Auto-Park for Social Robots

By Team Daedalus

Outline

- Project Description
- Use Case
- System-Level Requirements
- Functional Architecture
- Cyber-Physical Architecture
- System and Subsystem Descriptions
- Current System Status
- Project Management
  - Work Breakdown Structure

Description

- Motivations
    - Poor parking safety standards
        - Injuries – personal and vehicular
    - Parking industry growth potential
    - Competitive advantage
    - Money
    - Time

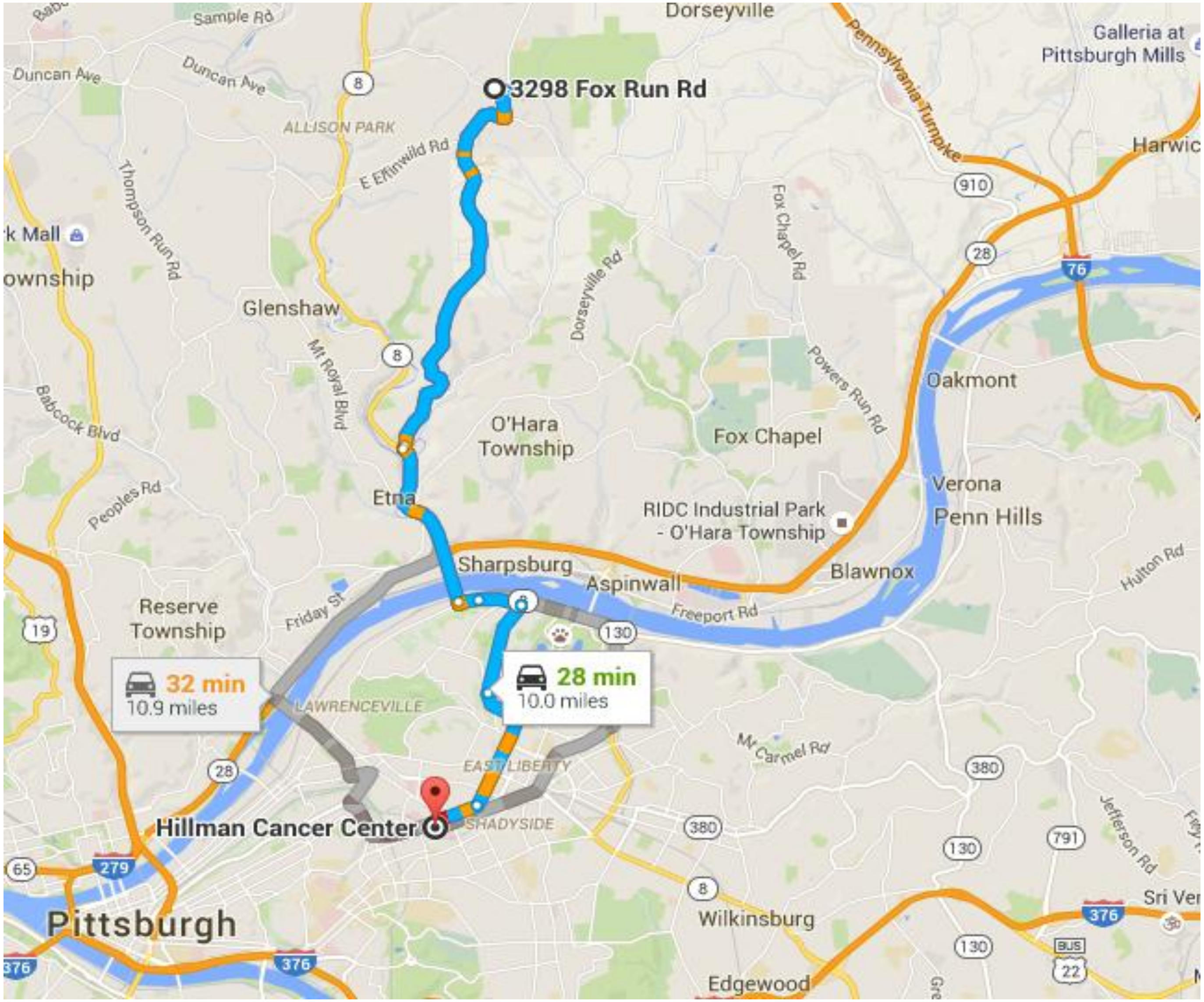
Keywords

- **Vehicle** – Also called **Mobile Platform** or **Robot.**
- **Vehicle Status:**
  - **Free**
  - **Parking**
  - **Parked**
  - **Returning**
  - **Returned**
- **Parking Lot**
- **Optimal Spot**
- **Optimal Route**

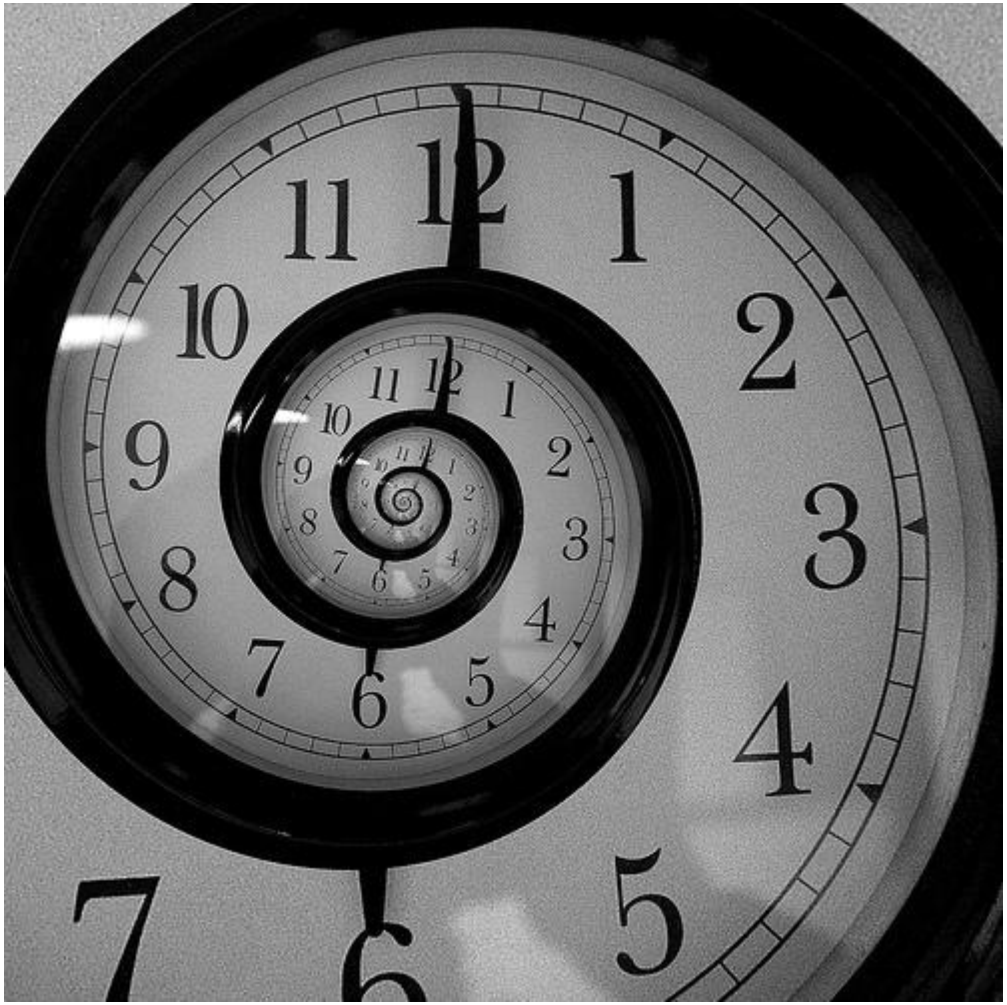
Use Case – Meet Benjamin

Ben has prostate cancer ☹

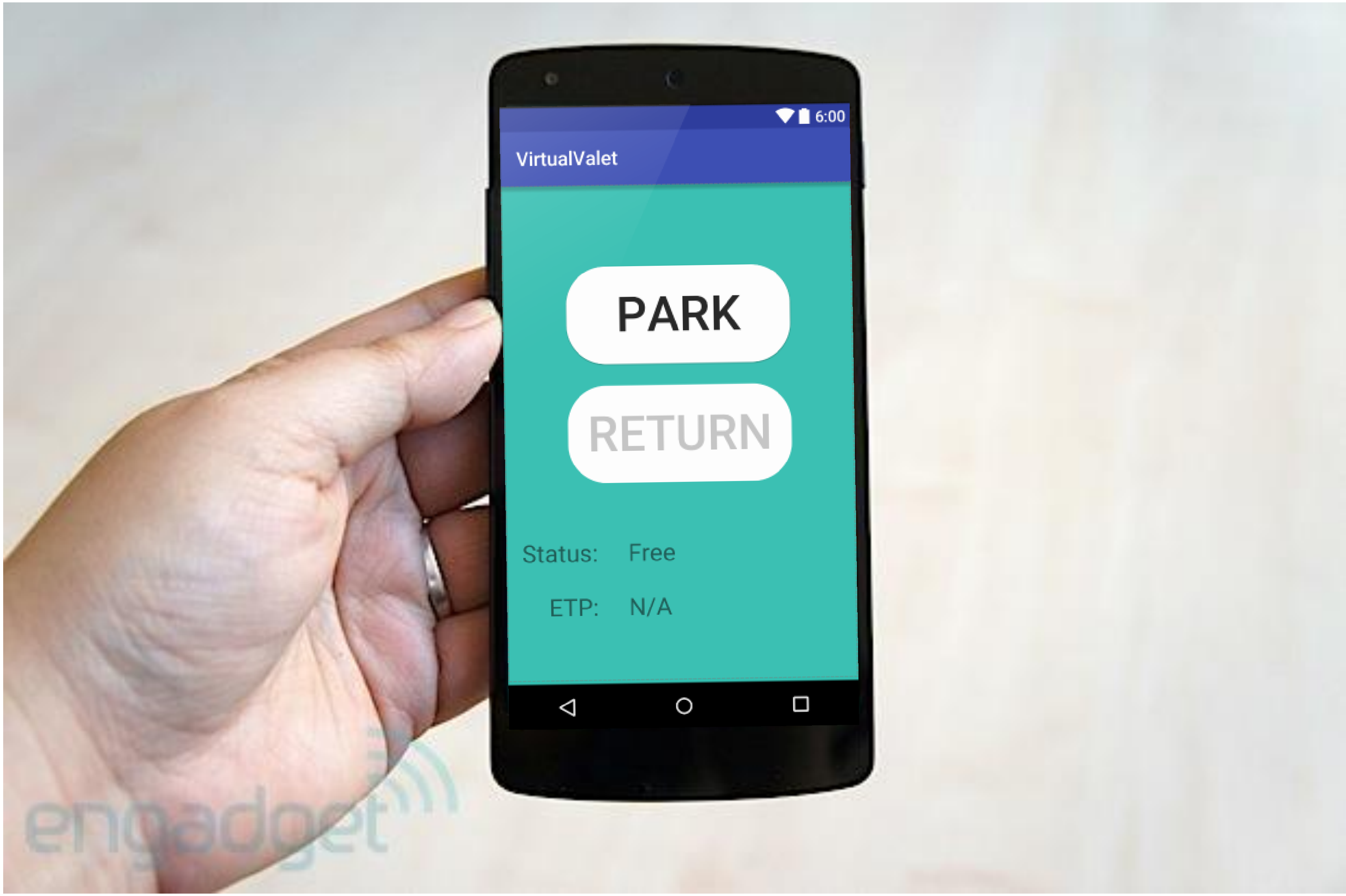
© iStockphoto / Thinkstock


3298 Fox Run Rd
Hillman Cancer Center
32 min
10.9 miles
28 min
10.0 miles
Dorseyville
Galleria at Pittsburgh Mills
Pennsylvania Turnpike
Harwic
Sample Rd
Duncan Ave
Duncan Ave
Allison Park
E Elfinwild Rd
Thompson Run Rd
k Mall
ownship
Glenshaw
Mt Royal Blvd
Dorseyville Rd
Fox Chapel Rd
Powers Run Rd
Oakmont
O'Hara Township
Fox Chapel
Verona
Penn Hills
Babcock Blvd
Peoples Rd
Etna
RIDC Industrial Park - O'Hara Township
Sharpsburg
Aspinwall
Blawnox
Hulton Rd
Freeport Rd
Reserve Township
Friday St
Lawrenceville
East Liberty
Shadyside
Mt Carmel Rd
Jefferson Rd
Pittsburgh
Wilkinsburg
Edgewood
Sri Ver
8
910
28
76
19
130
380
65
279
376
791
22
BUS

