CSE 478 Robot Autonomy
Anatomy of an Autonomous Vehicle

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Logistics

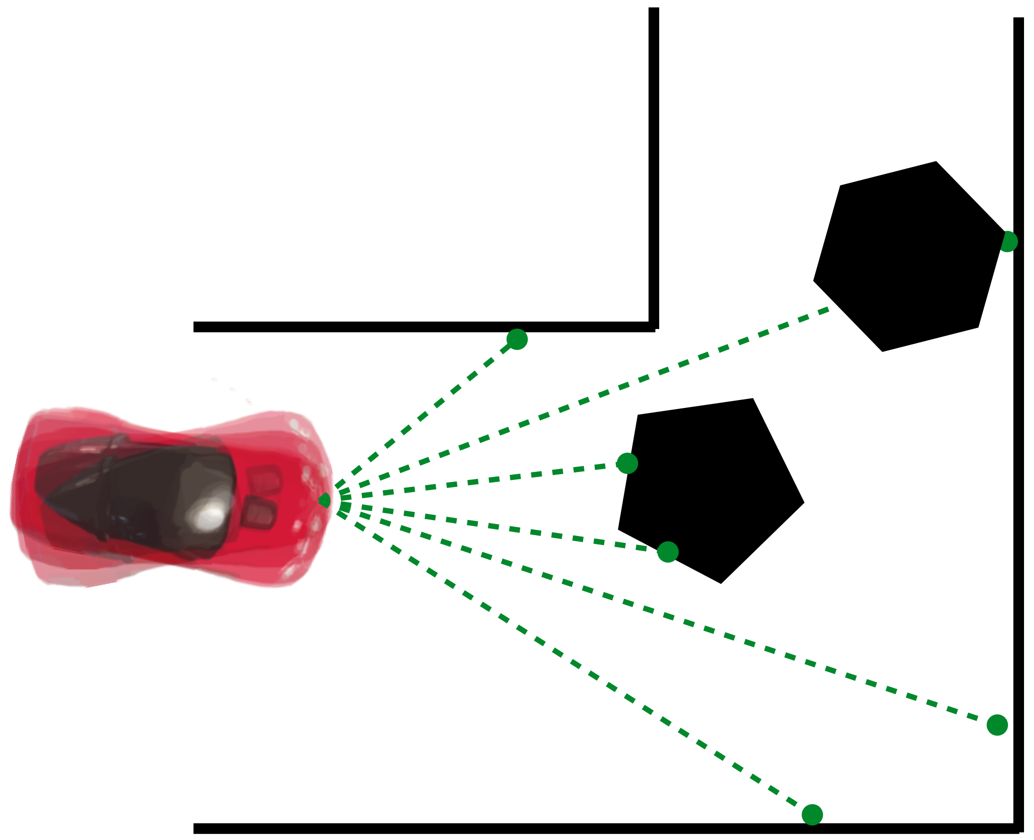
- Submit knowledge survey ASAP
- Each team will be assigned a car and a computer tomorrow during lab office hours.
- Come to office hour and start working on Project 1.
- Project 1 (intro to ROS, due 4/17)

Today’s objective

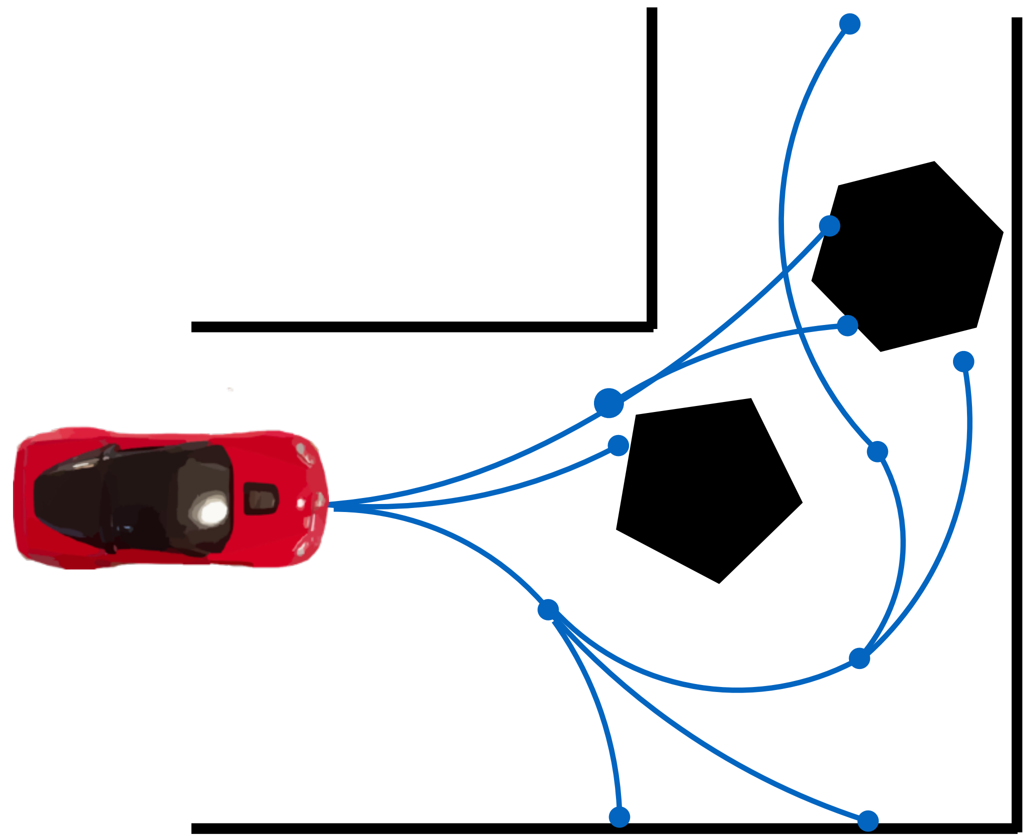
1. Learn how to architect a mobile robotic system

2. Step through a set of fundamental lessons
that shape robot system / algorithm design

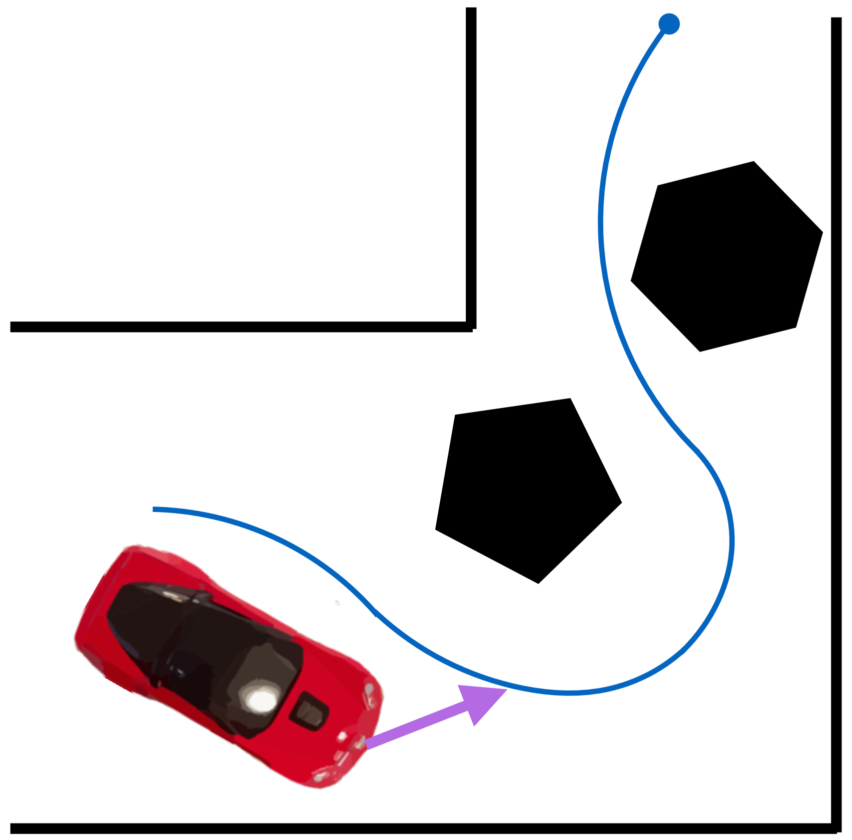
Estimate state



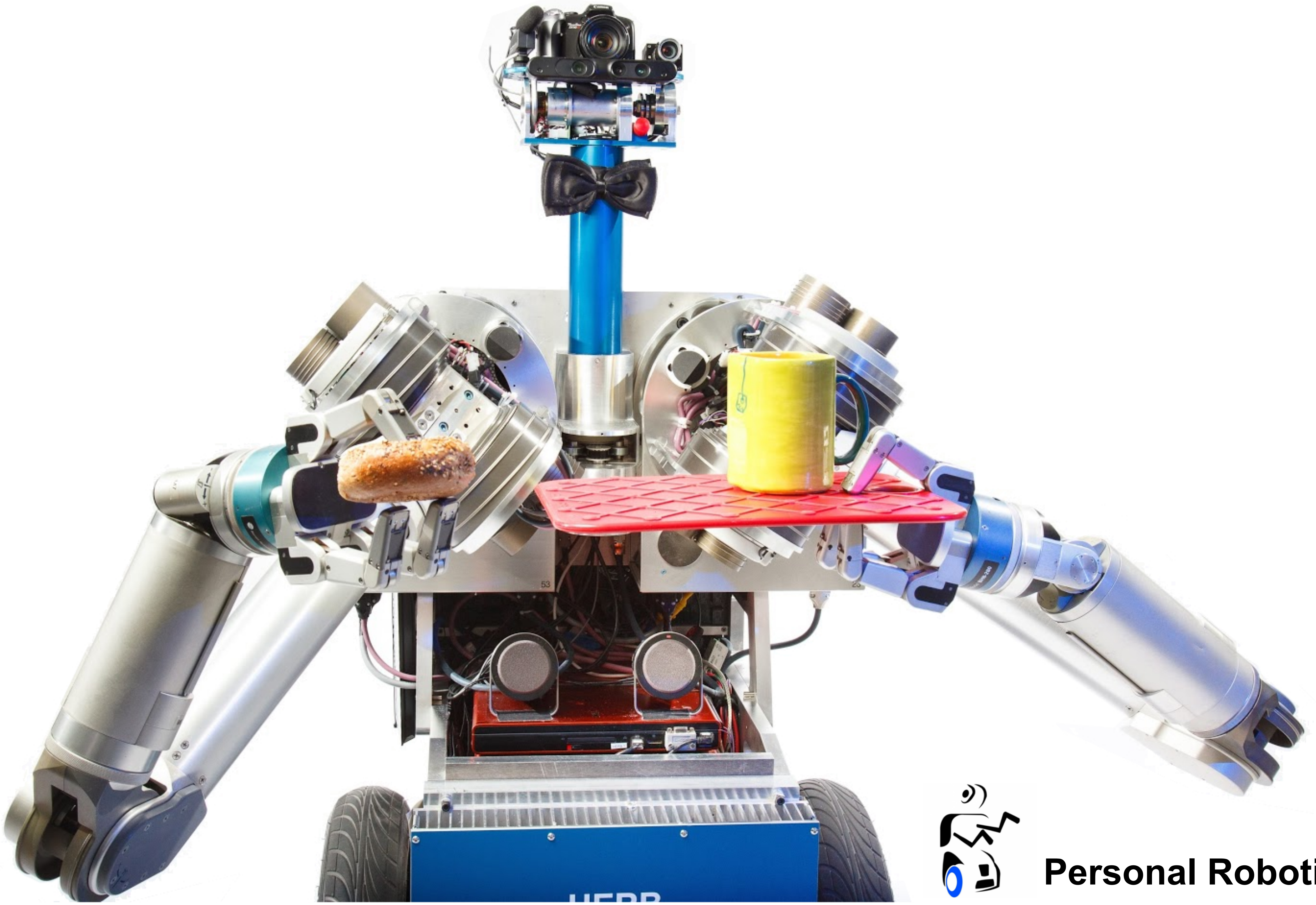
Plan a sequence of motions



Control robot to follow plan



Mobile Manipulators



Personal Robotics Lab

Humanoids

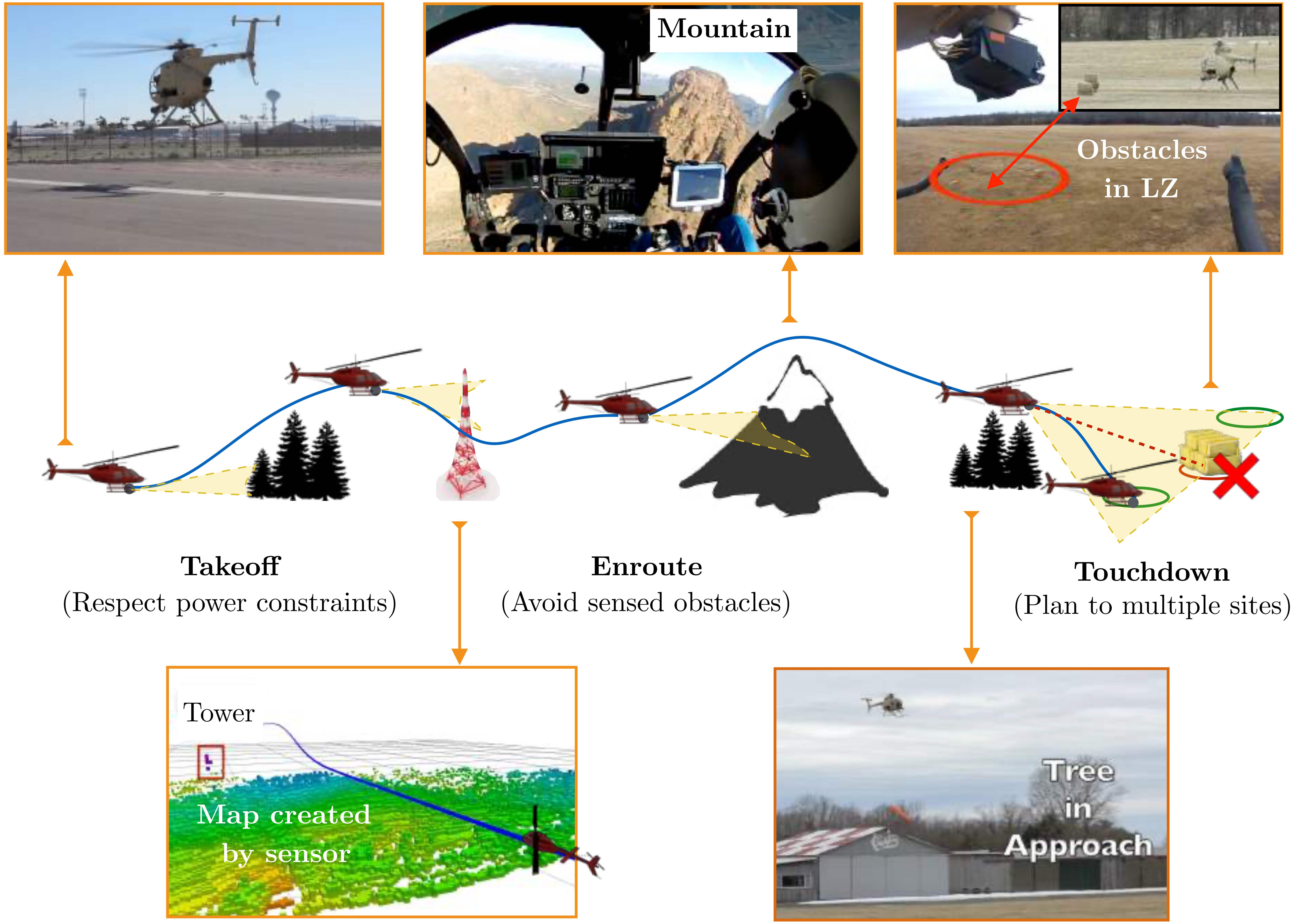
Self-driving Cars

Flying vehicles

Anatomy of a flying vehicle

Mission: Takeoff to Landing

Mission


Mountain
Obstacles in LZ
Takeoff
(Respect power constraints)
Enroute
(Avoid sensed obstacles)
Touchdown
(Plan to multiple sites)
Tower
Map created by sensor
Tree in Approach

