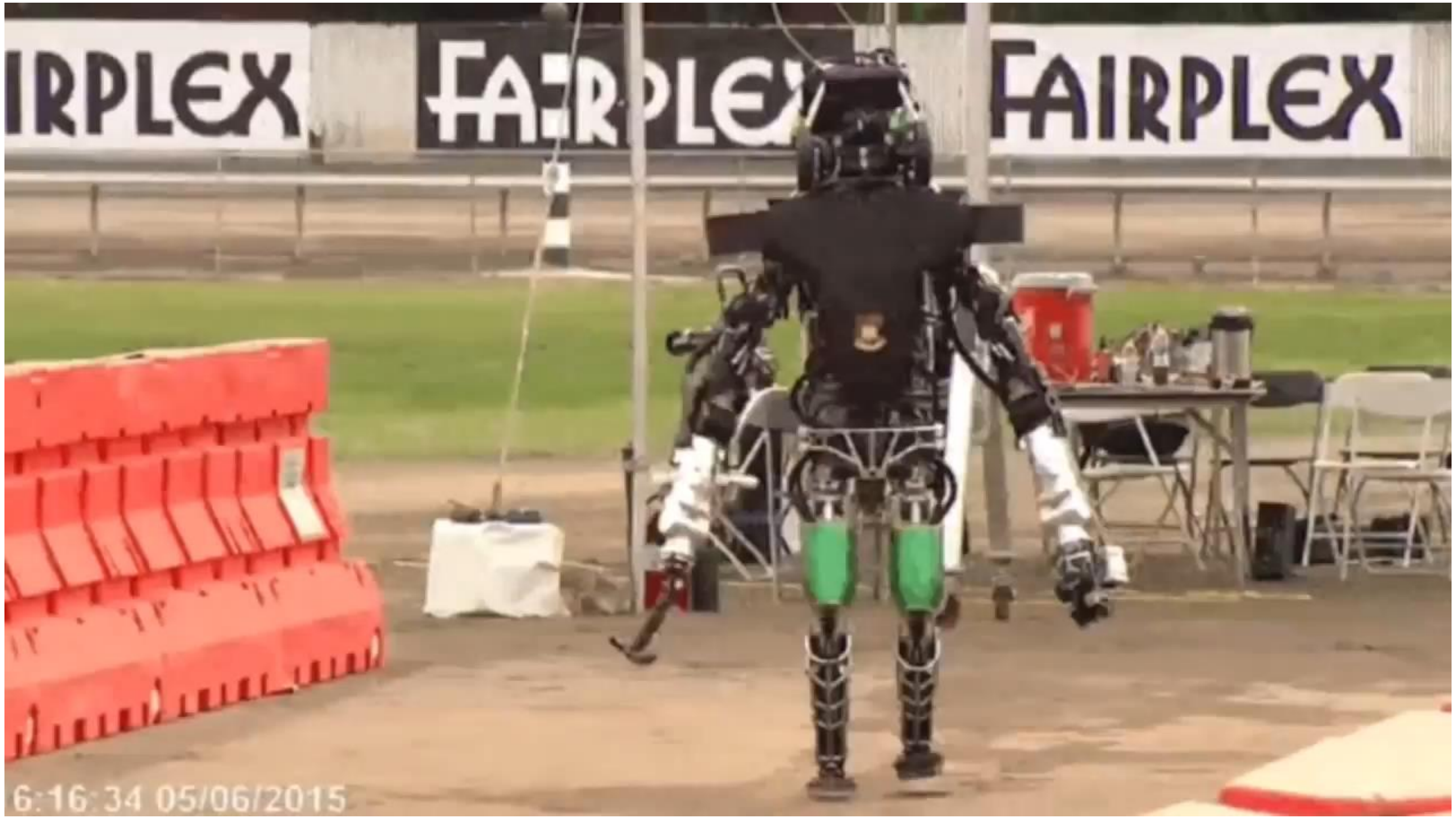
Top 6
teams

$

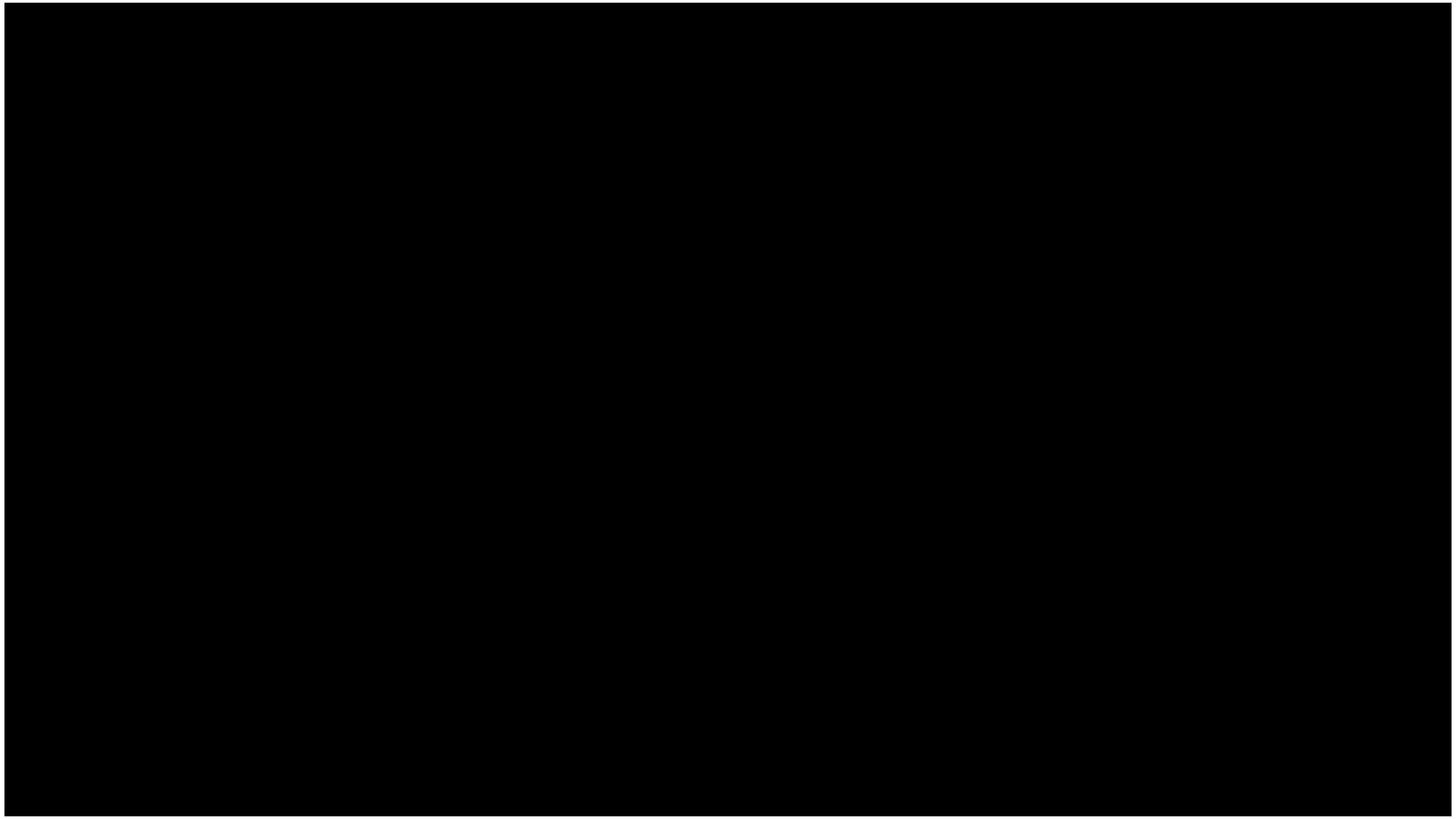
The DARPA Robotics Challenge Finals
(June 2015)



