Sample Collection with Limited Fuel

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Problem Statement

A robot must visit two locations on a while refueling in between

Why?

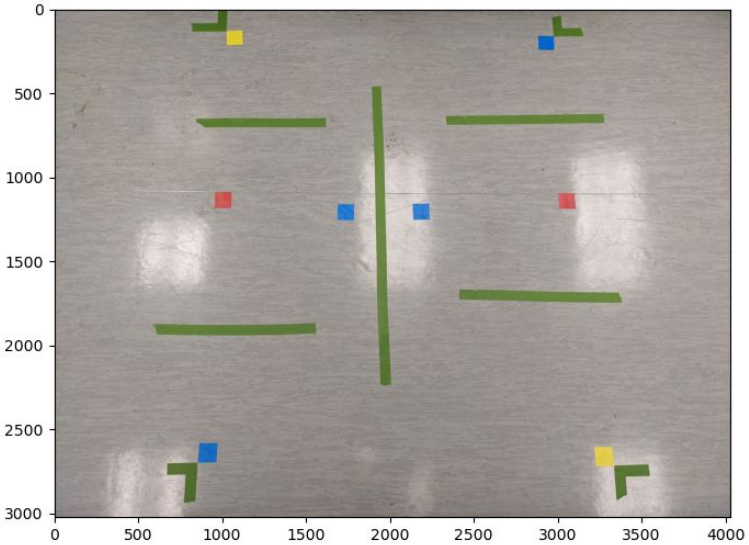
- Jeff Bezos is creating a mars rover that must pick up element X for his new hair restoration cream from two mining sites but the mining sites are too far away to reach with a single battery charge

- Pizza delivery company's self driving car must deliver pizza to two local customers and it is running low on gas

Procedure

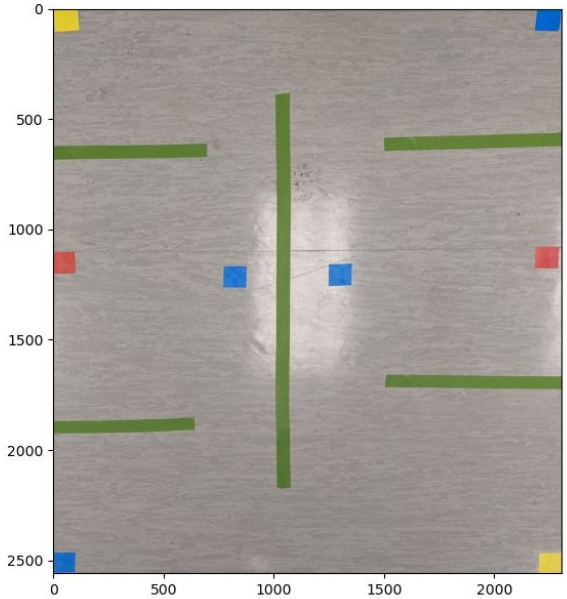
- Detect obstacles on world
- Construct map of viable travel areas
- Create automata (FSM) of valid physical paths
- Construct LTL formula
- Convert LTL formula to automata
- Calculate product automata to construct valid paths
- Apply Dijkstra's algorithm to find shortest path
- Strip states to physical paths
- Draw path on world

