Risk-Aware Off-Road Navigation via a Learned Speed Distribution Map

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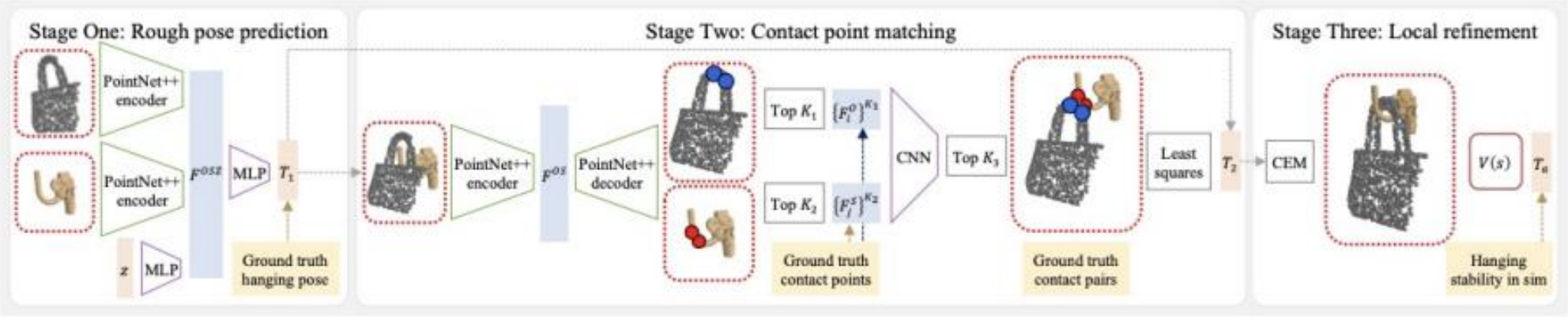
1. Where to hang



2. How to hang

Background Knowledge

Risk-Aware Planning

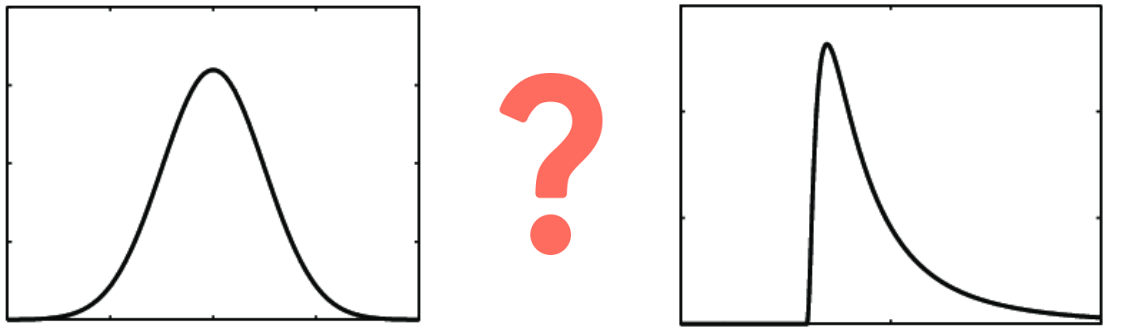
- What is Risk?
  - Depends on task
  - collision probability, classification uncertainty, etc.

- What is Risk-aware planning?
  - Planning method that aims at balancing efficiency and risk costs to find optimal trajectories