https://www.youtube.com/watch?v=g0TaYhjpOfo

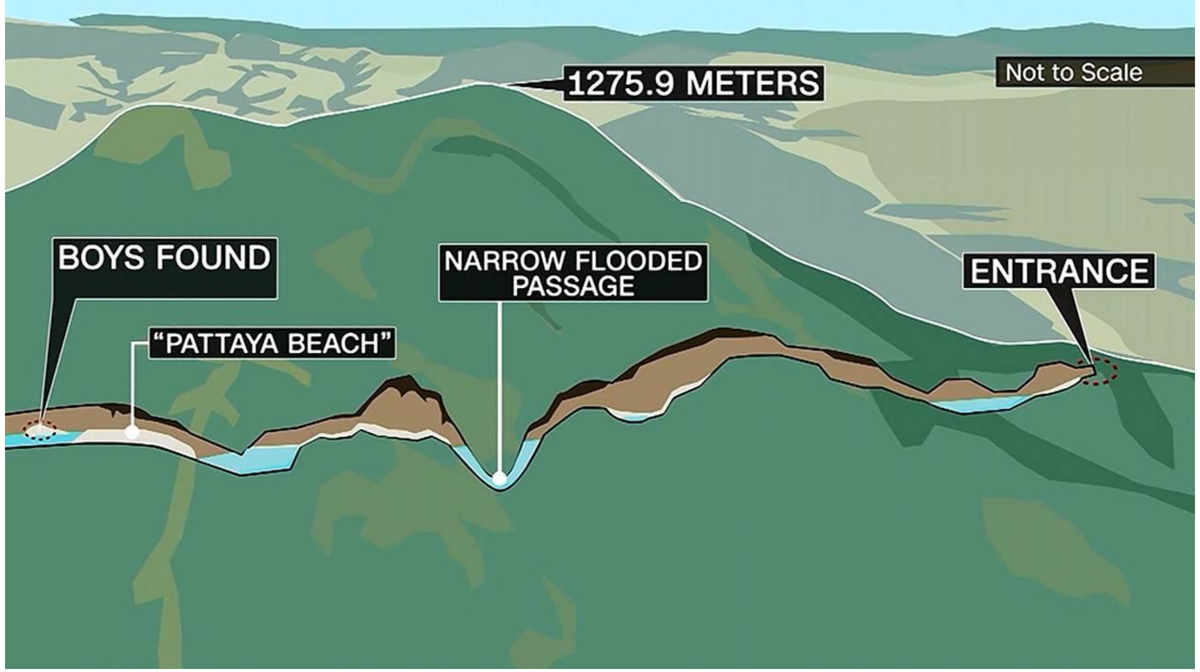


The DARPA Robotics Challenge (DRC)
(www.theroboticschallenge.org)



DARPA SubTerranean (SubT) Challenge





1275.9 METERS
Not to Scale
BOYS FOUND
"PATTAYA BEACH"
NARROW FLOODED PASSAGE
ENTRANCE

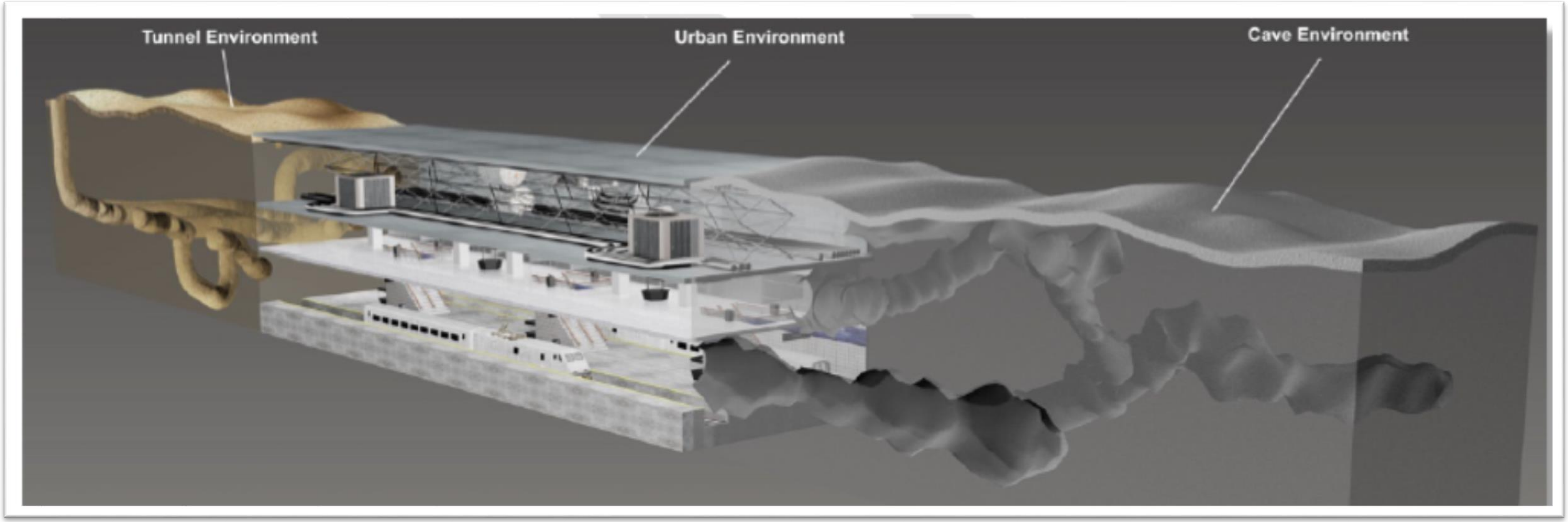
The DARPA Subterranean Challenge

(www.Subtchallenge.com)

Objective: Revolutionize autonomy/technologies needed for exploring extreme environments (tunnel, cave, lava tubes, pit craters, etc.) using robot teams.

Scope: 6 teams selected worldwide (DARPA awarded each ~$4.5M/3yrs).

Duration: 3 years with 4 competitions and practice events.



Scoring/metrics

- Positive
  - Complete the mission
  - Geo-locate objects (1m error in 1Km)
  - Map the environment (10cm resolution)
  - Network latency (1s per 500m path length)
  - Endurance
- Negative
  - Human intervention

Rules/details

- Entrance/exit is known
- No humans can enter the tunnel
- One human operator. But, with very high penalty
- No manipulation is required
- The length of tunnel, size and types of obstacles will be announced ahead of the competition.
- Narrow passages: different sizes – minimum human crawlable
  - Hvac vents
  - Storm drain

Very Aggressive Schedule

Project Started
Sep 1, 2018

November
JPL Tests in Mueller Tunnel

DARPA Single-robot Qualification
Dec 21, 2018

February
JPL Tests at Eagle Mine

DARPA SubT Integration Exercise (STIX)
April

May
DARPA Qualification round

Pittsbugh, PA
Coal Mine

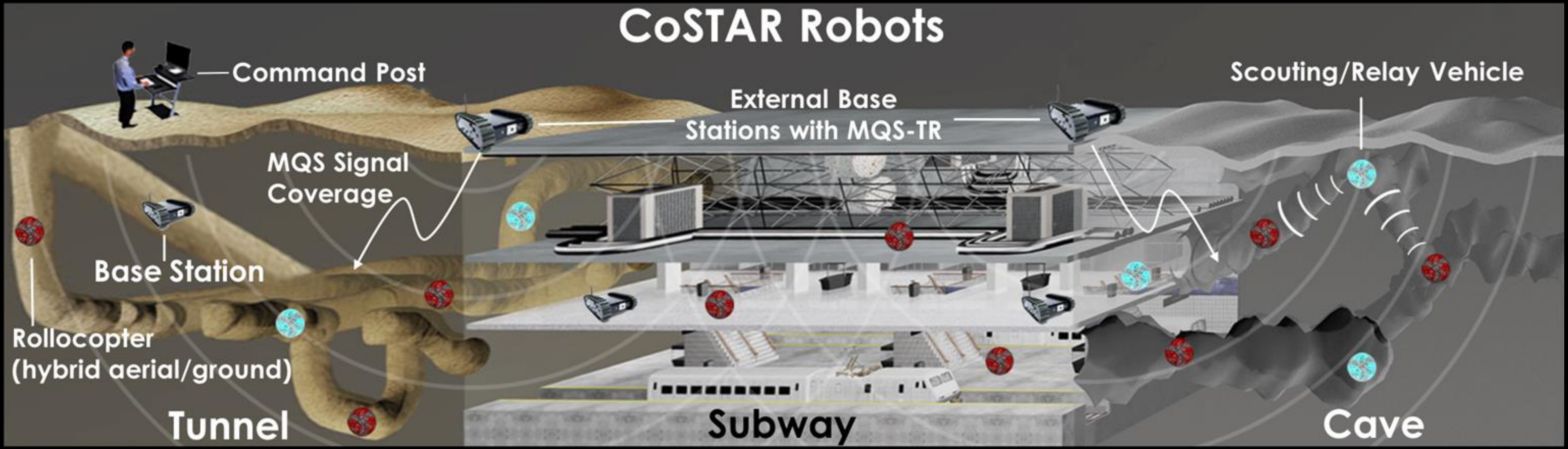
DARPA Tunnel Competition
August 2019

YEAR 2 & 3
void/submerged Caves
(multi km-long)

