

Prediction, Planning and Simulation for Autonomous Driving

Andreas Philipp

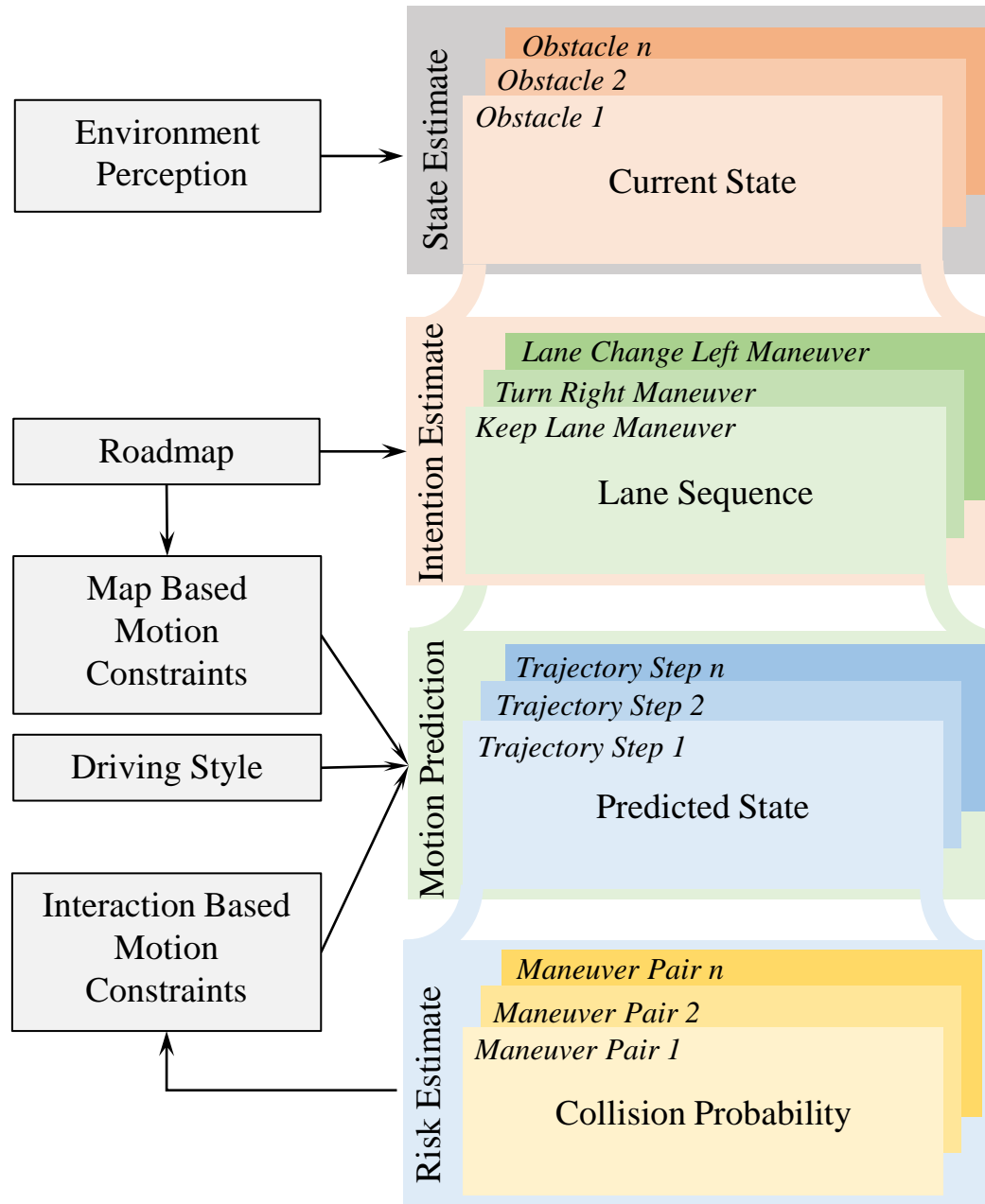
20.06.2022

Overview of the Prediction and Planning Method

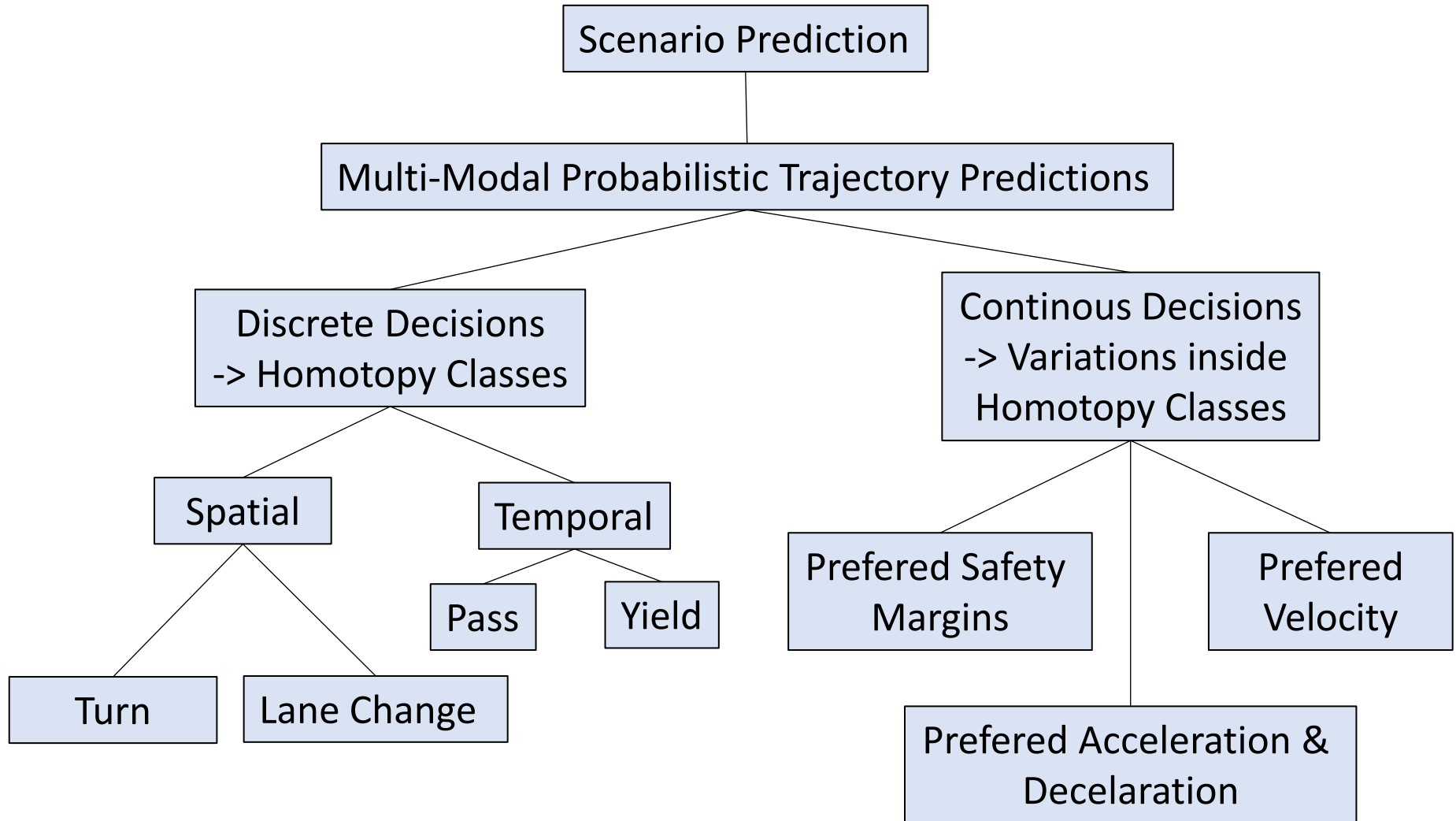
Integration in fub_roscar System

Use Cases and Interfaces