Risk Metric

- What is Risk Metric?
  - Set of possible outcomes Ω $(w \in \Omega)$
  - L: Set of all random variables on Ω
  - Risk Metric $\rho: L \rightarrow R$ $(maps\ a\ cost\ random\ variable\ to\ real\ number)$
  - 어떤 확률 분포를 가지는 random variable의 risk를 판단하는 기준
  - e.g. Expected value, CVaR (Fully satisfy Axioms)

$$1 < 2$$

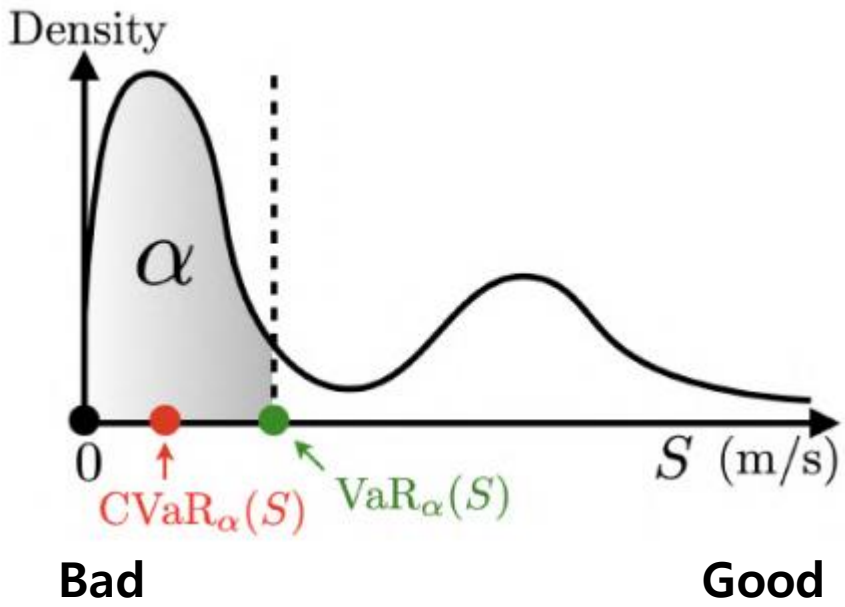


CVaR (Conditional Variance at Risk)

- What is CVaR?
  - One of the Risk Metric
  - 특정 위험 수준에서 예상되는 손실의 평균값

$$\mathrm{VaR}_{\alpha}(S) := \max\{s \mid p(S < s) \leq \alpha\}.$$

$$\mathrm{CVaR}_{\alpha}(S) := \frac{1}{\alpha}\int_{0}^{\alpha} \mathrm{VaR}_{\tau}(S)\, d\tau,$$



Overview

Overview

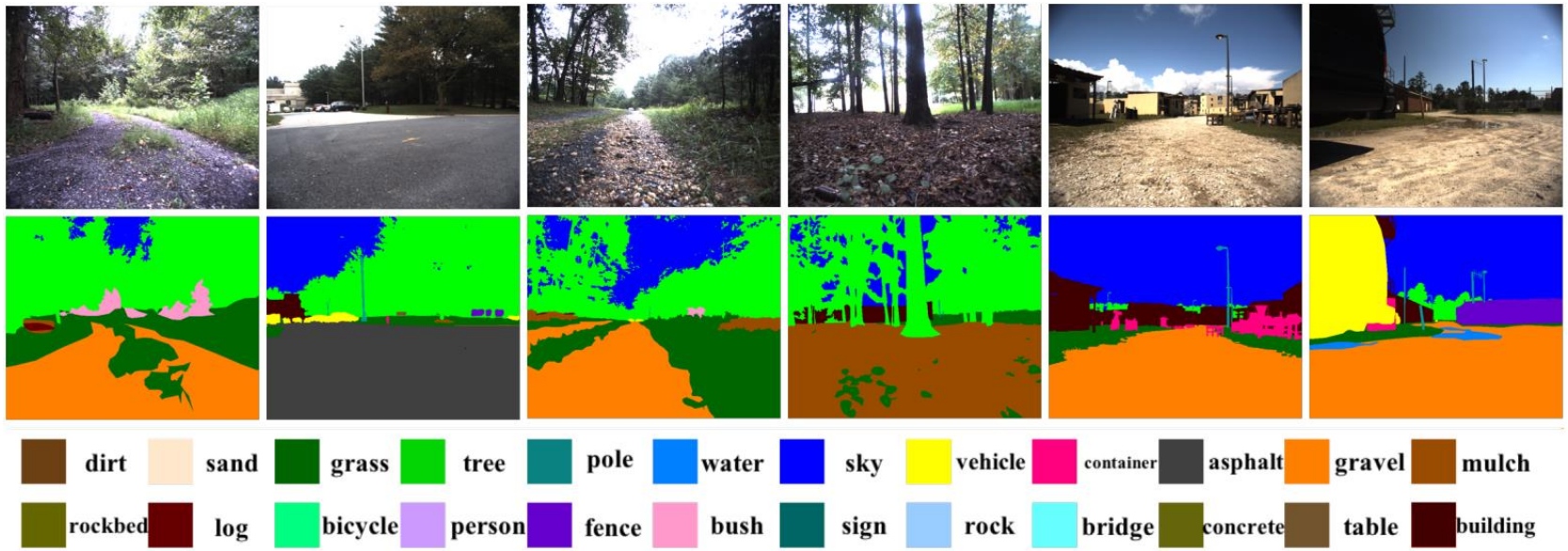
- **Problem**
  - **Recent works:** classify the world into a finite number of semantic categories
  - **Limitation:** not sufficient to capture the robot's ability(i.e. speed) to traverse off-road terrain