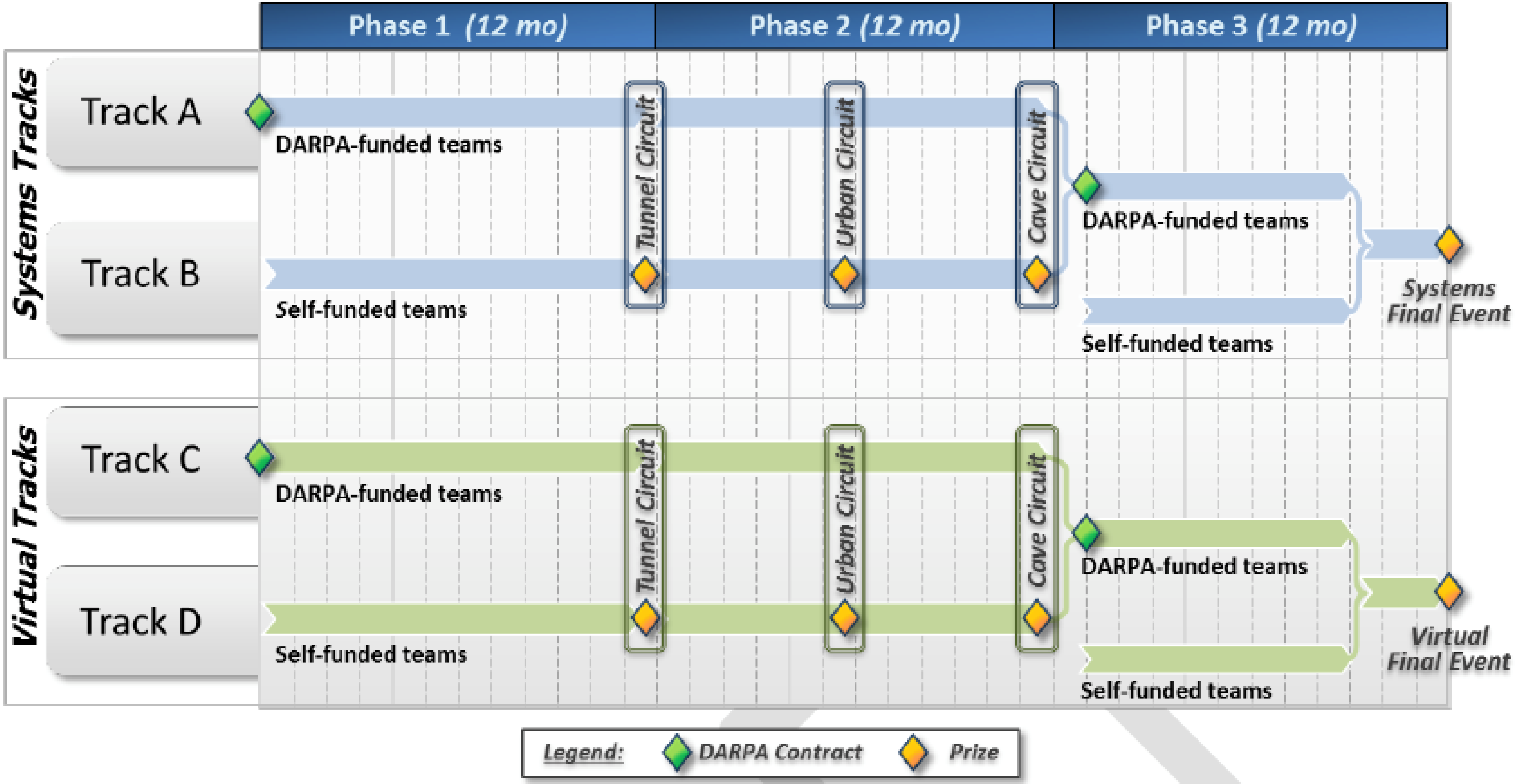
CoSTAR-bots

Collaborative SubTerranean Autonomous Resilient robots

subt.jpl.nasa.gov

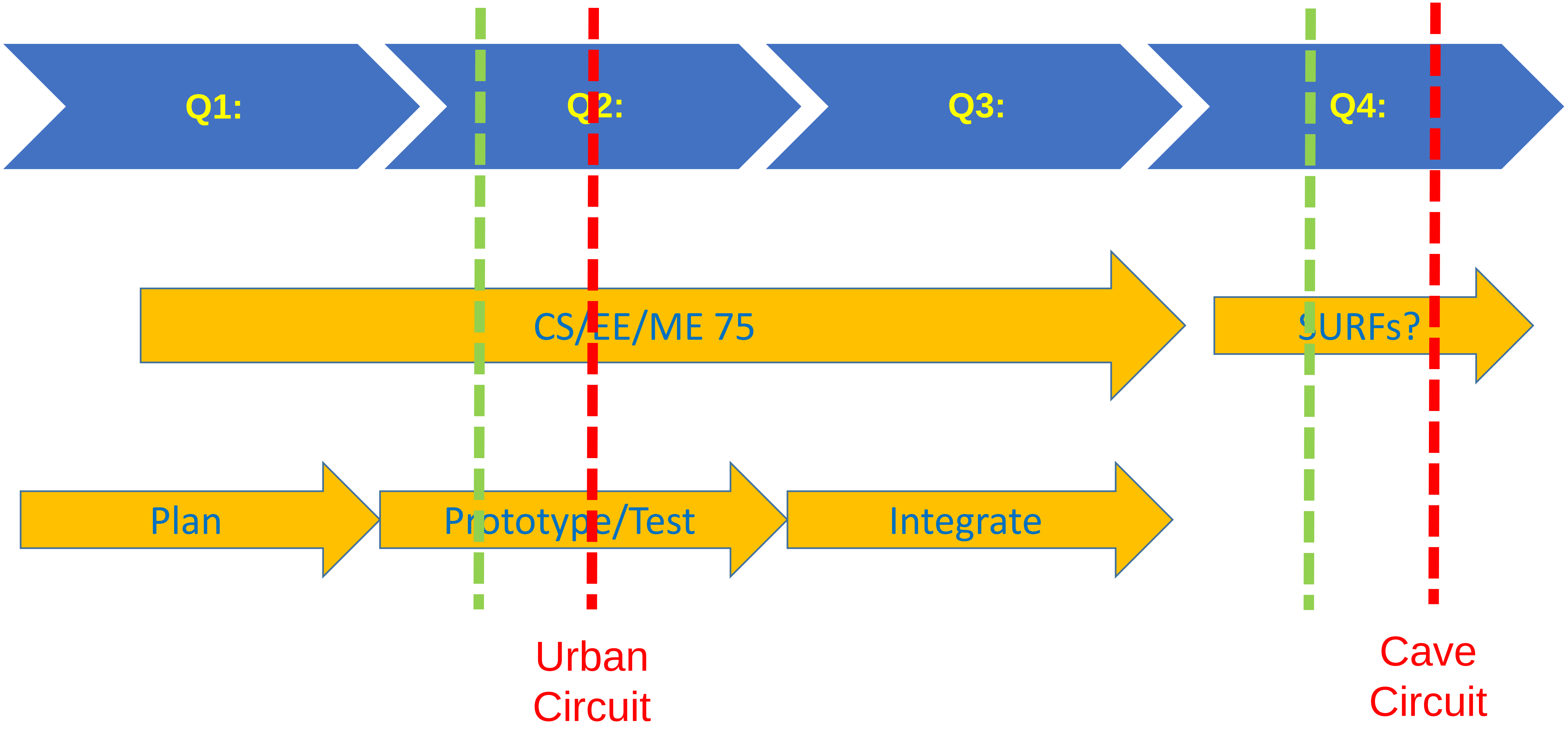


Timeline



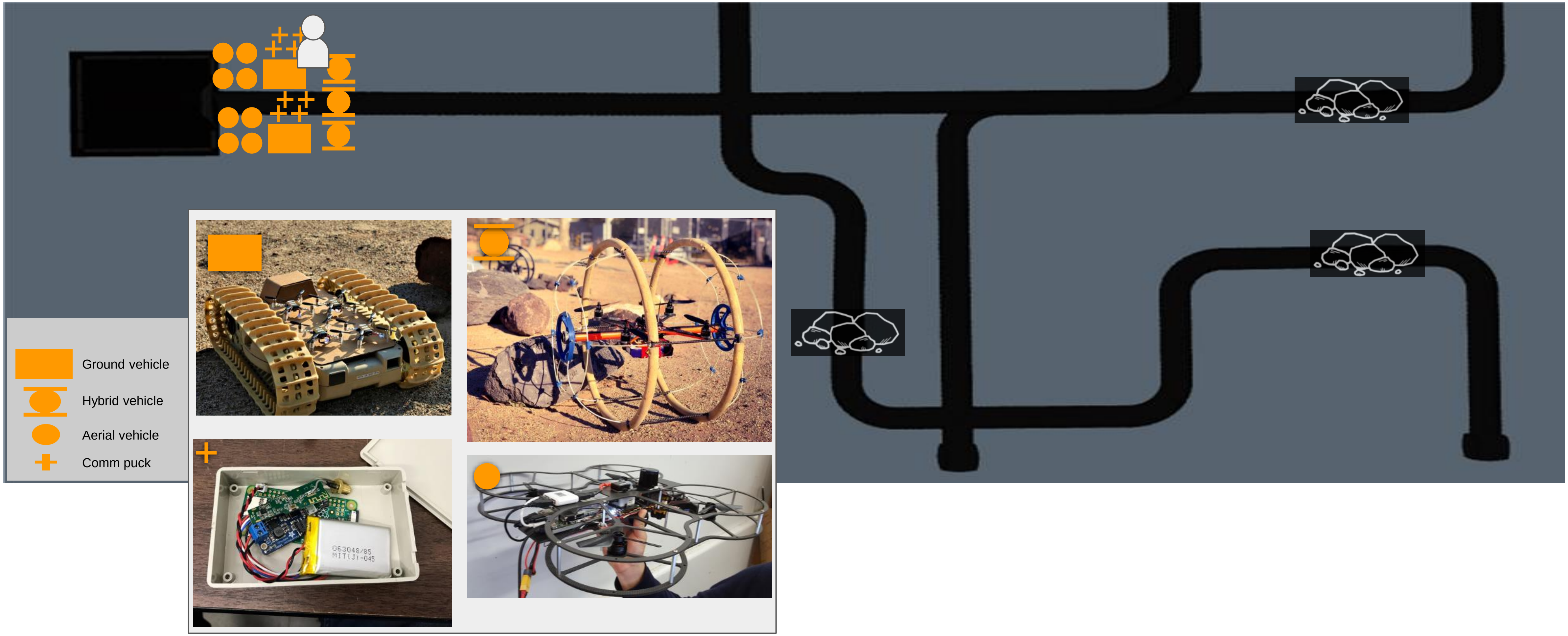
Phase 1 (12 mo)
Phase 2 (12 mo)
Phase 3 (12 mo)
Systems Tracks
Track A
Track B
DARPA-funded teams
Self-funded teams
Tunnel Circuit
Urban Circuit
Cave Circuit
DARPA-funded teams
Self-funded teams
Systems Final Event
Virtual Tracks
Track C
Track D
DARPA-funded teams
Self-funded teams
Tunnel Circuit
Urban Circuit
Cave Circuit
DARPA-funded teams
Self-funded teams
Virtual Final Event