61A DOWNTOWN VIA OAKLAND
5311
THERE
HERE
61A DOWNTOWN VIA OAKLAND
015
5311
HERE THERE
PORT AUTHORITY

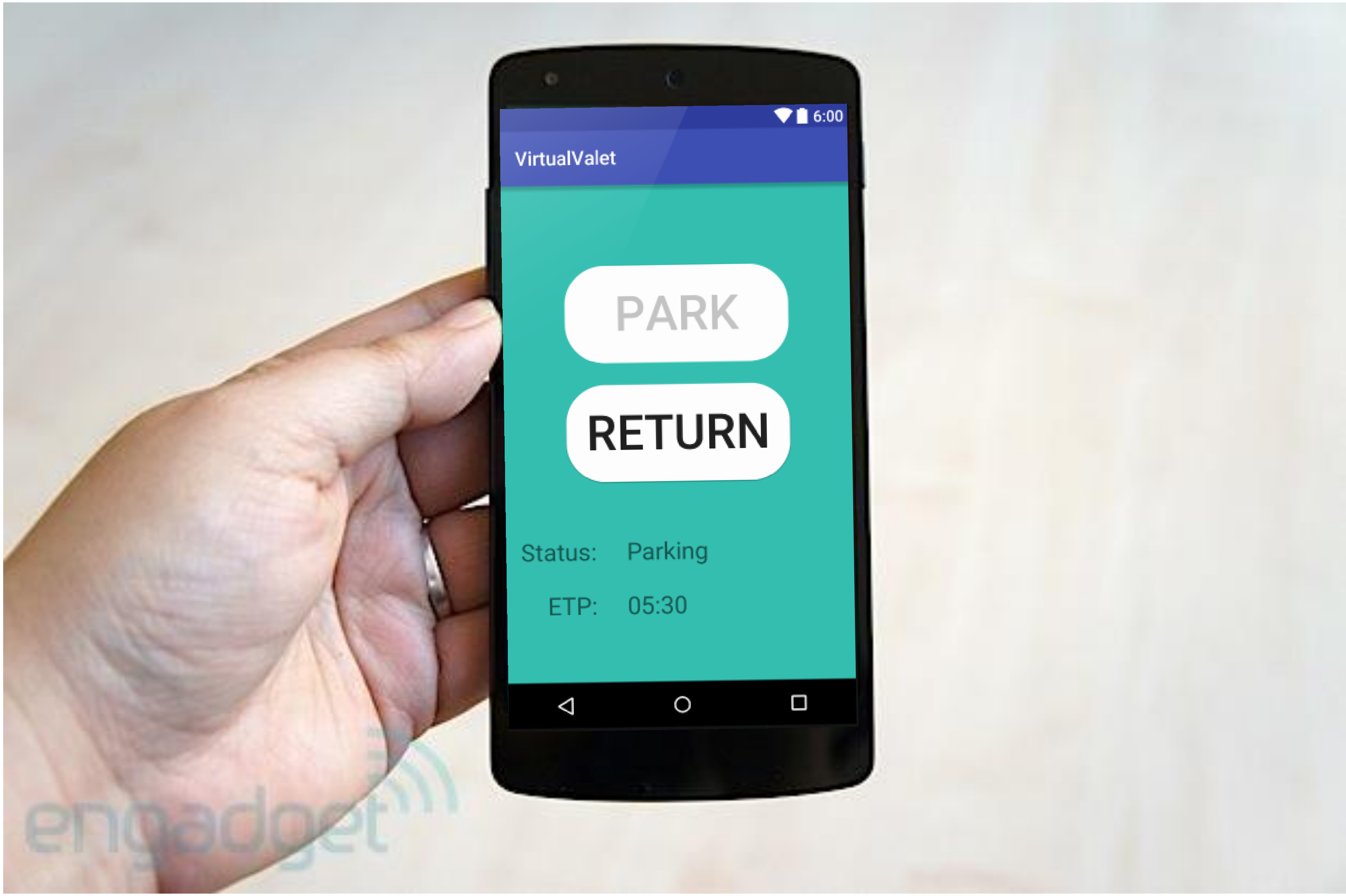


CMU-UTRC Auto-Park



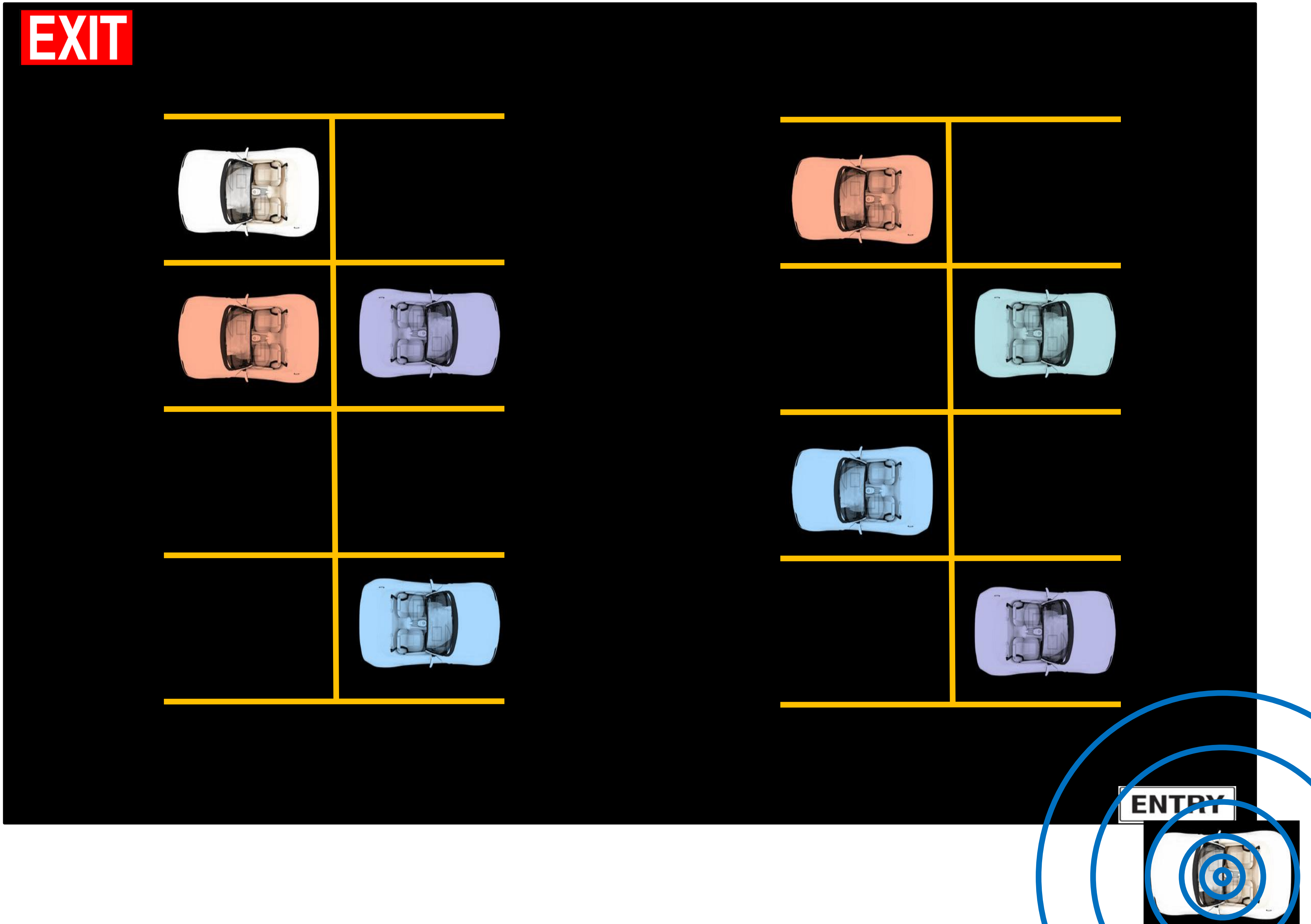
Status: Free

ETP: N/A



Status: Parking

ETP: 05:30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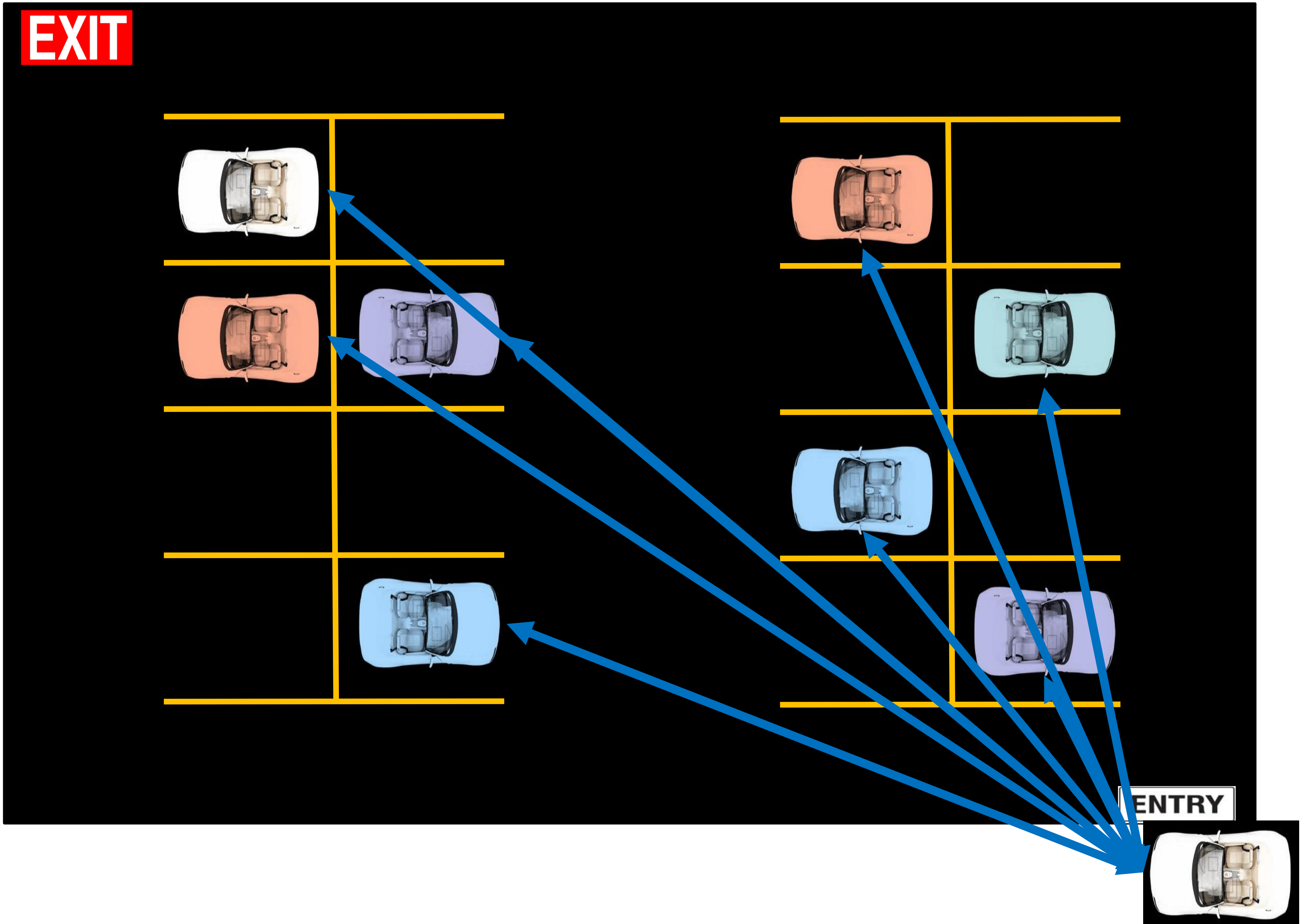
ENTRY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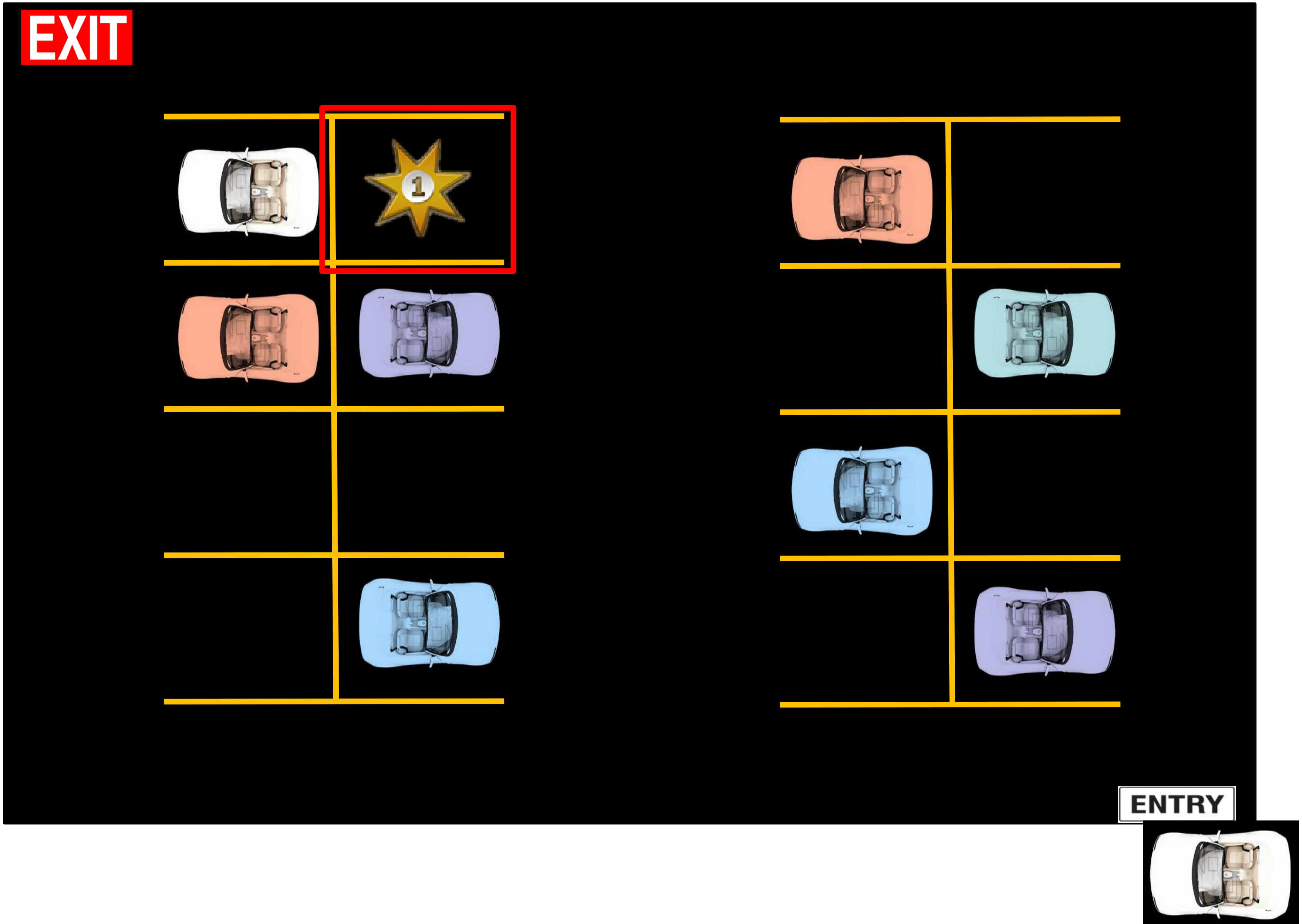
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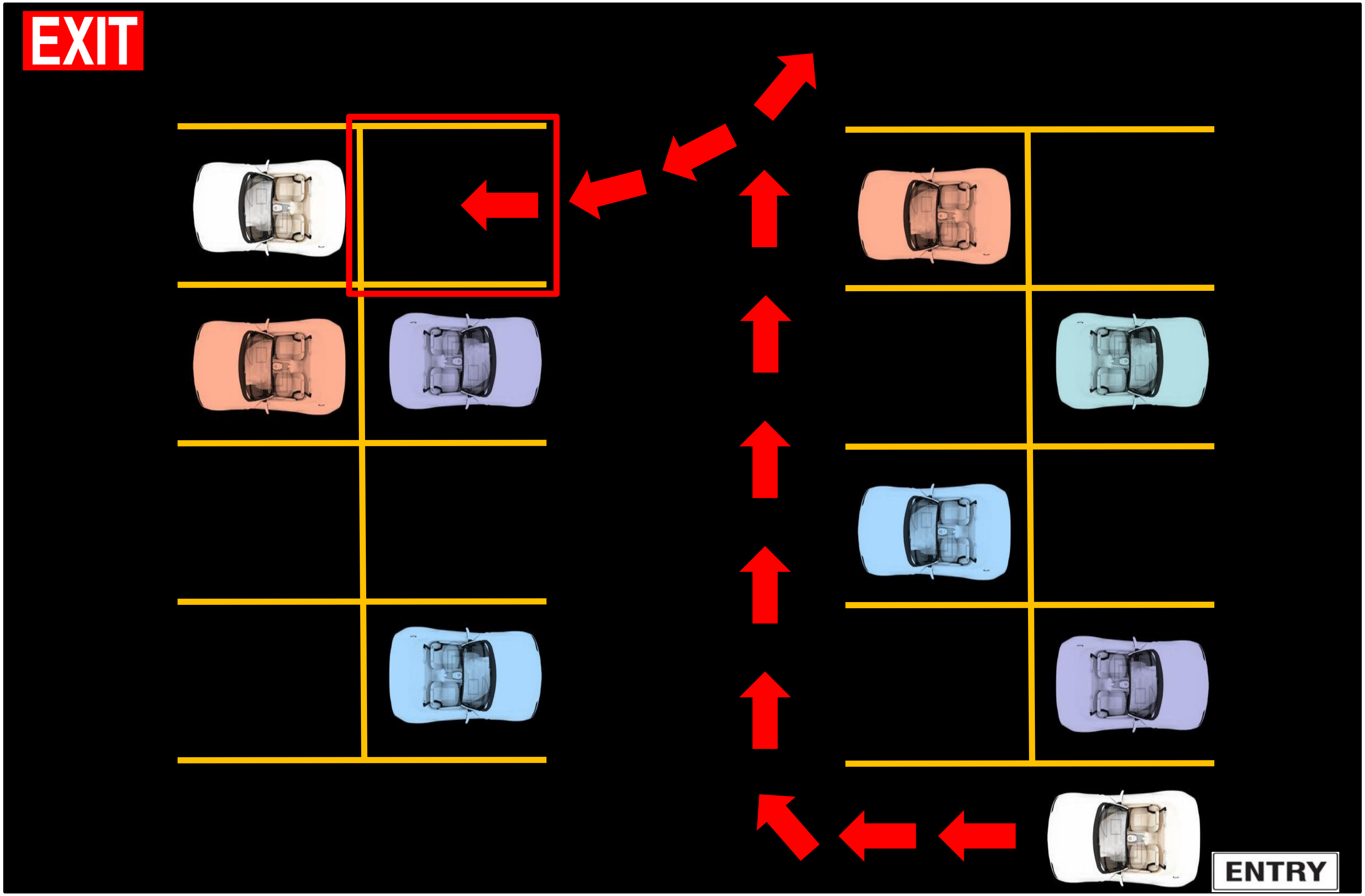