- **Proposed Method**
  - **New representation of traversability** based exclusively on robot speed (from data)
  - Achieve **faster** average time-to-goals, **higher** success rate

Related Works & Contribution

Recent Works

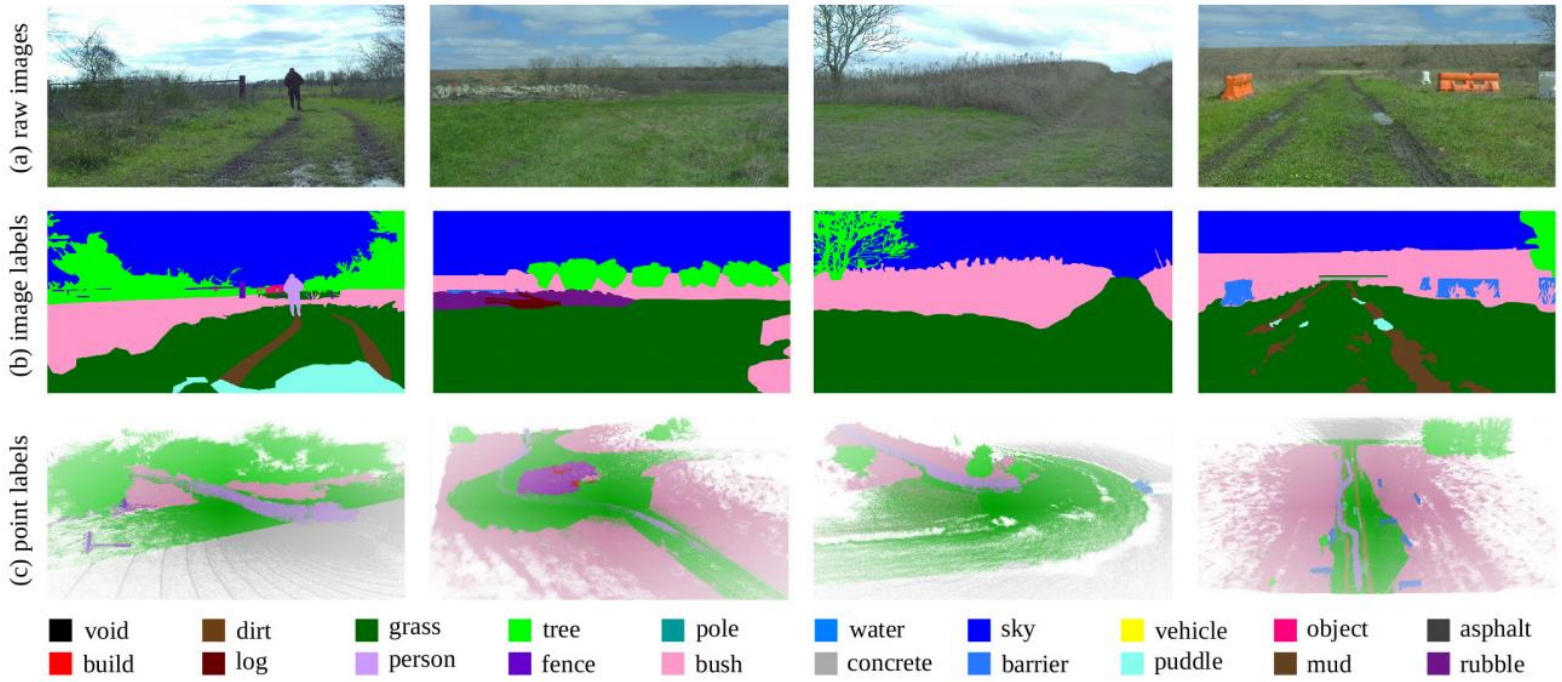
A rugd dataset for autonomous navigation and visual perception in unstructured outdoor environments (IROS, 2019)