Legend: DARPA Contract Prize

CS/EE/ME 75(b)


Q1:
Q2:
Q3:
Q4:
CS/EE/ME 75
SURFs?
Plan
Prototype/Test
Integrate
Urban Circuit
Cave Circuit

System Design Overview

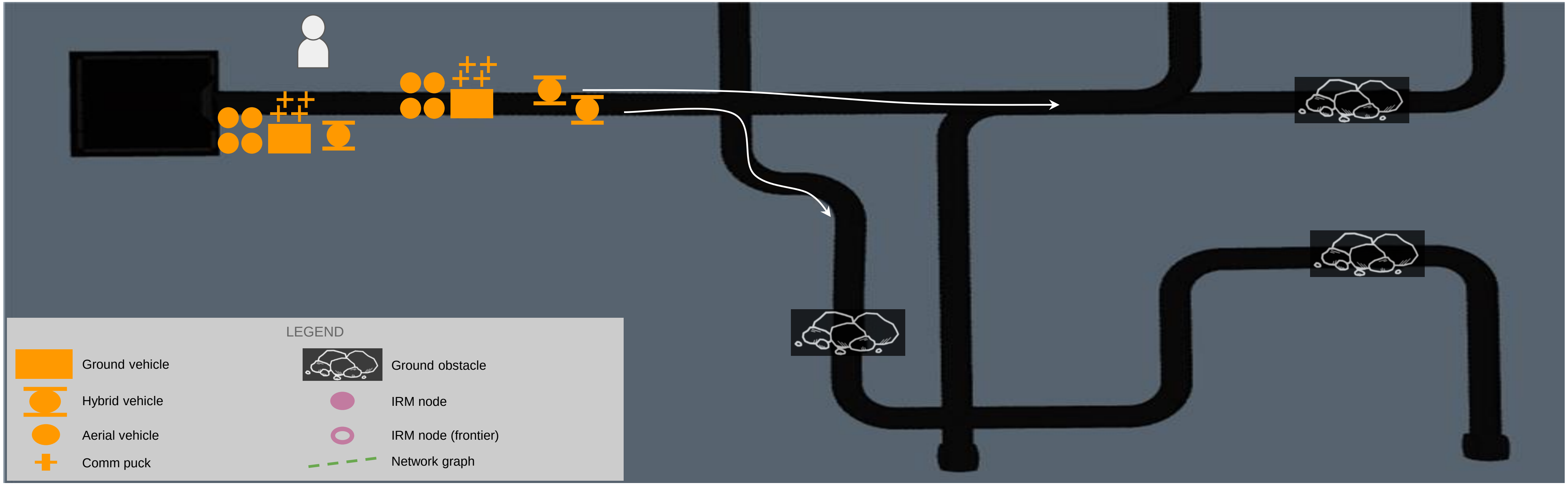
Simplified CONOPS



Begin with a heterogeneous set of platforms at the base station

System Design Overview

Simplified CONOPS

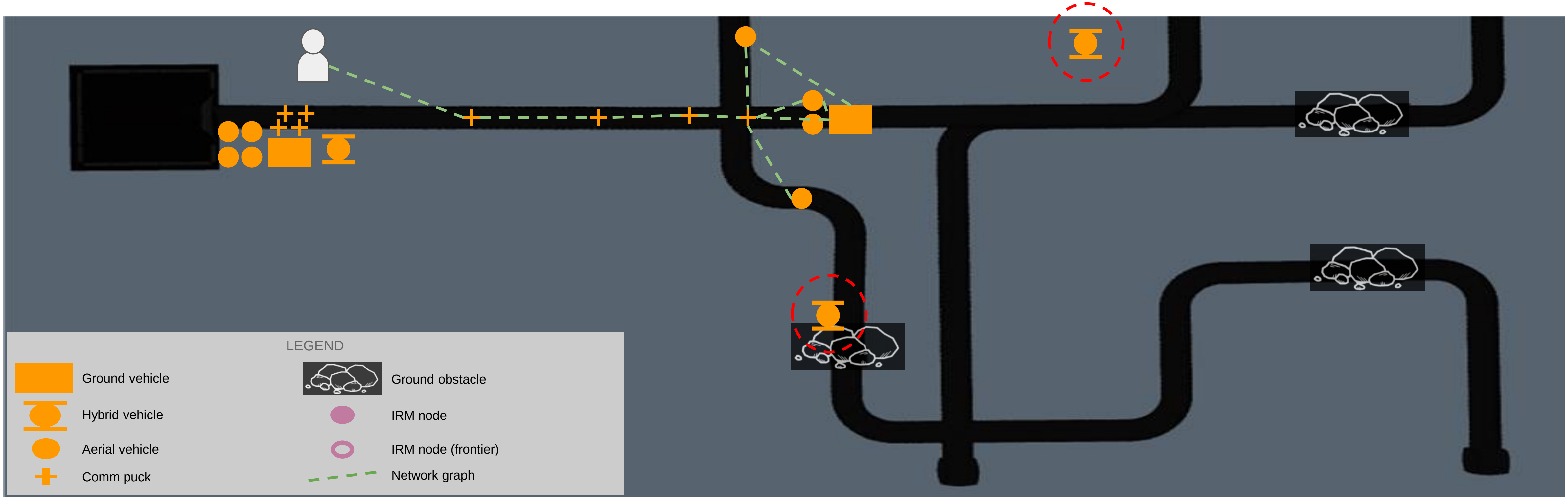


Thrust 1: *Explore the frontier* with a **vanguard** of hybrid ground/air vehicles with highly capable sensing for mapping and artifact detection.

Also: Ground vehicle carries in smaller platforms for future use.