Task: A contract the robot has to satisfy

Given:

- Start (latitude, longitude), Goal (latitude, longitude)
- List of no-fly-zones (unsafe air space)
- Coarse terrain map of continental USA
- Sensors - GPS, Laser, etc

Objective:

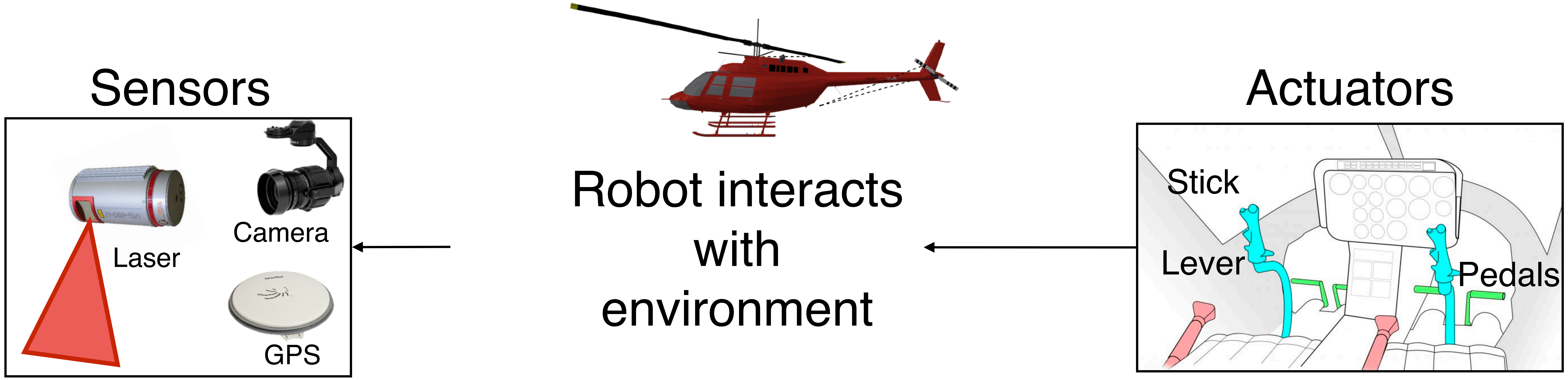
- Minimize time it takes to complete mission

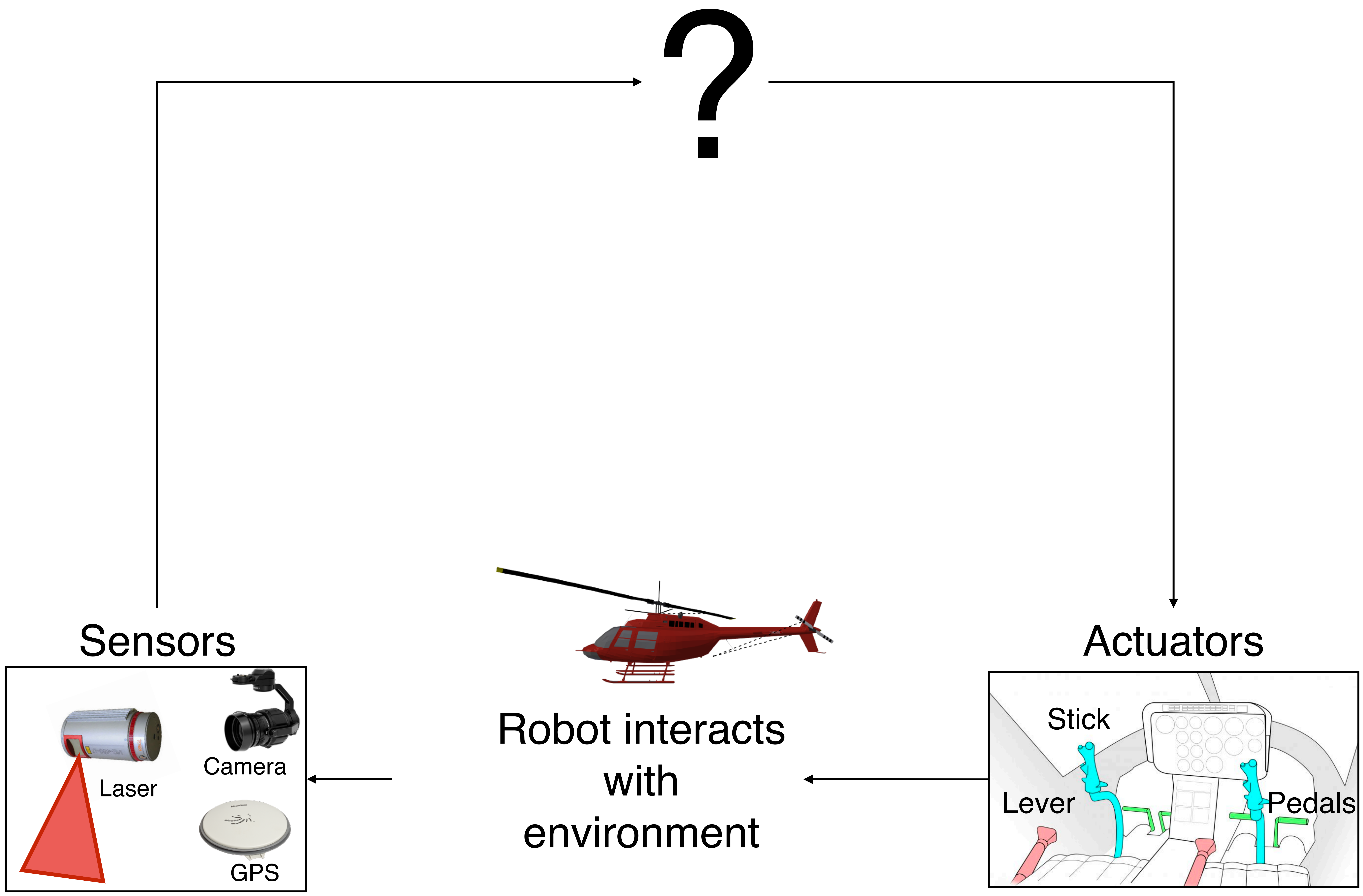
Constraint:

- Don’t come close to obstacles / don’t enter no-fly-zones
- Don’t exceed limits of the vehicle (flying upside down)
- Don’t run out of fuel!

How do we tractably solve the task?

Begin with a blank slate


Sensors
Laser
Camera
GPS
Robot interacts with environment
Actuators
Stick
Lever
Pedals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Lesson 0: Look at one piece at a time

Q1: Assume we know everything about the world.

What commands should we send to the actuator?

Q2: How do we use raw sensor data to update what we know about the world?

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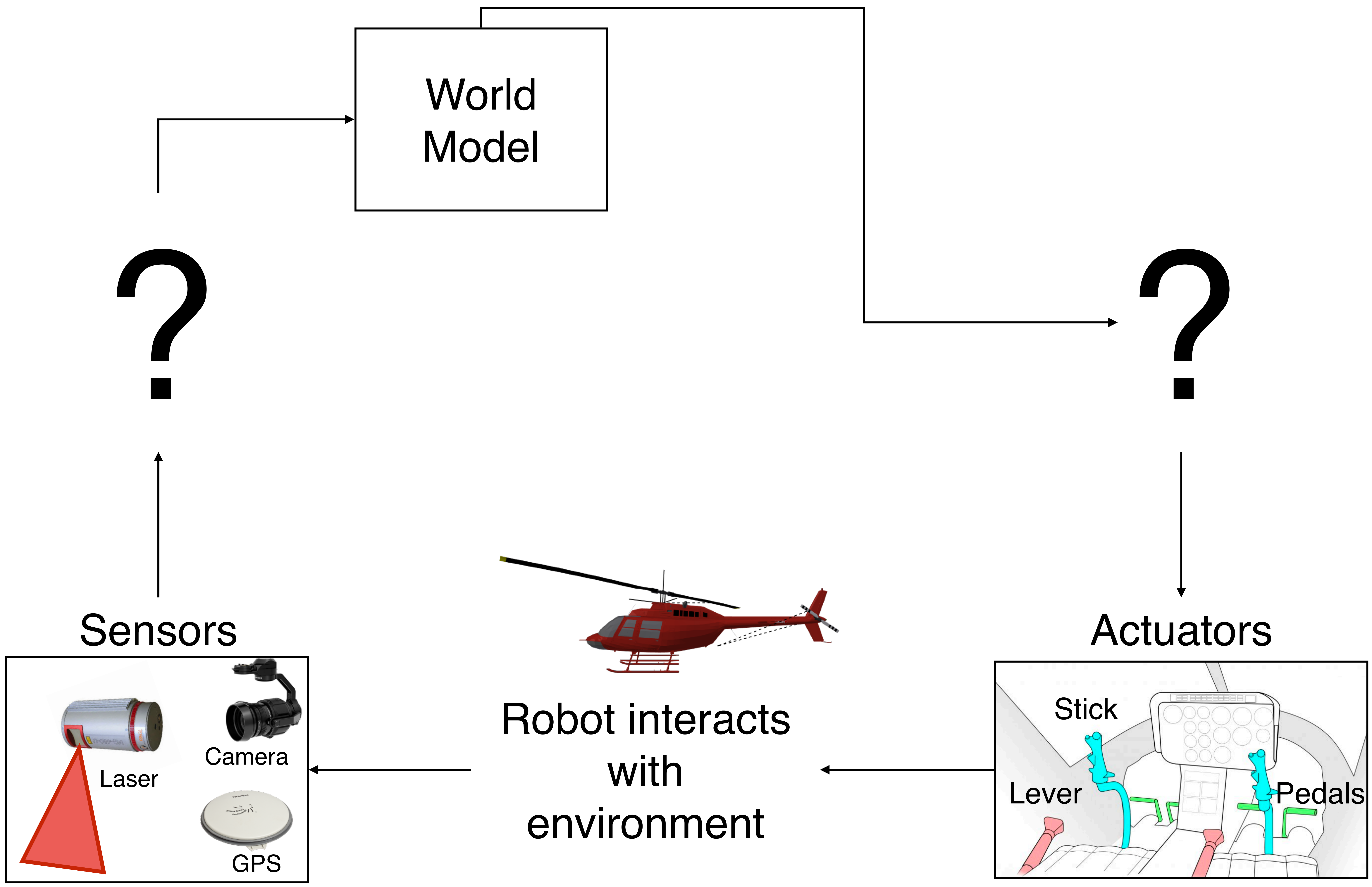

World Model
?
?
Sensors
Laser
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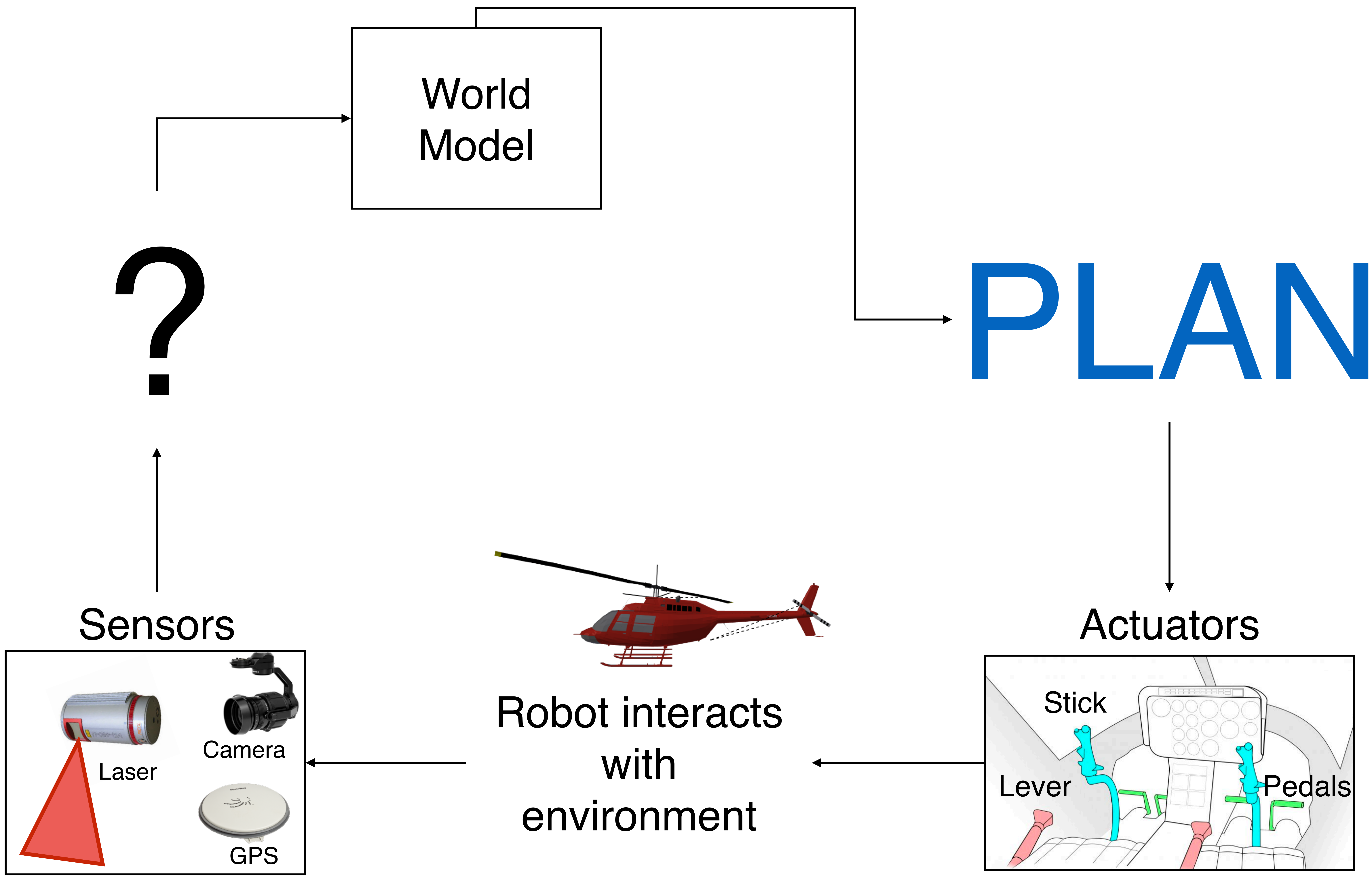
What is the world model?