- **RUGD Dataset**
  - **Video Dataset for Visual Perception and Autonomous Navigation in Unstructured Environments**
  - **Classify the image obtained by the RGB camera into 24 classes**

Recent Works

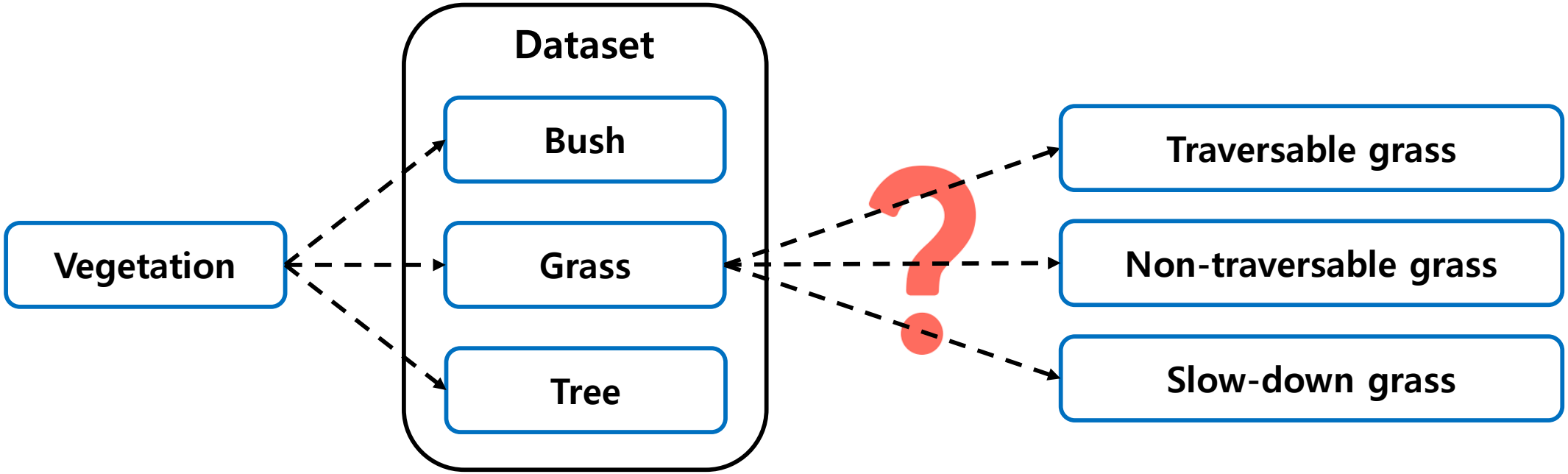
RELLIS-3D Dataset: Data, Benchmarks and Analysis (ICRA, 2021)