Major Elements of Scenario Prediction



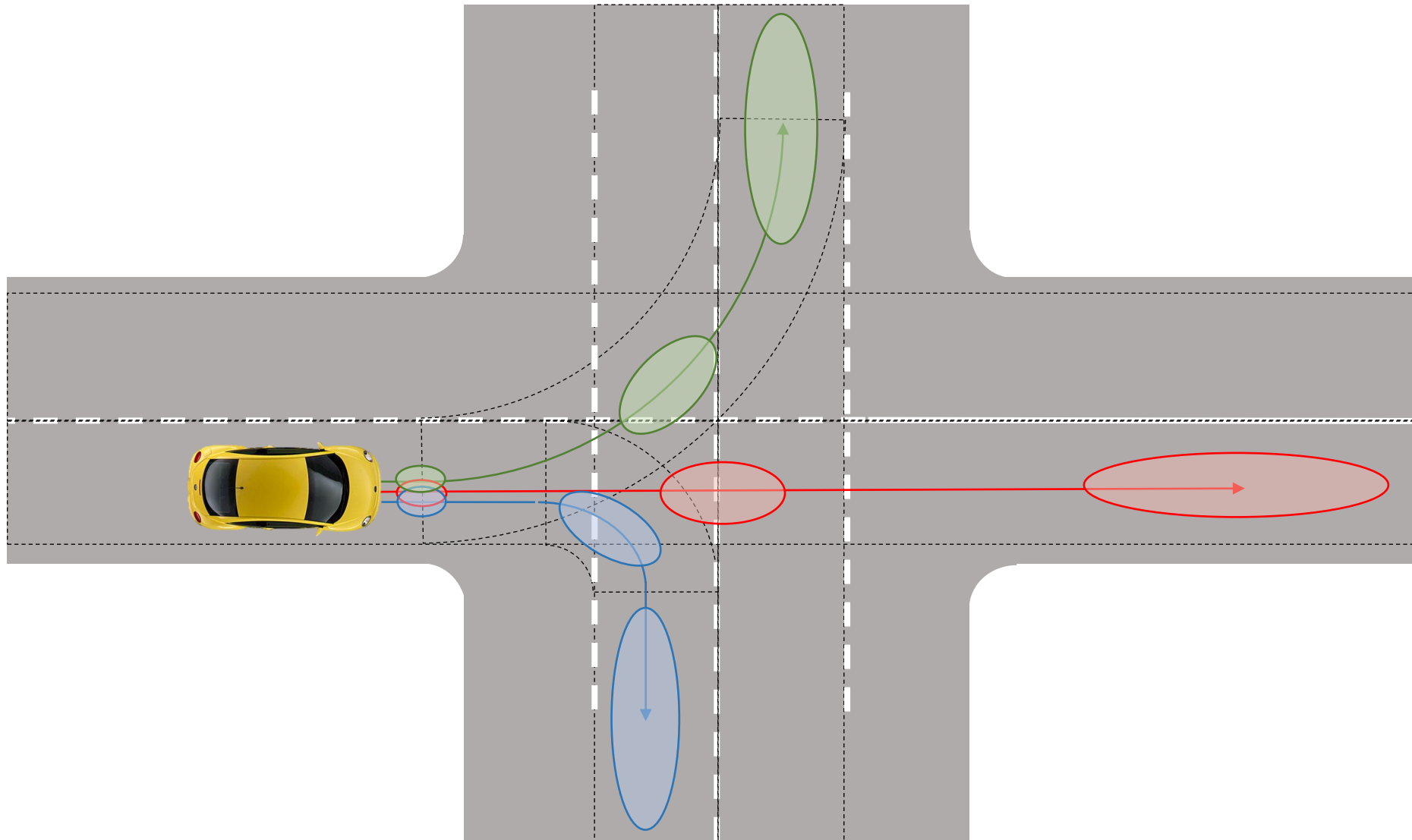
Structure of Scenario Prediction



Homotopy Classes for Trajectory Prediction

Lane Bound Maneuvers (Lawful)									Trash Maneuver (Const. Velocity / Const. Accel.)