List of everything we need to know to accomplish the task

- Where is the robot in the world? What is its *state*?
- What are the obstacles in the world?
- What type are the obstacles (radio towers, trees)?
- What are the no-fly-zones?
- Are there other aircrafts?
- What is the wind, temperature, etc?


World Model
?
PLAN
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What is planning?

Planning is an optimization problem in which …

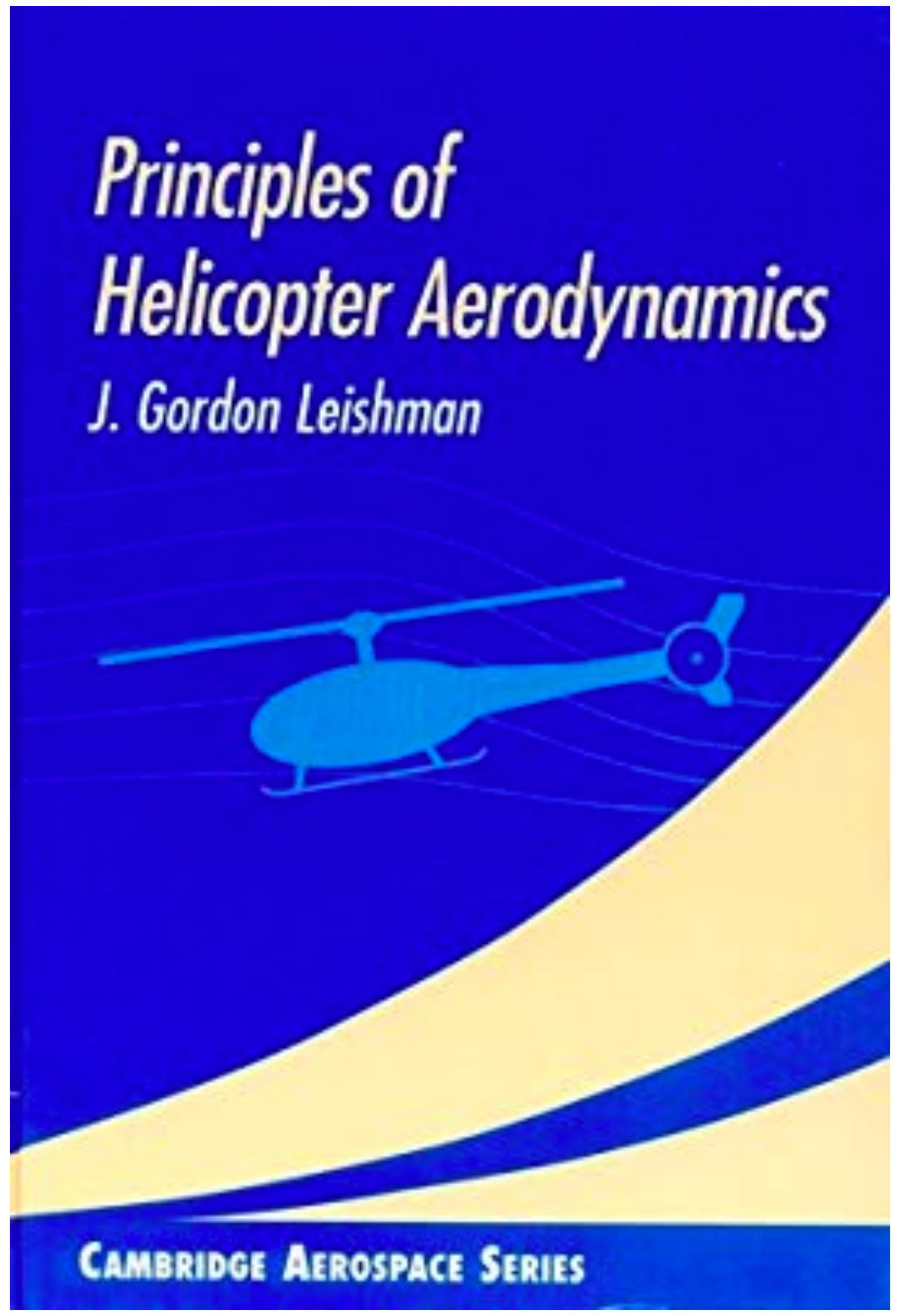
we search over a sequence of actions…

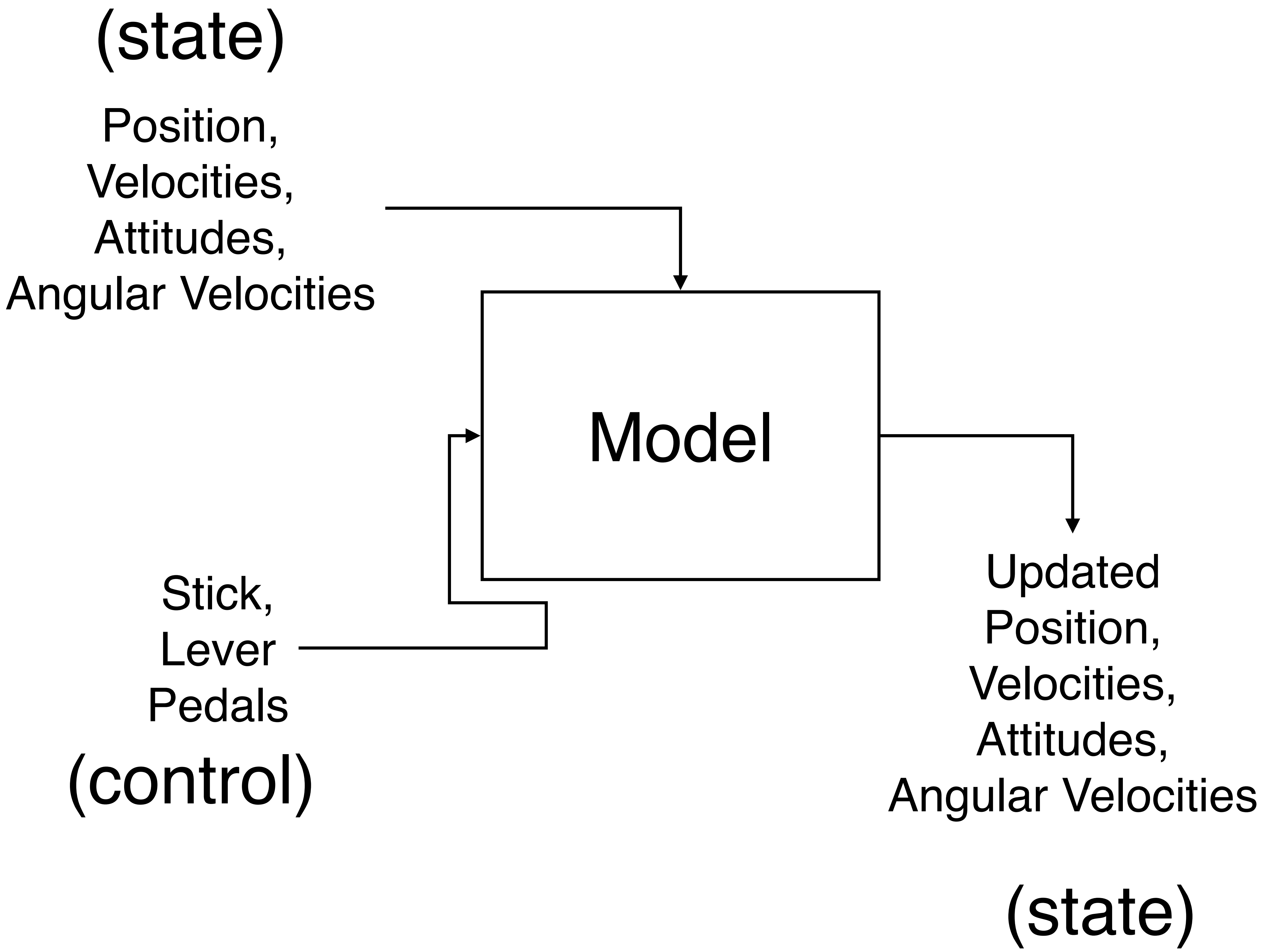
towards minimizing a cost function (e.g., time)…

using a model of the robot to predict where it will go…

while making sure we are not violating constraints (e.g. crash).

How do we get a model of the helicopter?



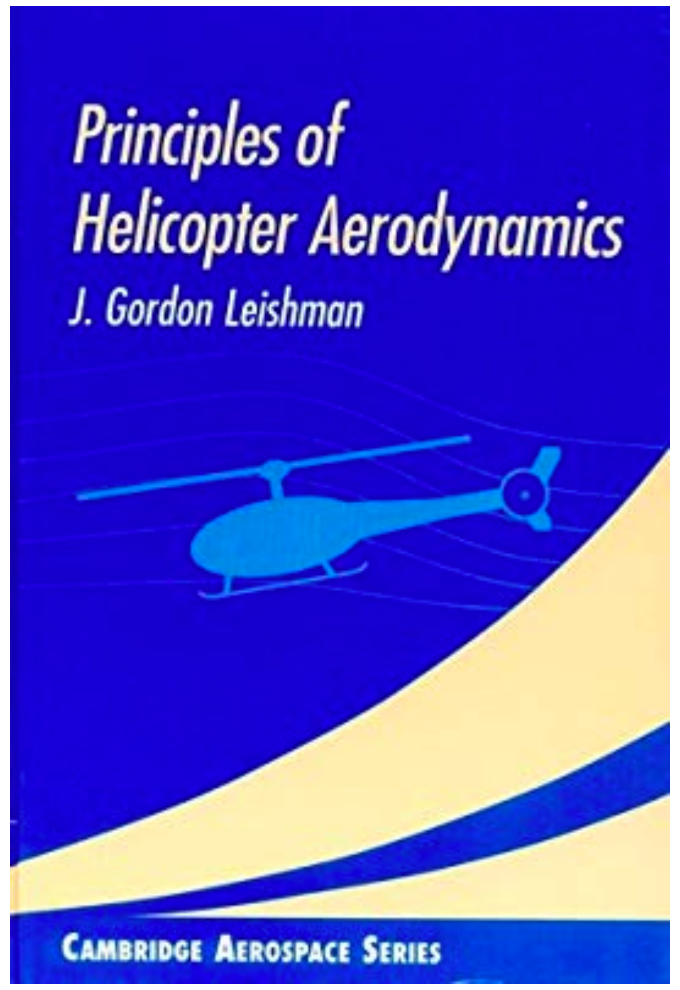


Problem: Model is very complicated! Intractable to plan with it.

Insight

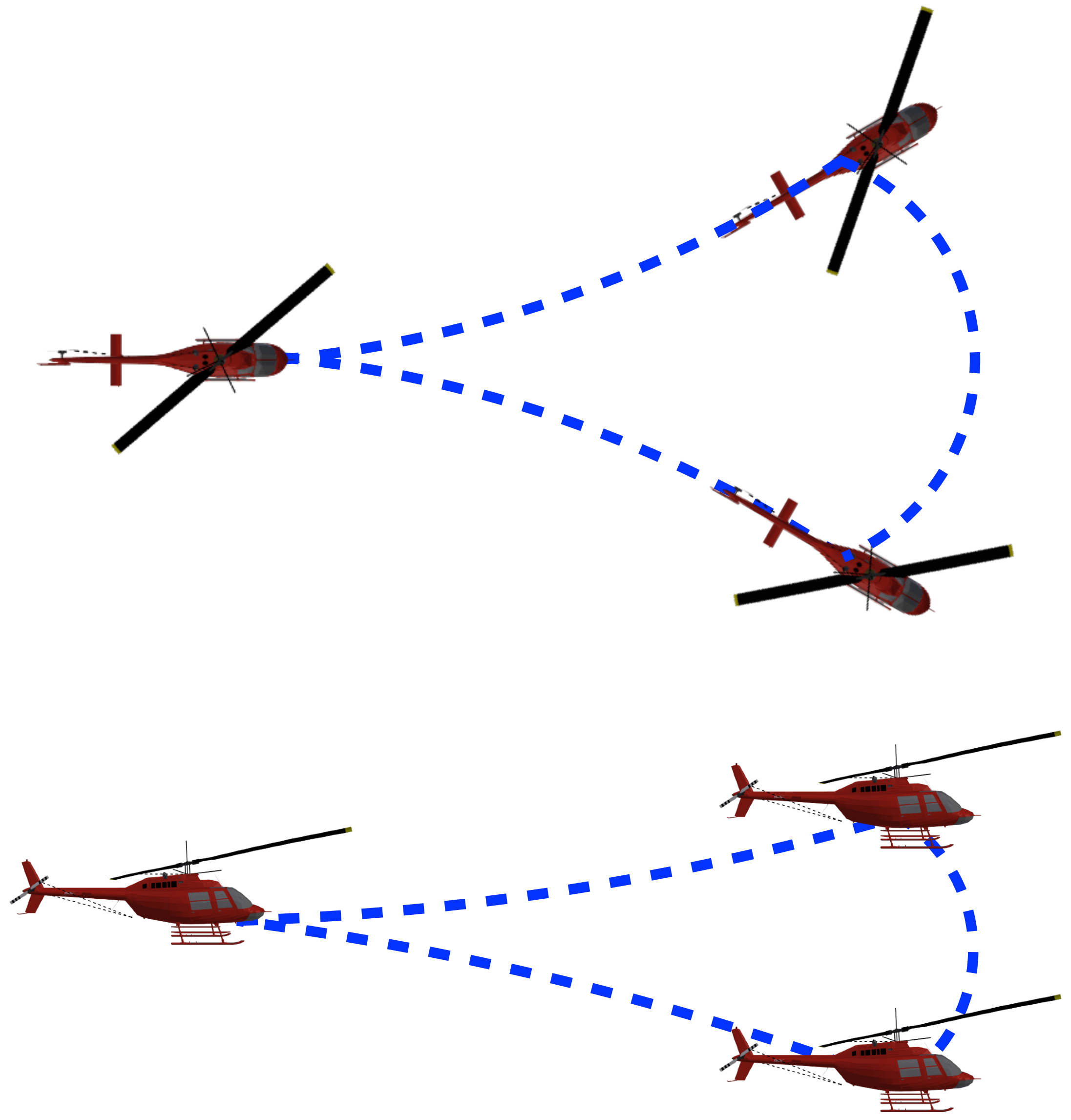
“All models are **wrong**, but some are **useful**”
-George Box