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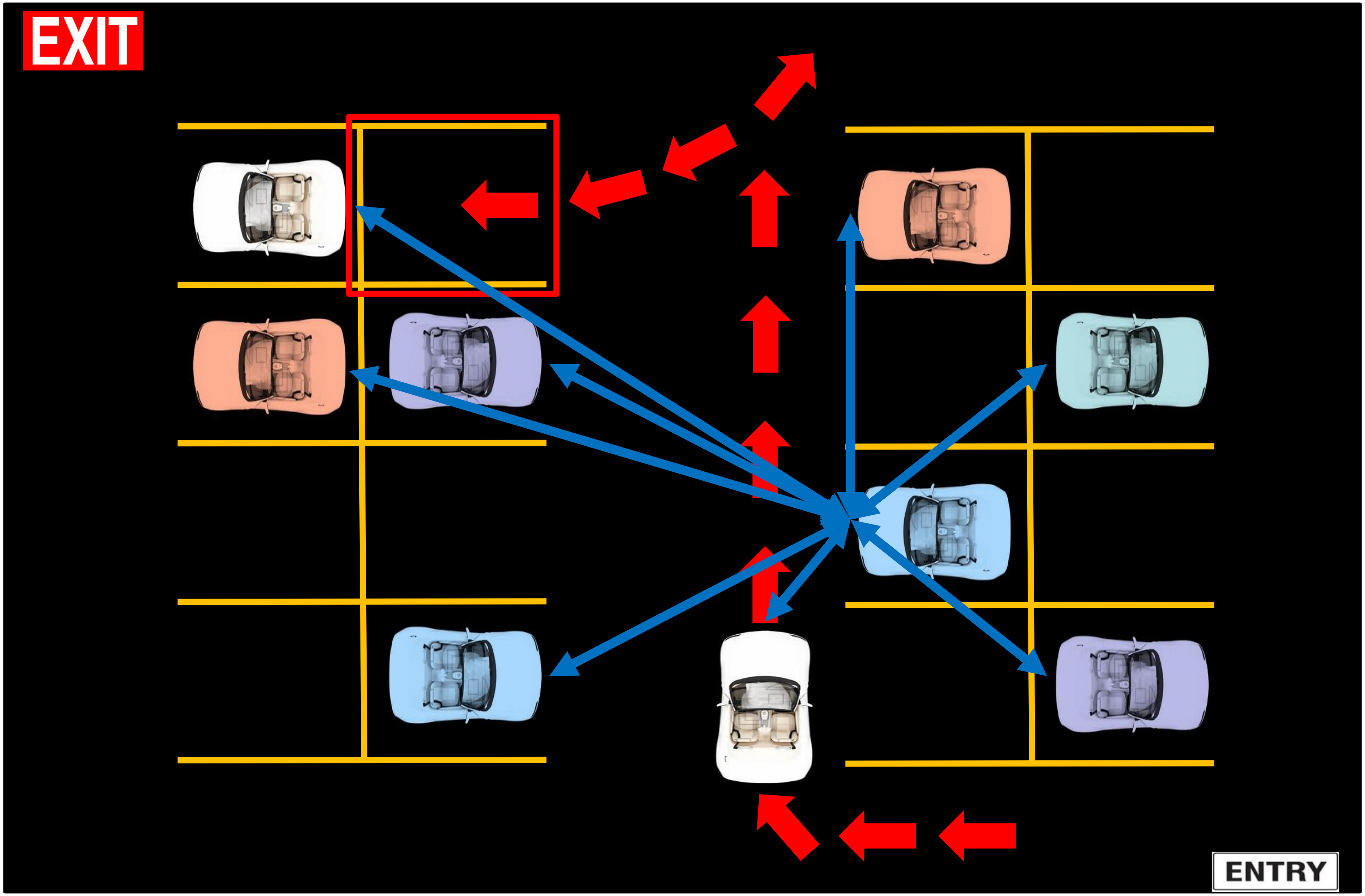
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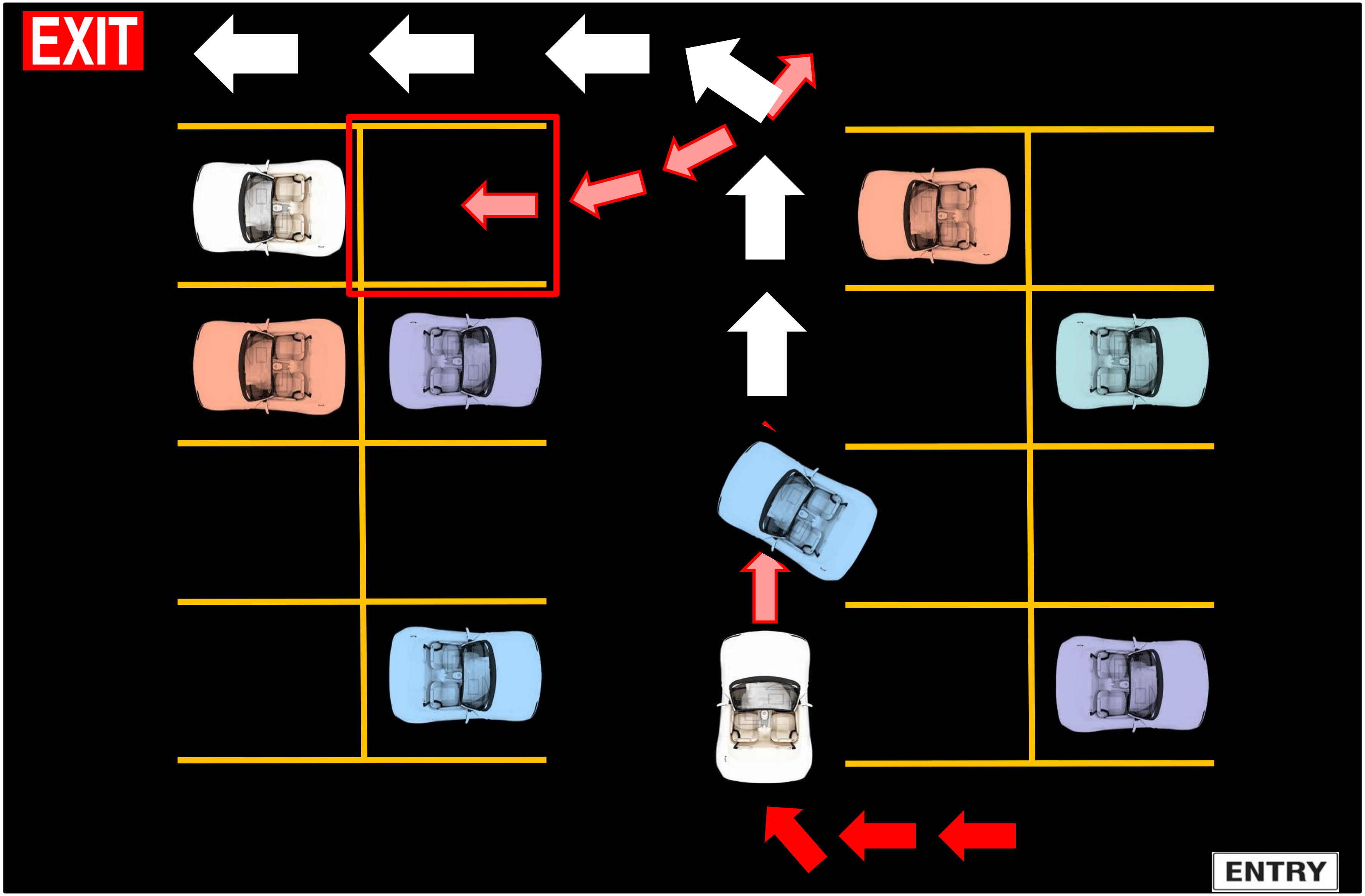
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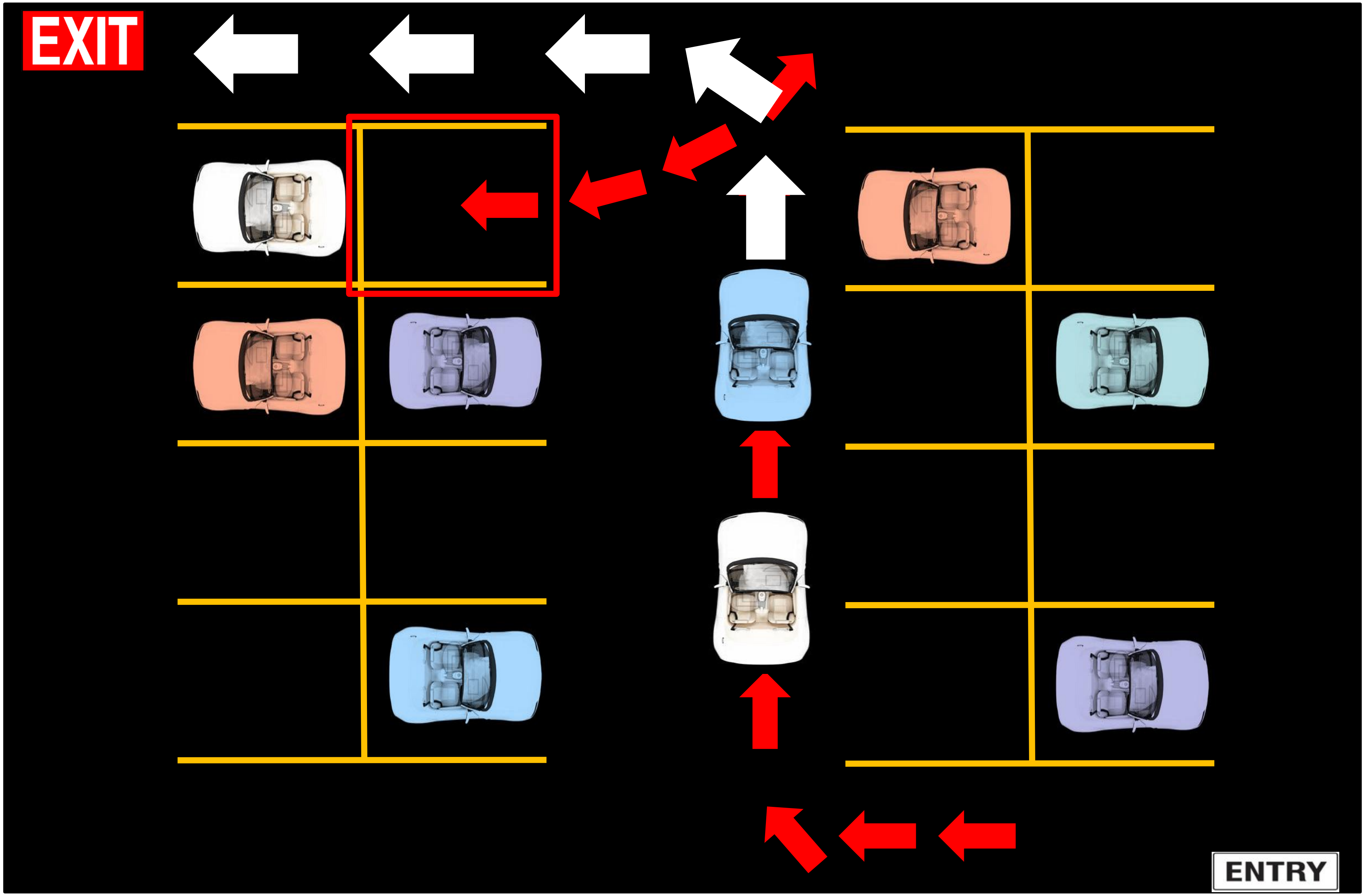
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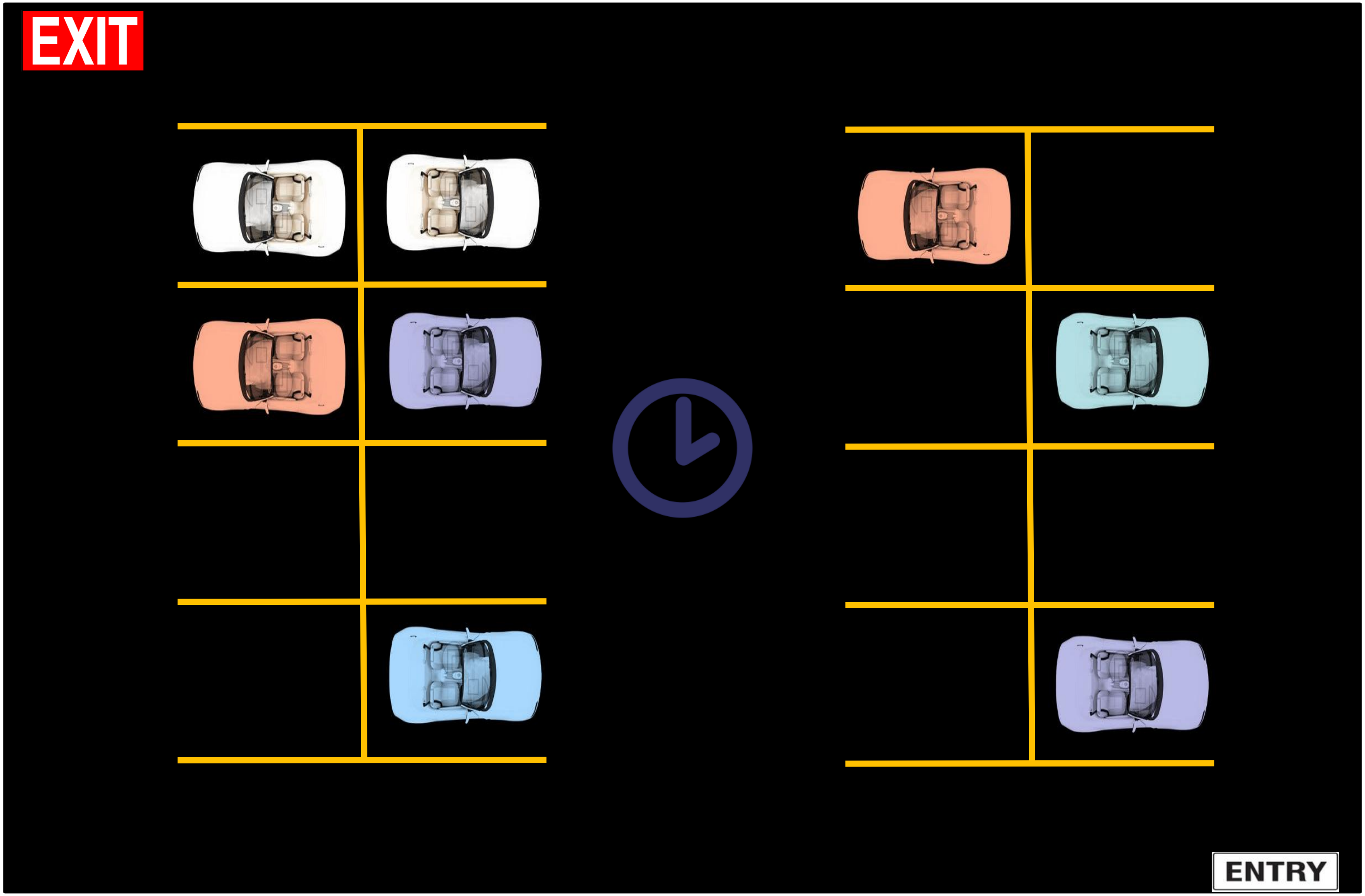
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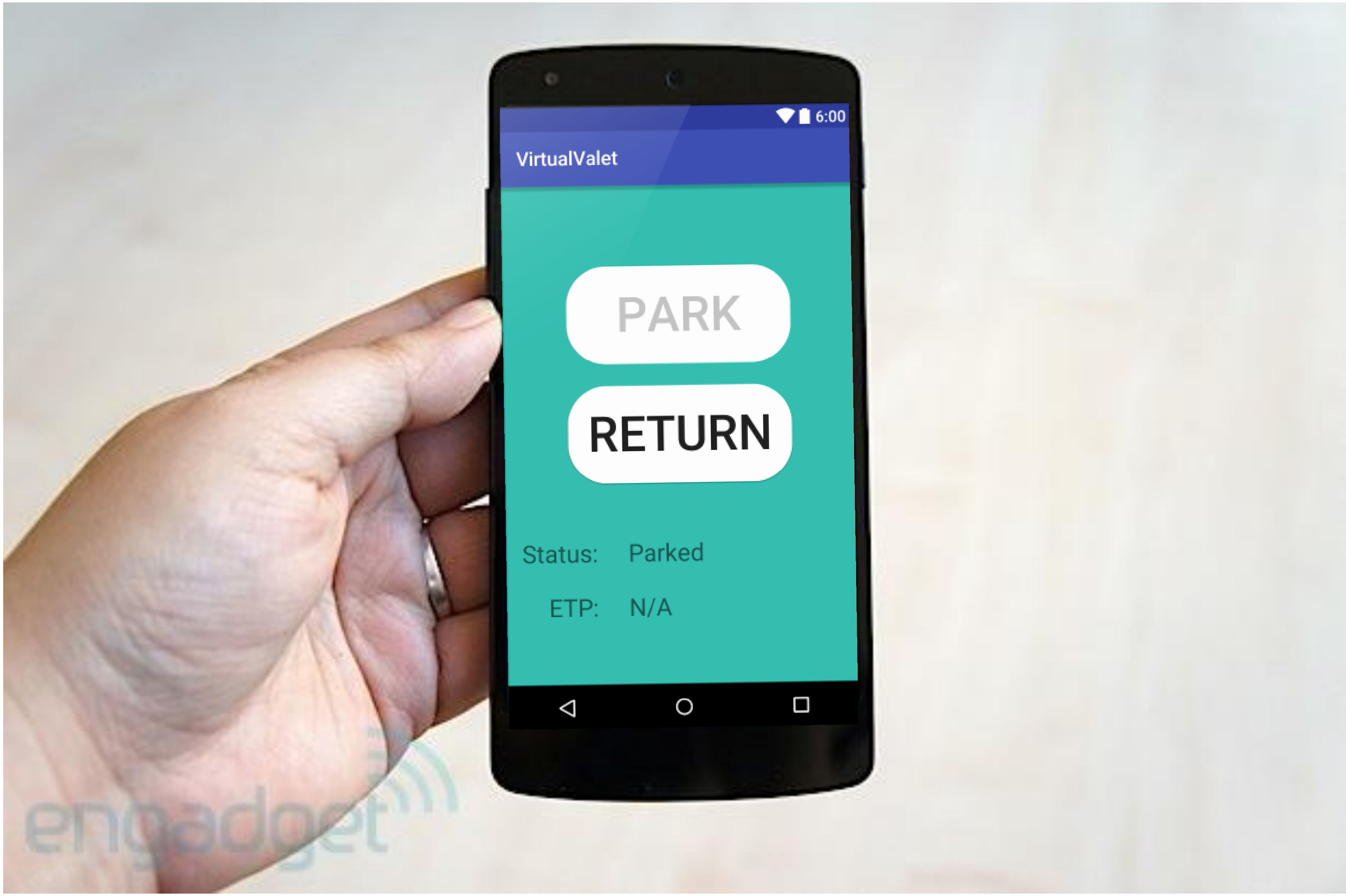
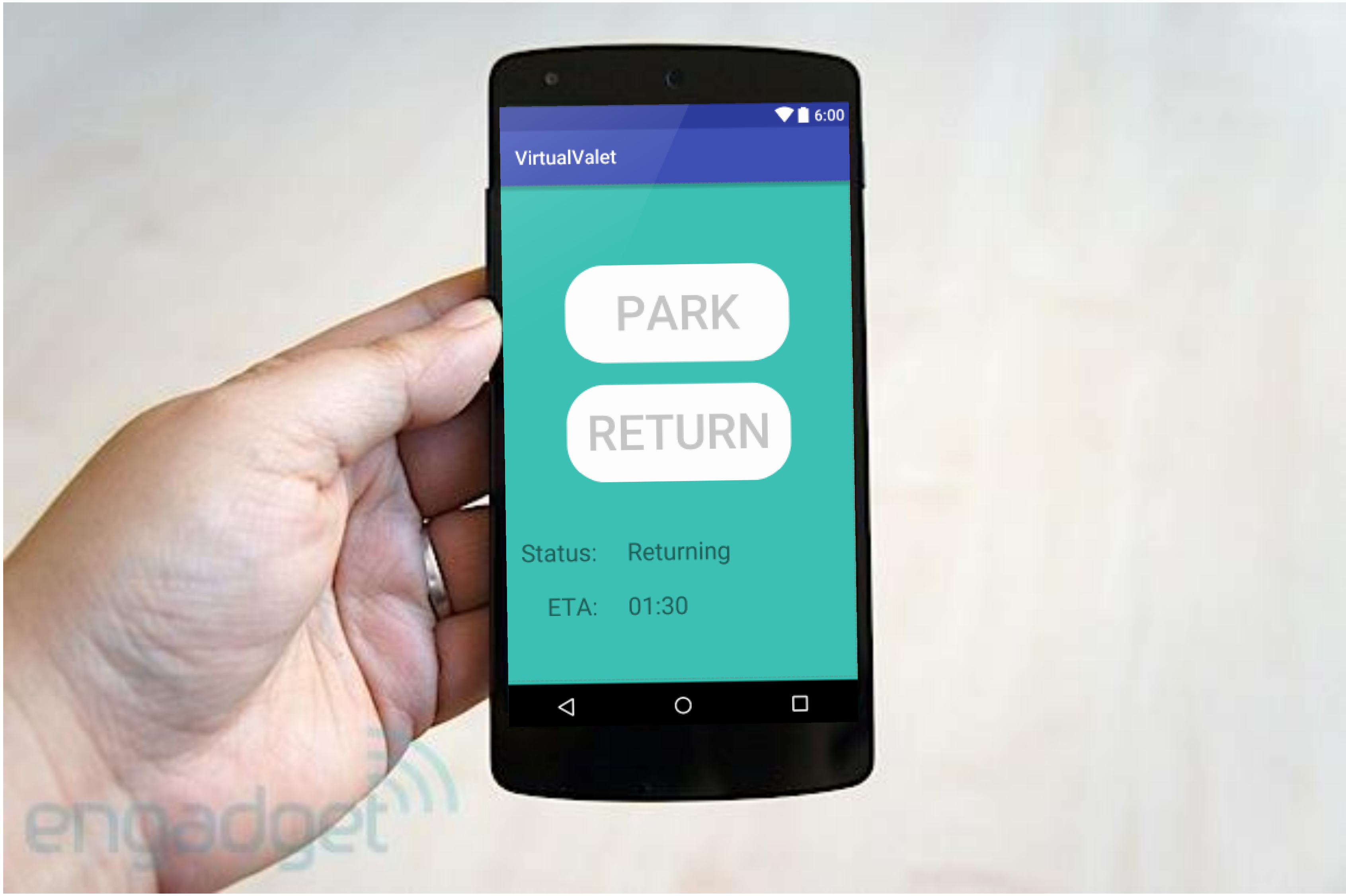