Spatial (Discrete Lateral Behaviour)					Temporal (Discrete Longitudinal Behaviour)				
Turn Left	Lane Change Left	Keep Lane	Lane Change Right	Turn Right	Lane Cross.	Merge	Car Follow.	LC Start	

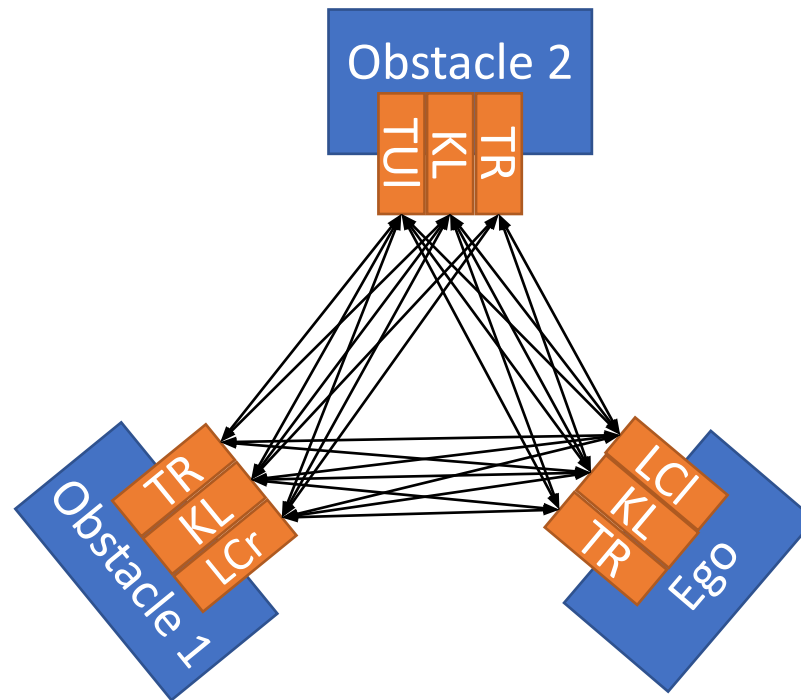
Multi-Modal Prediction with Gaussian Uncertainty