Lesson 1: Plan with simple models



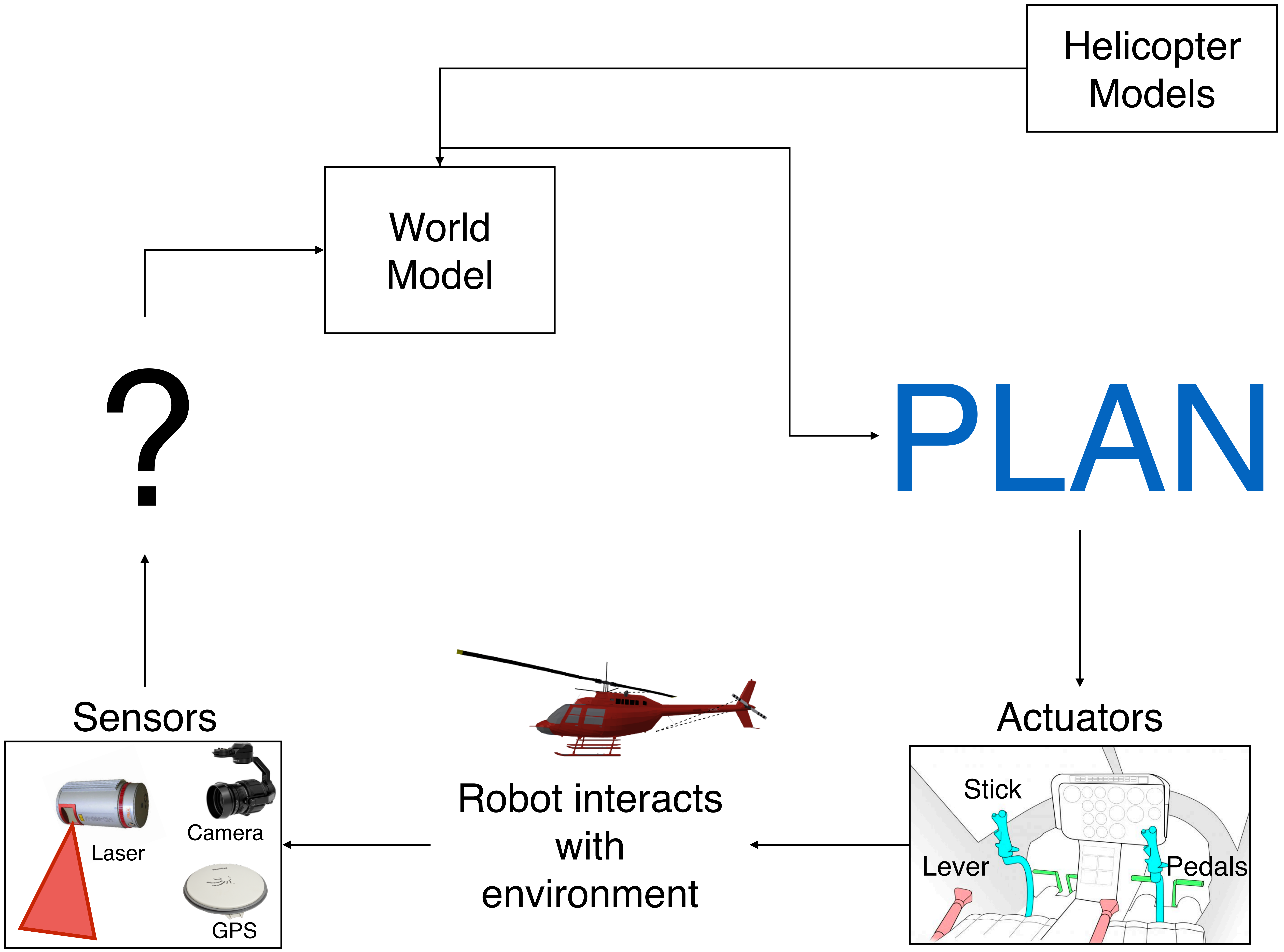
Complex aerodynamical model

Use domain knowledge to simplify model



Flying unicycle at high speeds!

Different models at different flight regimes


Helicopter
Models
World
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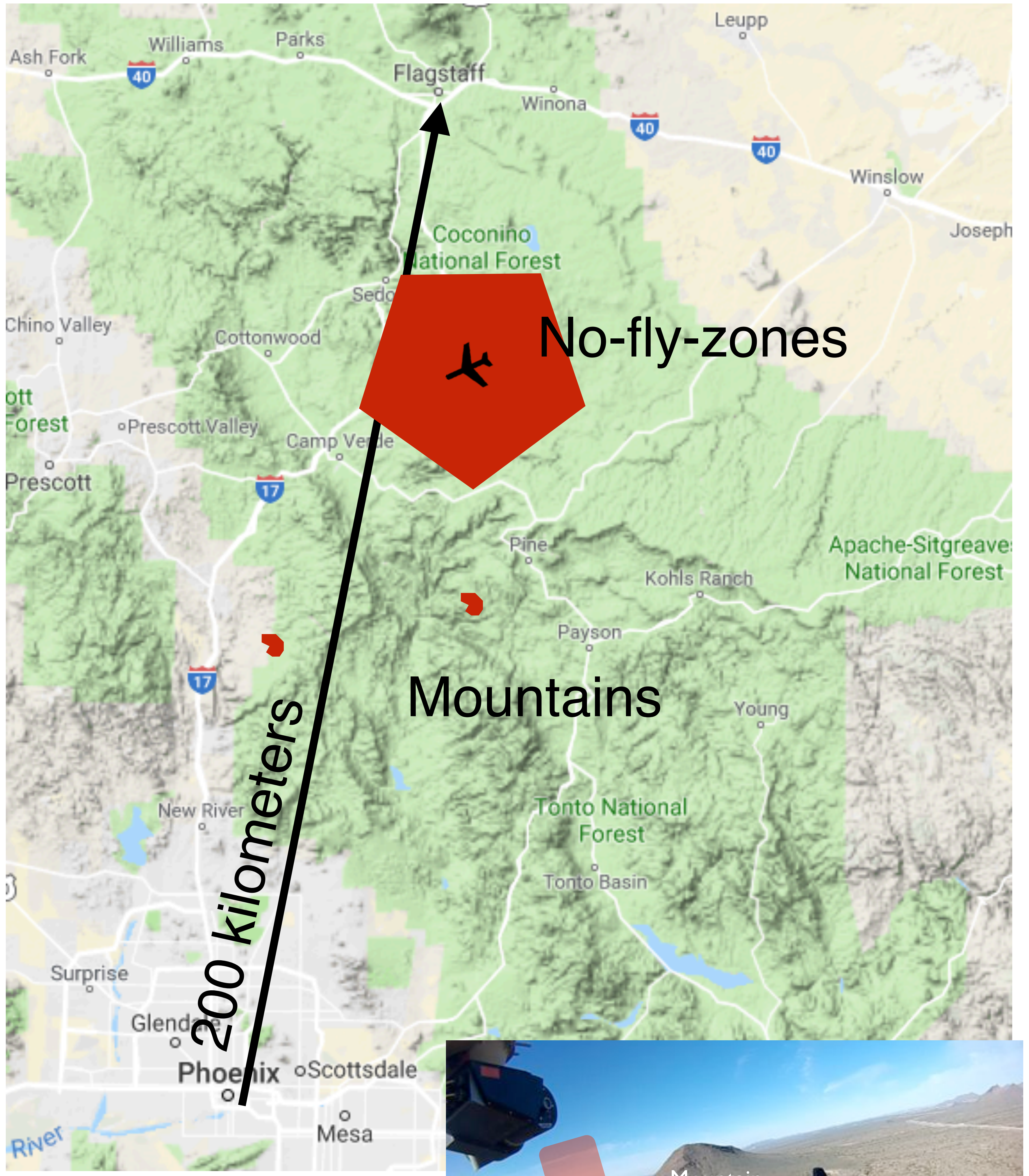
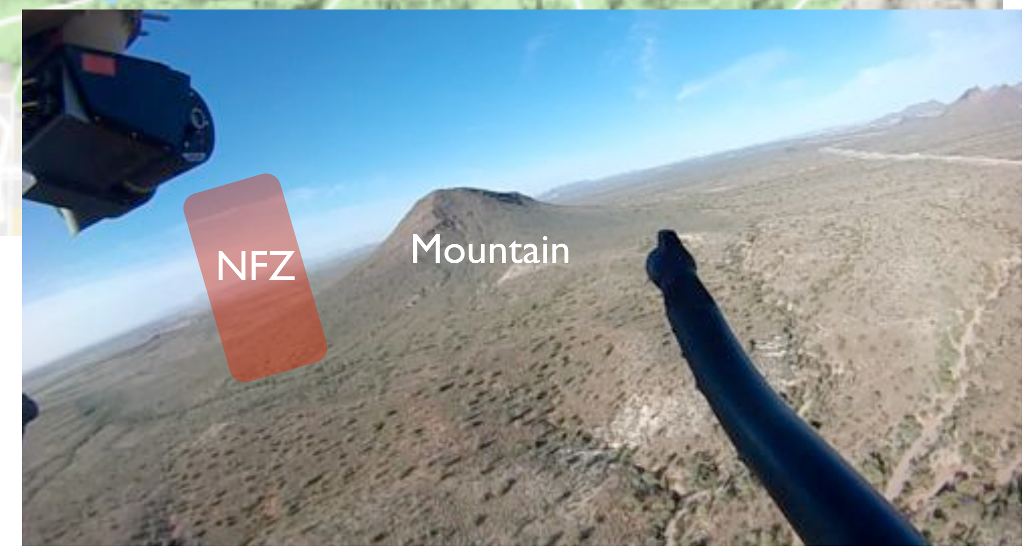
What resolution should we plan at?





Example mission:

Fly from Phoenix to Flagstaff as fast as possible (200 km)

Avoid mountains, no-fly-zones, radio towers, wires, bad weather

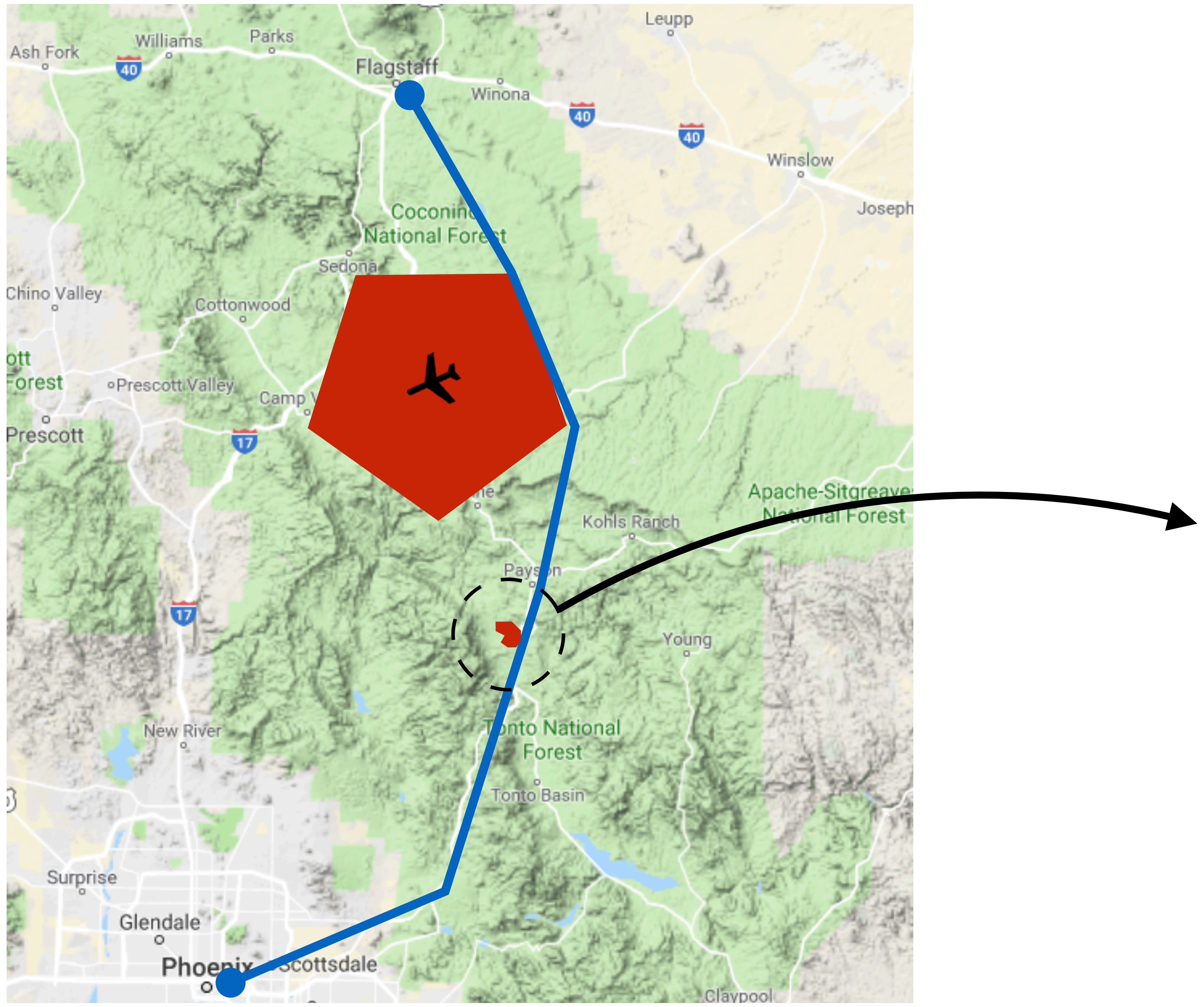
Pass through narrow gaps

Problem:

Take forever to plan at high resolution ALL the way to goal

Lesson 2: Plan at multiple resolutions

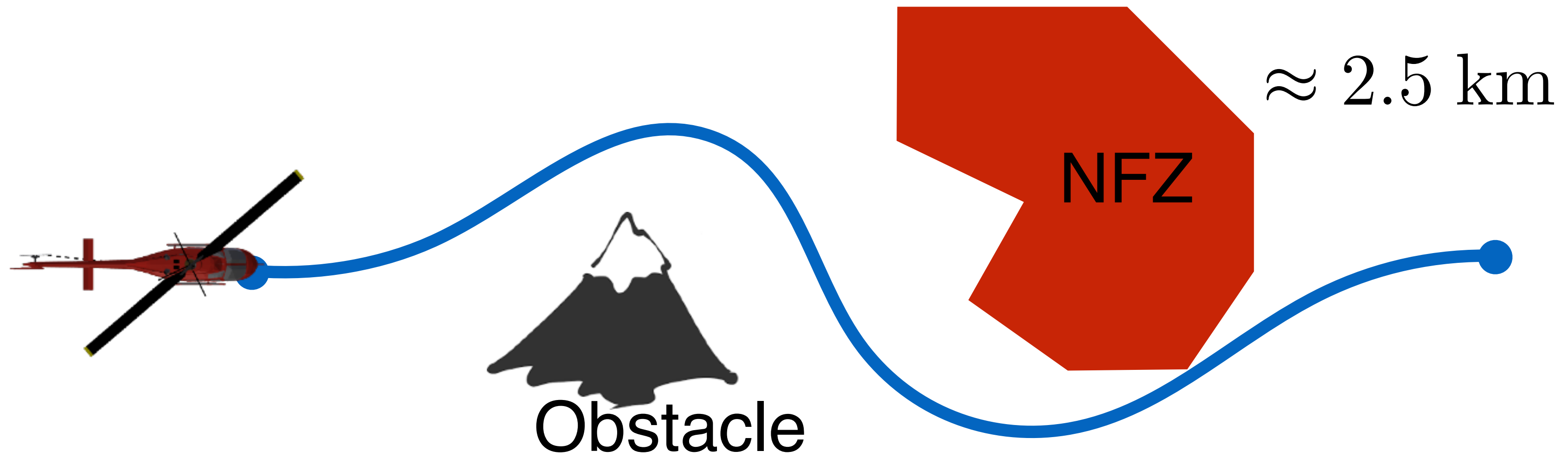
Global planner



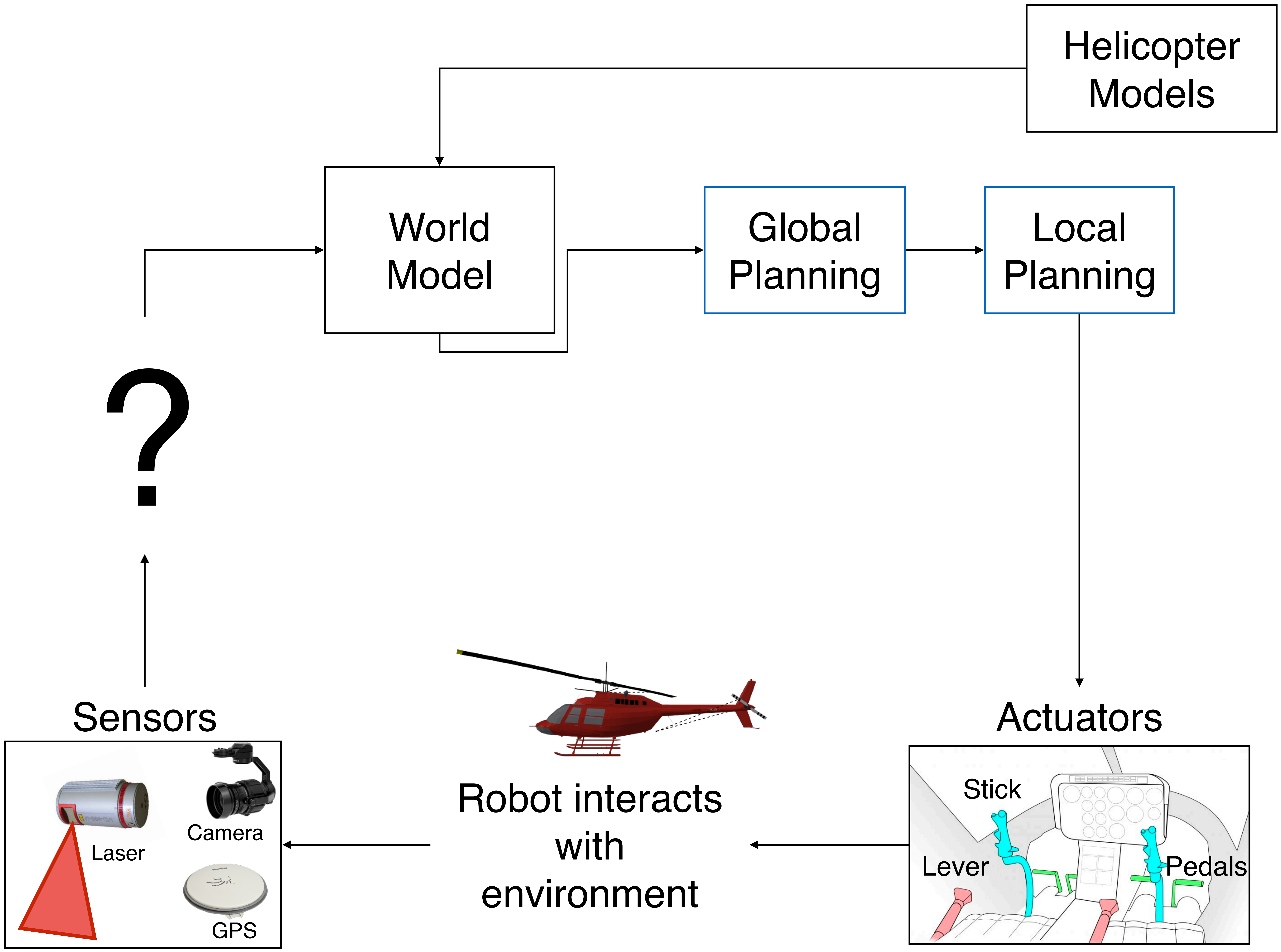
Plan at coarse (1km) resolution,
compute entire route from start to goal
avoid large obstacles, no-fly-zones etc

(only consider factors that
significantly affect mission time)

Local planner



Plan at high (10 m) resolution,
follow the global route,
avoid all obstacles, produce
smooth
dynamically feasible paths



Helicopter Models
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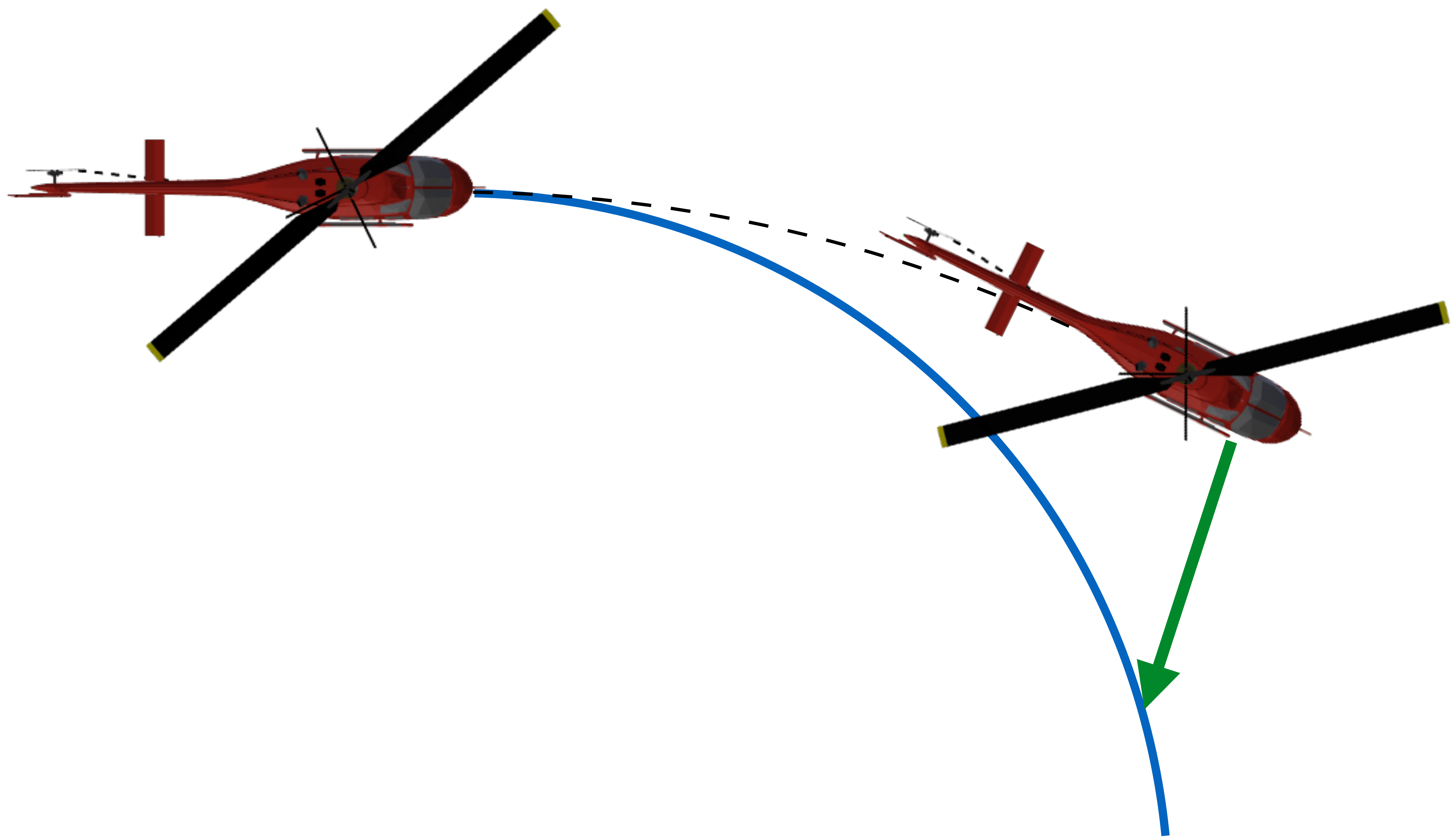
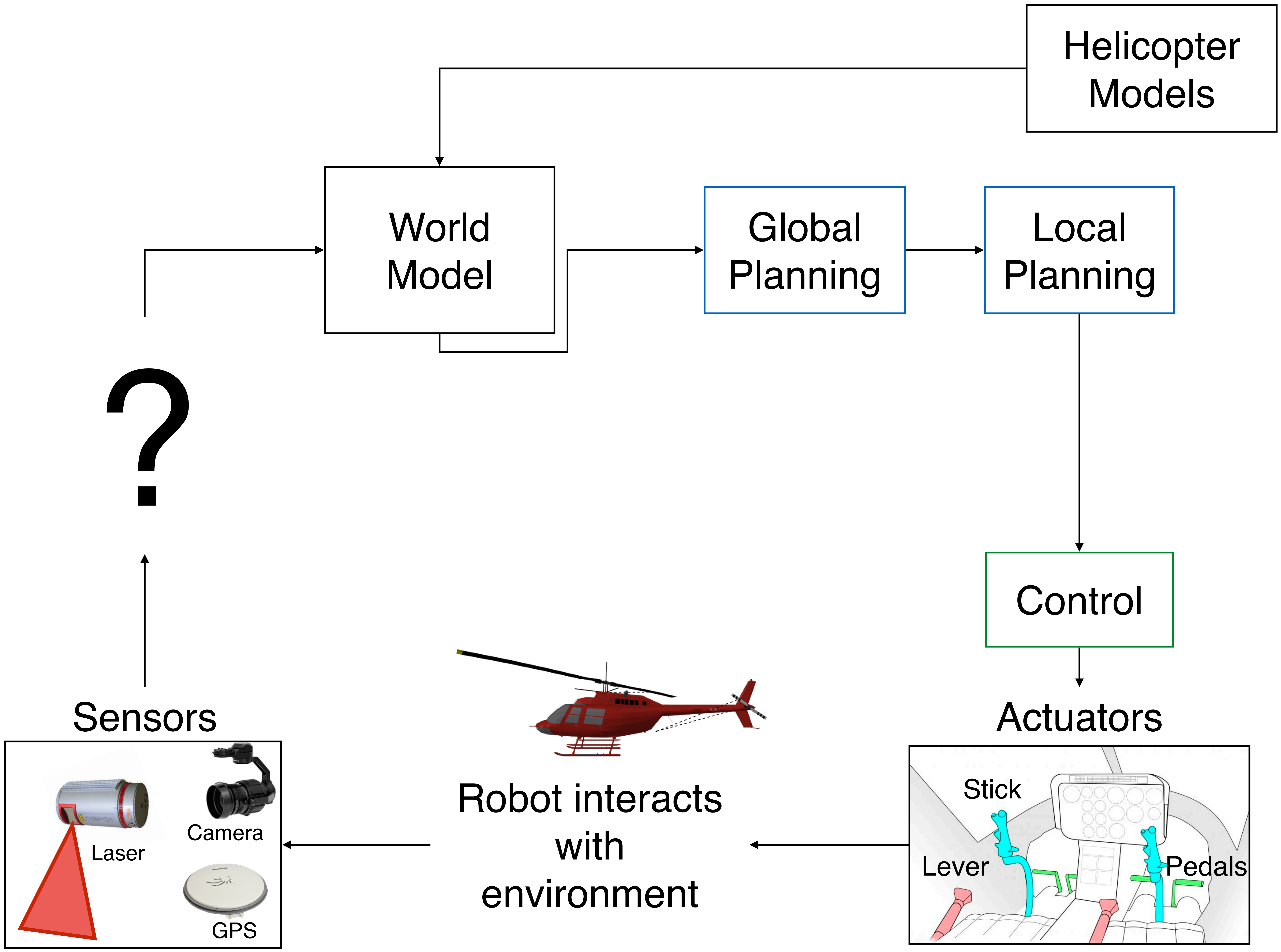
Lesson 3: Open loop planning is not enough



Robot will go “off” the plan for many reasons
(disturbance, model errors, actuation errors, …)

