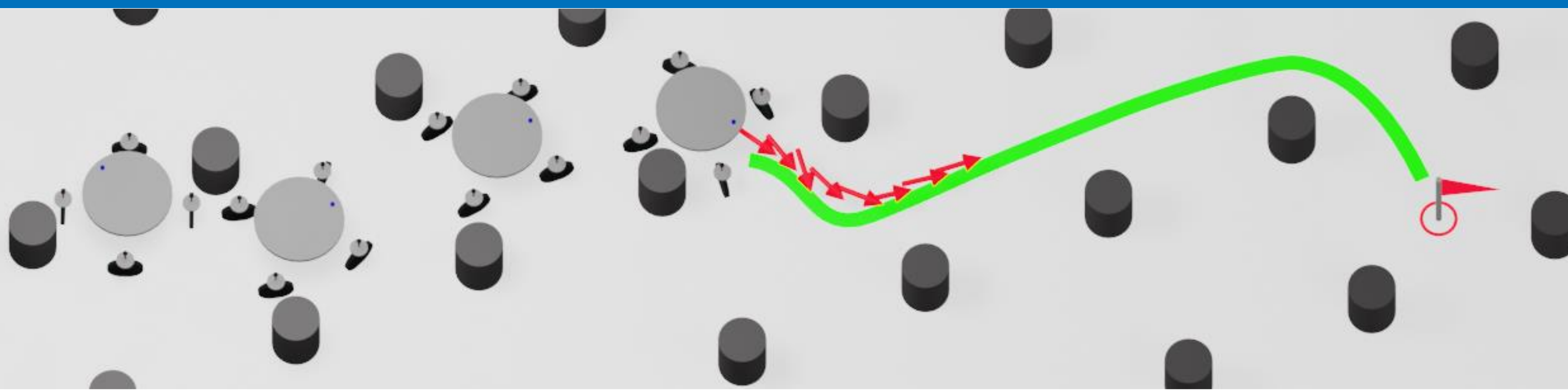# Switching Sampling Space of Model Predictive Path-Integral Controller to Balance Efficiency and Safety in 4WIDS Vehicle Navigation

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Website (All Contents Here)
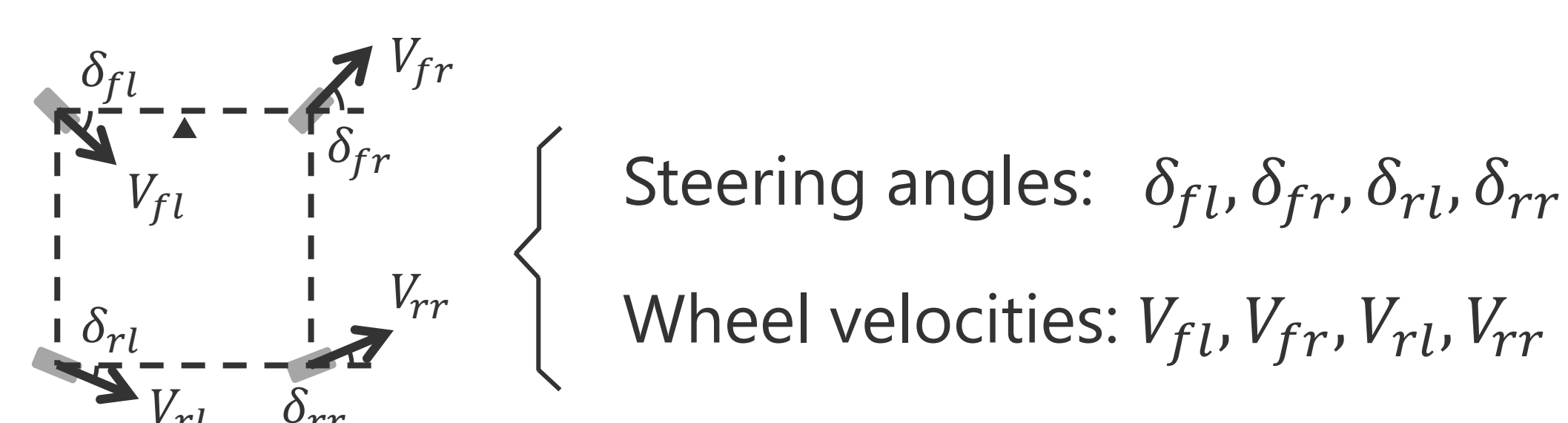
mizuhoaoki.github.io /projects/iros2024

Take Home Messages

- Selection of sampling space for MPPI has a significant impact on its optimality.
- Switching sampling space depending on the real-time situation improves performance.

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1 Issue

4WIDS vehicle has 8 Degrees of Freedom.