Constraints and Parameters for Trajectory Rollout

Map Based Motion Constraints			Interaction Based Motion Constraints				Drive Style (IDM Parameters)				
Speed Limits	Legal										
	Curvature										
	Visibility										
	Lane Marker										
	Traffic Sign (Stop/Give Way)										
	Traffic Light										
	Car Follower										
	Lane Changer										
	Subordinate Lane Merger										
	Subordinate Lane Crosser										
	Counterpart of Trash										
	Desired Velocity Factor [%]										
	Minimum Spacing [m]										
	Time Headway [s]										
	Preferred Acceleration [m/s^2]										
	Comfortable Braking [m/s^2]										

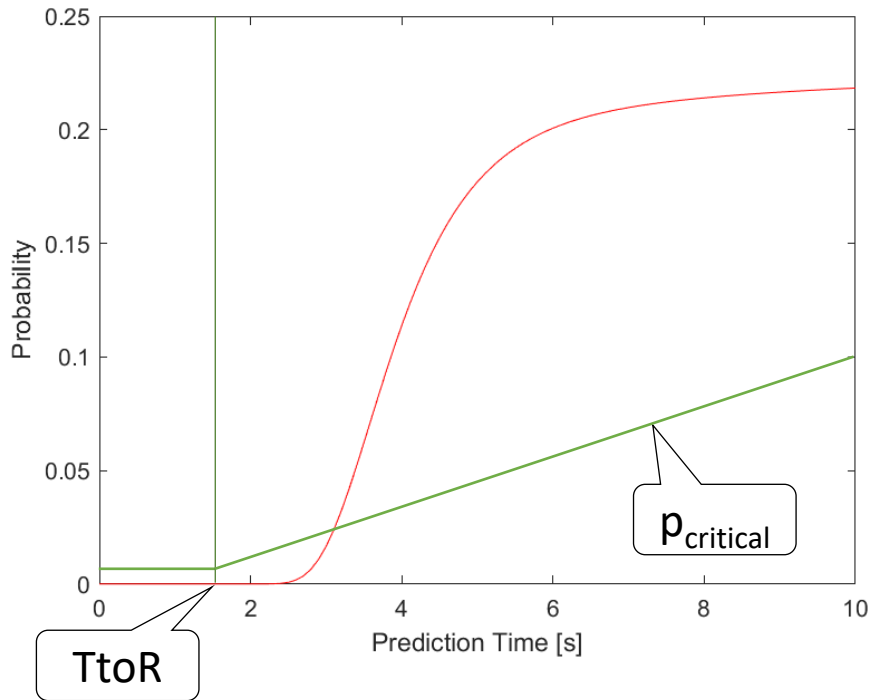
Interaction Awareness between Maneuvers



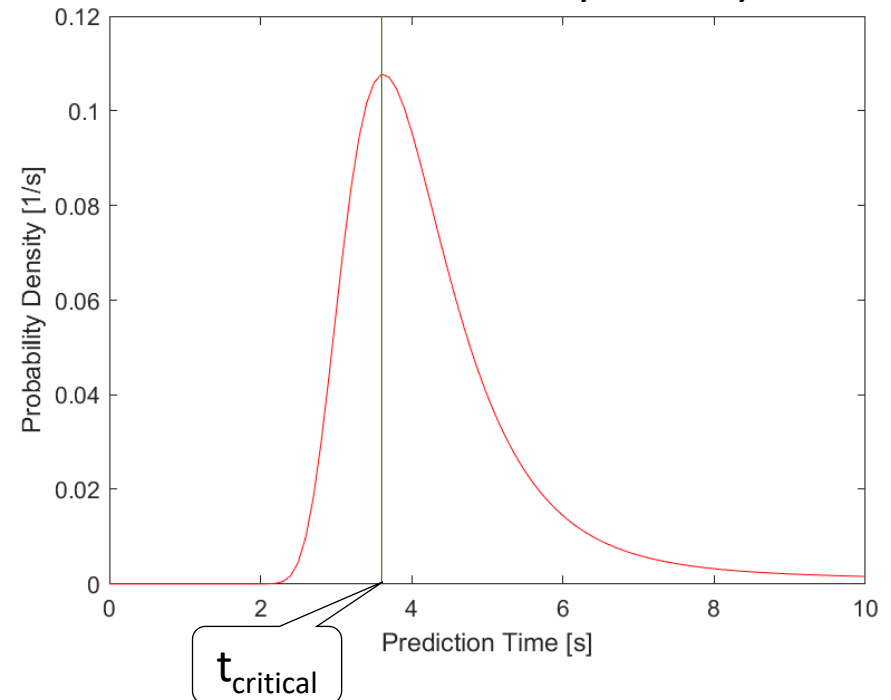
$$I = \frac{(M^2 - 1) \cdot N \cdot (N - 1)}{2}$$