Detecting Obstacles on World



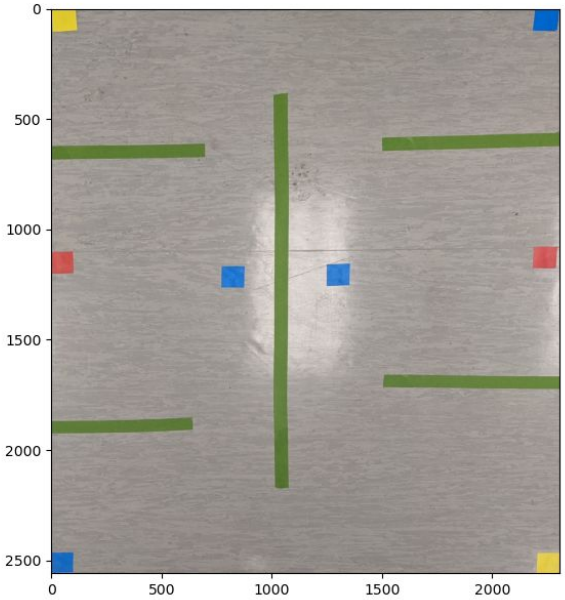
Original Image

Perspective
Warp
&
Crop

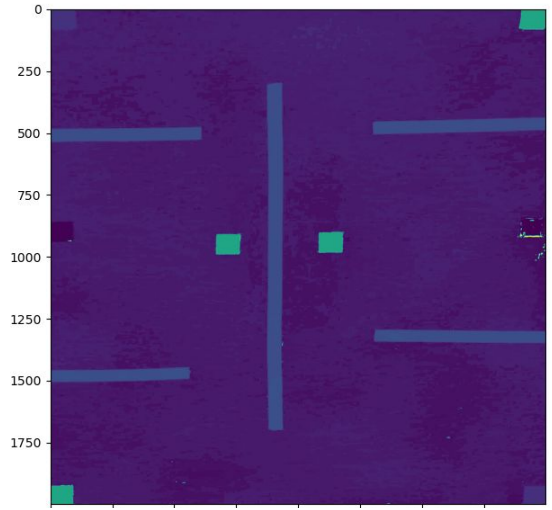


Final Image

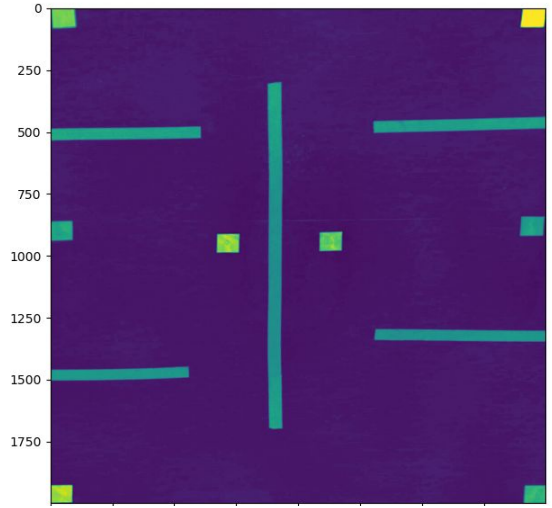
Detecting Obstacles on World



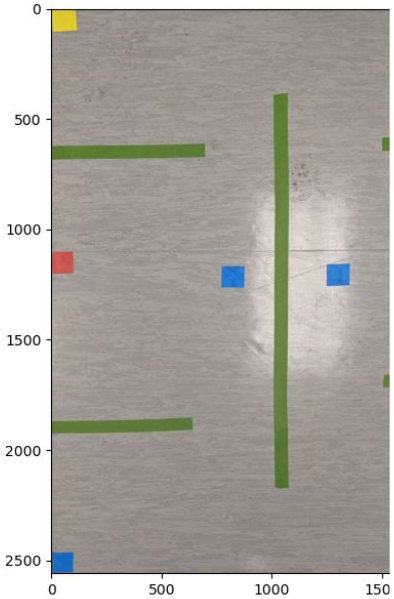
Hue Channel

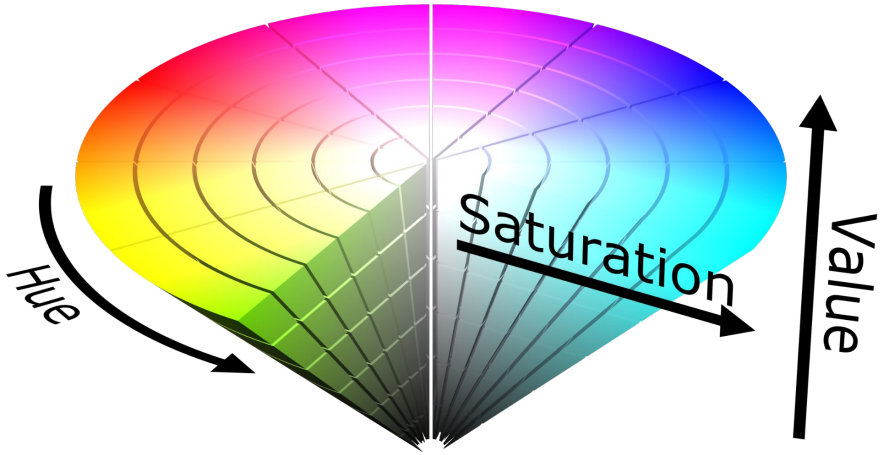


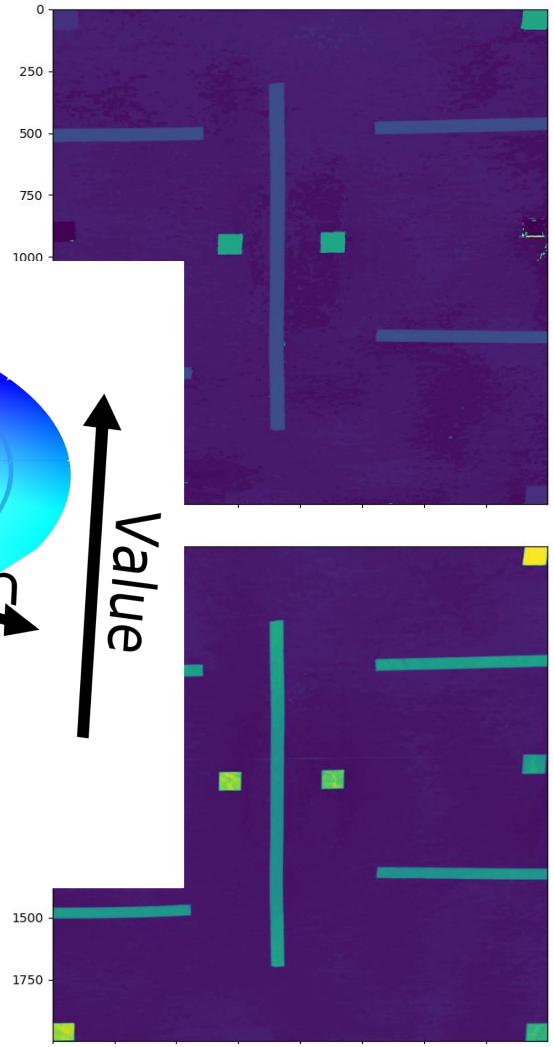
Saturation Channel



Detecting Obstacles on World

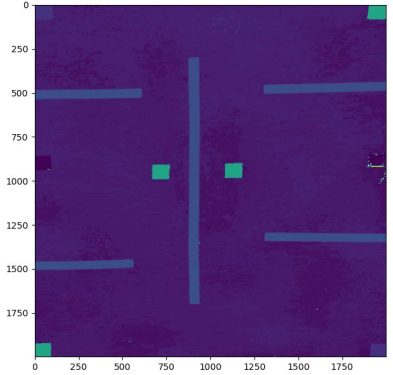






Detecting Obstacles on World

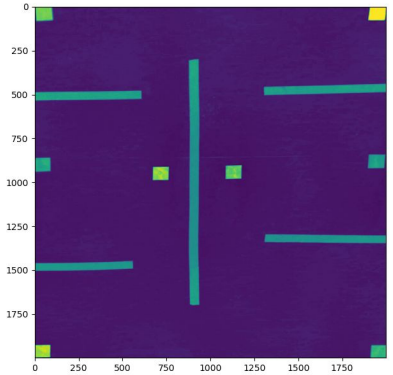
H



[40, 50]