- **RELLIS-3D Dataset**
  - **Off-Road driving data including RGB, LiDAR, GPS, IMU, Stereo, etc.**
  - **Classify the image obtained by the RGB camera into 20 classes**

Limitations

- **Limitations**
  - **not sufficient to capture the robot's ability(i.e. speed) to traverse off-road terrain**
  - **Varying degree of traversability within each class is not captured**



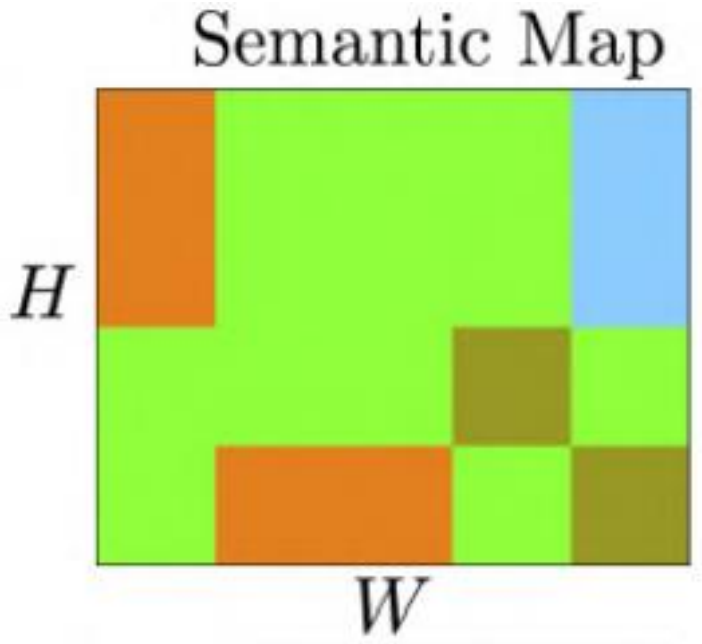
Contribution

- New representation of traversability as a probability distribution of speeds the robot could achieve
- New risk-aware minimum-time planner based on Model Predictive Path Integral (MPPI)
- Demonstration of a robot reaching its goal with up to 30% improvement in success rate than a risk-unaware algorithm

Methods

Environment Setting

- **Grid & Semantic Map**
  - **Known semantic label** (including unknown)
  - **Known H, W**
  - **2D map**



Methods

- **Data Collection**
  - **O: semantic label**
  - **s^{cmd}: command speed**
  - **s: actual speed**

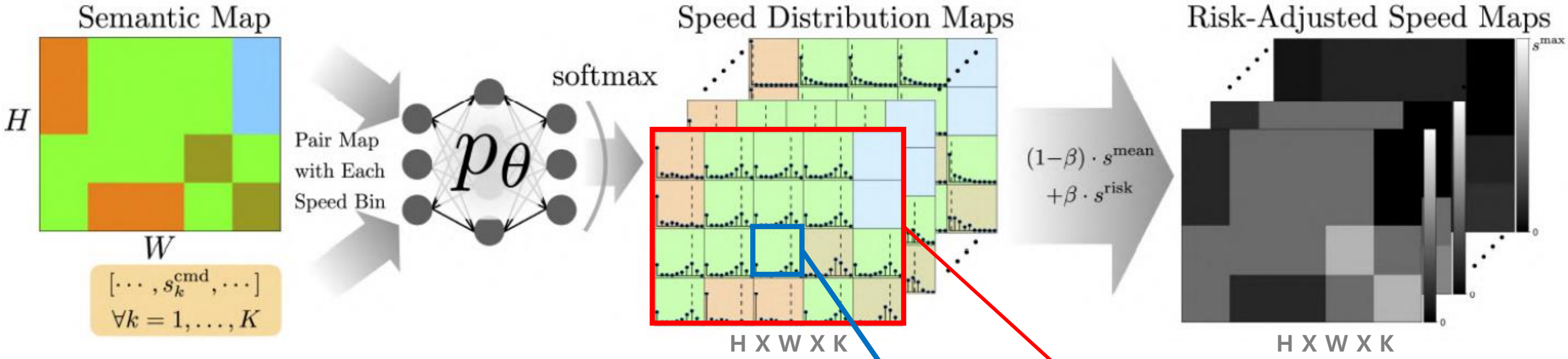
$$p_\theta(s \mid s^{\mathrm{cmd}}, o) : S \mid S \times O \rightarrow \mathbb{R},$$