Collision Probability between 2 Maneuvers over Time

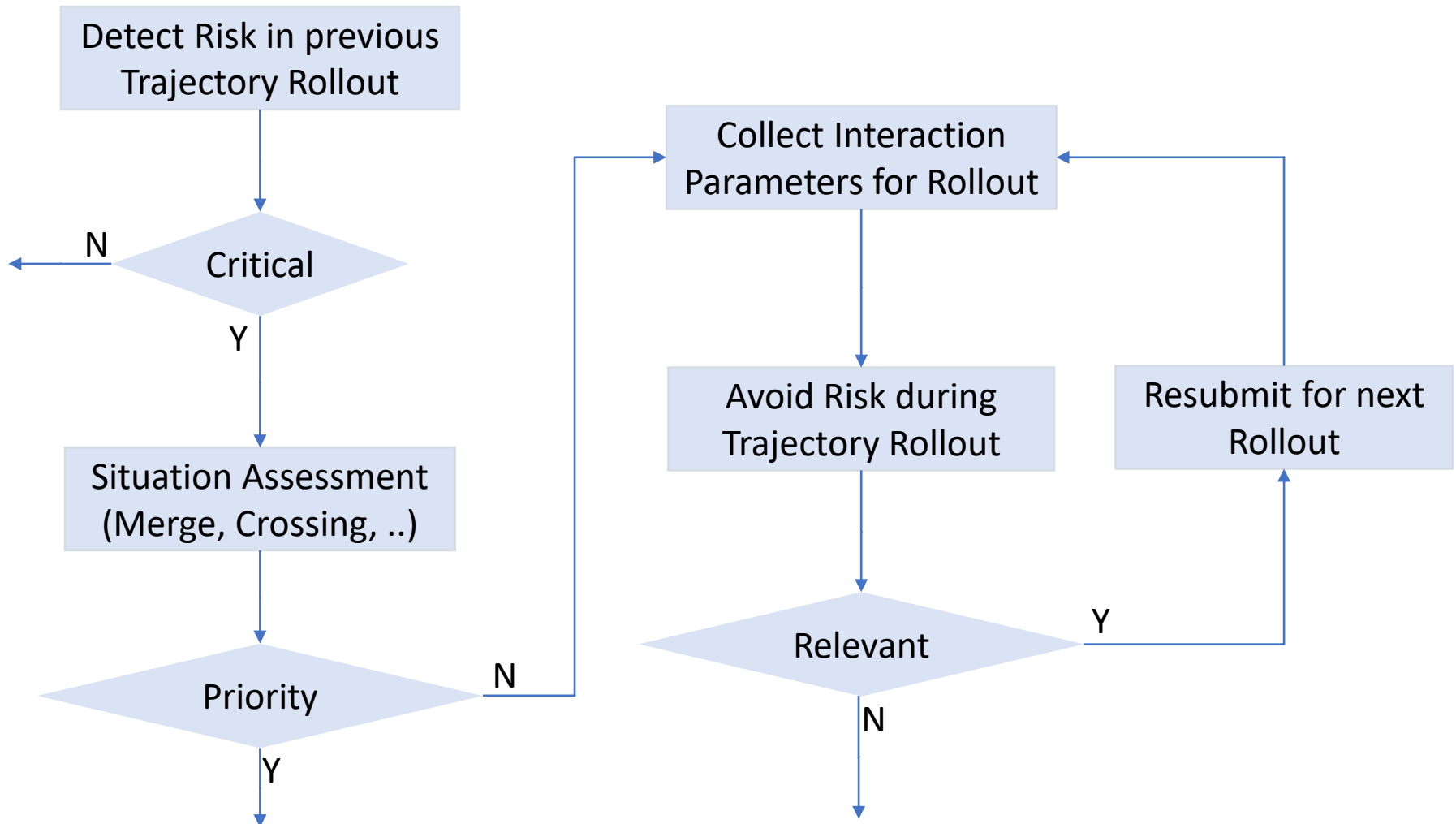
Accumulated Collision Probability



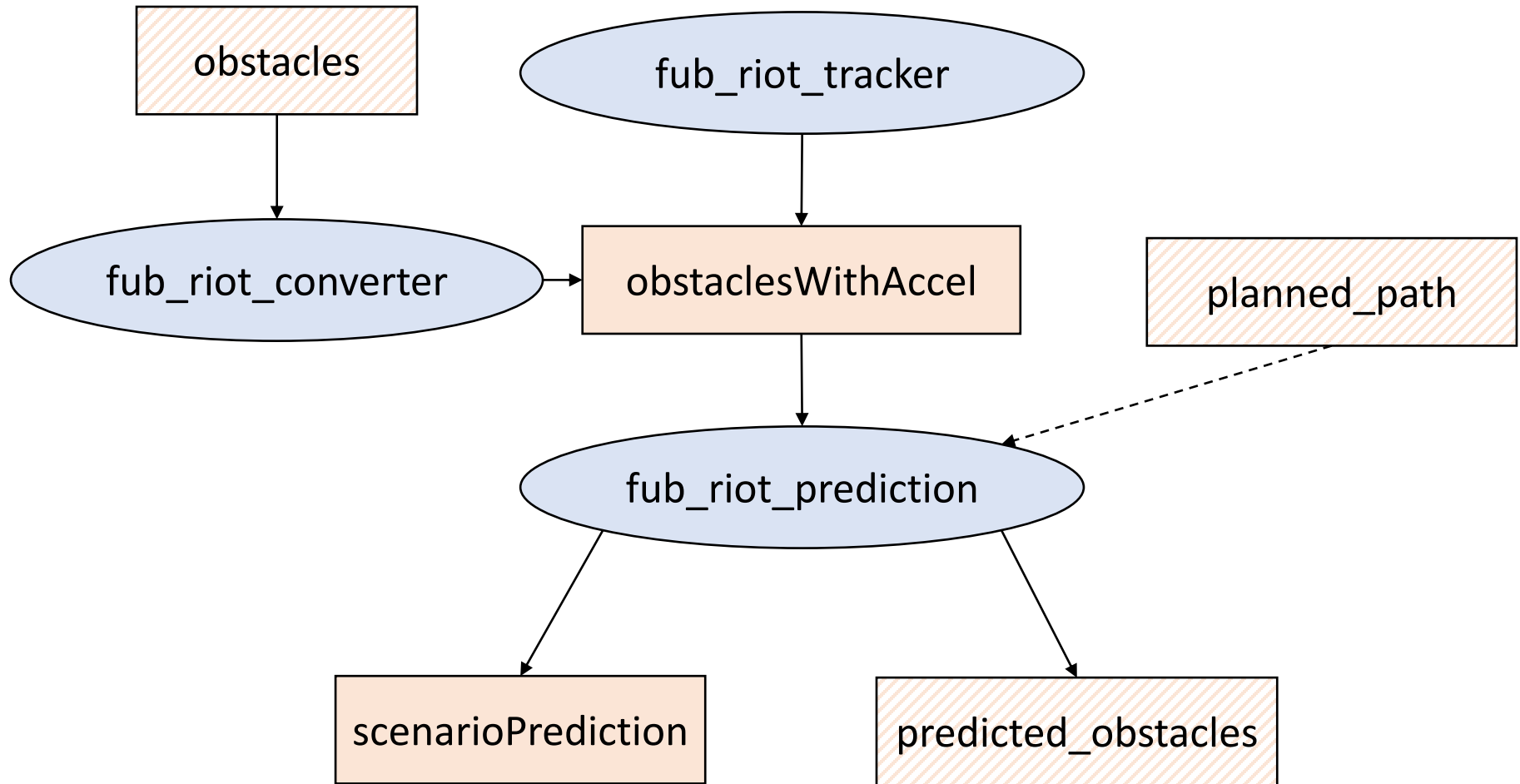
Collision Probability Density



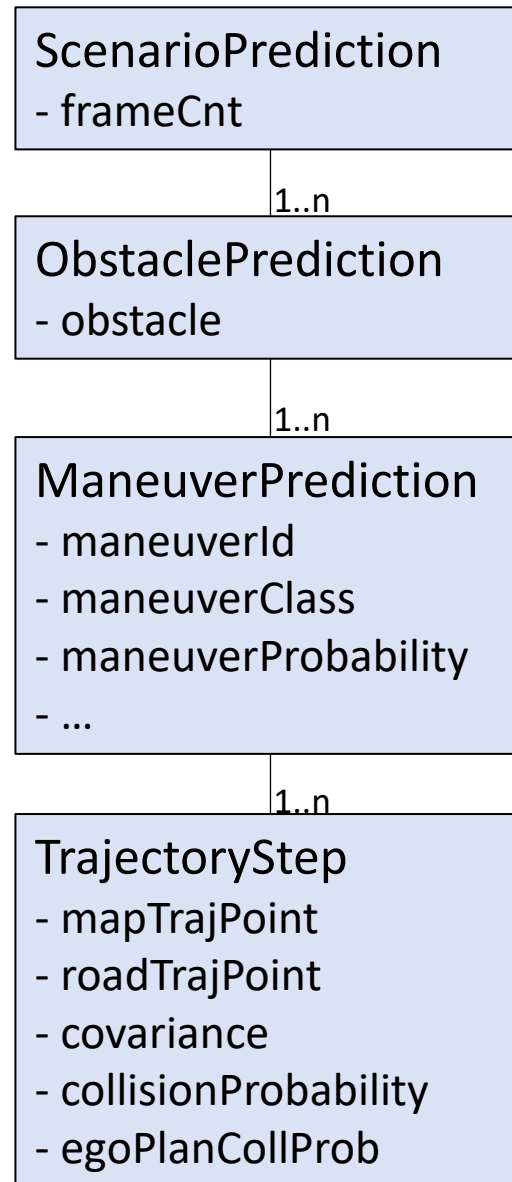
Interaction Based Motion Prediction



ROS Nodes and Topics for Scenario Prediction



Structure of Scenario Prediction Message



Example Output from Risk Calculation

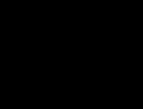
EGOPLANCOLL.txt - LibreOffice Calc

File Edit View Insert Format Styles Sheet Data Tools Window Help

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A376:AMJ383 fx Σ = 0

	A	B	C	D		BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA			
1	Frm	Obst	ManId	ManClass	ManProb	TP-69	TP-70	TP-71	TP-72	TP-73	TP-74	TP-75	TP-76	TP-77	TP-78	TP-79	TP-80	TP-81	TP-82	TP-83	TP-84	TP-85	TP-86	TP-87	TP-88	TP-89	TP-90	TP-91	TP-92	TP-93	TP-94	TP-95	TP-96	TP-97	TP-98	TP-99			
359	170	18	15LCr	-	1.84	12.12	14.09	16.04	17.92	19.69	21.3	22.72	23.94	24.92	25.67	26.18	26.45	26.54	26.56	26.56	26.56	26.56	26.57	26.58	26.6	26.63	26.66	26.69	26.72	26.75	26.79	26.82	26.84	26.87	26.9	26.92	26.92		
360	170	ALL	-	ALL	-	0.22	0.26	0.3	0.33	0.36	0.39	0.42	0.44	0.46	0.47	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.5	0.5	0.5	