Steering angles: $\delta_{fl}, \delta_{fr}, \delta_{rl}, \delta_{rr}$

Wheel velocities: $V_{fl}, V_{fr}, V_{rl}, V_{rr}$

To explore high-dimensional optimal input with MPPI, selecting proper sampling space is essential to ensure solution quality.

What is MPPI ?

Model Predictive Path-Integral Control (MPPI) is a sampling-based optimal control algorithm.

Randomly sampling control input sequence of the near future, and compute the cost value to be minimized for each sample.

- Bad samples because of collision
- Good samples without collisions
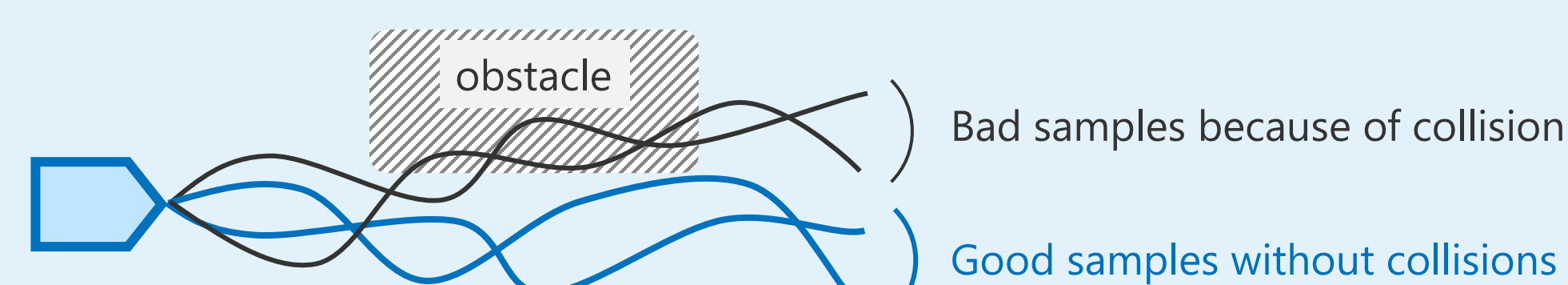
The better (i.e. less costly) samples are assigned larger weights, and obtain the optimal solution as weighted sum of the samples.

- Weighted sum of all samples
- Optimal solution

PROS Wide range of applicability by gradient-free algorithm.

CONS Bad selection of <u>sampling space</u> leads to poor solution quality. (i.e. proposal distribution)

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2 Approach

Among several sampling spaces tested, the <u>two best options</u> are selected.

> 3D space and 4D space

Let's find which strategy works best.