- **Training**
  - **Train parameter θ**

Inference stage

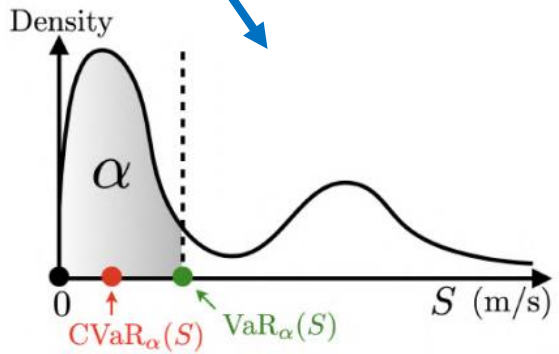
$$s^{cmd}, o \rightarrow probability\ distribution$$

Methods



- **Speed Distribution Maps**
  - **Divide v_{min} and v_{max} by K**

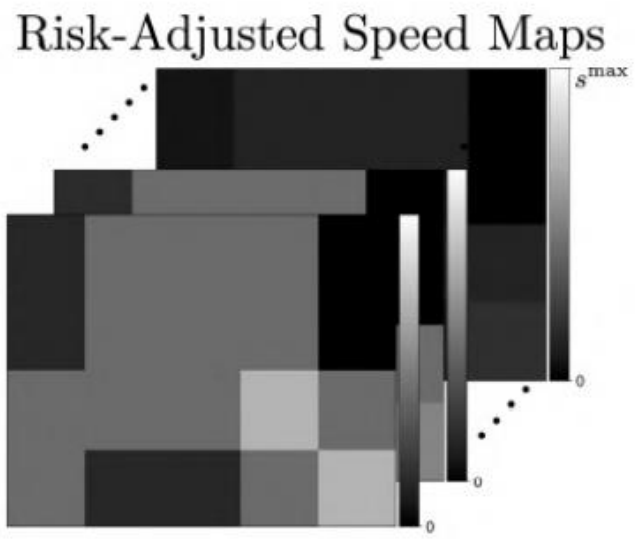
Speed Distribution Map for v_{max}

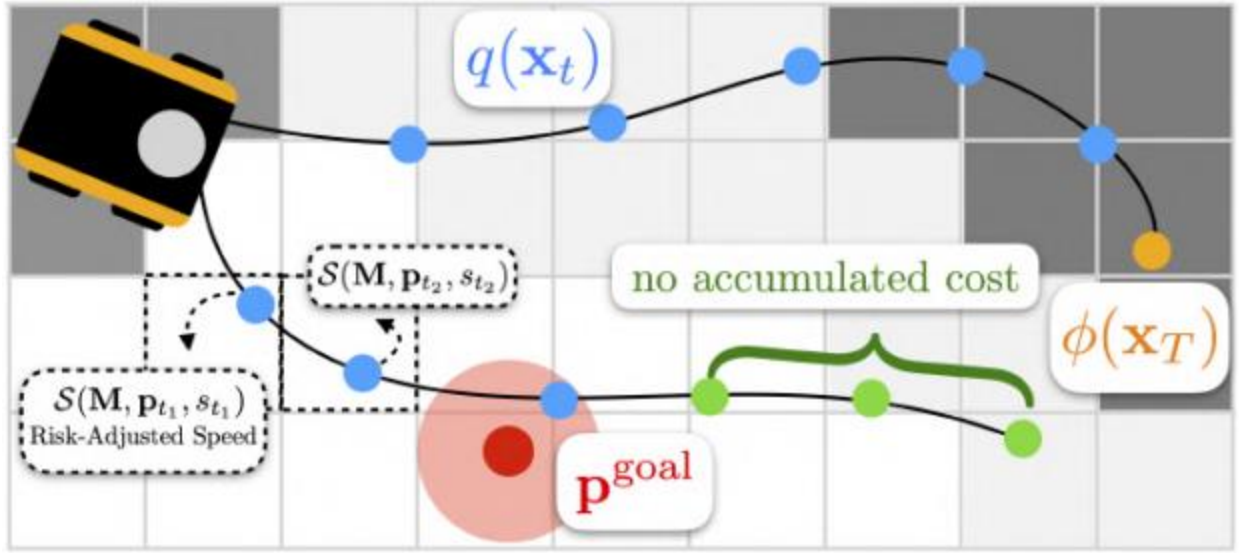


s^{mean}: ***expected value***