361	171	18	15LCr	-	1.53	13.86	15.81	17.7	19.47	21.09	22.52	23.75	24.74	25.5	26.01	26.28	26.38	26.4	26.4	26.4	26.41	26.42	26.44	26.46	26.49	26.52	26.55	26.58	26.61	26.64	26.67	26.69	26.72	26.74	26.76	26.76	26.76	26.76	
362	171	ALL	-	ALL	-	0.21	0.24	0.27	0.3	0.32	0.35	0.36	0.38	0.39	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	
363	172	18	15LCr	-	1.34	15.58	17.48	19.26	20.88	22.33	23.56	24.57	25.33	25.85	26.12	26.22	26.24	26.24	26.24	26.25	26.26	26.28	26.3	26.32	26.33	26.36	26.38	26.41	26.44	26.47	26.49	26.52	26.54	26.56	26.58	26.6	26.6	26.6	
364	172	ALL	-	ALL	-	0.21	0.23	0.26	0.28	0.3	0.32	0.33	0.34	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
365	173	18	15LCr	-	1.22	17.25	19.04	20.68	22.13	23.37	24.39	25.16	25.68	25.96	26.06	26.08	26.08	26.09	26.1	26.11	26.14	26.16	26.19	26.22	26.24	26.27	26.27	26.3	26.32	26.34	26.37	26.38	26.4	26.42	26.43	26.43	26.43	26.43	
366	173	ALL	-	ALL	-	0.21	0.23	0.25	0.27	0.28	0.3	0.31	0.31	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	
367	174	7	5LCI	-	98.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.31	0.31		
368	174	18	15LCr	-	1.14	18.78	20.43	21.9	23.15	24.18	24.96	25.49	25.78	25.88	25.9	25.9	25.9	25.91	25.92	25.93	25.95	25.98	26	26.03	26.05	26.08	26.1	26.13	26.15	26.17	26.19	26.2	26.22	26.23	26.24	26.24	26.24		