[MPPI-3D] Always use 3D space
[MPPI-4D] Always use 4D space
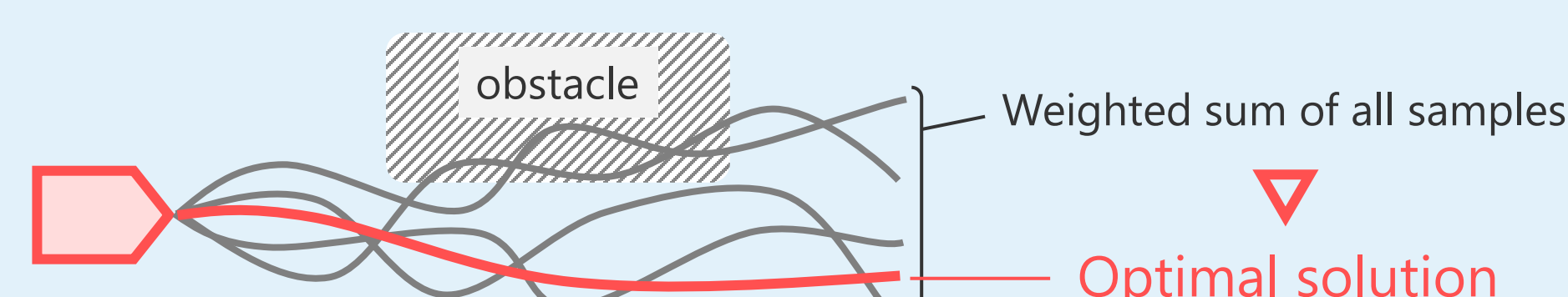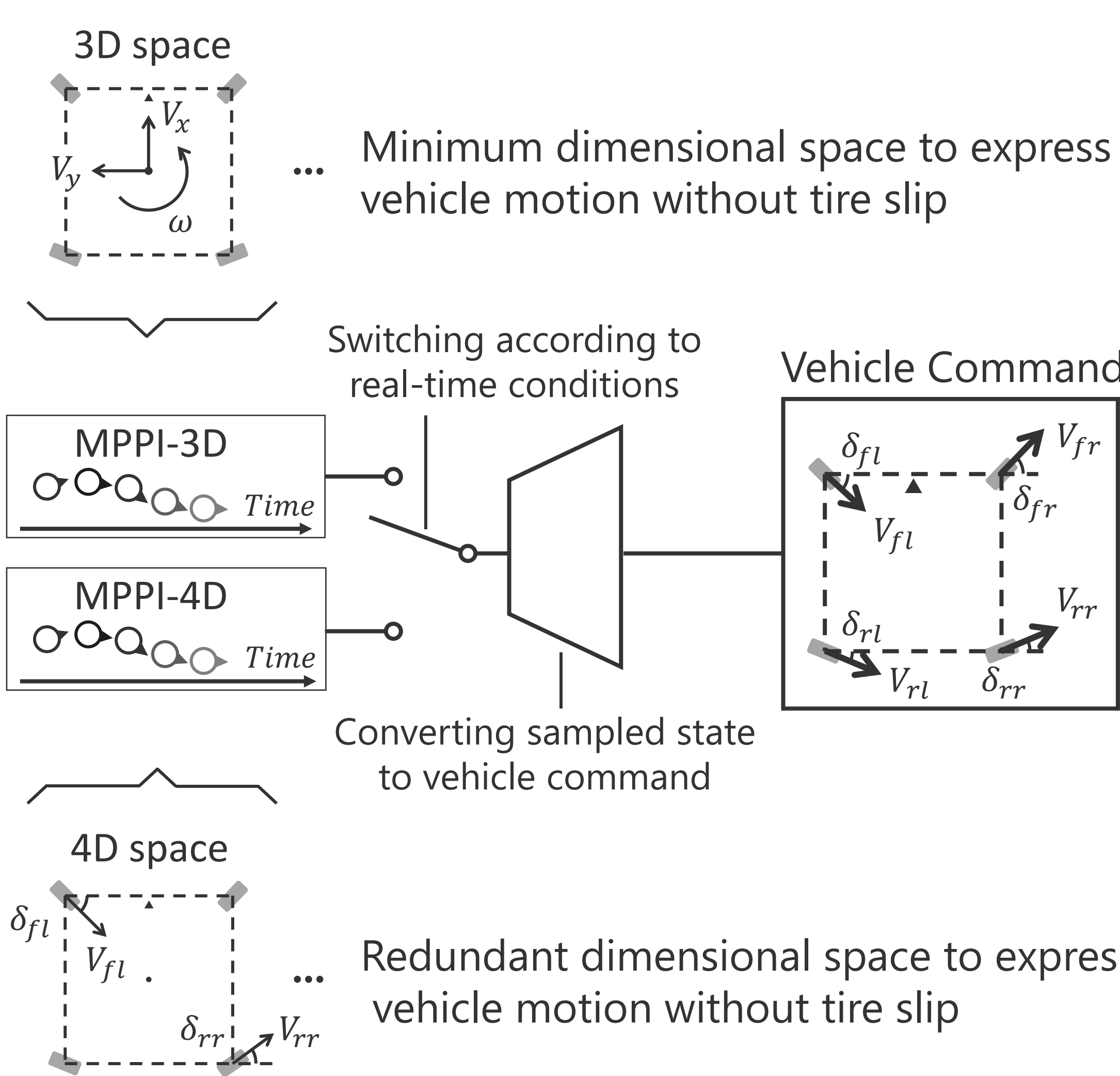[MPPI-H   ] Hybrid use of 3D space and 4D space

Architecture of Switching Sampling Space

3D space — Minimum dimensional space to express vehicle motion without tire slip

Switching according to real-time conditions

Vehicle Command

MPPI-3D · · · Time
MPPI-4D · · · Time

Converting sampled state to vehicle command

4D space — Redundant dimensional space to express vehicle motion without tire slip

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3 Result

Switching sampling space in real-time (MPPI-H) result in better driving behavior.

	Quickness	Safety
MPPI-3D	😐	🙁
MPPI-4D	🙁	🙂
MPPI-H	🙂	🙂

Trajectory Comparison

Example Scenario · Initial Pose · Goal Pose

- MPPI-3D — Vehicle Trajectory · Large Turning Radius · Close to Collision
- MPPI-4D — Turn in Place
- MPPI-H — MPPI-3D is Active · MPPI-4D is Active · Turn in Place