System Design Overview

Simplified CONOPS

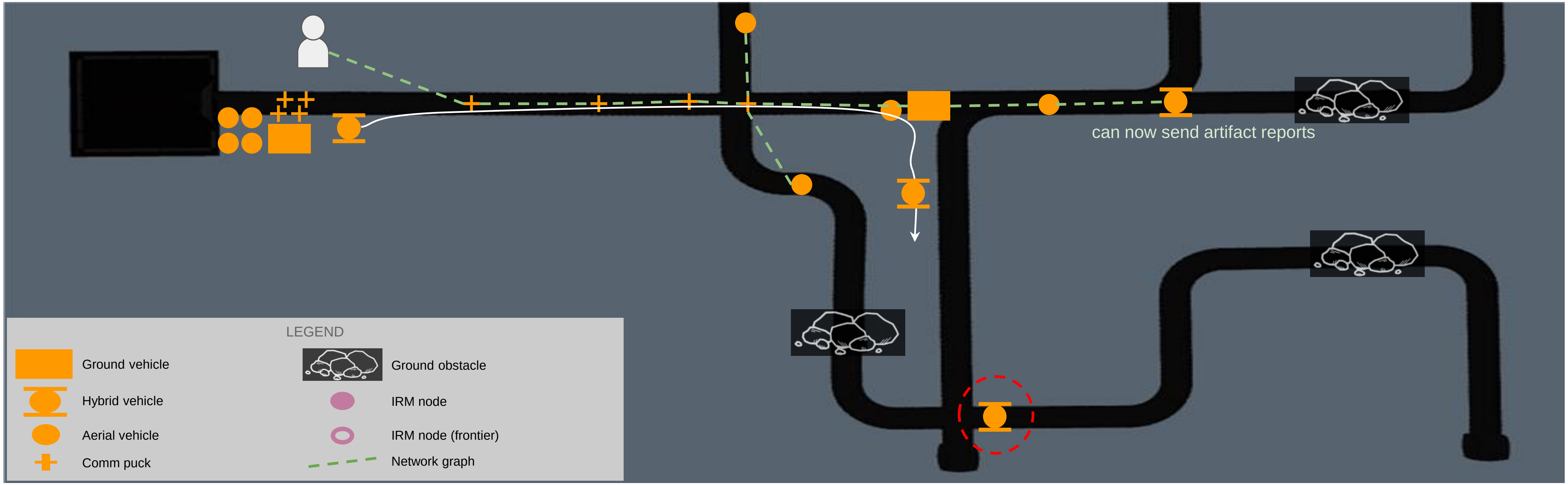


Thrust 2: *Extend the reach of the human supervisor* by tasking robots to create and propagate a **mesh** network for communications.

Ground robot deploys communication pucks, and aerial scouts can self-deploy for either comms relays or added sensing—as directed by either Supervisor or Autonomy.

System Design Overview

Simplified CONOPS



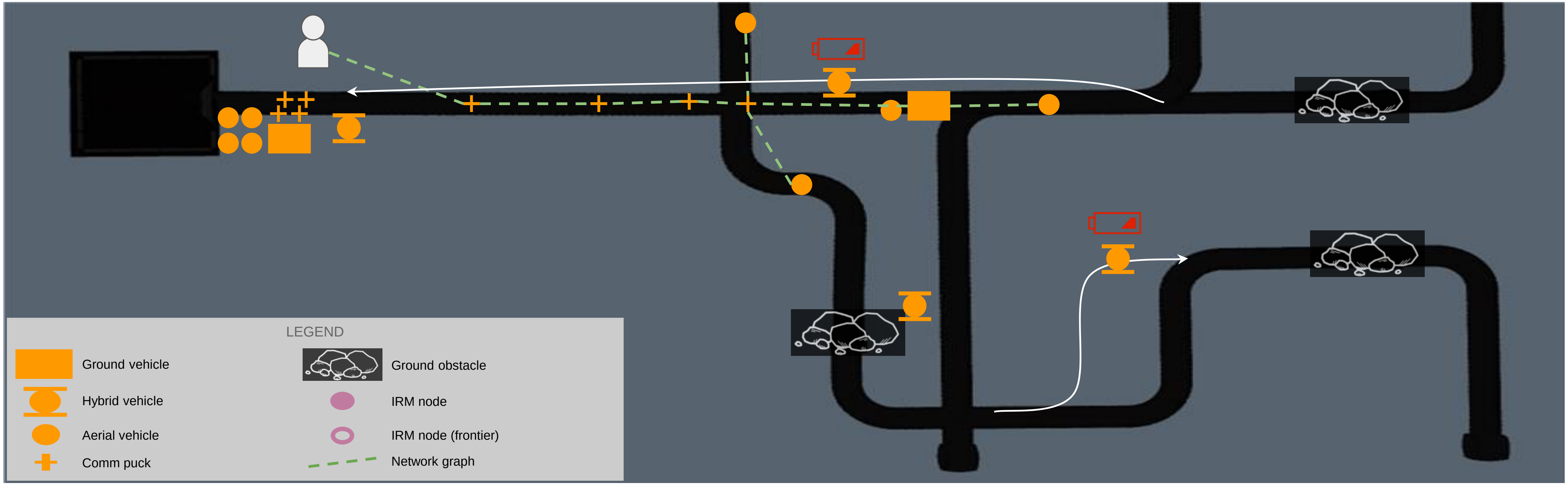
Continue simultaneous frontier exploration and mesh building.

Deploy further vehicles at the discretion of Supervisor.

Supervisor can re-task or re-position any vehicle in the mesh network.

System Design Overview

Simplified CONOPS

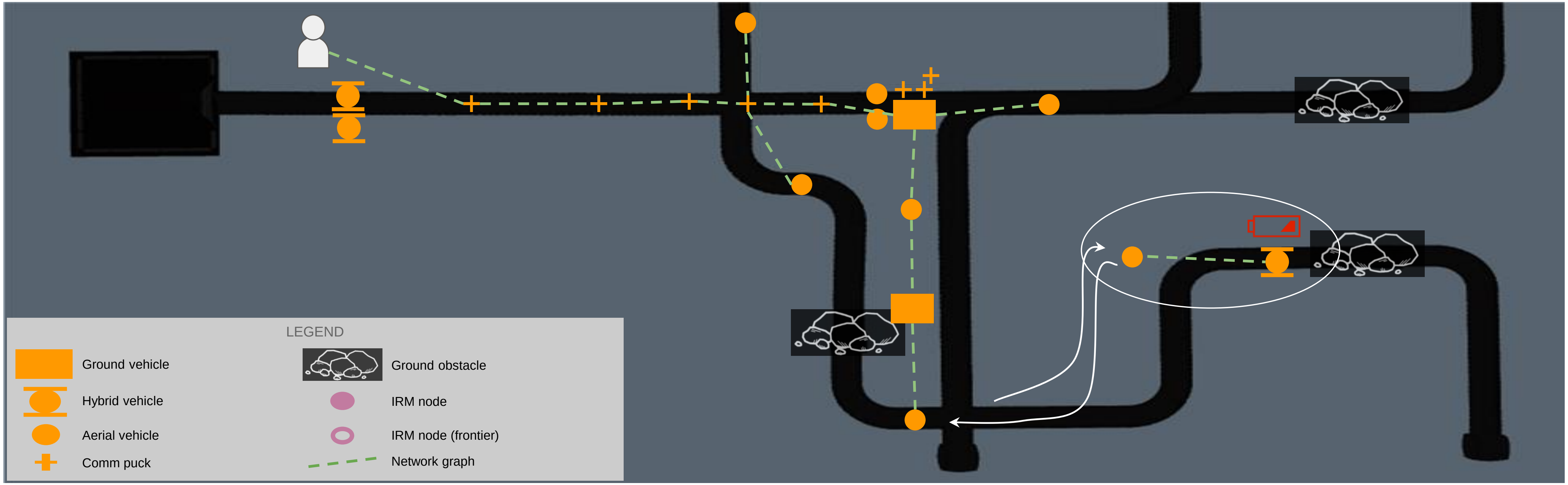


Vehicles can be configured (by Supervisor or Autonomy) for one of the following behaviors near battery depletion:

1. Return to Base—battery swap possible at base
2. Return to Mesh—ensure the data are exfiltrated, then continue
3. Explore Frontier—continue as is, aggressively prioritizing coverage