A **controller** immediately corrects for any tracking error
and gets the robot back on the path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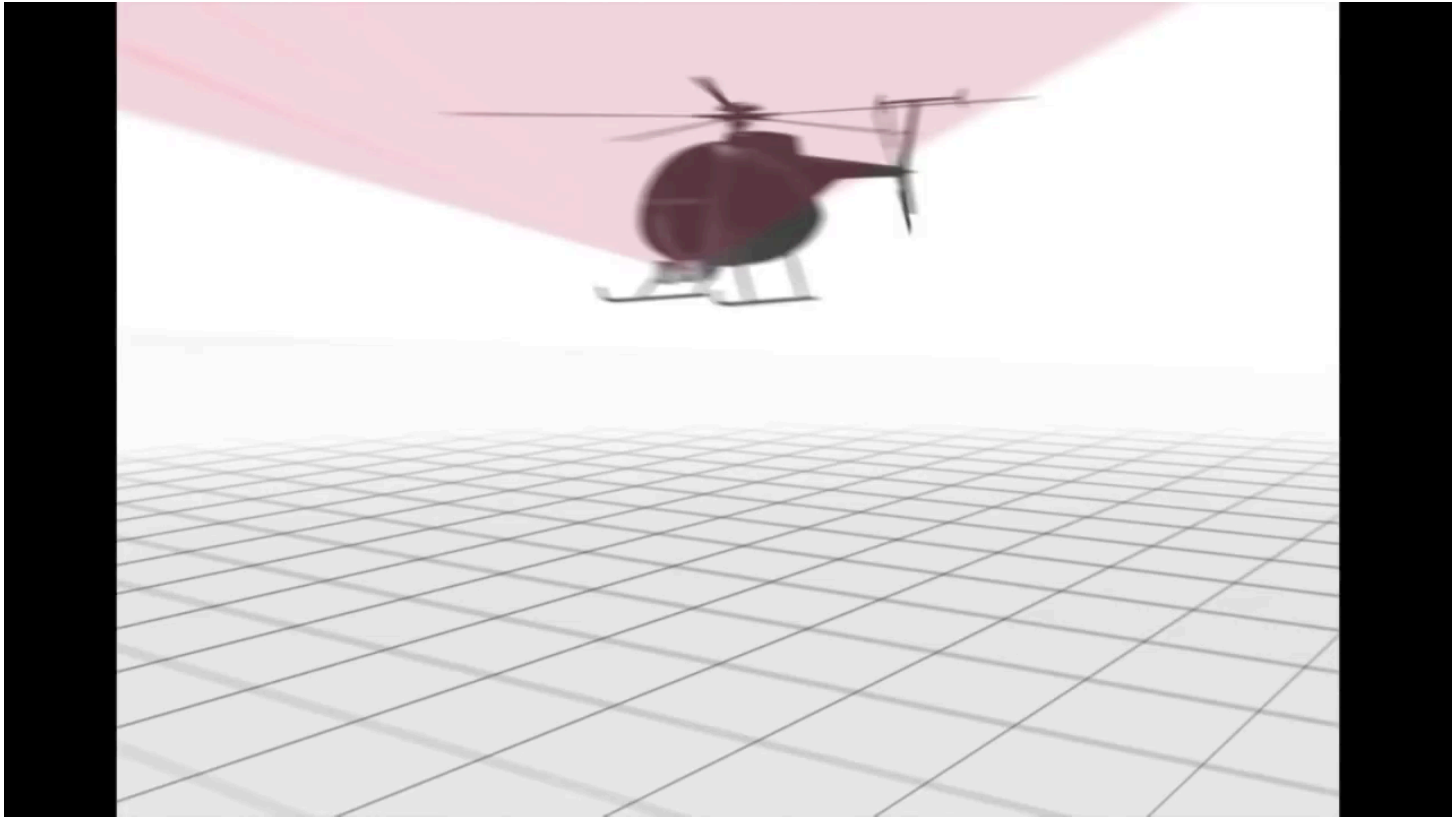
data to update what we know about the world?

What is the world model?

List of everything we need to know to accomplish the task

- Where is the robot in the world? What is it's state?	GPS
- What are the obstacles in the world?	Laser
- What type are the obstacles (radio towers, trees)?	Camera
- What are the no-fly-zones?	Radio
- Are there other aircrafts?	Radio
- What is the wind, temperature, etc?	Pitot tube, barometer, etc

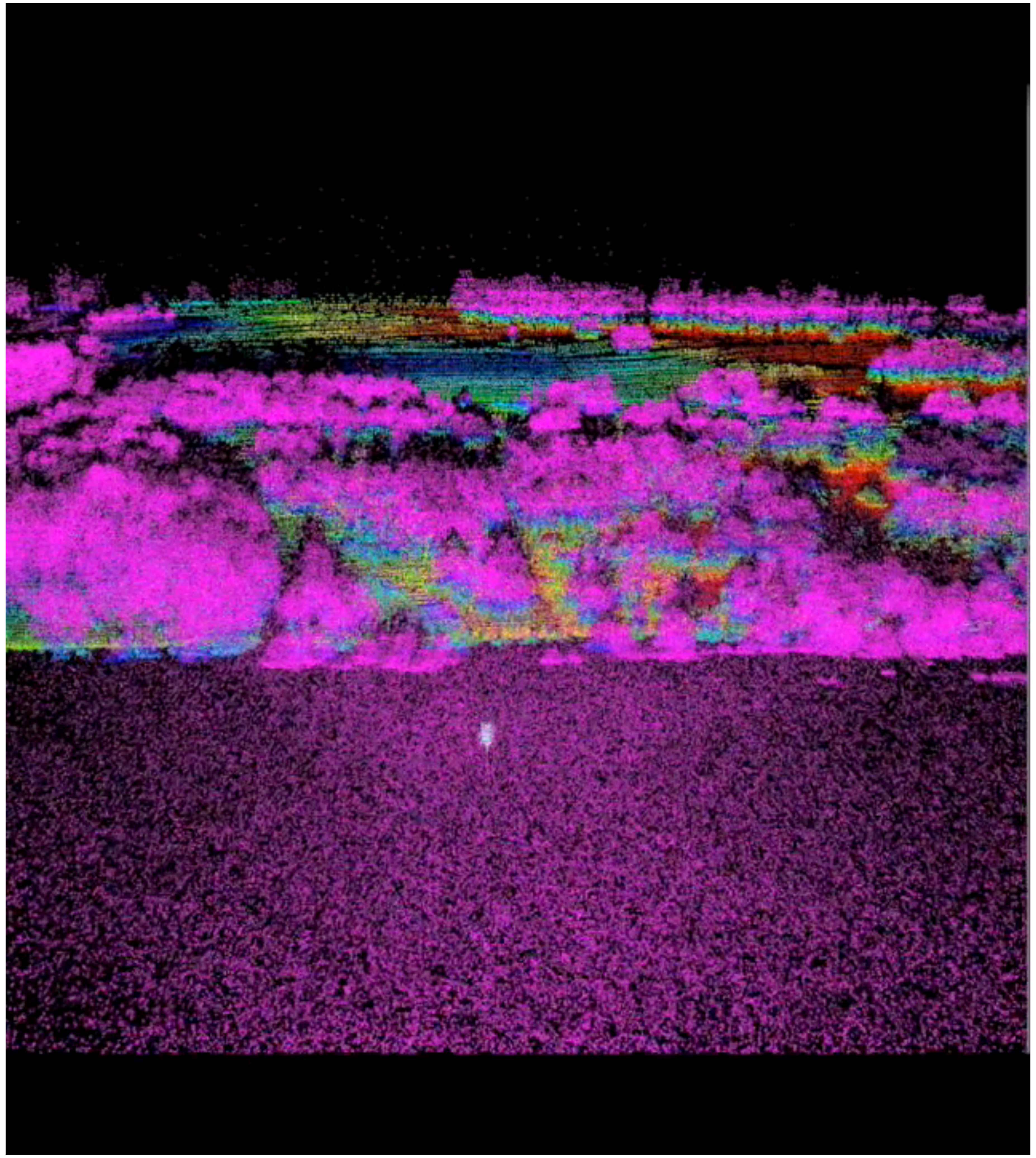
Can we simply "fuse" laser readings to map the world?



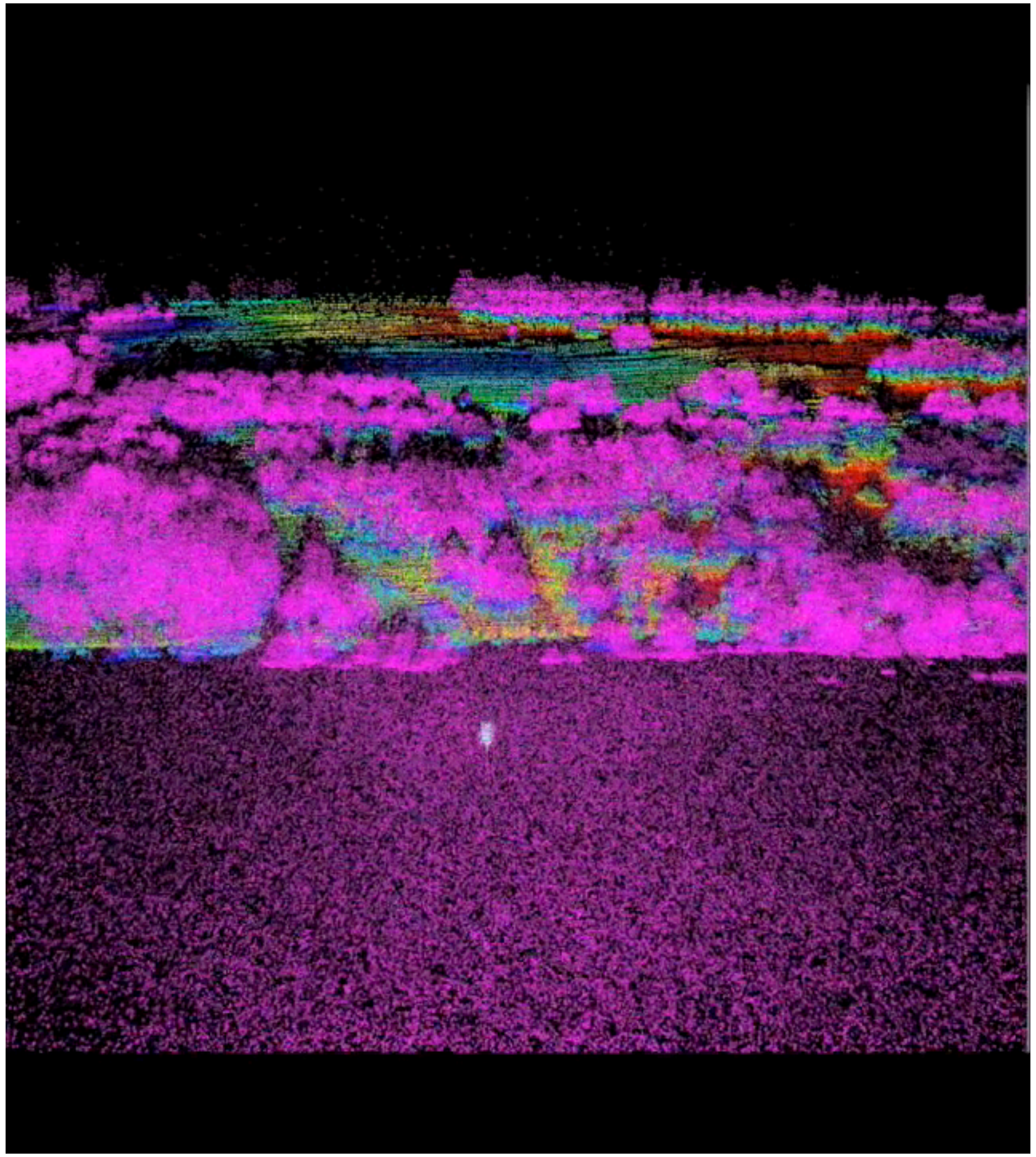
(courtesy Chamberlain et al.)