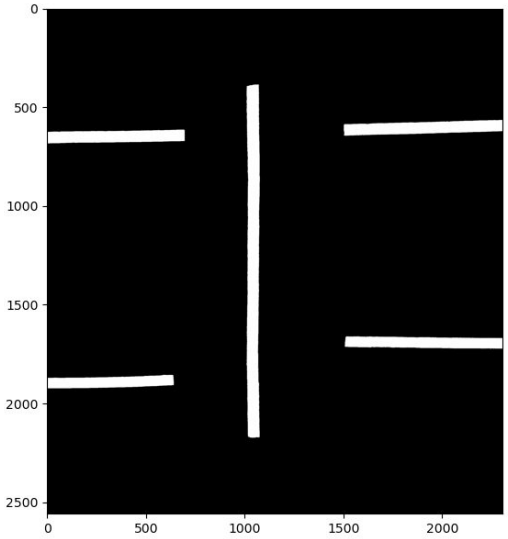
AND

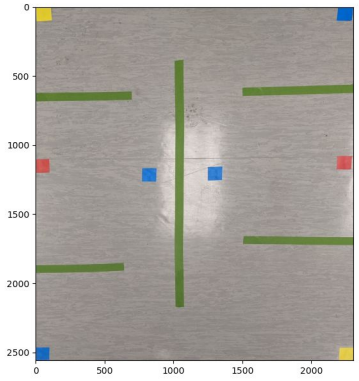
S



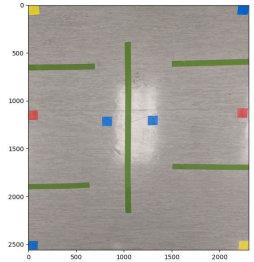
[100, 255]

Green Channel

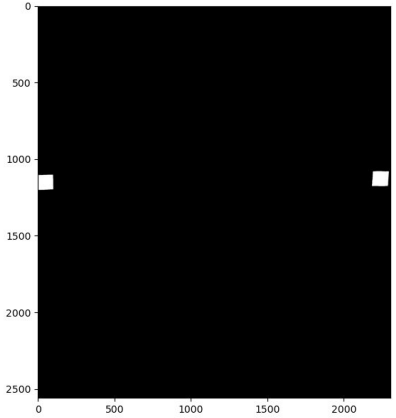


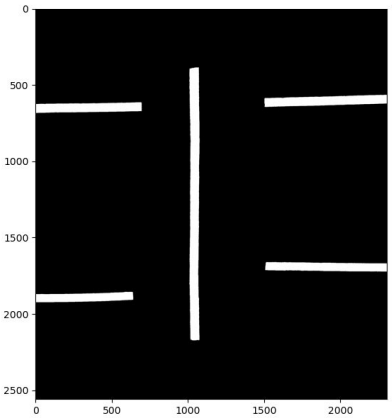


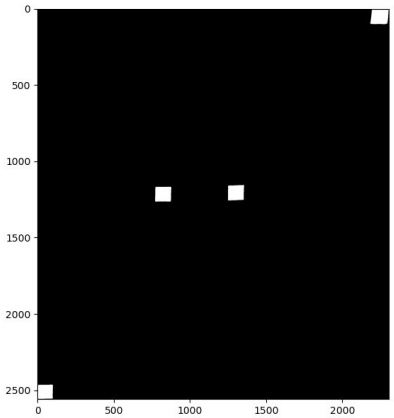
Detecting Obstacles on World

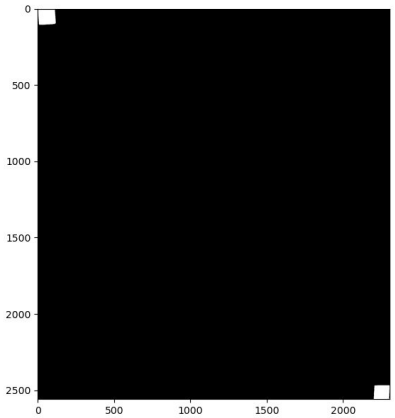


Red Channel	Green Channel	Blue Channel	Yellow Channel
Hue $\in$ [0, 5] or Hue $\in$ [175, 180]	Hue $\in$ [40, 50]	Hue $\in$ [100, 110]	Hue $\in$ [20, 30]

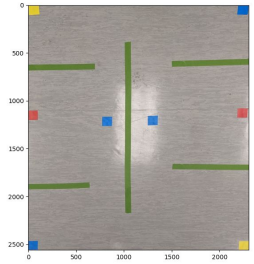






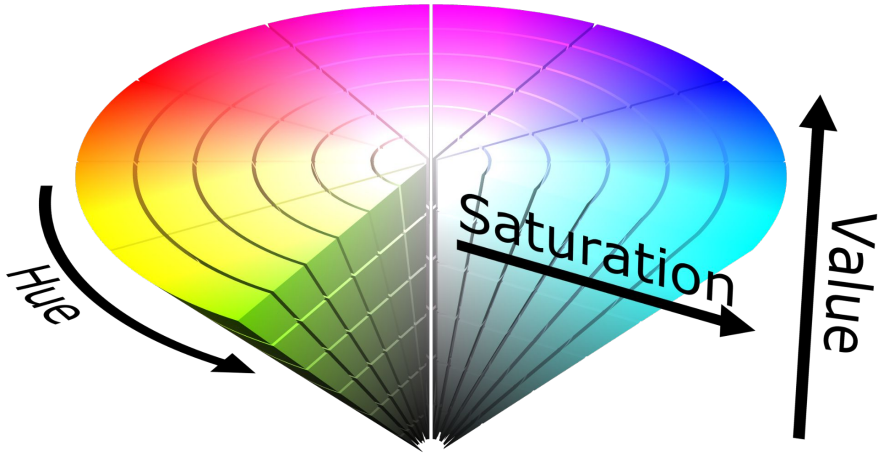


Detecting Obstacles on World



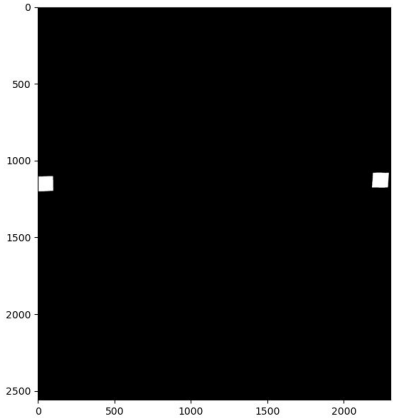
Red Channel

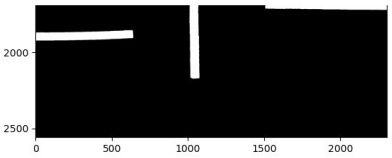
Hue ∈ [0, 5]
or
Hue ∈ [175, 180]