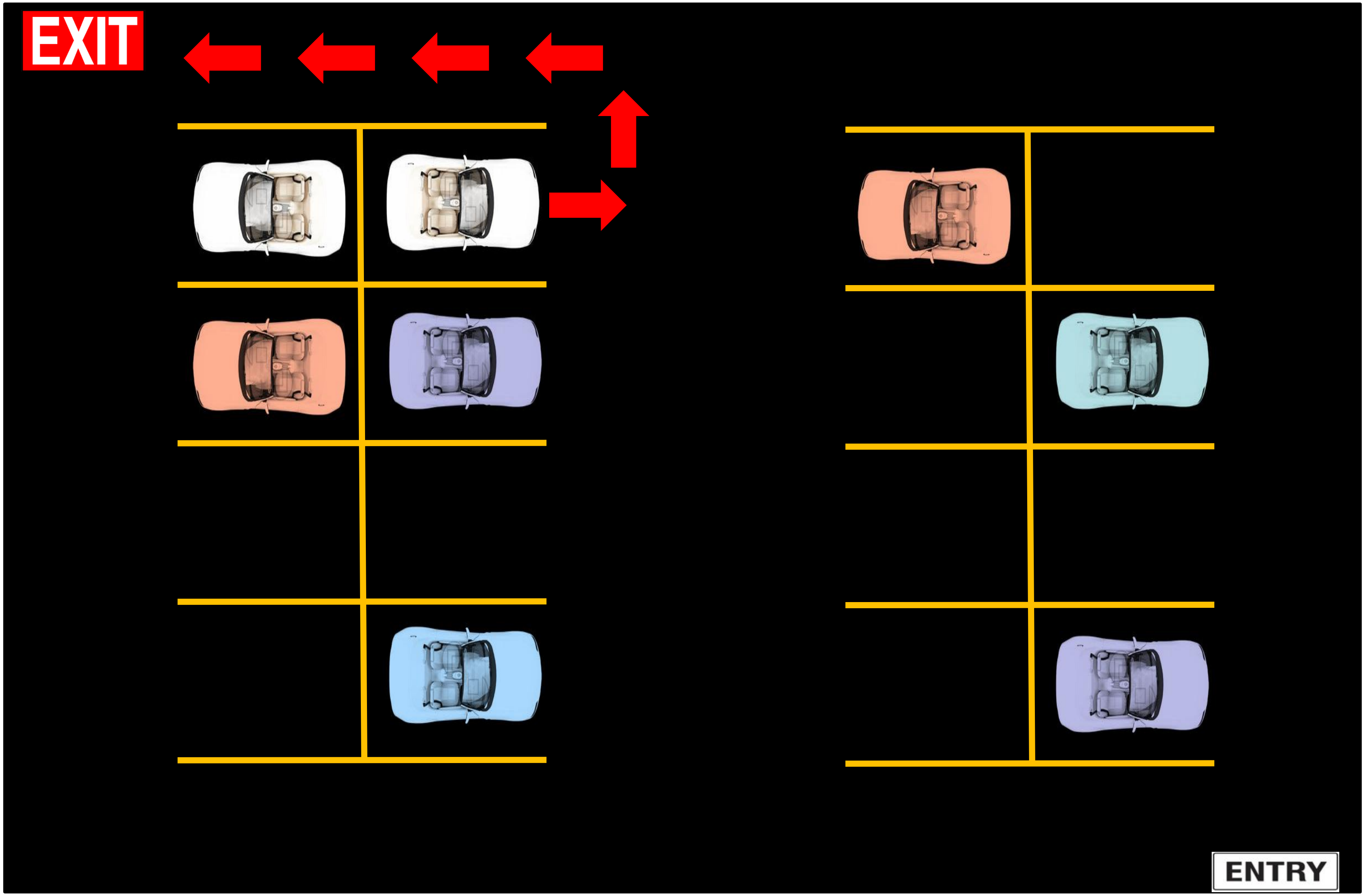
Status: Parked

ETP: N/A



Status: Returning

ETA: 01:30


EXIT
ENTRY

System-Level Requirements

Mandatory Functional Requirements

ID	Requirement	Performance Metric(s)
MF.1	Receive ‘Park’ and ‘Return’ commands from user via smartphone app	95% of messages will be received
MF.2	Share location, parking spot, obstacles related data with other vehicles	Join network within 30 seconds of approaching the parking lot 90% of messages will be received
MF.3	Navigate autonomously through parking lot	100% of navigation will be autonomous
MF.4	Plan optimal route to exit	Exit parking lot within 90 seconds of receiving command
MF.5	Follow optimal route to exit	Maintain a velocity between 0 and 10 cm/sec
MF.6	Park inside a parking spot	Park 100% within a parking spot within 2 attempts. Be within 35° of parallel with the neighboring vehicles or the lines of the spot, as applicable
MF.7	Exit parking spot	Exit the spot within 2 attempts without collision
MF.8	Sense obstacles in the environment	Avoid obstacles between 1-50 cm high and 2-120 cm wide
MF.9	Avoid infrastructure	Maintain a distance of 30.48 cm (1 ft.) between vehicle and infrastructure
MF.10	Stop in the event of an emergency	Stop within 3 seconds of an emergency (obstacle or internal vehicle error)

Mandatory Non-Functional Requirements

ID	Requirement	Performance Metric(s)
MN.1	Use smartphone app to display vehicle status	95% of messages are received
MN.2	Communicate reliably between local vehicles	Rejoin network within 30 seconds of connection loss
MN.3	Efficiently exits the parking spot	Will take no more than 45 seconds to exit the parking spot
MN.4	Return to user as quickly as possible	The vehicle will arrive at the exit within 90 seconds of receiving the “Return” command
MN.5	Make minimal changes to infrastructure	There will be ZERO changes to the infrastructure
MN.6	Be within stipulated budget	Budget is $4000

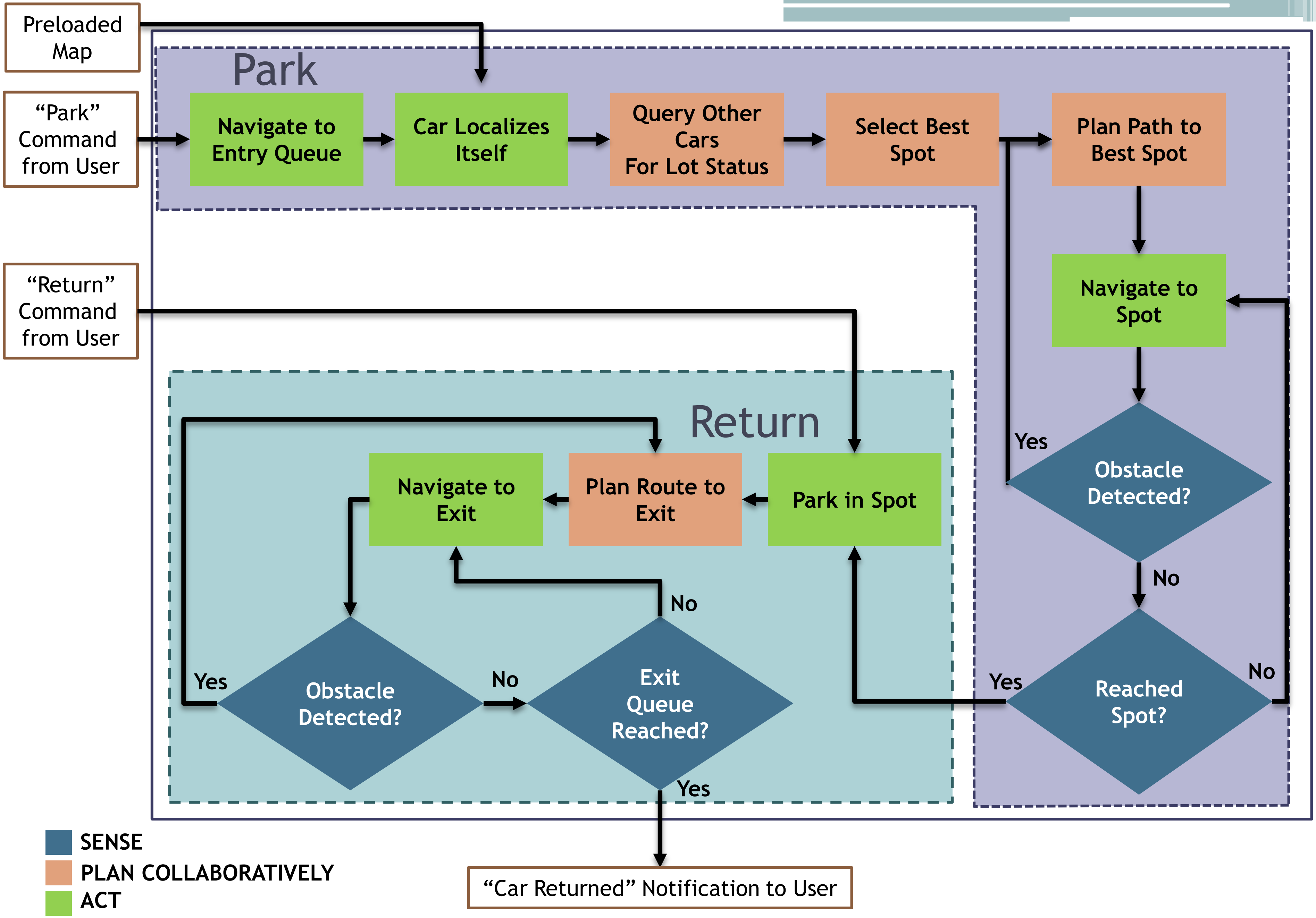
Desirable Functional Requirements

ID	Requirement	Performance Metric(s)
DF.1	Identify optimal parking spot	Identify optimal spot 98% of the time If incorrect spot is chosen, it is within 5% of optimal spot
DF.2	Plan optimal route to spot	Optimal path is chosen 90% of time
DF.3	Follow optimal route to spot	Vehicle maintains a velocity between 0 and 10 cm/sec
DF.4	Avoid other vehicles	Vehicle maintains at least 60.96 cm (2 ft.) between the front of one moving vehicle and the back of another moving vehicle