369	174	ALL	-	ALL	-	0.21	0.23	0.25	0.26	0.28	0.29	0.29	0.29	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.61	0.61
370	175	7	5LCI	-	98.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.31	1.33	1.33			
371	175	18	15LCr	-	1.12	20.26	21.73	23	24.03	24.81	25.35	25.64	25.74	25.76	25.76	25.76	25.76	25.77	25.79	25.81	25.83	25.85	25.88	25.9	25.93	25.95	25.97	25.99	26.01	26.03	26.05	26.06	26.06	26.07	26.08	26.09	26.09	26.09	
372	175	ALL	-	ALL	-	0.23	0.24	0.26	0.27	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	
373	176	7	5LCI	-	98.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.3	1.3	4.24	4.24		
374	176	18	15LCr	-	1.08	21.53	22.8	23.84	24.64	25.18	25.48	25.58	25.6	25.6	25.6	25.6	25.6	25.61	25.63	25.64	25.67	25.69	25.71	25.73	25.76	25.78	25.8	25.82	25.84	25.85	25.87	25.88	25.89	25.9	25.91	25.92	25.92	25.92	
375	176	ALL	-	ALL	-	0.23	0.25	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
376	177	7	5LCI	-	98.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0.18		
377	177	21	7FR	-	92.47	0	0	0	0	0.01	0.03	0.11	0.44	1.57	4.51	9.77	15.51	19.96	22.75	24.4	25.47	26.25	26.86	27.36	27.78	28.15	28.48	28.78	29.06	29.3	29.52	29.72	29.89	30.05	30.2	30.2	30.2		
378	177	21	9LCr	-	4.25	0	0	0	0	0.01	0.03	0.11	0.44	1.57	4.51	9.77	15.51	19.96	22.75	24.4	25.47	26.25	26.86	27.36	27.78	28.15	28.48	28.78	29.06	29.3	29.52	29.72	29.89	30.05	30.2	30.2	30.2		