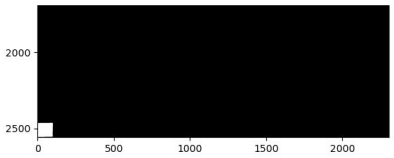


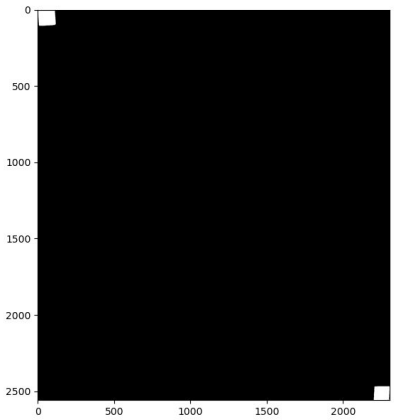
Yellow Channel

Hue ∈ [20, 30]

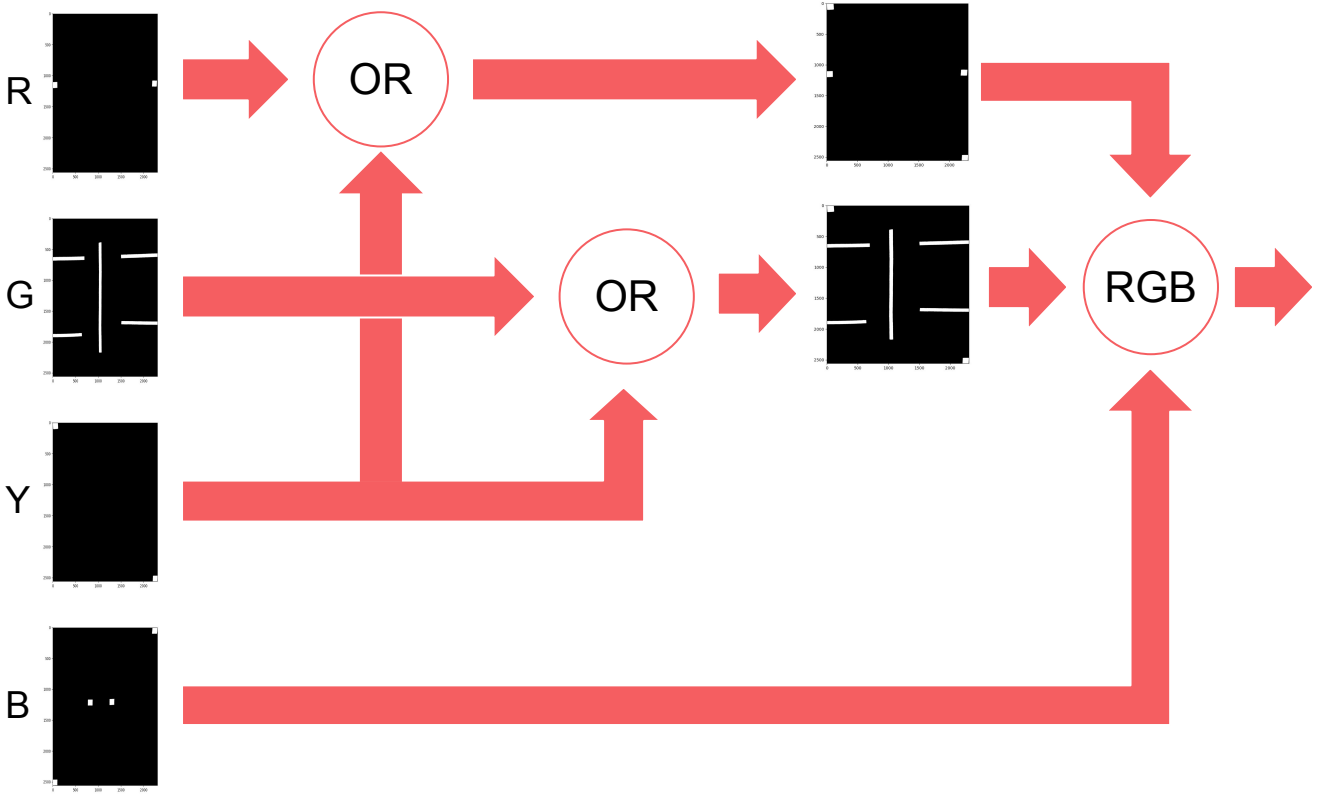


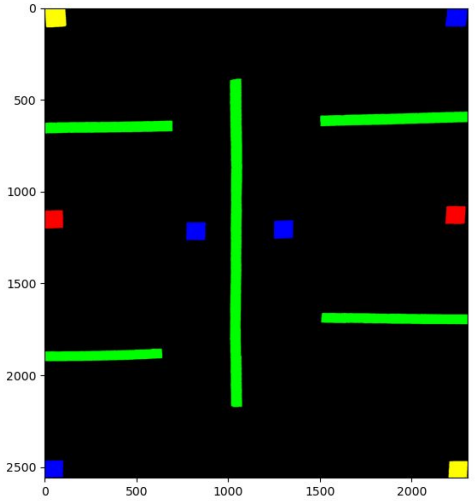






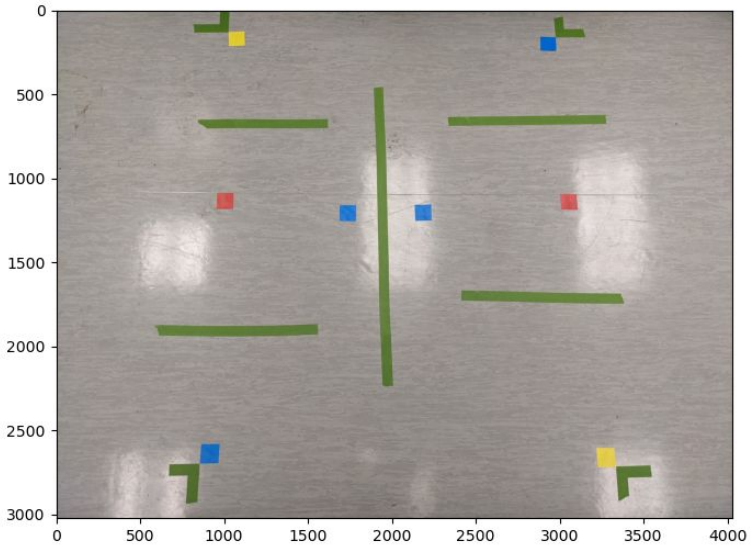
Detecting Obstacles on World

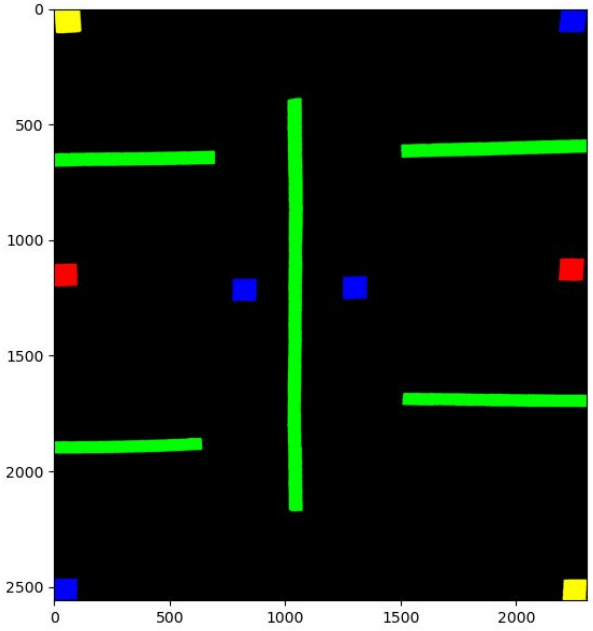




Yellow = Red + Green

Detecting Obstacles on World





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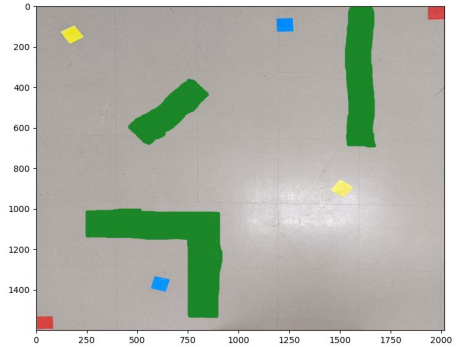
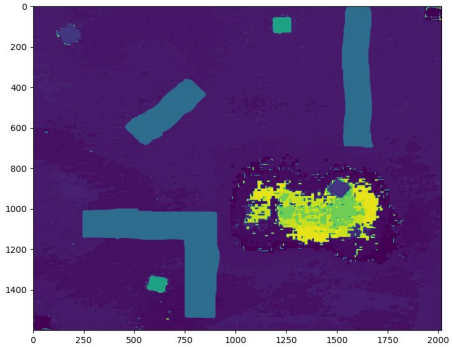
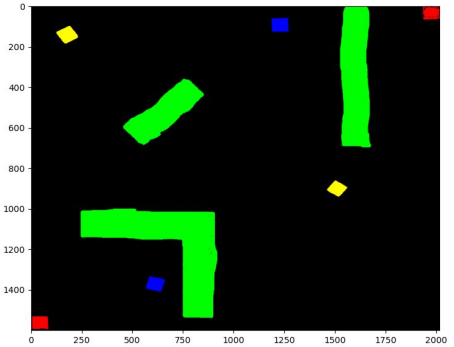