s^{risk}: ***CVaR value***

Methods





$$m_{k,h,w} = \beta \cdot s^{\text{risk}}_{k,h,w} + (1-\beta) \cdot s^{\text{mean}}_{k,h,w}$$

Small: SLOW
Big: FAST

$$\boldsymbol{Cost \propto 1/m}$$

Find control sequence that minimize the cost function
(MPPI)

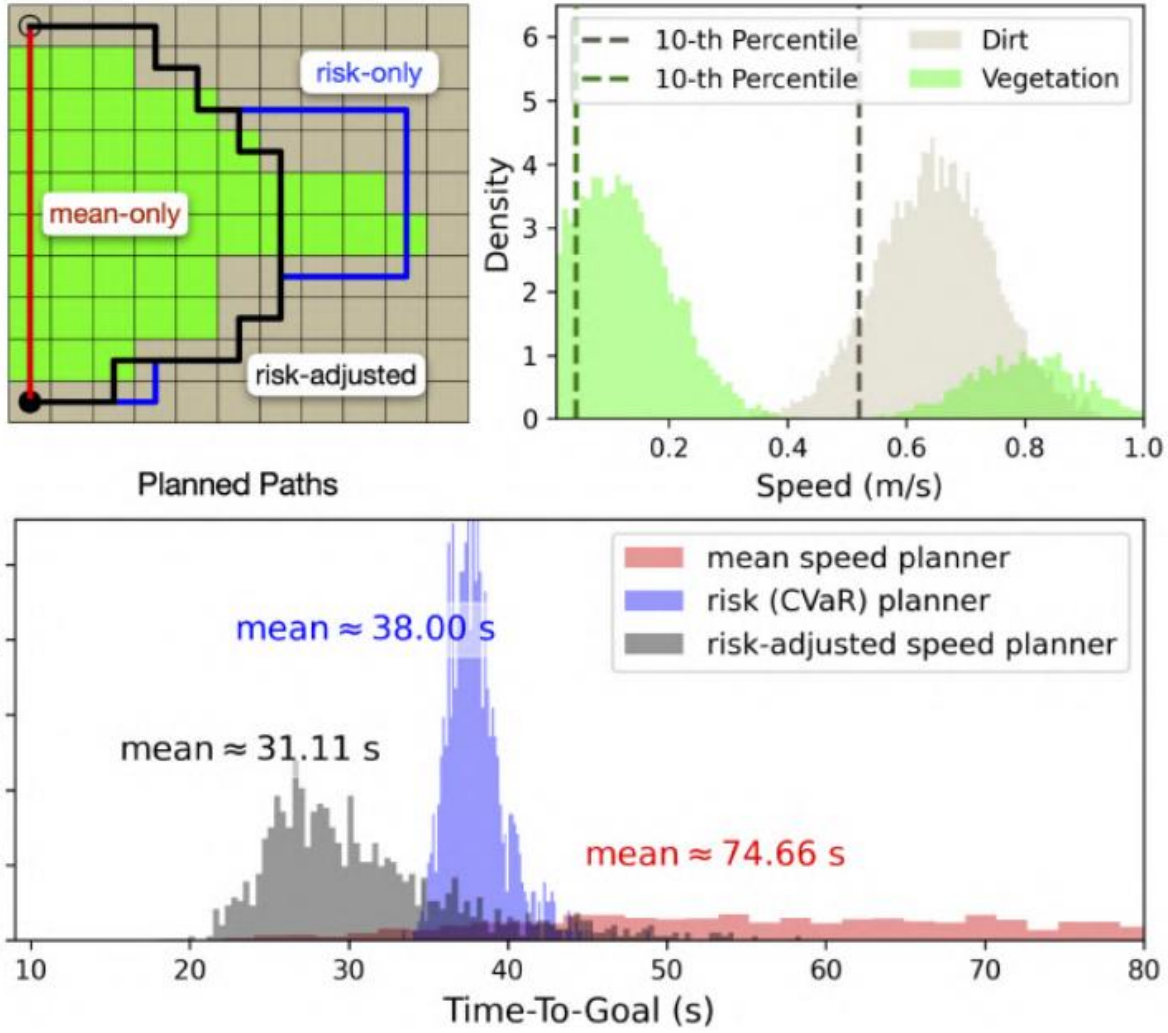
$$C(\mathbf{x}_{0:T}) = \phi(\mathbf{x}_T) + \sum_{t=0}^{T-1} q(\mathbf{x}_t)$$