Desirable Non-Functional Requirements

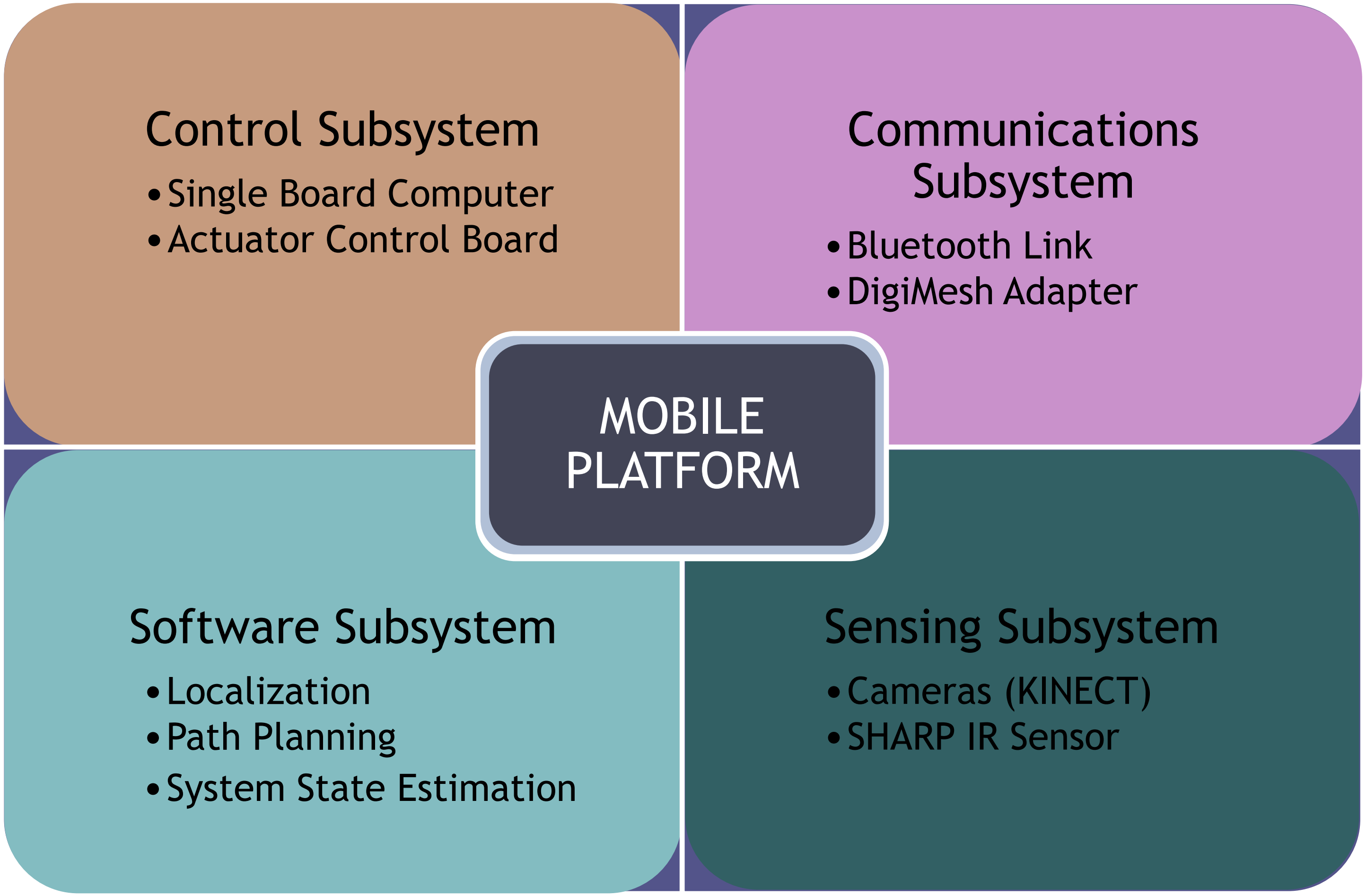
ID	Requirement	Performance Metric(s)
DN.1	Maintain scalable network of vehicles	Network able to accommodate at least 3 vehicles
DN.2	Efficiently maneuver throughout the lot	Vehicle takes the fastest route (in time) 98% of the time
DN.3	Efficiently enter the parking spot	Vehicle backs into parking spot within 2 attempts Takes no more than 45 seconds to back into spot

Functional Architecture



🟦 SENSE
🟧 PLAN COLLABORATIVELY
🟩 ACT

Cyber-Physical Architecture



Control Subsystem

- Single Board Computer
- Actuator Control Board

Communications Subsystem

- Bluetooth Link
- DigiMesh Adapter

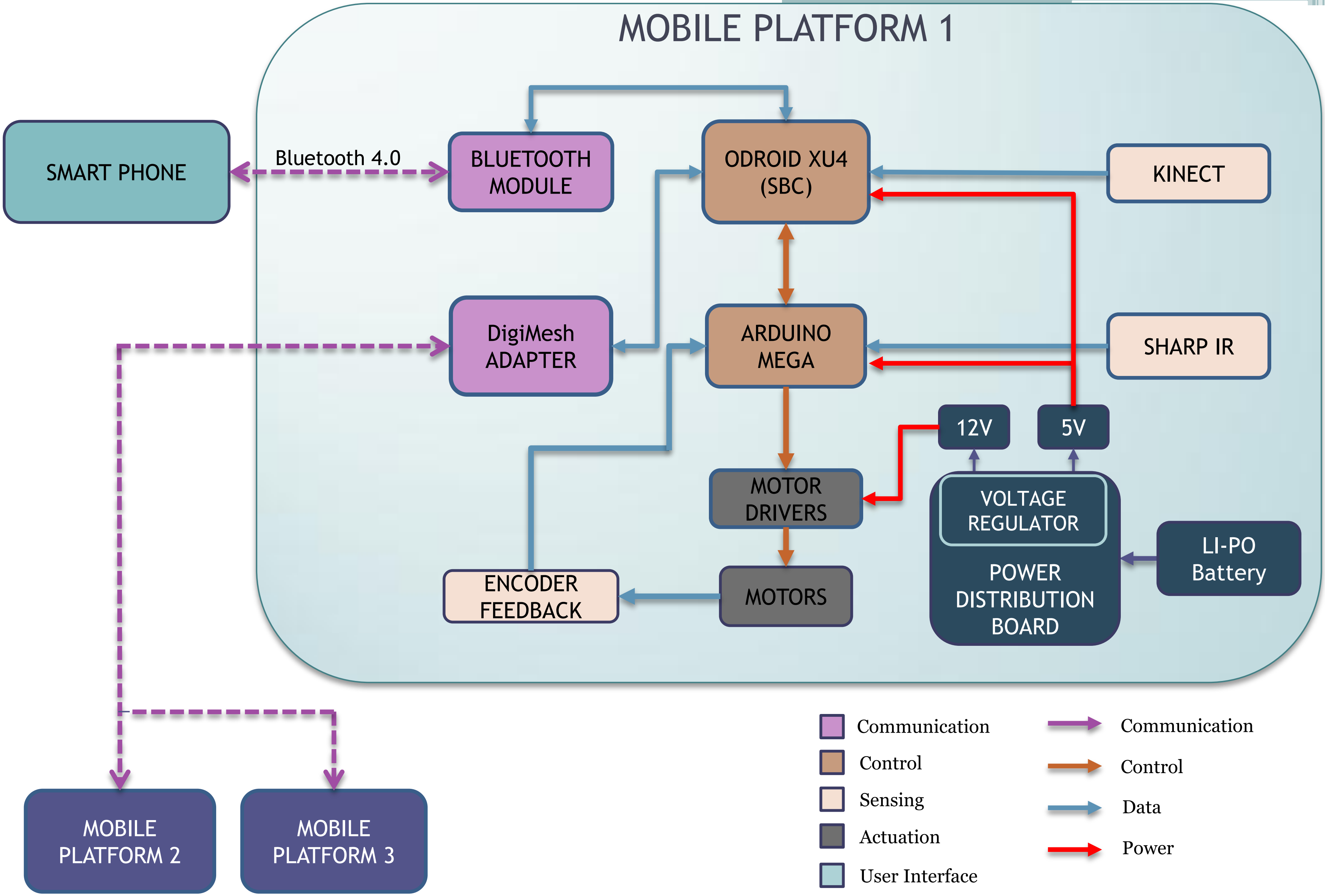
MOBILE PLATFORM

Software Subsystem

- Localization
- Path Planning
- System State Estimation

Sensing Subsystem

- Cameras (KINECT)
- SHARP IR Sensor



MOBILE PLATFORM 1

SMART PHONE

Bluetooth 4.0

BLUETOOTH MODULE

ODROID XU4 (SBC)

KINECT

DigiMesh ADAPTER

ARDUINO MEGA

SHARP IR

12V

5V

MOTOR DRIVERS

VOLTAGE REGULATOR

POWER DISTRIBUTION BOARD

LI-PO Battery

ENCODER FEEDBACK

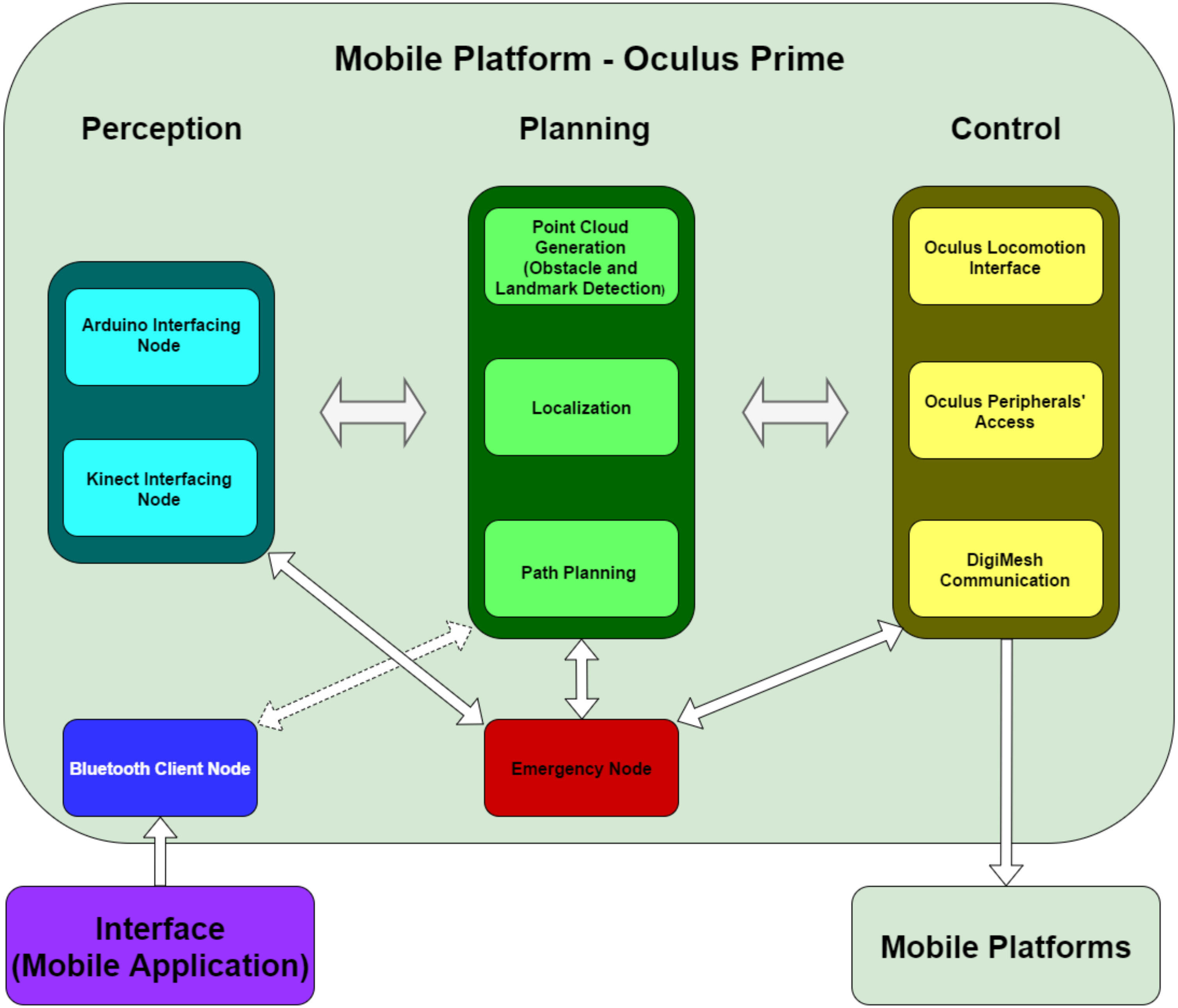
MOTORS

MOBILE PLATFORM 2

MOBILE PLATFORM 3

🟪	Communication	→	Communication
🟫	Control	→	Control
▢	Sensing	→	Data
⬛	Actuation	→	Power
▢	User Interface		

Software Architecture



Mobile Platform - Oculus Prime

Perception

Planning

Control

Arduino Interfacing Node

Kinect Interfacing Node

Point Cloud Generation (Obstacle and Landmark Detection)

Localization

Path Planning

Oculus Locomotion Interface

Oculus Peripherals' Access

DigiMesh Communication

Bluetooth Client Node

Emergency Node

Interface (Mobile Application)

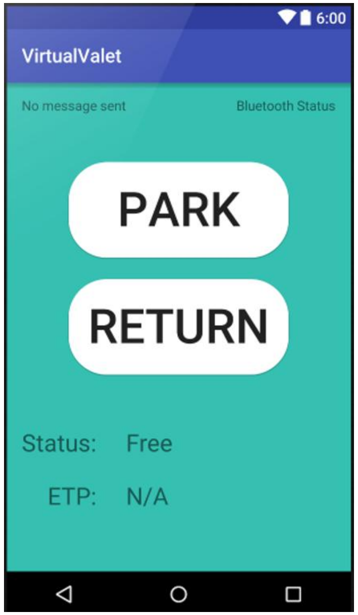
Mobile Platforms

System and Subsystem Descriptions

- User Interface
- Control
- Navigation
- Sensing and Perception
- Communications