Original Image

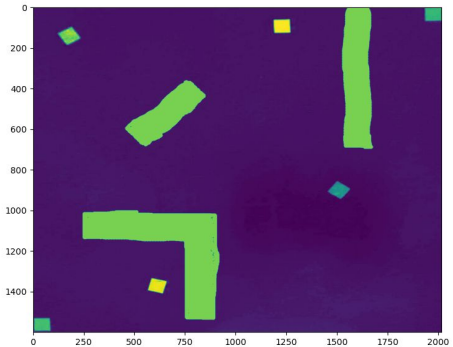


Hue Channel



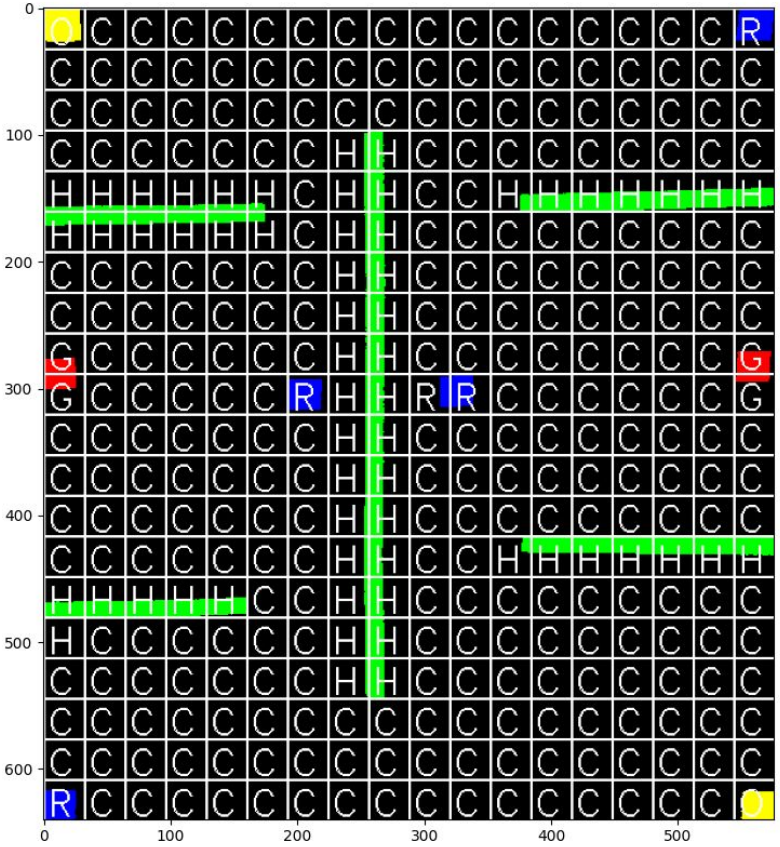
Final Image

$m_{(x,y)}$ = True if $h_{(x,y)} \in (250, 255]$ & $s_{(x,y)} \in (100, 255]$

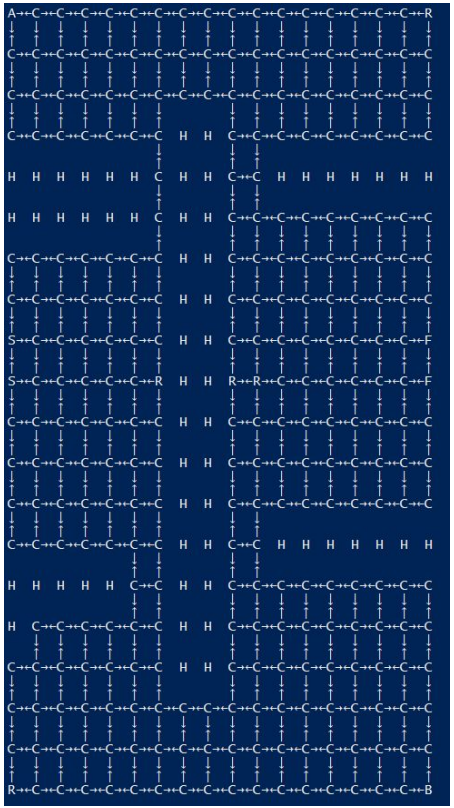


Saturation Channel

Construct map of viable travel areas



Create automata (FSM) of valid physical paths



Premature Dijkstra's Algorithm Example

Construct LTL formula

LTL Formula: (!r U a) && F(b)

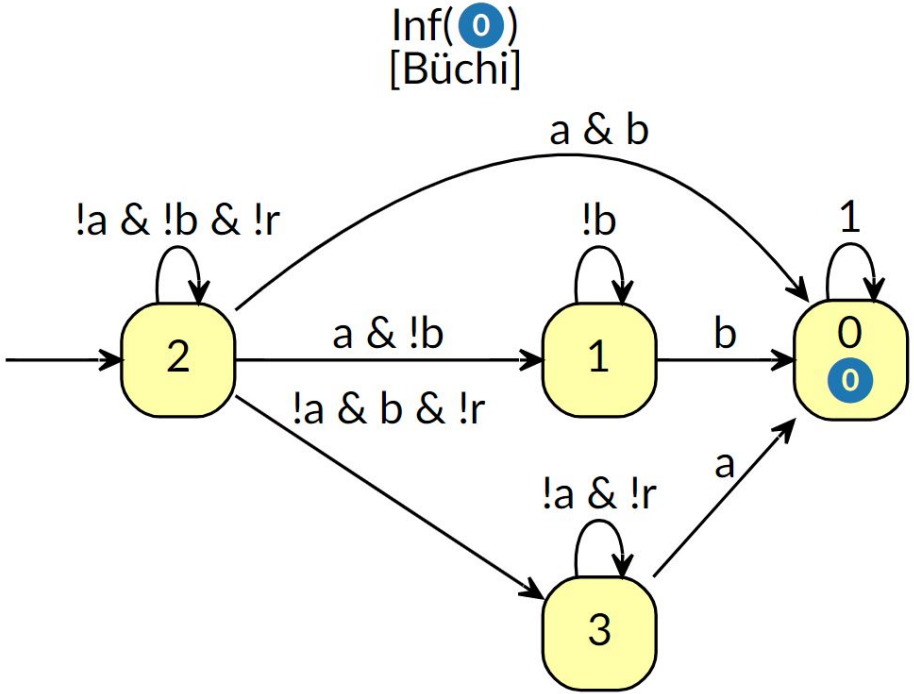
- U: Until
- F(): Eventually