System Design Overview

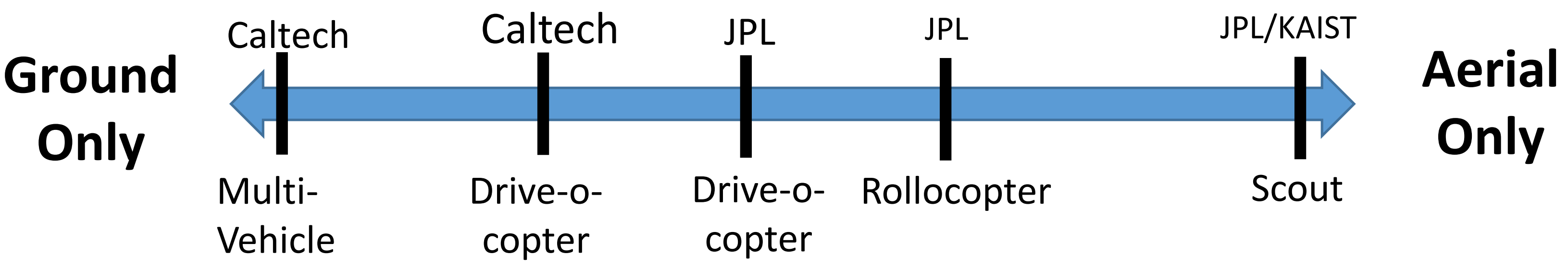
Simplified CONOPS

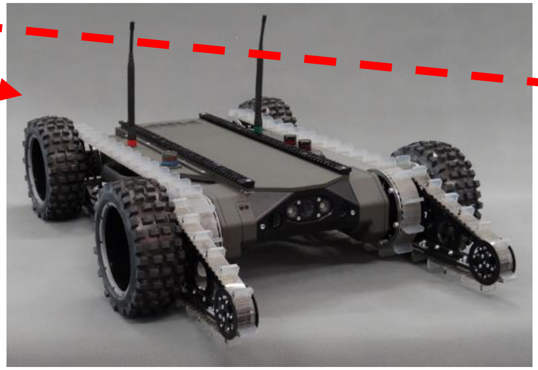


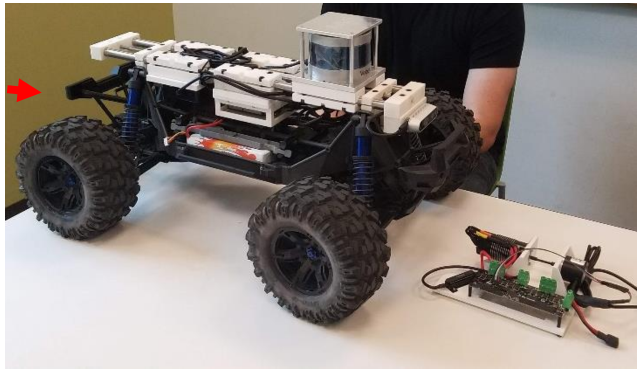
To enable vehicles to continue exploration beyond communication range, agents may be assigned to serve as **data mules**.

These behaviors continue until the entire course is explored.

Cross-Domain Mobility







Mobility: 4-wheel Skid Steer

- Not good in sandy terrains
- Poor on stairs

Roles:

- Towing vehicle
- compute node
- MQS/IMU node

Mobility: Tracks

- Stairs
- Handles poor terrain

Roles:

- Light towing vehicle
- Mapper
- Stair Access

Mobility: Ackerman 4WD

- tunnels, urban circuit

Roles:

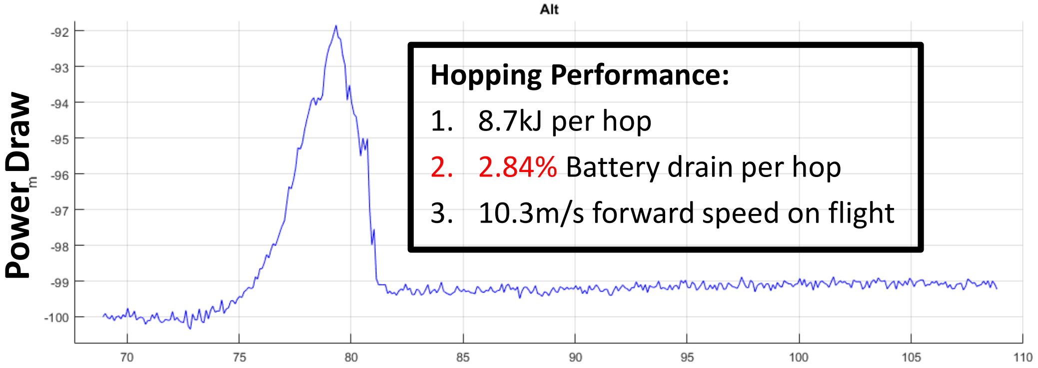
- “Scout-like” exploring vehicle
- Mapping/Detection
- Fast vehicle on moderate terrain

Drive-o-Copter

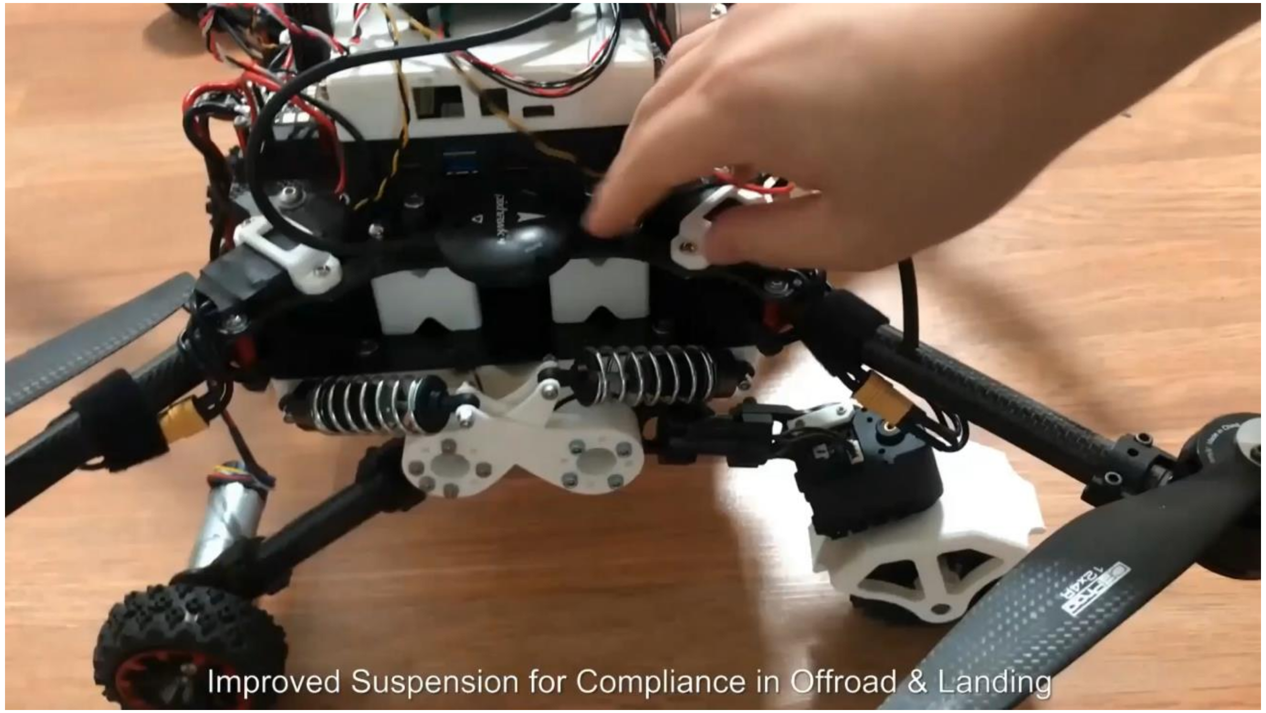
Principle: primarily a driving machine which can "hop" or fly as needed

- Solves dust problem by ground transit
- "Easy-Swap" chasses
- **ConOps:** 8 km travel, 12 hops, 1 hour autonomous operation