Related to Speed

Distance to Goal

Results

Results



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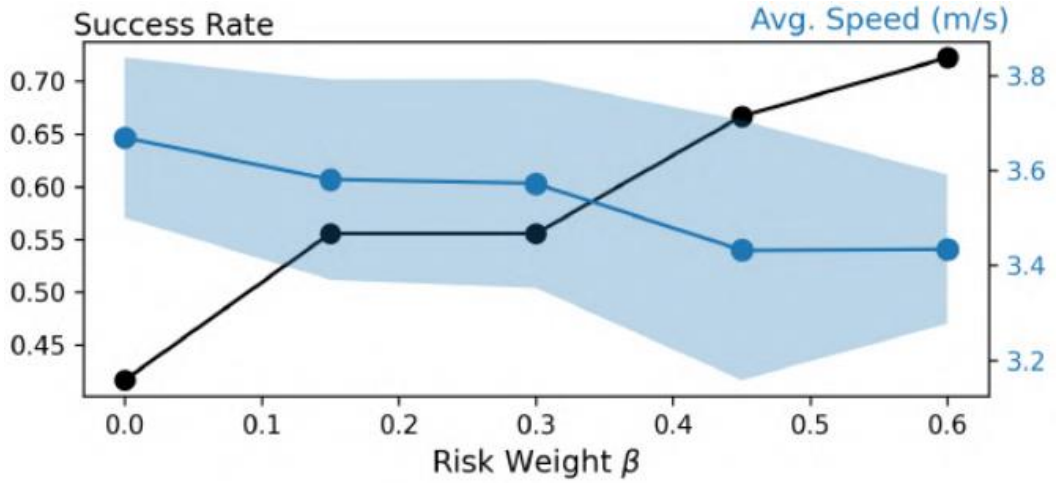

Thank You & Questions

Quiz

- **Q1. Which "Risk Metric" did this paper use? (단답형)**
  - **1. Expected value**
  - **2. ???**

- **Q2. Which ability did this paper focus on for robots? (객관식)**
  - **1. Speed**
  - **2. Collision Avoidance**
  - **3. Push**