Flying in a snow storm

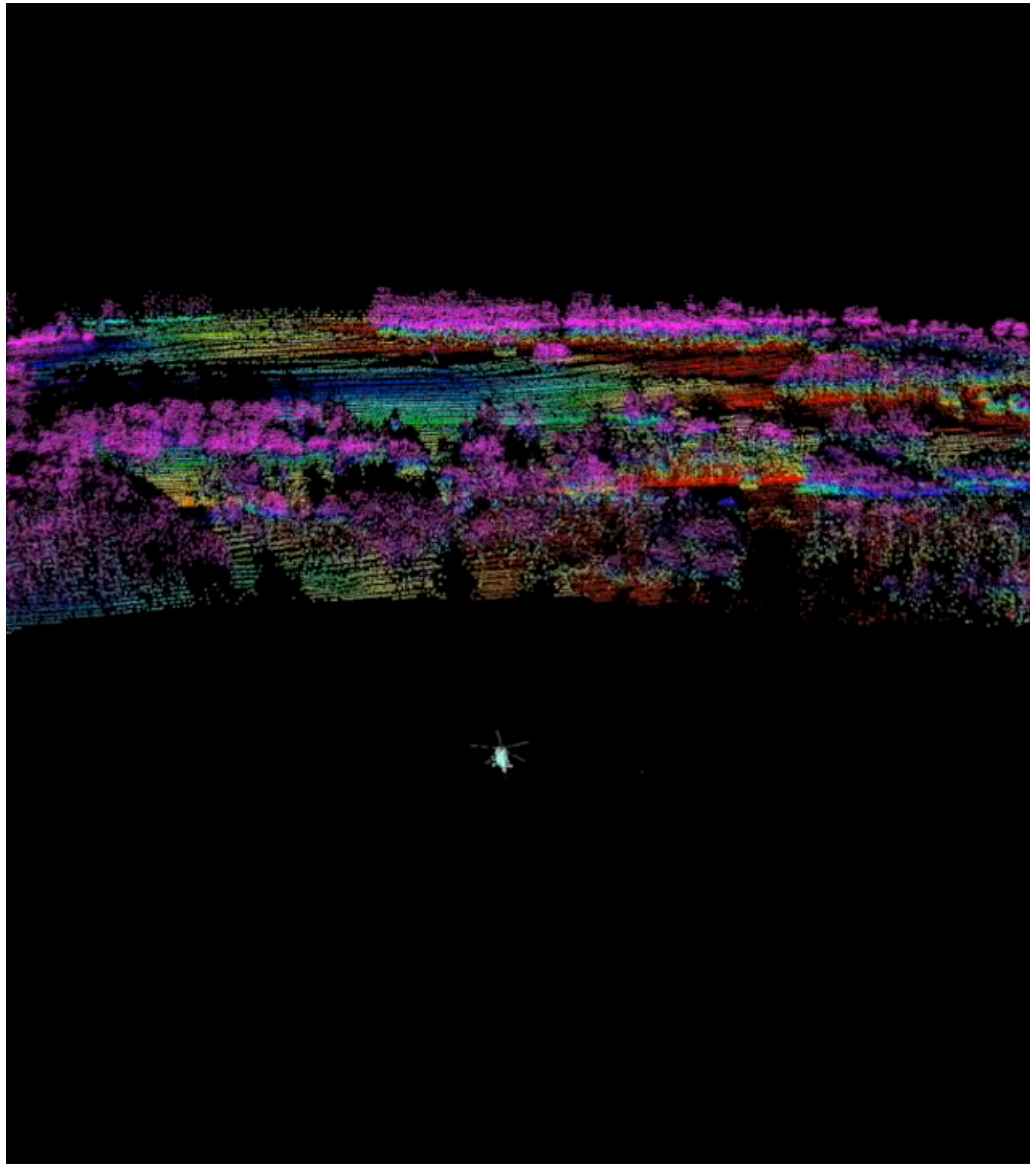
Flying in a snow storm



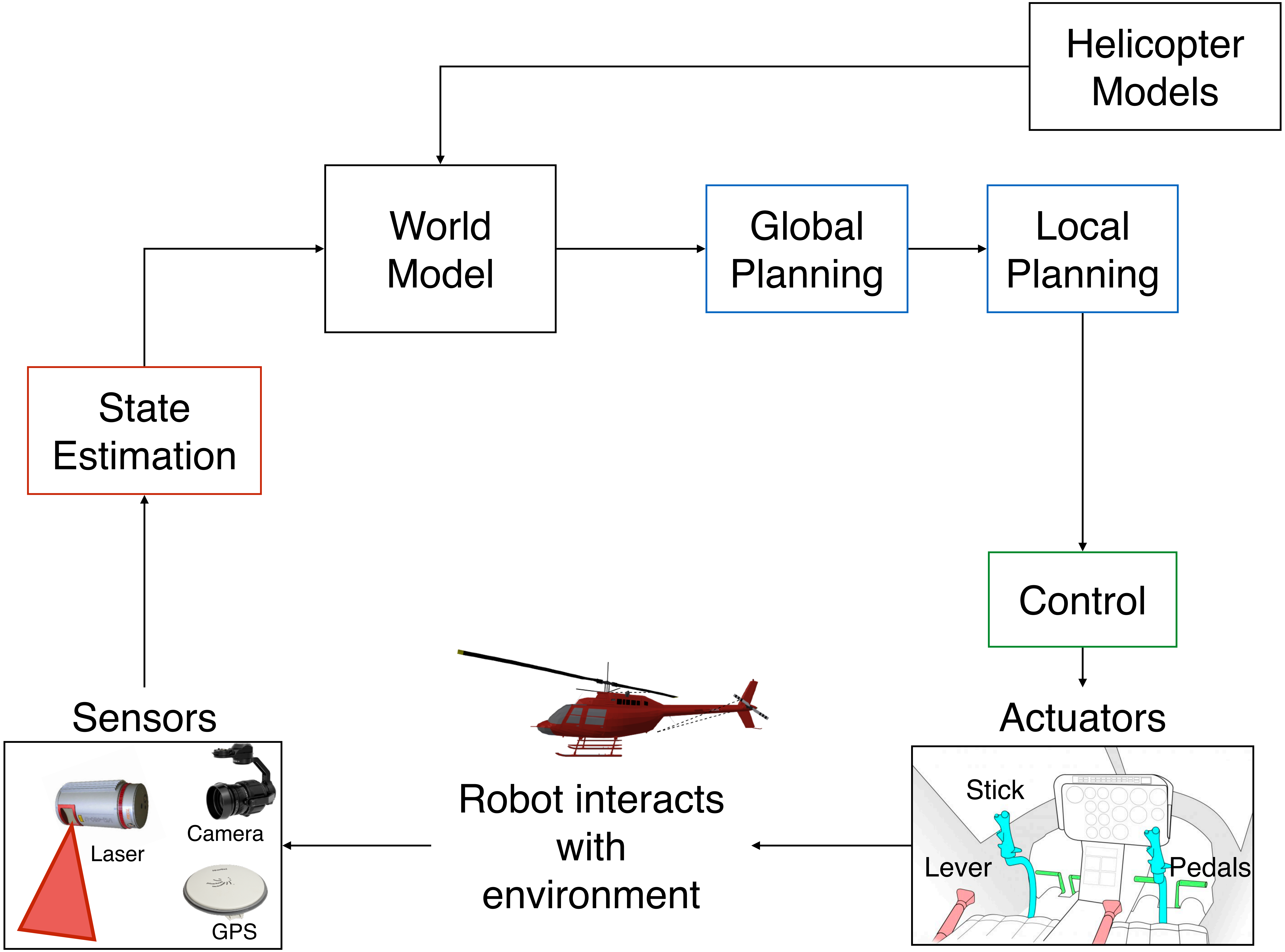
Lesson 4: Use probabilistic models of the sensor



Laser reflected by snow!



Correctly fused laser data
using probabilistic models



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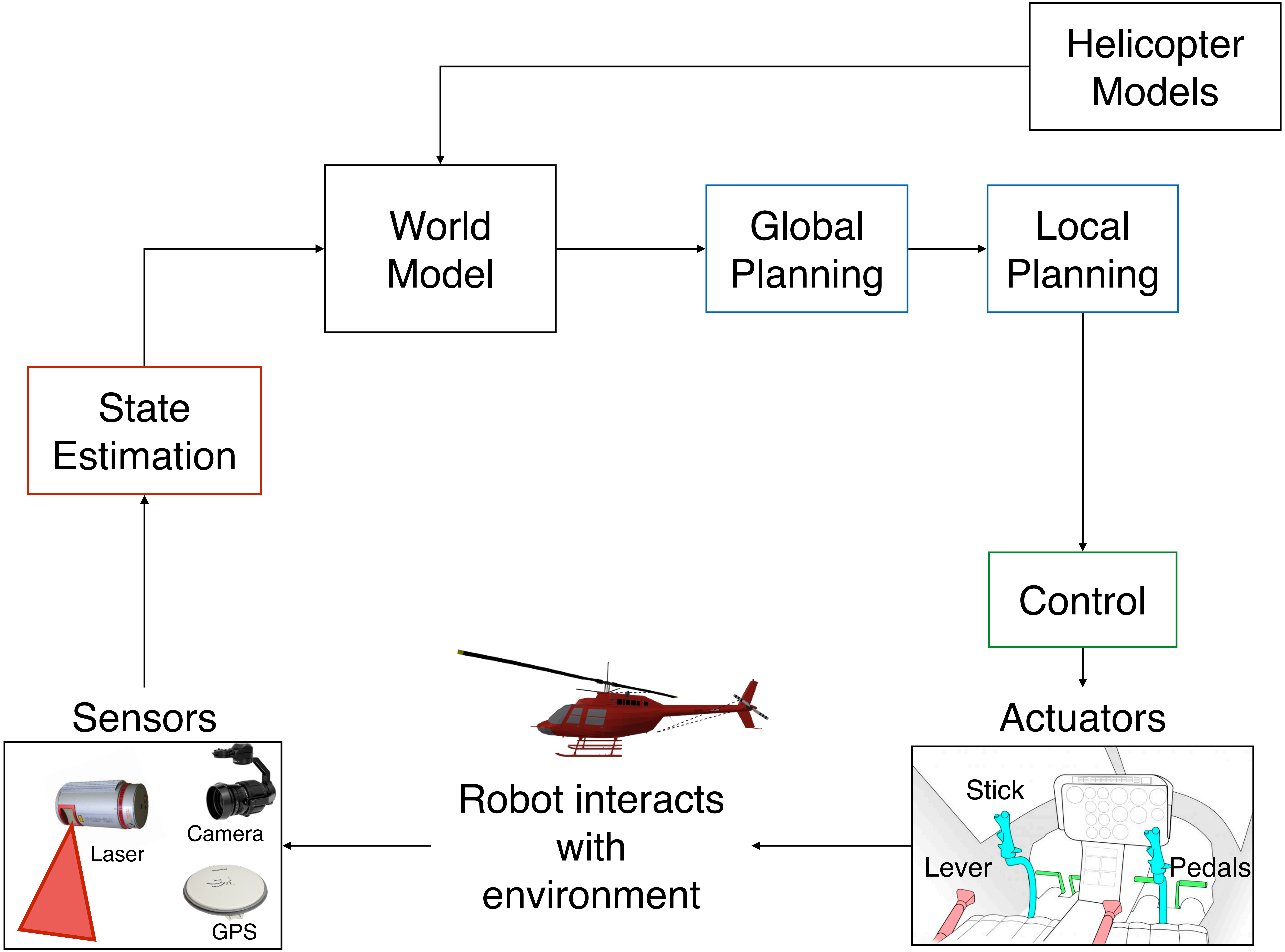
What is state estimation?

Given raw sensor data, use probabilistic models to estimate world model

$$P(\text{world model}|\text{data})$$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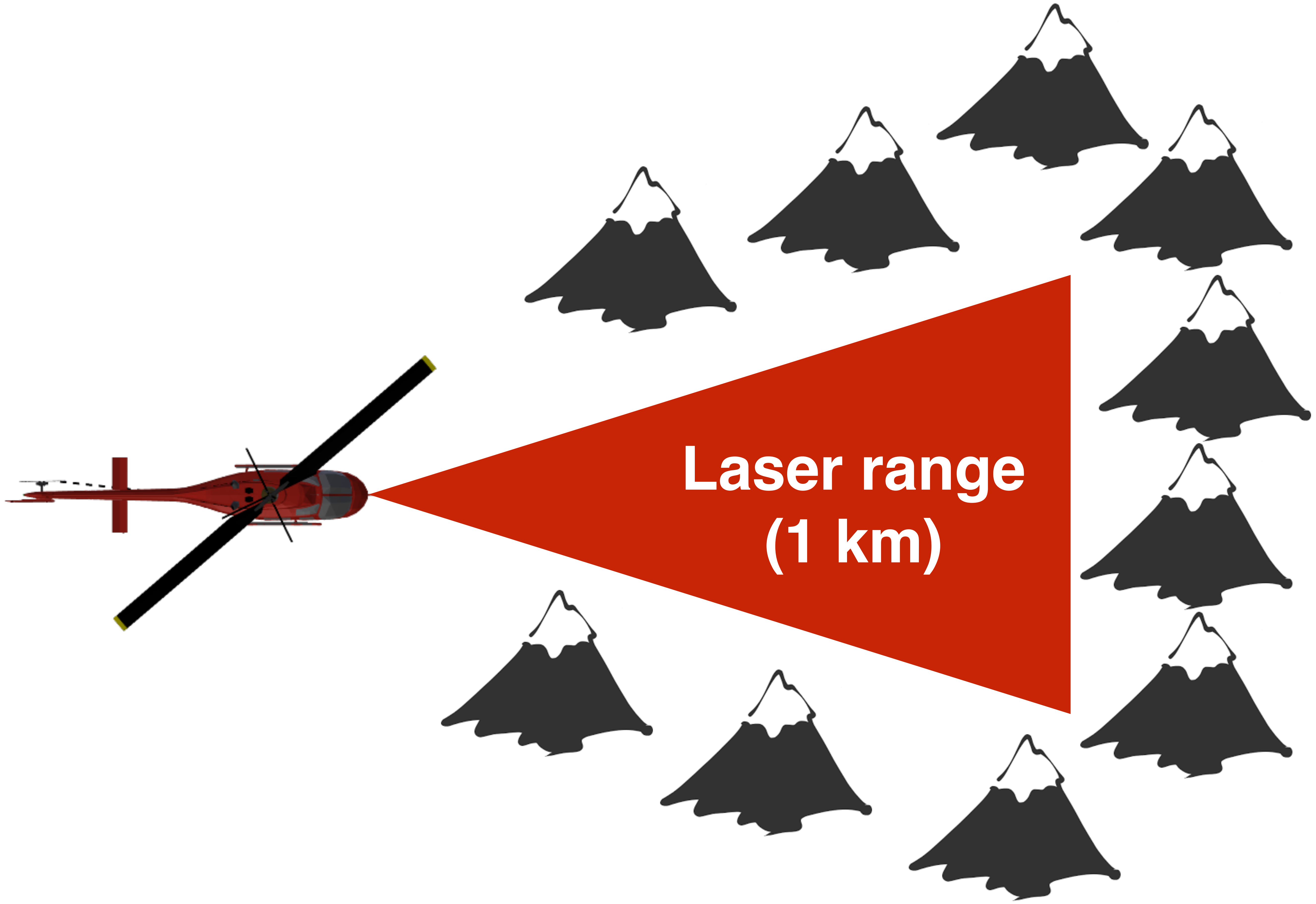
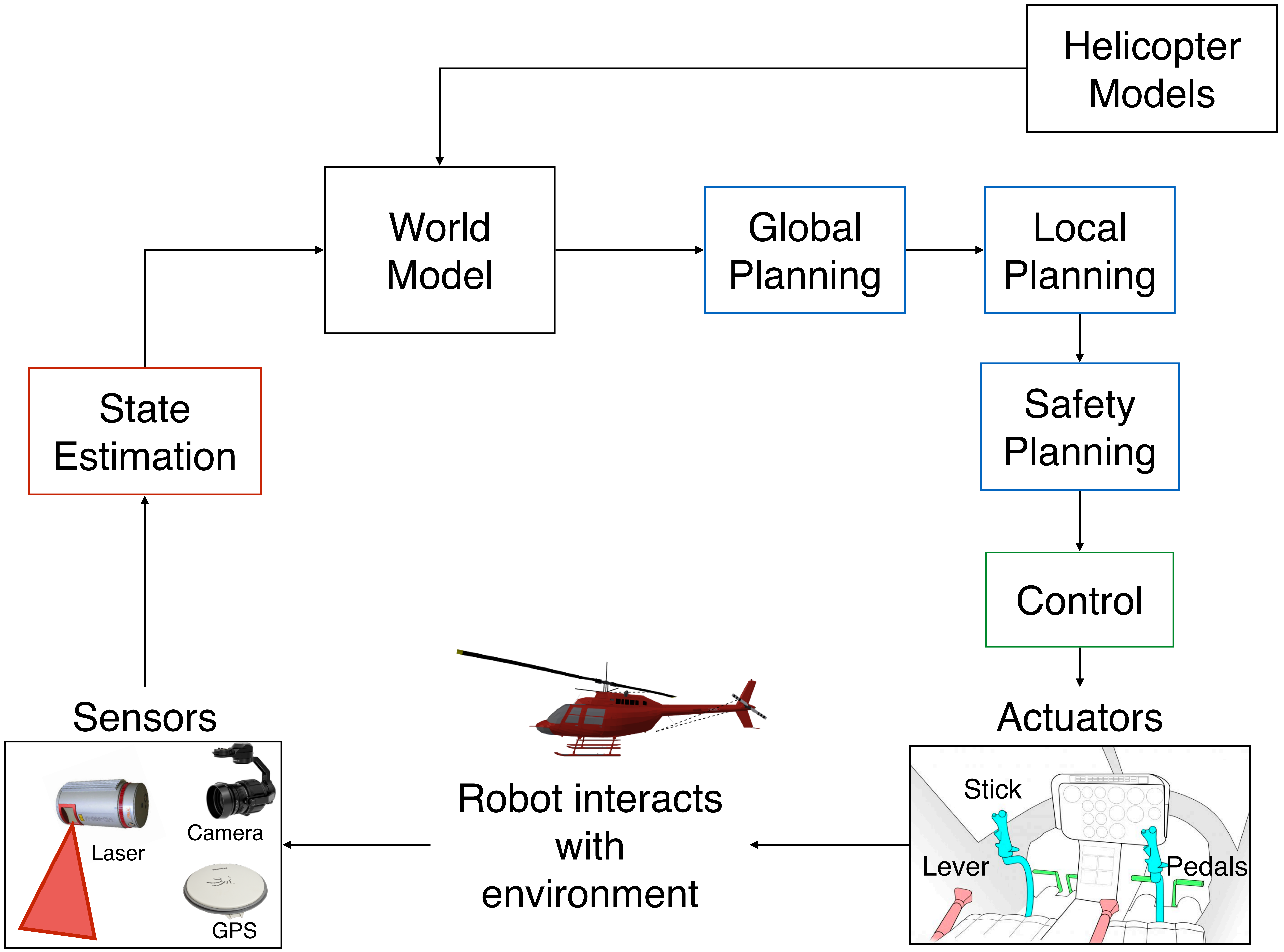
Lesson 5: Guarantee safety