Translation: Do not r (refuel) until we reach a (objective a) and eventually reach b (objective b)

Convert LTL Formula to Automata

LTL Formula: (!r U a) && F(b)

Python Library: Spot



Construct LTL formula

LTL Formula: G(X(X(X(r)))) && F(a) && F(b)

- G(): Always
- X(): Next

Literal Translation: Always visit refuel area in the state after the next state of the next state of the current state

Translation: Always visit refuel area within next 3 states.

Construct LTL formula

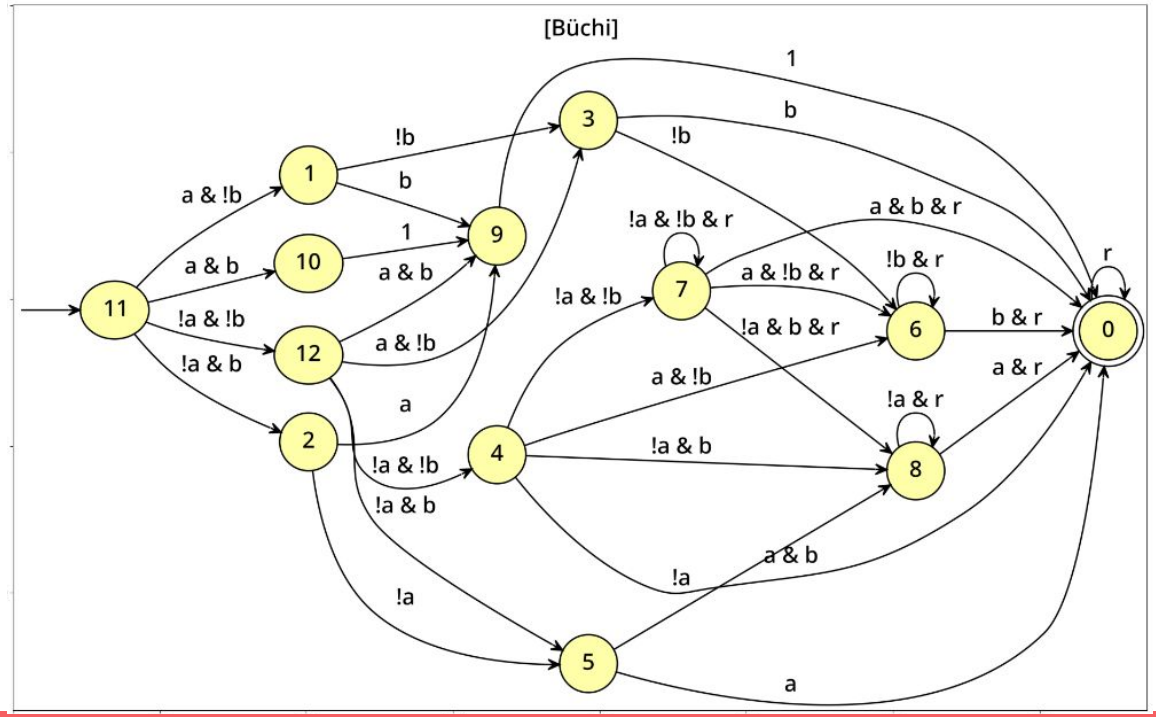
LTL Formula: G(X(X(X(r))) || X(X(r)) || X(r)) && F(a) && F(b)