MPPI-H can safely turn the vehicle (strength of MPPI-4D), achieving quick driving in open areas (strength of MPPI-3D).
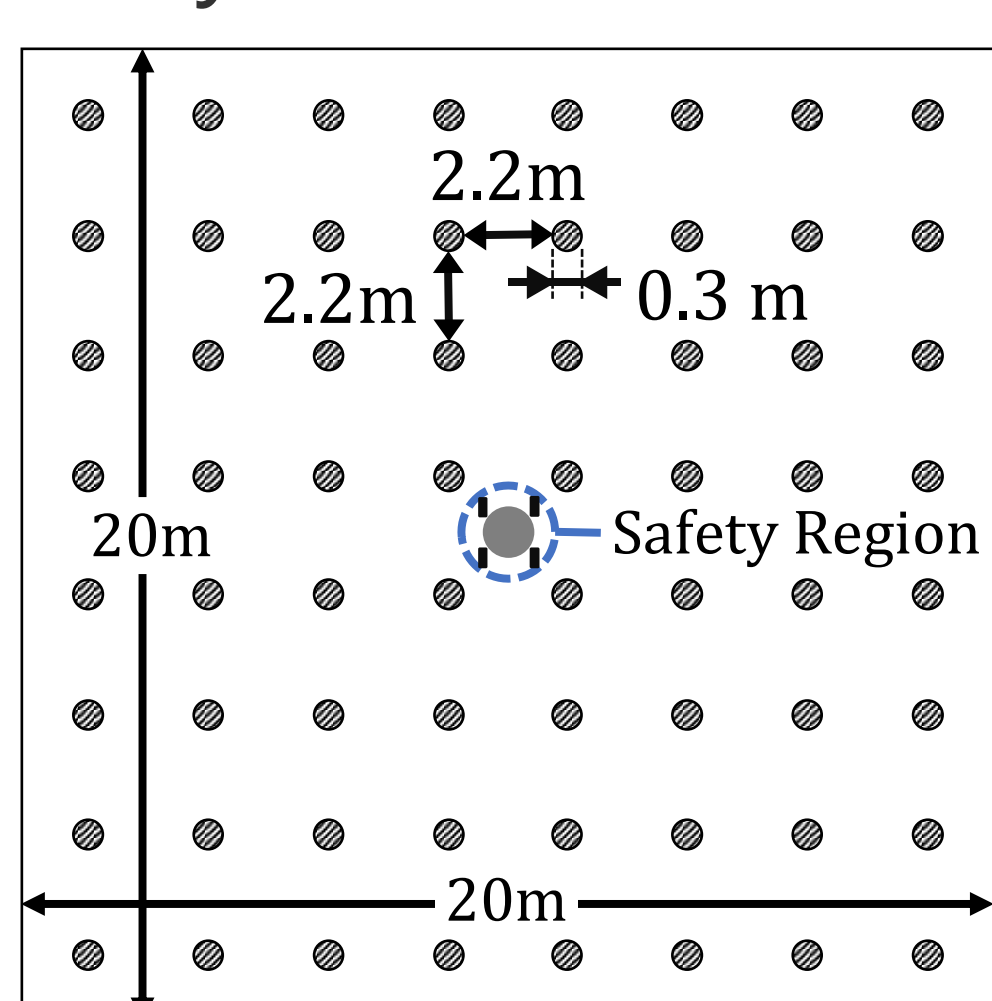

Evaluation Details

- ✓ Goal poses are randomly selected.
- ✓ Vehicle drives for safe, quick, and smooth operation.
- ✓ Obstacles are avoided by detection with LiDAR sensor.
- ✓ <u>Two maps</u>, each with 100 episodes tested.

Cylinder Garden

Maze

TABLE I: Evaluation Results of 100 Navigation Episodes
blue value is the best score, and red value is the worst score of all four controllers.

Field	Cylinder Garden				Maze			
Method Control Space	MPPI-3D(a) $[V_x, V_y, \omega]$	MPPI-3D(b) $[V_x, V_y, \omega]$	MPPI-4D $[V_{fl}, V_{rr}, \delta_{fl}, \delta_{rr}]$	MPPI-H 3D(a) / 4D	MPPI-3D(a) $[V_x, V_y, \omega]$	MPPI-3D(b) $[V_x, V_y, \omega]$	MPPI-4D $[V_{fl}, V_{rr}, \delta_{fl}, \delta_{rr}]$	MPPI-H 3D(b) / 4D
Cost [-] ↓	3241.7	1900.5	1455.8	2425.4	10030.4	3918.8	2452.3	2887.6
Calc. Time [ms] ↓	24.1	23.0	27.6	26.6	19.7	19.9	24.0	21.0
Steering Rate [rad/s] ↓	4.5	3.1	3.6	4.0	6.0	3.6	5.0	3.5
Wheel Acc. [m/s²] ↓	5.03	3.36	4.08	4.98	6.02	3.77	4.85	4.02
Trajectory Length [m] ↓	51.9	46.0	40.8	42.6	72.1	64.8	55.2	55.3
Episode Time [s] ↓	36.4	41.3	38.4	31.2	49.6	55.9	52.1	44.8
Success Rate [%] ↑	76	89	100	99	33	58	98	96