What if the robot encounters unexpected obstacles?

Safety planner that guarantees the robot can stay safe



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Today's objective

1. Learn how to architect a mobile robotic system

2. Step through a set of fundamental lessons
that shape robot system / algorithm design

Anatomy of a self-driving car

BOSS: CMU’s winning entry to DARPA challenge

(2007)

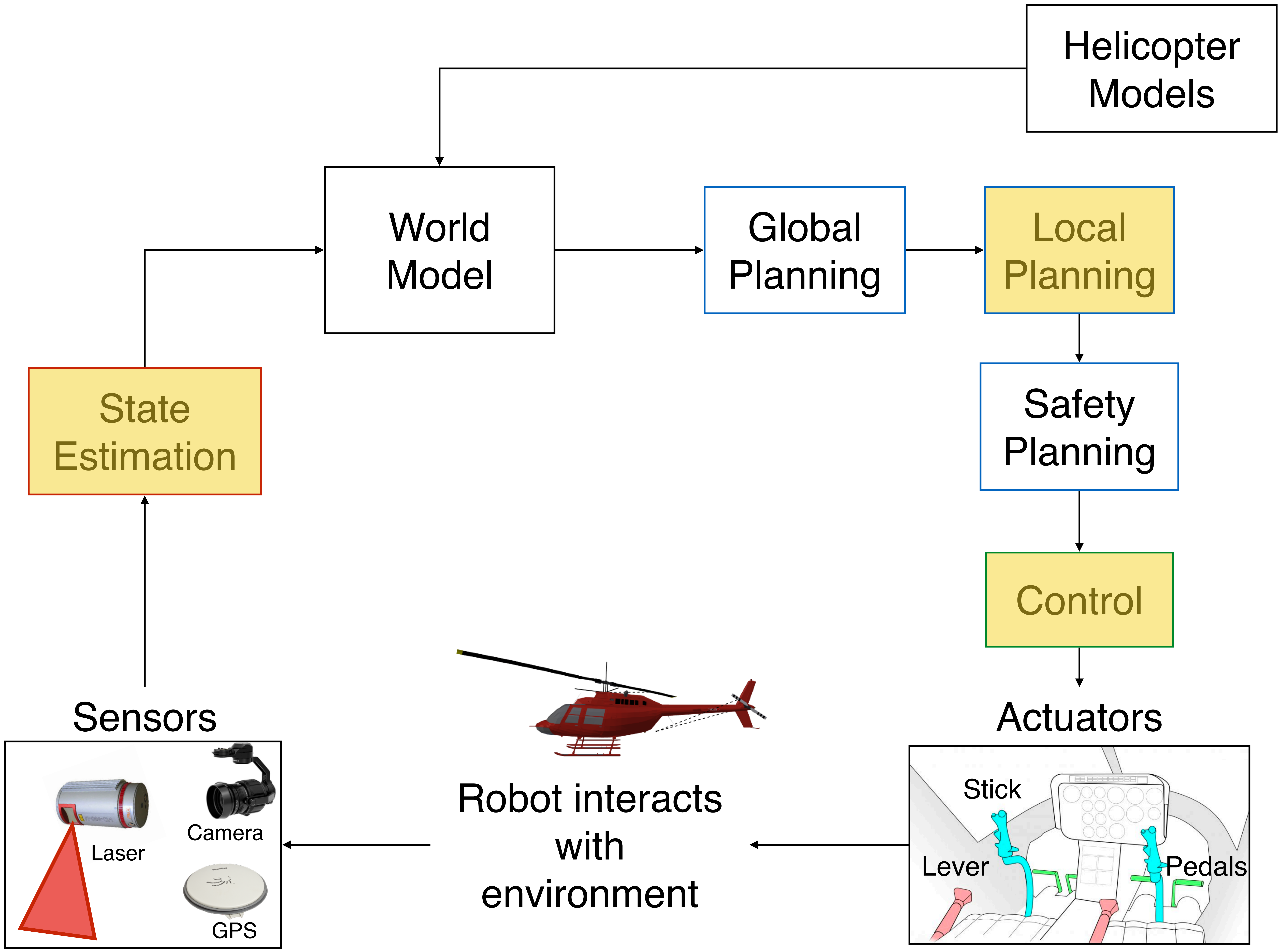

CAT
19

BOSS in action!

1. World Model
2. Car Model
3. State Estimation
4. Global Planner
5. Local Planner
6. Safety Planner
7. Control

Additional challenges: Predict human drivers

Looking ahead…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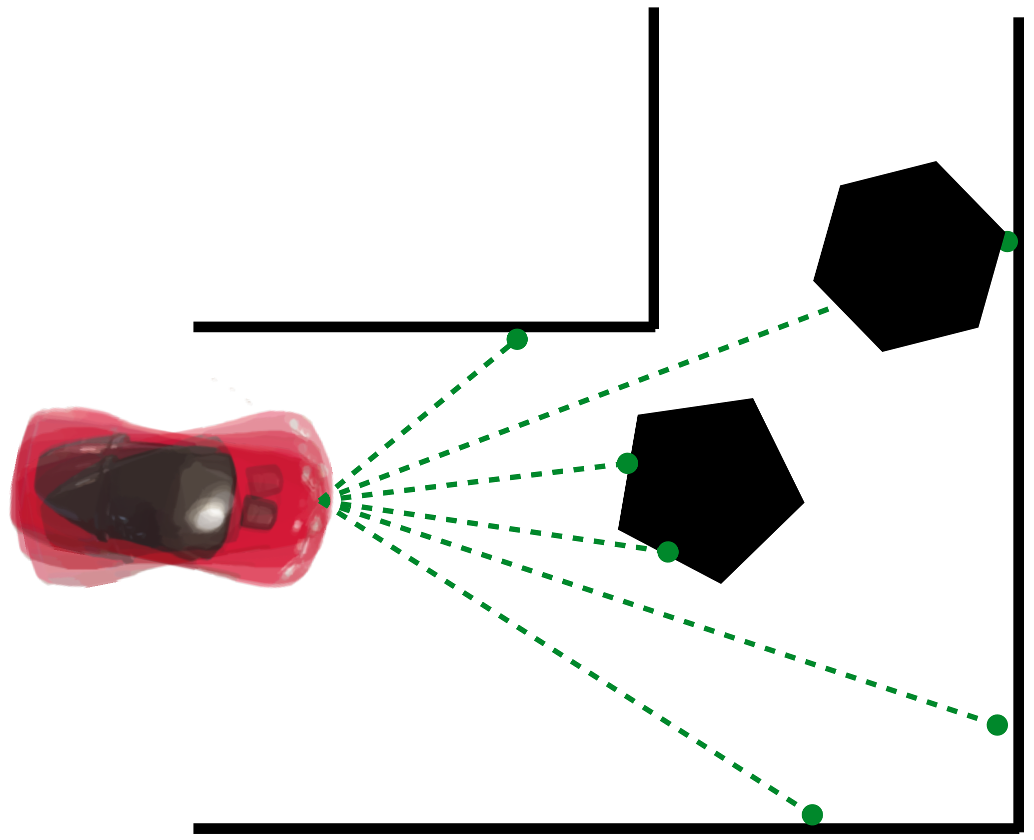
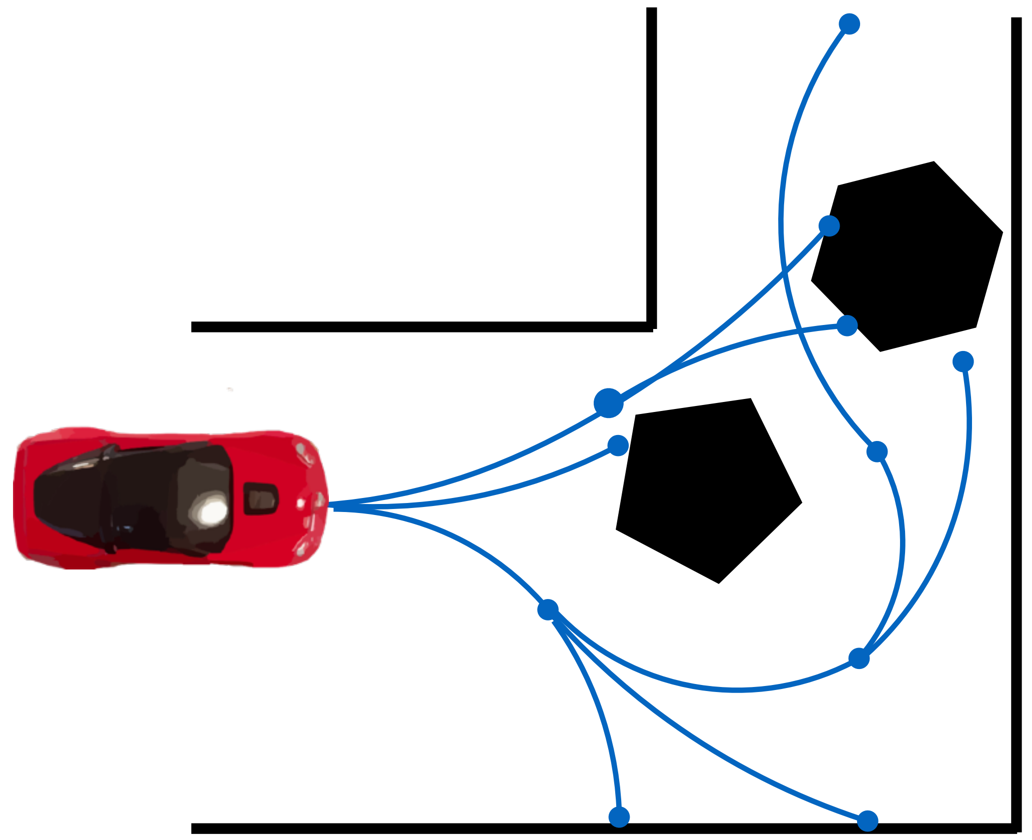
Class Overview

Estimate state



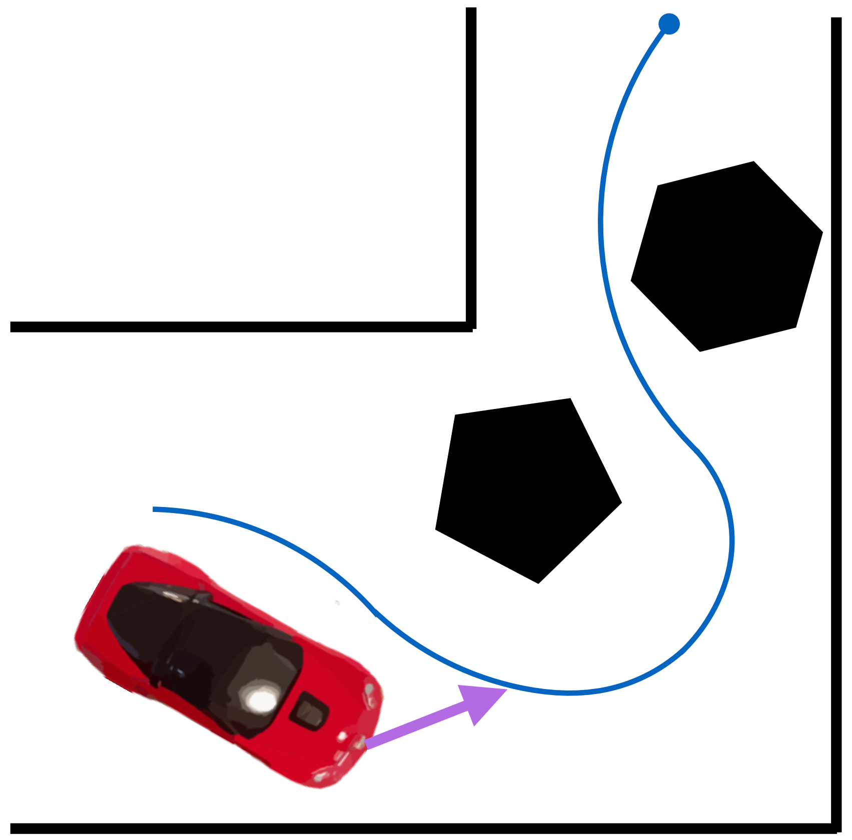
Weeks 2-4

Plan a sequence of motions



Weeks 7-8

Control robot to follow plan



Weeks 5-6

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