- F(): Eventually

Translation: Eventually visit a and Eventually visit b

Construct LTL formula

LTL Formula: G(X(X(X(r))) || X(X(r)) || X(r)) && F(a) && F(b)



Construct LTL formula

LTL Formula: G(X(X(X(r))) || X(X(r)) || X(r)) && F(a) && F(b)

Construct LTL formula

LTL Formula: $G(X_{15}(r)) \&\& F(a) \&\& F(b)$

Translation:

Calculate product automata to construct valid paths

States in physical map FSM: `18x20 = 360`

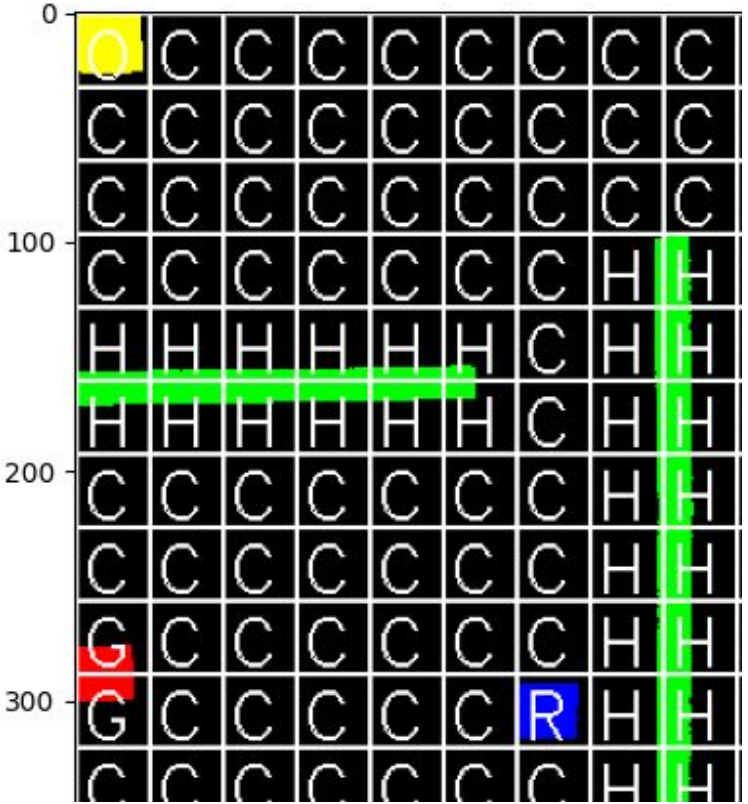
States in LTL Buchi automata: `4`

Total states: `360x4 = 1440`

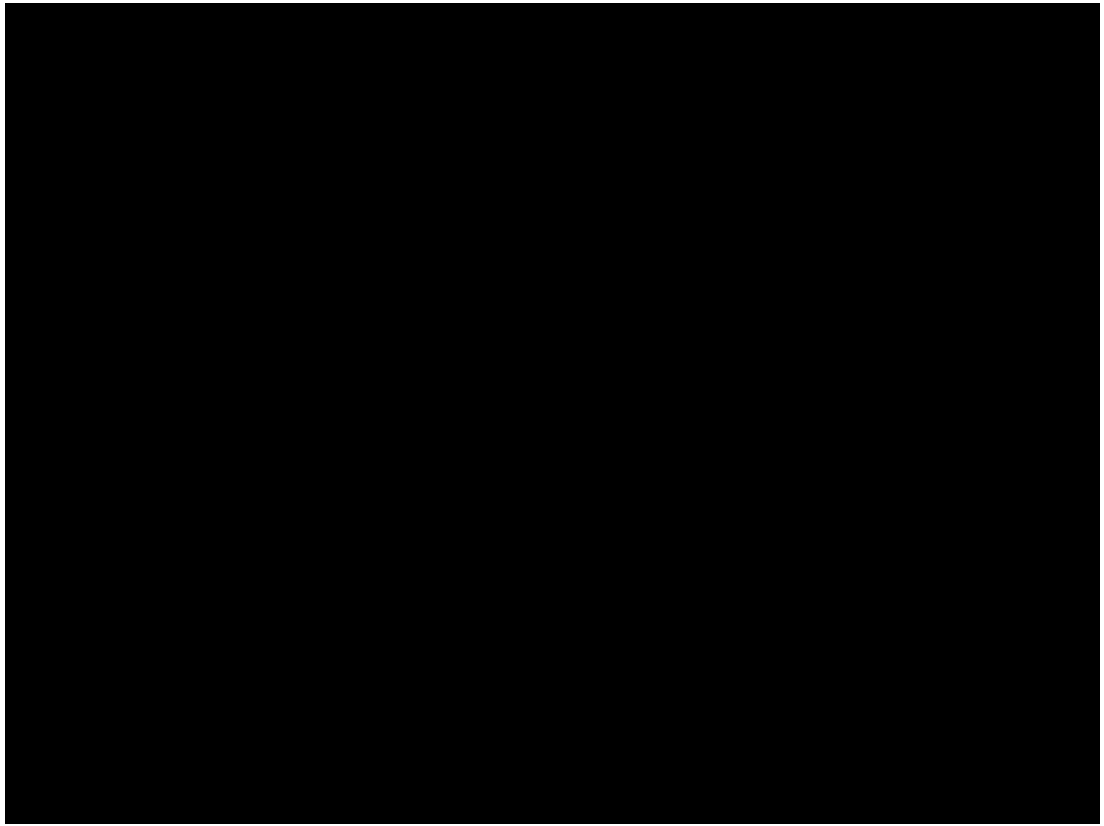
$x\text{-}y,j$:

x,y if $\exists$ $cell_{x,y}$, $j \in Q_{ltl}$

Path from $u\text{-}v,i$ to $x\text{-}y,j$ exists if path from $u\text{-}v$ to $x\text{-}y$ exists AND path from i to j exists given state at $x\text{-}y$

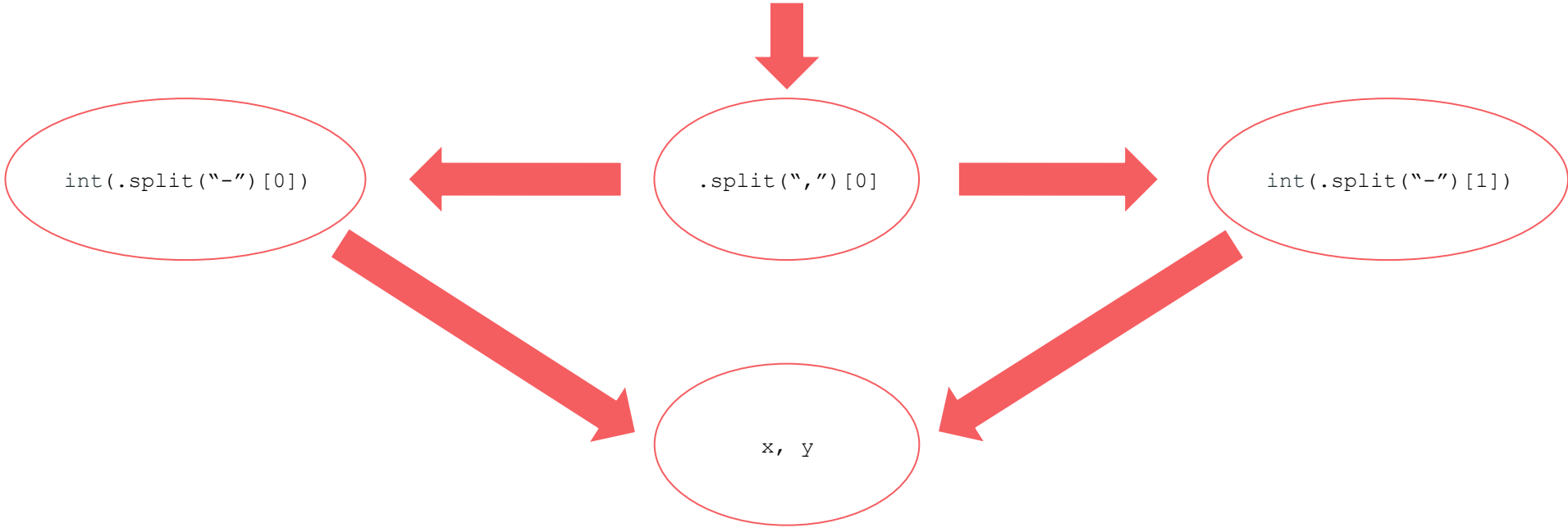


Apply Dijkstra's algorithm to find shortest path

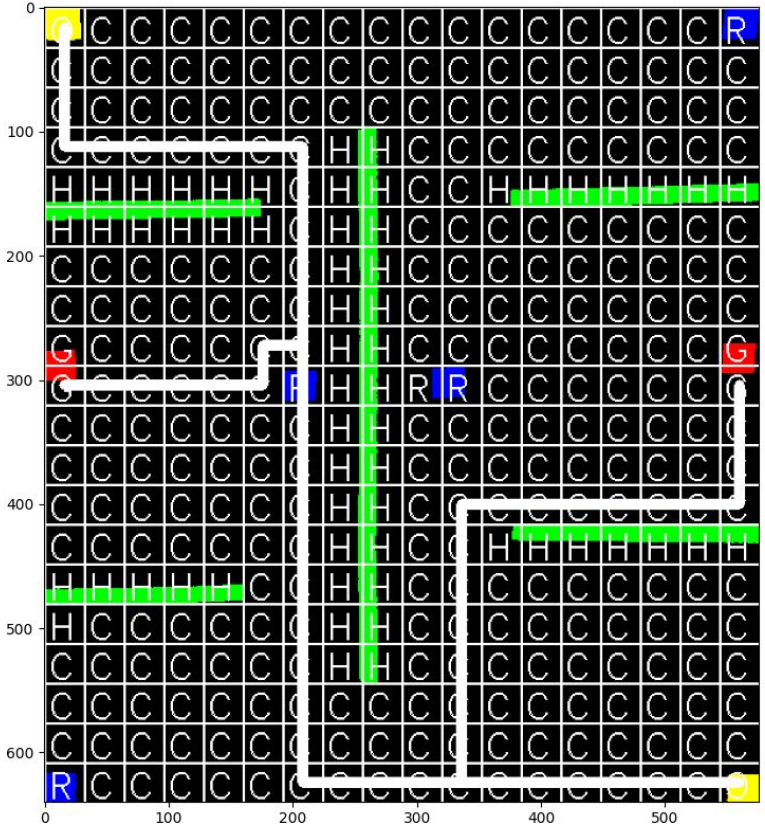


Strip states to physical paths

Current State Format: `f"{phys_x}-{phys_y},{ltl_state}"`



Draw path on world



Sources

Spot: https://spot.lrde.epita.fr/

OpenCV: https://opencv.org/

Code:
https://github.com/aryan-gupta/grad-thesis/tree/main/coar-lab-presentation

Questions?