User Interface

- Android Application
- Bluetooth Link
- Mobile Platform



6:00

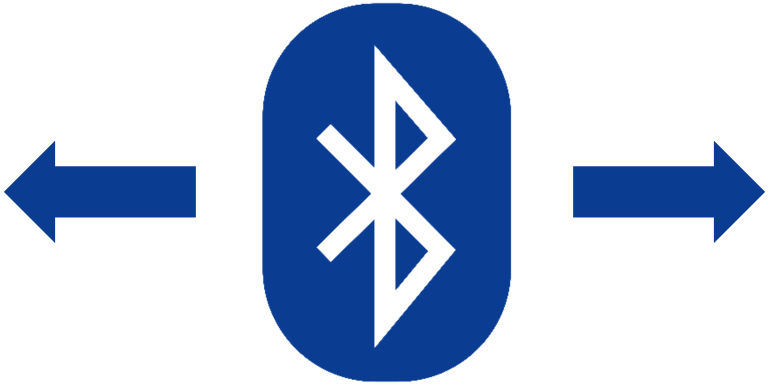
VirtualValet

No message sent

Bluetooth Status

Status: Free

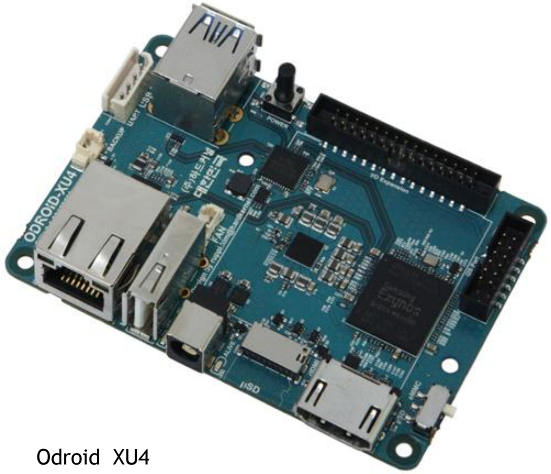
ETP: N/A



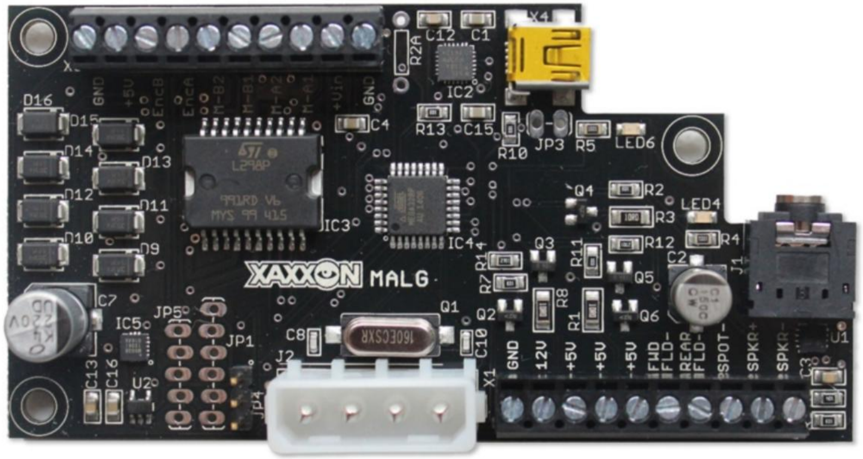
Oculus Prime
http://www.xaxxon.com/

Control

- Single Board Computer
- Actuator Control Board
- ROS Environment



Odroid XU4
http://www.hardkernel.com/main/products/prdt_info.php

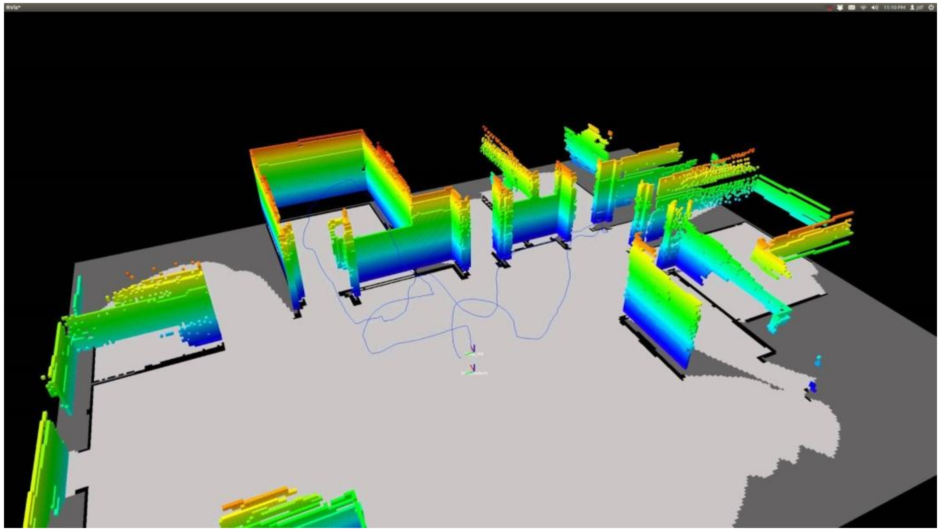


Xaxxon MALG PCB
http://www.xaxxon.com/resources/malg_datasheet.pdf

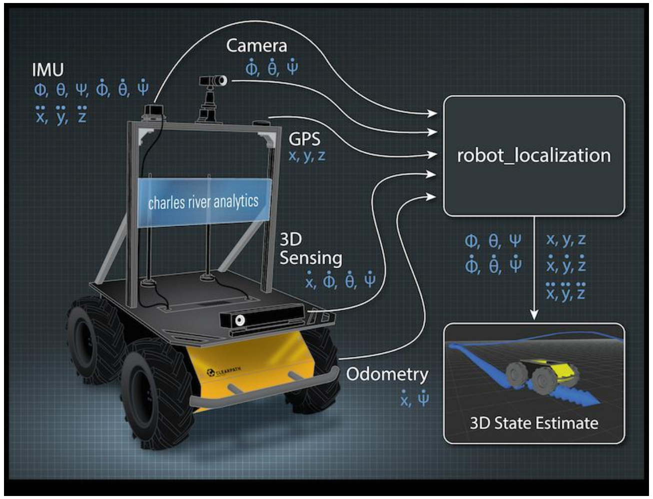
Oculus Prime
http://www.xaxxon.com/

Navigation

- Map Generation
- Localization
- Path Planning

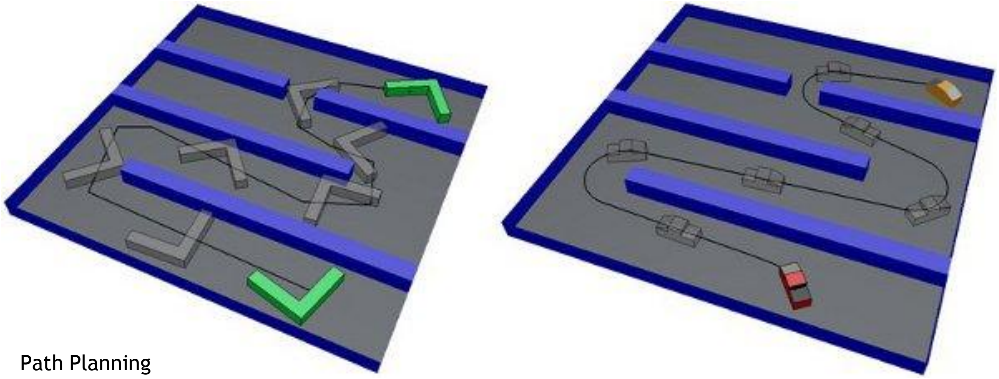


Visualizing LIDAR data in Rviz
https://www.youtube.com/watch?v=quqF5_ZE_fI



IMU
$\phi, \theta, \psi, \dot{\phi}, \dot{\theta}, \dot{\psi}$
$\ddot{x}, \ddot{y}, \ddot{z}$
Camera
$\dot{\phi}, \dot{\theta}, \dot{\psi}$
GPS
x, y, z
charles river analytics
3D Sensing
$\dot{x}, \dot{\phi}, \dot{\theta}, \dot{\psi}$
Odometry
$\dot{x}, \dot{\psi}$
robot_localization
ϕ, θ, ψ
$\dot{\phi}, \dot{\theta}, \dot{\psi}$
x, y, z
$\dot{x}, \dot{y}, \dot{z}$
$\ddot{x}, \ddot{y}, \ddot{z}$
3D State Estimate

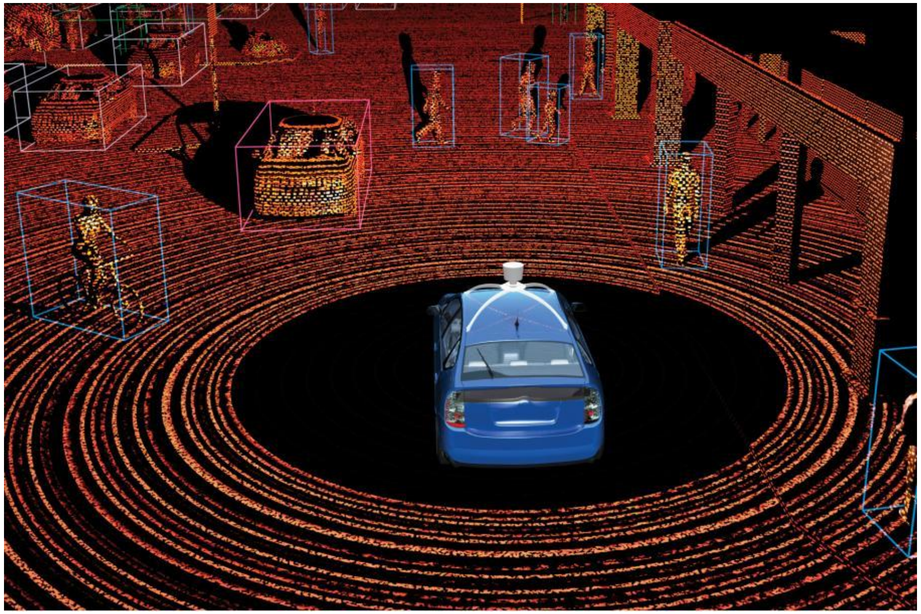
Localization using Sensor Fusion
http://wiki.ros.org/robot_localization



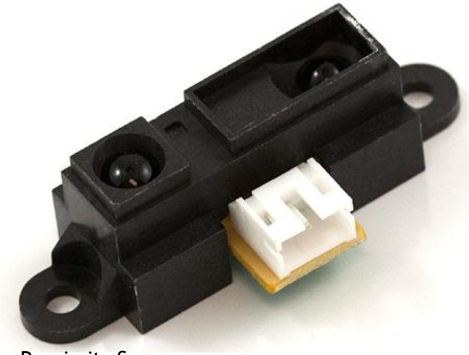
Path Planning
http://www.coppeliarobotics.com/helpFiles/en/pathPlanningModule.htm

Sensing and Perception

- Kinect
- SHARP IR



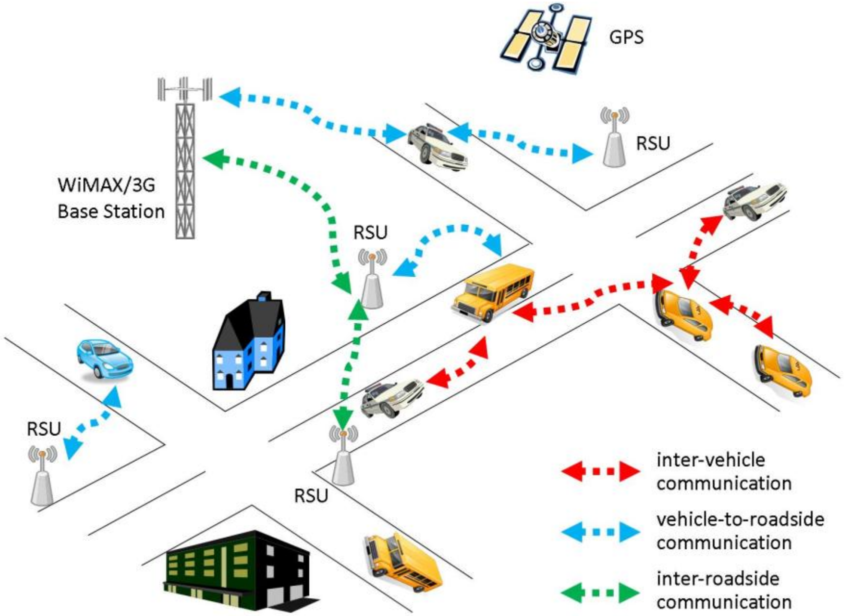
Sensing the Environment
http://www.universaldesignstyle.com/see-google-self-driving-car-sees/



Proximity Sensor
https://www.sparkfun.com/products/242

Communications

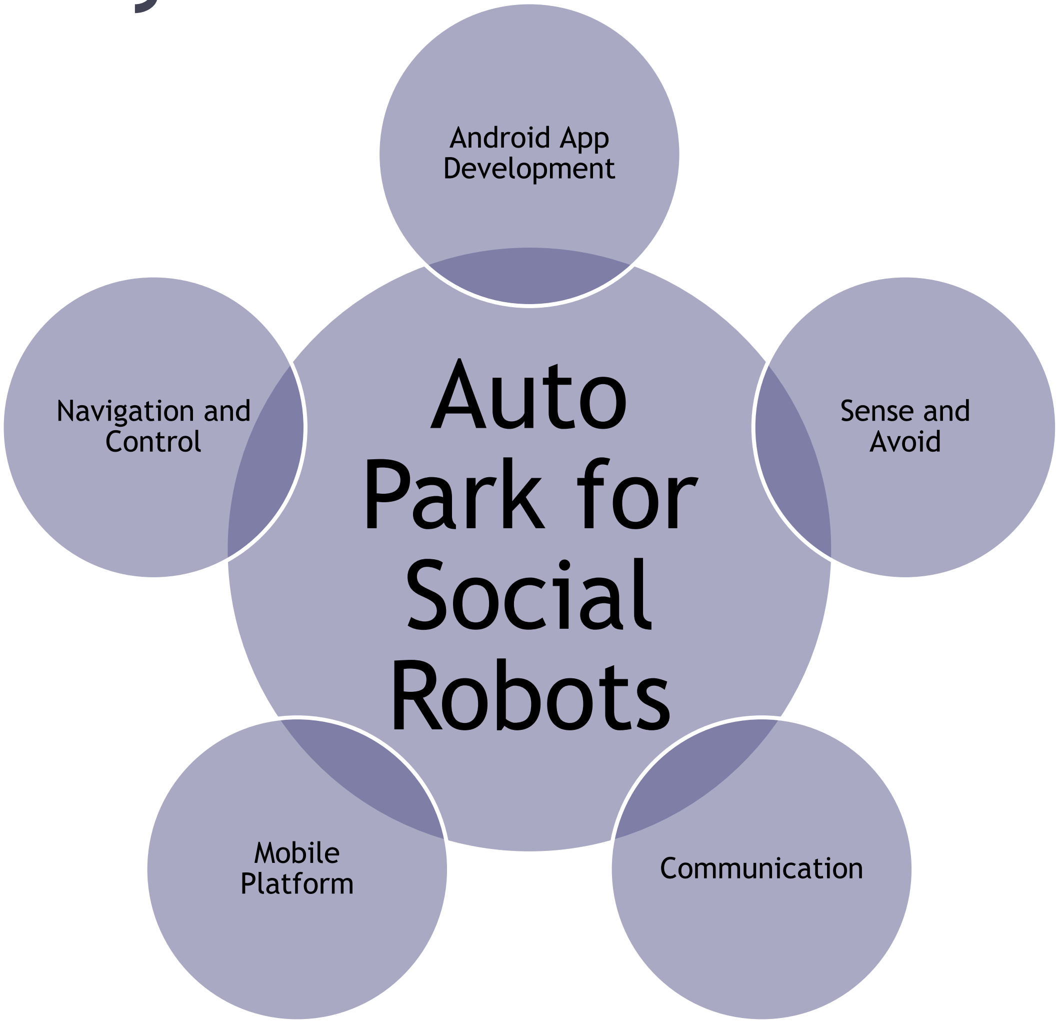
- Hardware
- Architecture


GPS
RSU
WiMAX/3G
Base Station
RSU
RSU
RSU
inter-vehicle communication
vehicle-to-roadside communication
inter-roadside communication