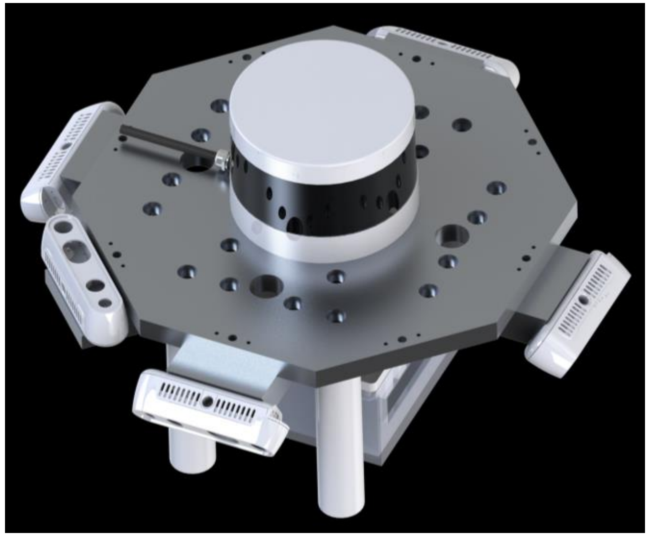
4WD "Swerve" Steer version



Hopping to a higher-level Platform

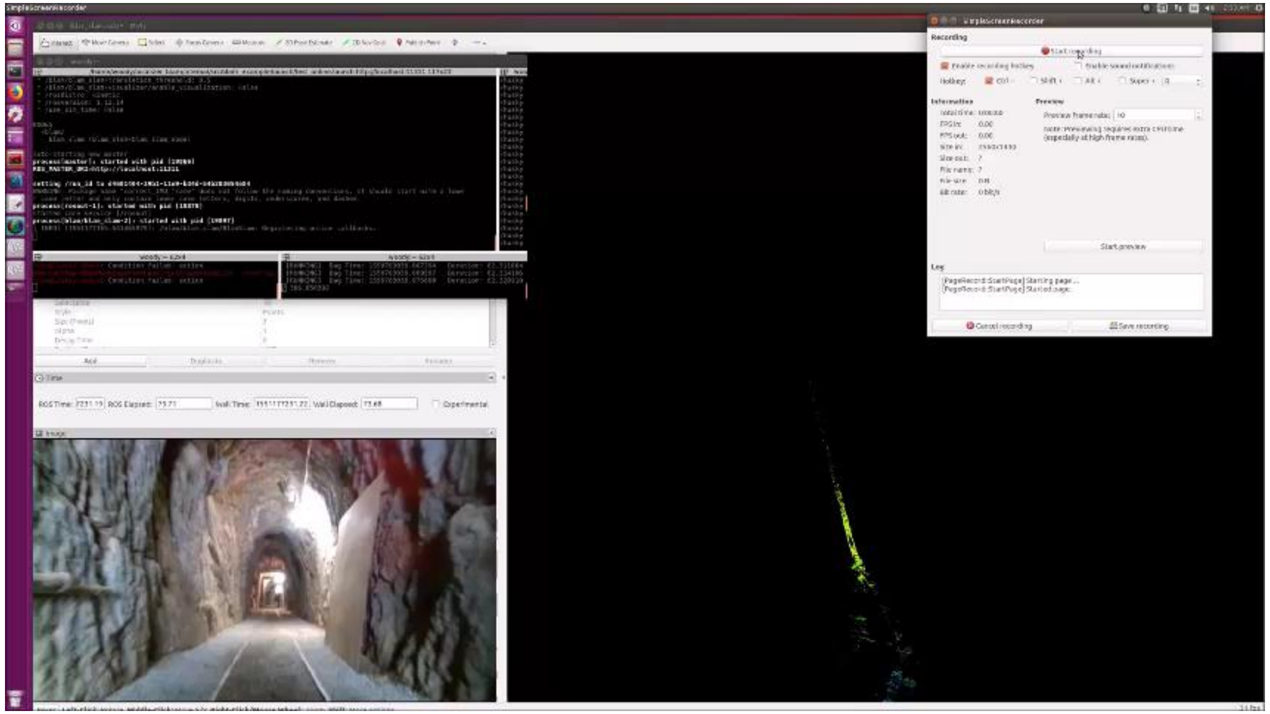


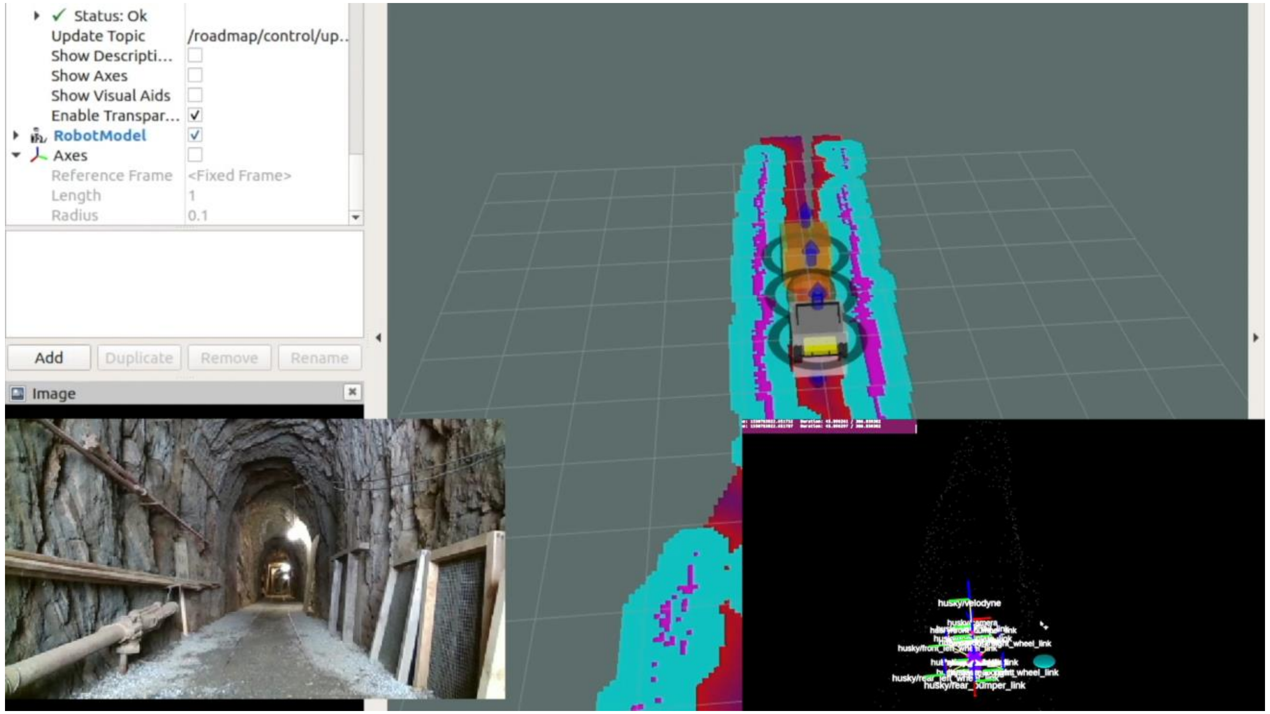
Modular Cross-Platform Mobility Autonomy



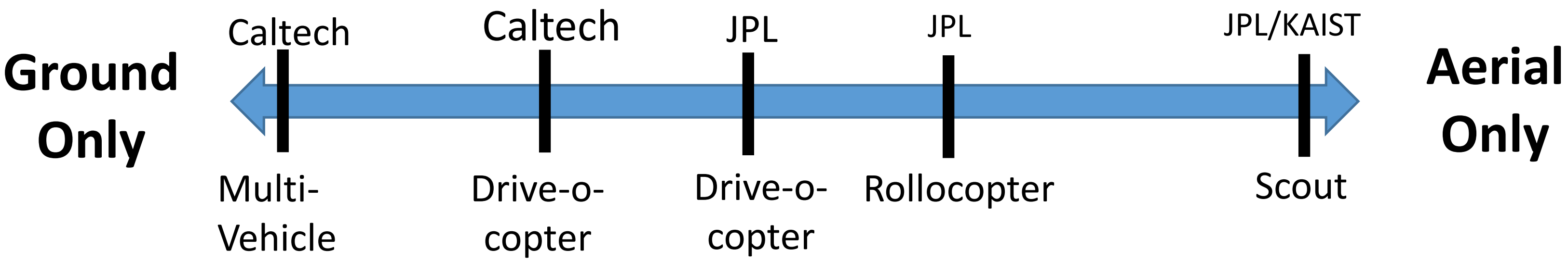
Autonomy/Perception Package" for ground vehicles.