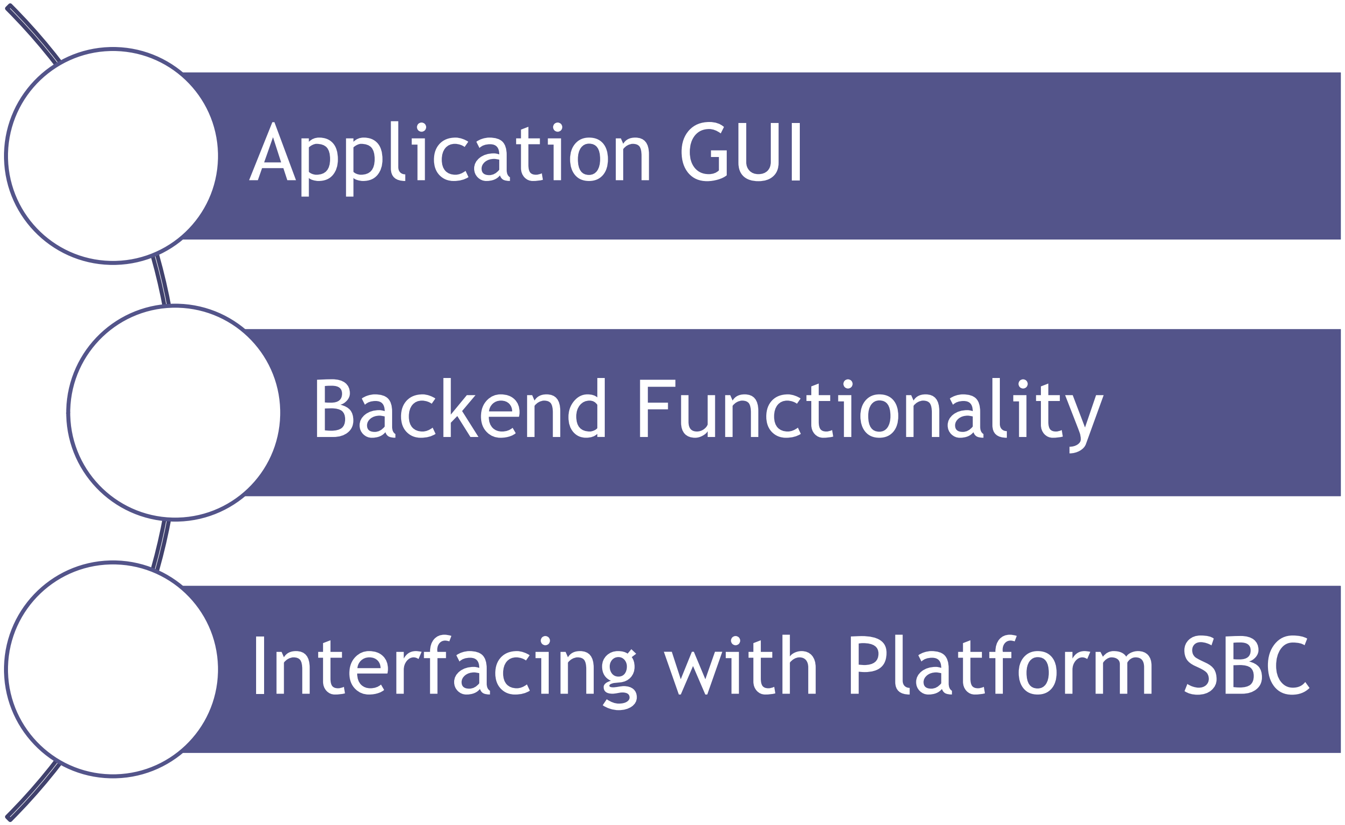
VANETS – George Corser
https://www.youtube.com/watch?v=DrH-1505-Mg

DigiMesh RF 900Mhz Module
http://www.digi.com/products/xbee-rf-solutions/modules/xbee-pro-900hp

Current System Status



Android App Development

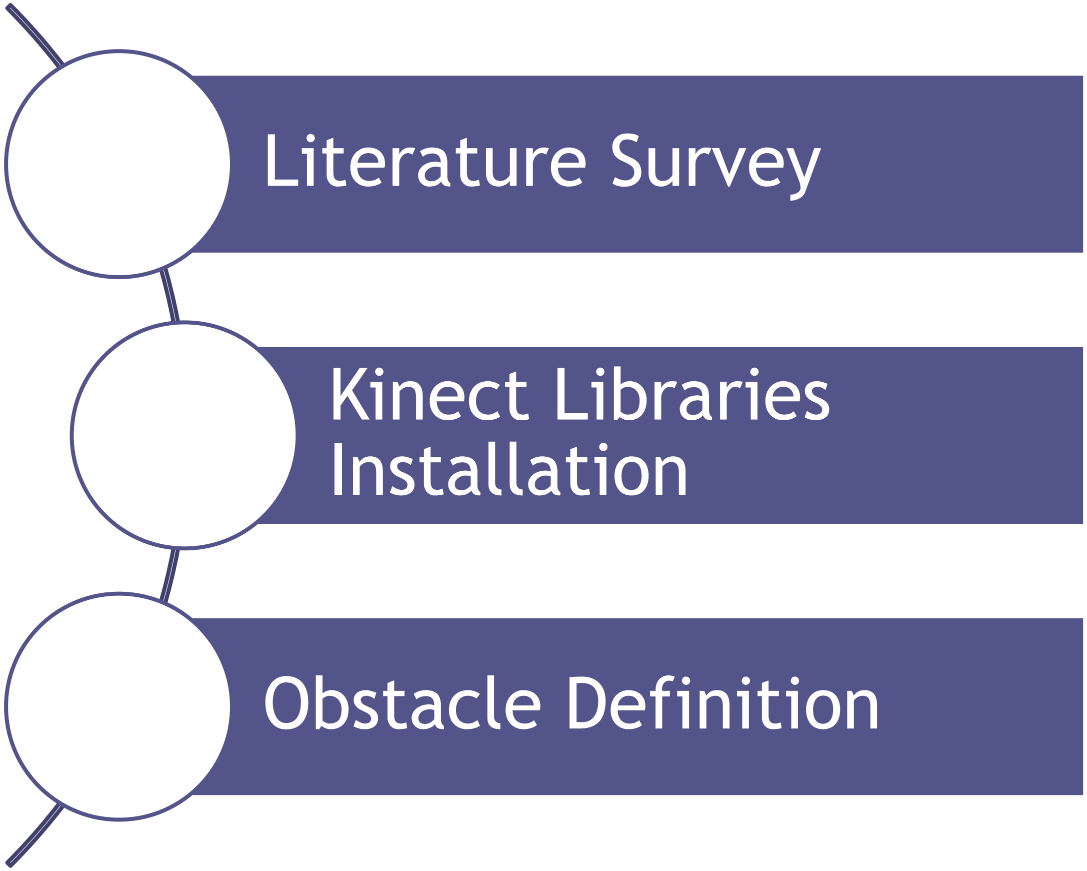


Application GUI

Backend Functionality

Interfacing with Platform SBC

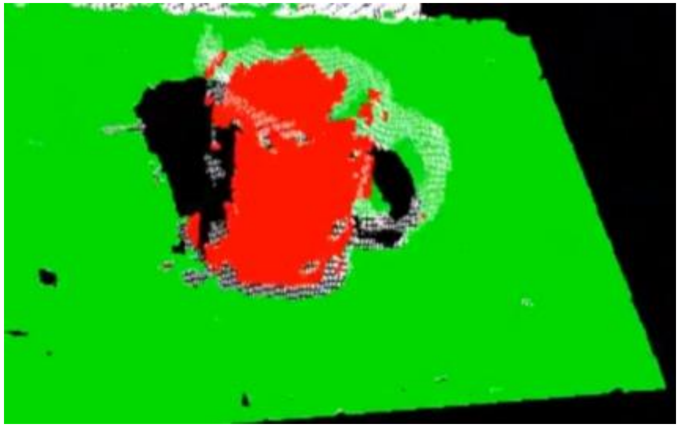
Sensing and Perception



Literature Survey

Kinect Libraries Installation

Obstacle Definition



Communication System

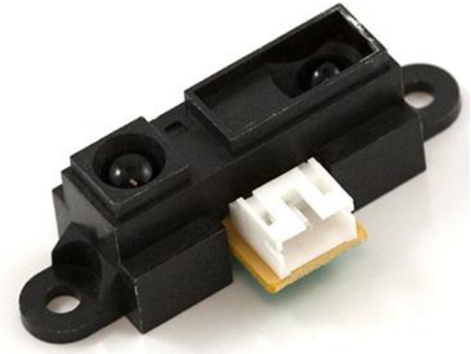
- Literature Survey
- Hardware Procurement
- Preliminary Testing

Mobile Platform

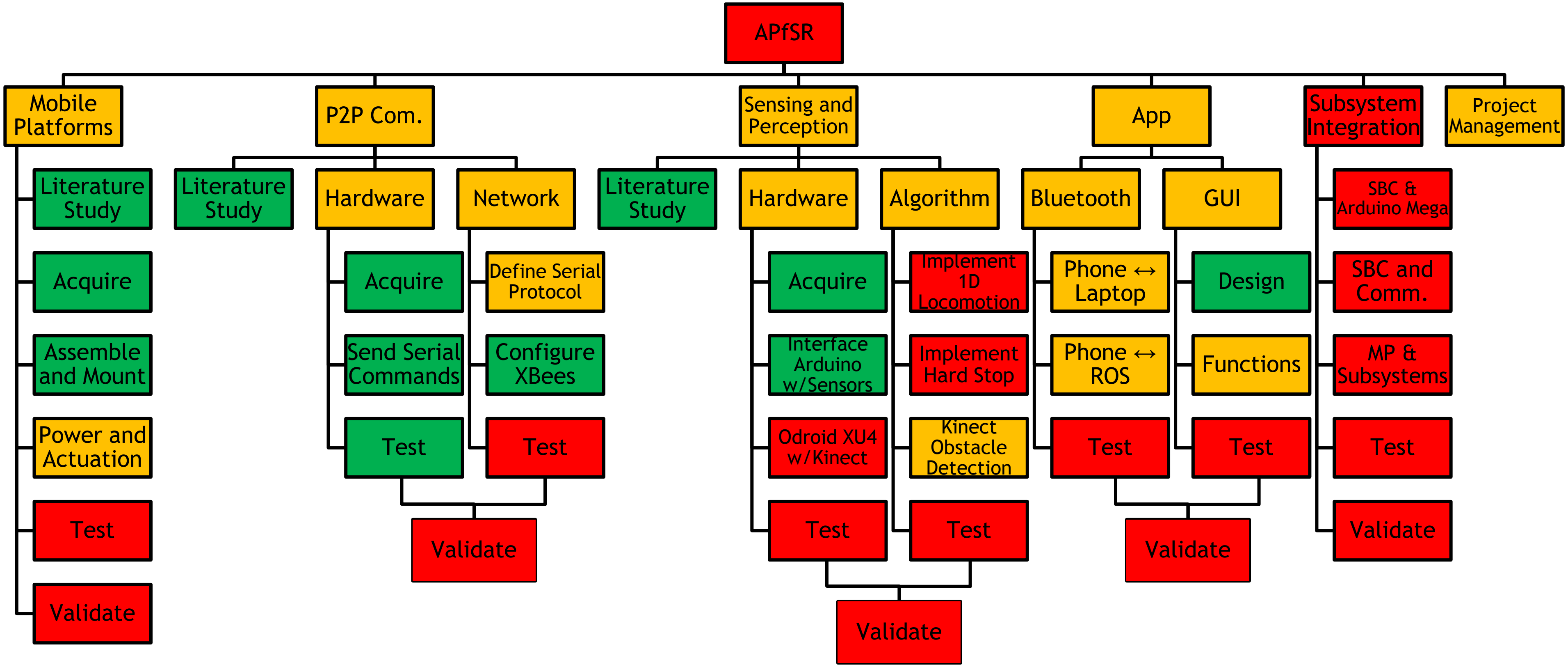
- Literature Survey
- Test Platform Procurement

Navigation and Control

- Sensor Integration
- Concept Definition

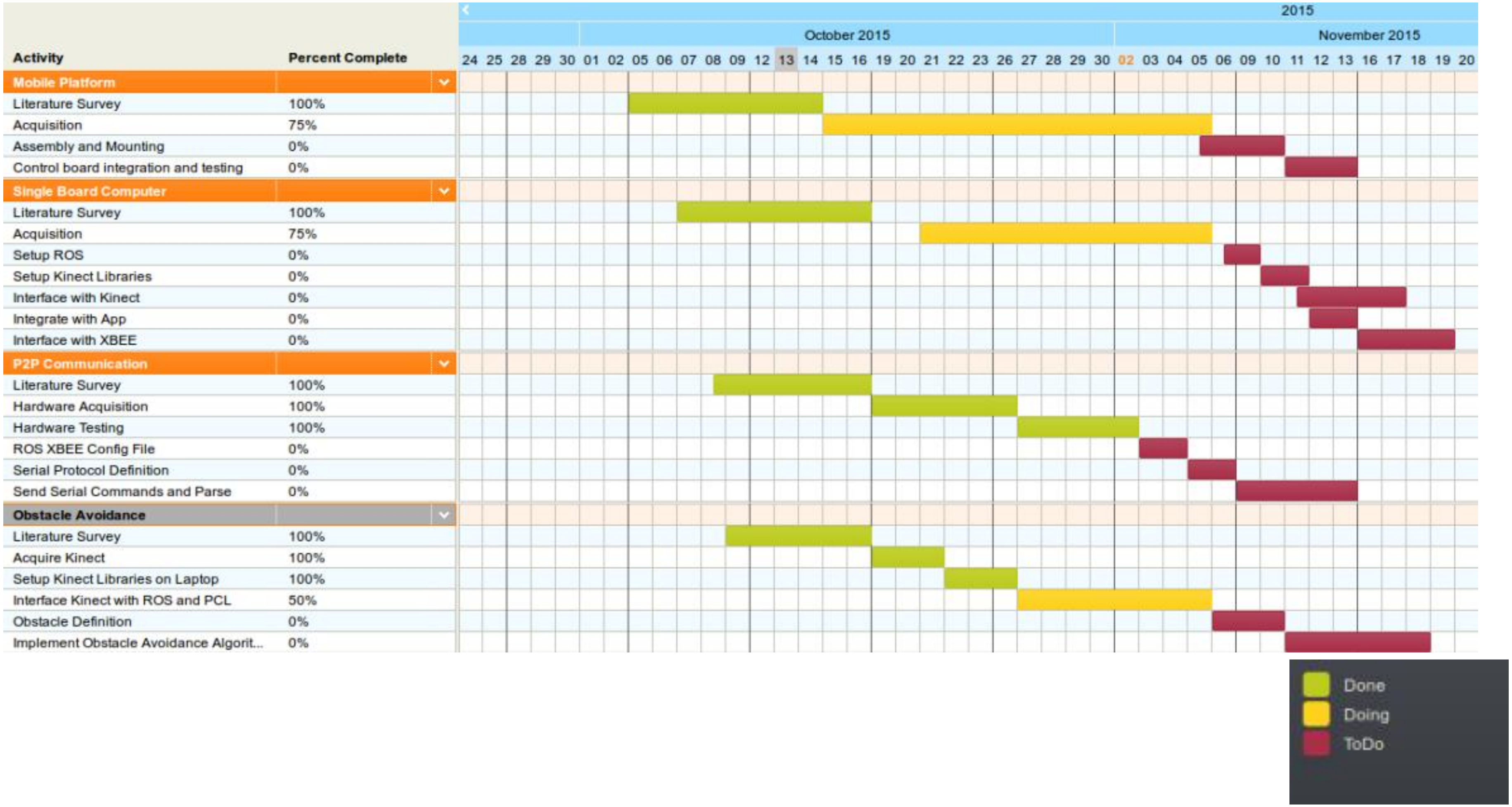


Work Breakdown Structure



- APfSR
  - Mobile Platforms
    - Literature Study
    - Acquire
    - Assemble and Mount
    - Power and Actuation
    - Test
    - Validate
  - P2P Com.
    - Literature Study
    - Hardware
      - Acquire
      - Send Serial Commands
      - Test
    - Network
      - Define Serial Protocol
      - Configure XBees
      - Test
    - Validate
  - Sensing and Perception
    - Literature Study
    - Hardware
      - Acquire
      - Interface Arduino w/Sensors
      - Odroid XU4 w/Kinect
      - Test
    - Algorithm
      - Implement 1D Locomotion
      - Implement Hard Stop
      - Kinect Obstacle Detection
      - Test
    - Validate
  - App
    - Bluetooth
      - Phone ↔ Laptop
      - Phone ↔ ROS
      - Test
    - GUI
      - Design
      - Functions
      - Test
    - Validate
  - Subsystem Integration
    - SBC & Arduino Mega
    - SBC and Comm.
    - MP & Subsystems
    - Test
    - Validate
  - Project Management