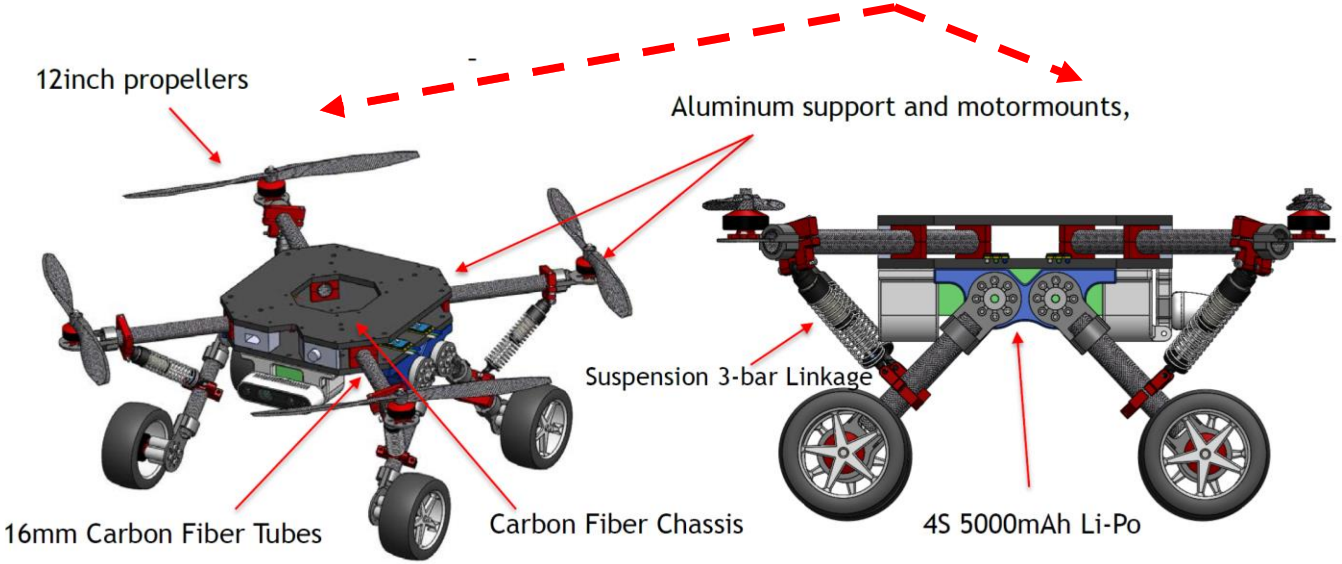
- Velodyne VLP-16, Intel RealSense, IMU, NUC computer,
- VIO, OrbSLAM BLAM, OctoMap, ...





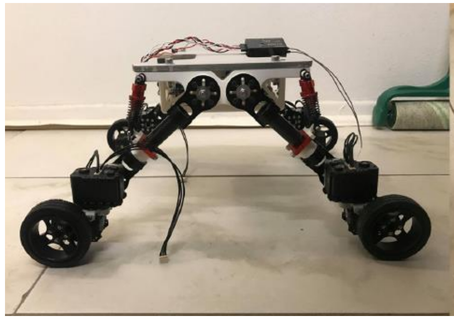
Cross-Domain Mobility

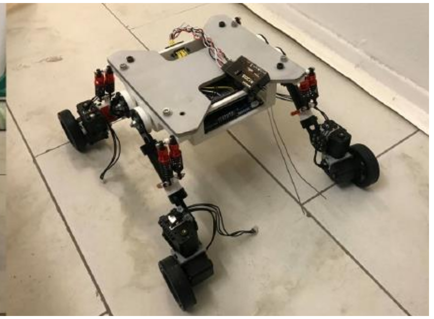




Principle: primarily a driving machine which can "hop" or fly up stairs as needed.

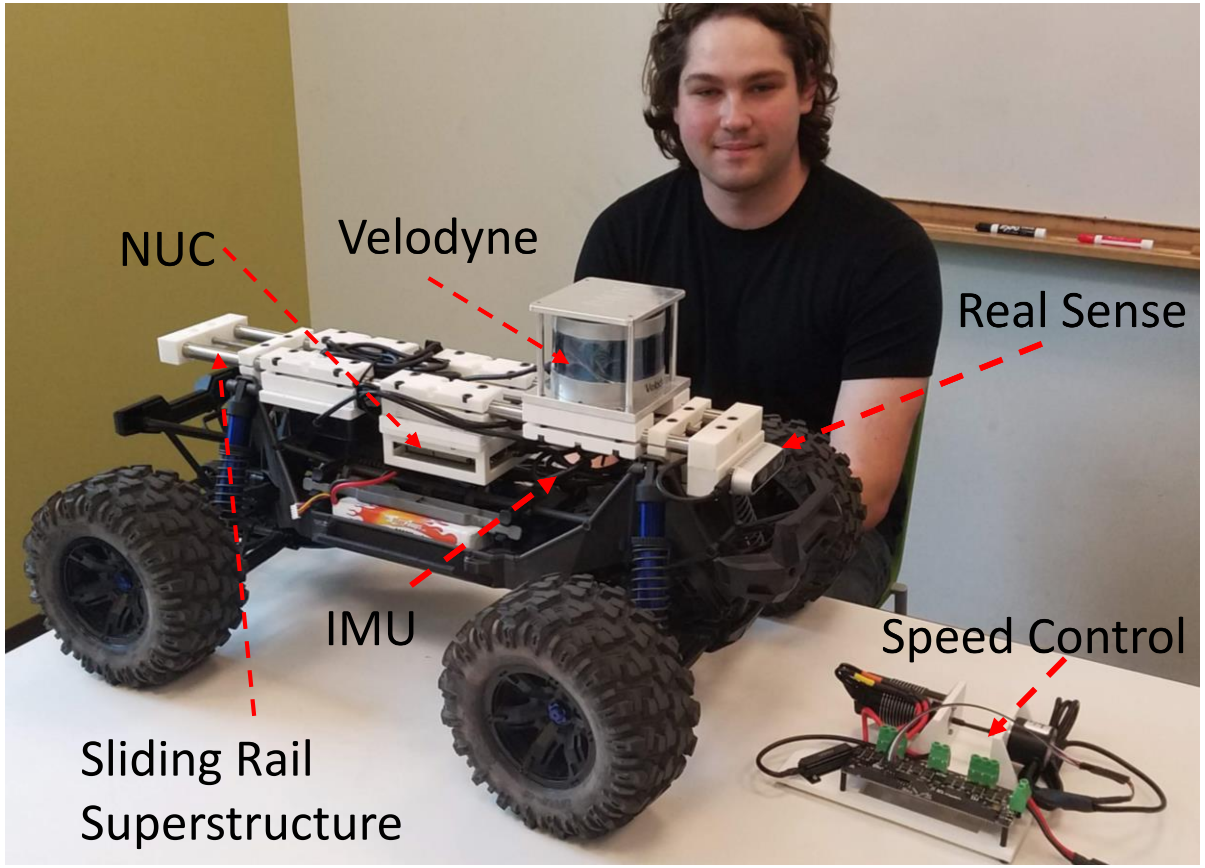
- Multiple drive configurations
- "Easy-Swap" chasses





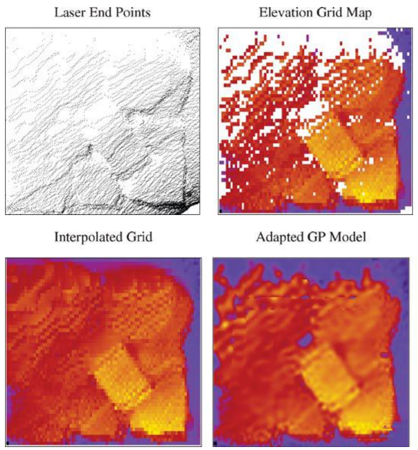
Automated RC Cars

(and associated research)

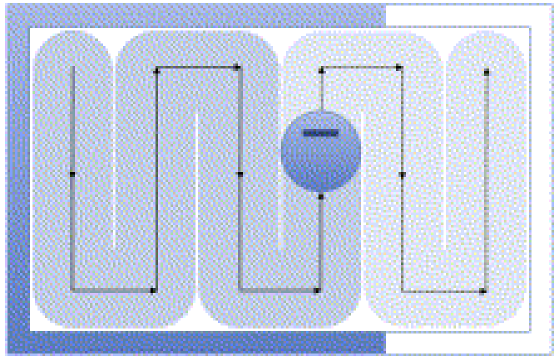


Many Advantages:

- Robust Mechanics
- Low Cost
- High Potential Speed (80 km/hr)
- Customizable



(Plageman, Mischke, et. al, 2009)



High Speed Rough Terrain Traversability analysis

Dynamic Coverage Algorithms in Uncertain Environments

$4,000 and 560 grams

$100 and ~120 grams

Interest in CS/EE/ME75 ?

Tentative Schedule

- 1 hour/week of lecture (try to be contiguous with one meeting) + team project meetings
- Units
  - 3 units: attend 1/hour week meeting, and small homeworks to “plan” your future projects
  - 6 or 9 units: attend 1/hour week, plan projects, work on projects