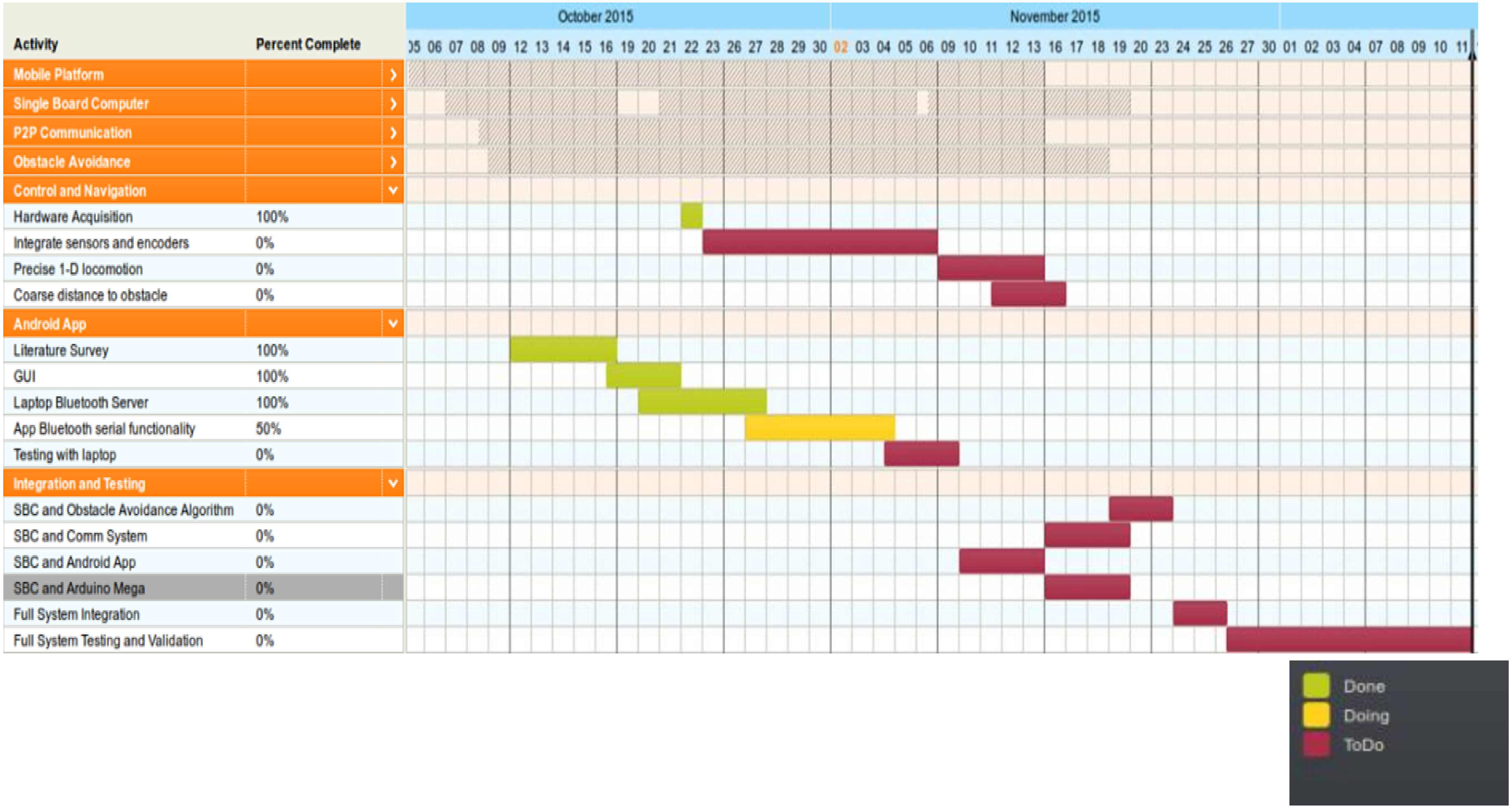
Schedule



Activity	Percent Complete
Mobile Platform	
Literature Survey	100%
Acquisition	75%
Assembly and Mounting	0%
Control board integration and testing	0%
Single Board Computer	
Literature Survey	100%
Acquisition	75%
Setup ROS	0%
Setup Kinect Libraries	0%
Interface with Kinect	0%
Integrate with App	0%
Interface with XBEE	0%
P2P Communication	
Literature Survey	100%
Hardware Acquisition	100%
Hardware Testing	100%
ROS XBEE Config File	0%
Serial Protocol Definition	0%
Send Serial Commands and Parse	0%
Obstacle Avoidance	
Literature Survey	100%
Acquire Kinect	100%
Setup Kinect Libraries on Laptop	100%
Interface Kinect with ROS and PCL	50%
Obstacle Definition	0%
Implement Obstacle Avoidance Algorit...	0%

🟩 Done
🟨 Doing
🟥 ToDo

Schedule



Activity	Percent Complete
Mobile Platform	
Single Board Computer	
P2P Communication	
Obstacle Avoidance	
Control and Navigation	
Hardware Acquisition	100%
Integrate sensors and encoders	0%
Precise 1-D locomotion	0%
Coarse distance to obstacle	0%
Android App	
Literature Survey	100%
GUI	100%
Laptop Bluetooth Server	100%
App Bluetooth serial functionality	50%
Testing with laptop	0%
Integration and Testing	
SBC and Obstacle Avoidance Algorithm	0%
SBC and Comm System	0%
SBC and Android App	0%
SBC and Arduino Mega	0%
Full System Integration	0%
Full System Testing and Validation	0%

Work Owners

SUBSYSTEM	WORK OWNER
Mobile Platform	Mohak
Control and Navigation	Shivam
Communication	Richa
Android App	Dorothy
SBC	Pranav
Obstacle Detection	Mohak
Project Management	Shivam

High-Level Test Plan

Progress Review 3

- Show progress regarding obstacle detection
- Show progress regarding communication system
- Show integrated Oculus Prime Platform

Progress Review 4

- Integrate obstacle detection with Oculus Prime Platform
- Integrate communication system with Oculus Prime

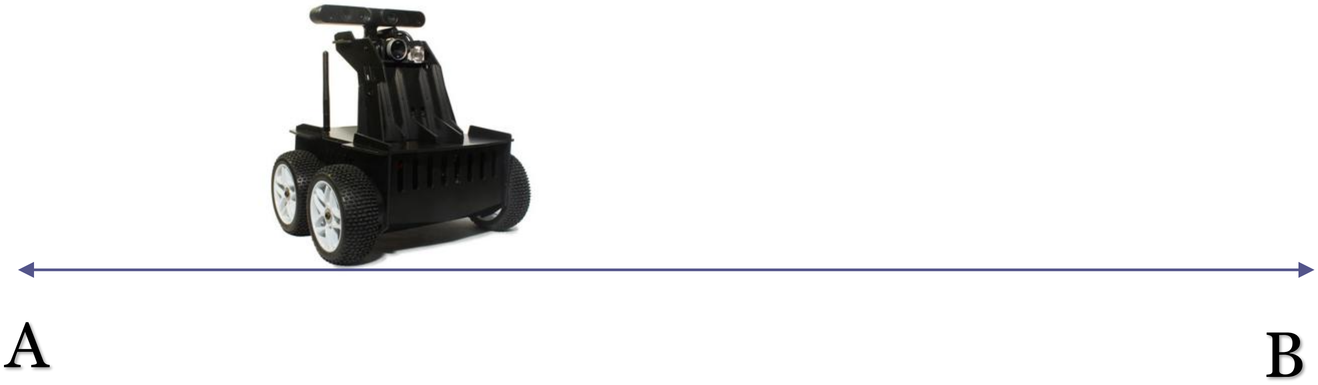
High-Level Test Plan

Spring Progress Reviews

- Show progress on obstacle avoidance
- Show platforms generating and sharing occupancy maps
- Show progress on path planning and localization
- Design and construct a test parking lot
- Show progress on entering and exiting a parking spot

Fall Validation Experiment

- **Location** : B Floor, Newell-Simon Hall
- **Date**: 3 Dec, 2015
- **Equipment Needed**: Oculus Prime Platform, Odroid XU4, Kinect, Monitor Screen, XBee Pro, Android Phone with Virtual Valet installed
- **Operating Area**: 10m x 10m (Open Space at B Floor)



Fall Demo 1

Task	Success Criteria
“Park” command sent to the mobile platform using the Android app	LED blinks to indicate command received
Vehicle begins locomotion upon receiving the command	Vehicle moves forward
“Return” command sent to the mobile platform via the Android app	Vehicle moves backward to original location

Fall Demo 2

Task	Success Criteria
“Park” command sent to the mobile platform using the Android app	LED blinks to indicate command received
Navigation direction set on second SBC	Platform moves according to set direction
Platform navigates to second position	Vehicle moves forward or backward, as appropriate
While navigating to the spot, the vehicle will encounter an obstacle and stop within a safe distance of the obstacle	Vehicle does not collide with obstacle

Requirements Validated at FVE

- **Functional**
  - Receive commands from user via smartphone app (MF.1)
  - Share data with other cars (MF.2)
  - Sense the environment (static obstacles) (MF.8)
  - Navigate through parking lot (MF.10)
- **Non-Functional**
  - Communicate reliably between local vehicles (MN.2)
  - Network of cars is scalable (DN.1)
  - Make minimal changes to infrastructure (MN.5)
  - Be within $4000 budget (MN.6)

Requirements Validated at FVE

- **Performance**
  - Establish communication with other vehicles within 30 seconds
  - Be able to handle collaboration between 2 vehicles
  - Detect obstacles within 20 cm of vehicle
  - Detect obstacles 1-50 cm high and 2-120 cm wide.

Spring Validation Experiment

- **Location**: B Floor, Newell-Simon Hall
- **Date**: May, 2016
- **Logistics**: Oculus Prime Platform(3), Odroid XU4 (3), Kinect (3), Monitor Screen, XBee Pro DigiMesh Adapter (3), Android Phone with Virtual Valet installed, Mock Parking Lot
- **Operating Area**: 10m x 10m (Open Space at B Floor)

Spring Demo

Task	Success Criteria
“Park” command sent to three mobile platform in succession using three Android phones with the app	LEDs blink to indicate command received
Mobile platforms will enter the parking lot and collaborate with other vehicles to choose the optimal parking spots	The three spots closest to the exit are chosen
Mobile platforms will navigate along optimal paths to the spot	The paths with the least amount of time are chosen
When a vehicle encounters an obstacle, it will plan a path around it	The platforms will not hit obstacles and will complete their journey

Spring Demo

Task	Success Criteria
A notification will be sent to each user when their vehicle is parked	Notification is received by three separate phones
When each user sends the command to return, the robot will exit the parking spot and navigate towards the exit spot along the optimal path	No collisions occur and mobile platforms exit as quickly as possible
When it reaches the exit, it will send the user a notification stating that it is at the exit	Apps update accordingly and notifications are received on three separate phones

Remaining Requirements Validated at SVE

- **Functional**
  - Plan optimal route to exit (MF.4)
  - Follow optimal route to exit (MF.5)
  - Park inside a parking spot (MF.6)
  - Exit parking spot (MF.7)
  - Avoid infrastructure (MF.9)
  - Identify optimal parking spot (DF.1)
  - Plan optimal route to spot (DF.2)
  - Follow optimal route to spot (DF.3)
  - Avoid other vehicles (DF.4)
- **Non-Functional**
  - Use smartphone app to display vehicle status (MN.1)
  - Efficiently exits the parking spot (MN.3)
  - Return to user as quickly as possible (MN.4)
  - Efficiently maneuver throughout the lot (DN.2)
  - Efficiently enter the parking spot (DN.3)

Budget

Item	Estimation	Current	Future
Mobile Platform (Oculus Prime)	$2200	$550	$1650
MS Kinect	$450	$0	$450
XBEE Pro DIGIMESH Adaptor	$500	$200	$300
Electronics	$700	$100	$600
Hardware	$150	$0	$150
TOTAL	**$4000 (100%)**	**$850 (21%)**	**$3150 (79%)**

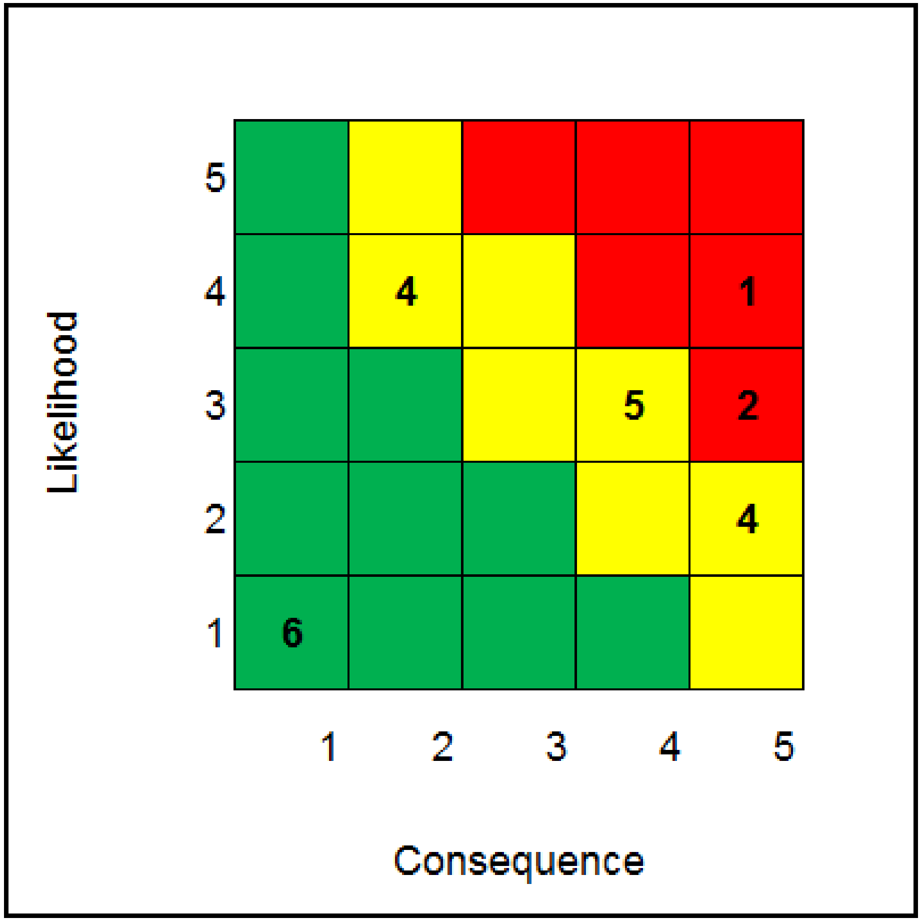
Risk Management

ID	Description	Owner	Area of Impact	Mitigation Plan	Status
1	No Mobile Platform	Mohak	Technical Schedule Cost	Purchase test platform Email list of MPs to sponsor Meet with Sponsor	In Progress
2	Inadequate Mobile Platform	Shivam	Technical	Review platform needs Only select adequate platform	Almost Closed
3	Unsuitable Smartphone Interface	Dorothy	Technical Programmatic	Frequent and Extensive Testing	Open
4	Subsystem Incompatibility	Pranav	Technical Schedule Cost Programmatic	Research on ROS to ensure compatibility Carry out low level cross compatibility tests Create an architecture to ease integration	In Progress

Risk Management

ID	Description	Owner	Area of Impact	Mitigation Plan	Status
5	Too Many Requirements	Shivam	Schedule Programmatic	Trimmed requirements Separated Mandatory from Desirable Appointed PM Begin big weekly scrums Add Kanban cards to lab workspace	In Progress
6	Inaccurate Parking Lot and Obstacles	Richa	Programmatic	Analyze parking lots IRL Scale to match mobile platform	Open

Risk Management



Likelihood					
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟨 4	🟨	🟥	🟥 1
3	🟩	🟩	🟨	🟨 5	🟥 2
2	🟩	🟩	🟩	🟨	🟨 4
1	🟩 6	🟩	🟩	🟩	🟨
	1	2	3	4	5

Consequence

Thank you!

Questions?