379	177	21	10LCI	-	3.27	0	0	0	0	0.01	0.03	0.11	0.44	1.57	4.51	9.77	15.51	19.96	22.75	24.4	25.47	26.25	26.86	27.36	27.78	28.15	28.48	28.78	29.06	29.3	29.52	29.72	29.89	30.05	30.2	30.2	30.2		
380	177	21	ALL	-	0	0	0	0	0	0.01	0.03	0.11	0.44	1.57	4.51	9.76	15.51	19.96	22.75	24.4	25.47	26.24	26.86	27.36	27.78	28.14	28.48	28.78	29.05	29.3	29.52	29.71	29.89	30.05	30.2	30.2			
381	177	22	5FR	-	99.71	0	0	0	0	0	0	0	0	0.02	0.1	0.37	0.95	1.83	2.84	3.81	4.68	5.47	6.21	6.93	7.57	8.13	8.68	9.5	10.02	10.29	10.43	10.48	10.5	10.51	10.51	10.51			
382	177	40	3LCI	-	4.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.05	0.19	0.68	1.99	4.15	4.15				
383	177	ALL	-	ALL	-	0	0	0	0	0.01	0.03	0.11	0.44	1.59	4.6	10.1	16.31	21.42	24.93	27.27	28.95	30.27	31.39	32.37	33.23	34.04	34.81	35.53	36.15	36.56	36.85	37.07	37.25	37.43	37.73	37.73	37.73		
384	178	7	5LCI	-	98.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.27	1.22	4.08	10.69	22.55	22.55			
385	178	ALL	-	ALL	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.27	1.2	4.01	10.5	22.15	22.15		
386	179	24	10LCI	-	12.59	0	0	0	0	0	0	0	0.01	0.02	0.05	0.11	0.22	0.39	0.66	1.05	1.6	2.32	3.24	4.39	5.75	7.35	9.16	11.17	13.38	15.75	18.27	20.92	23.65	26.46	29.32	29.32			
387	179	ALL	-	ALL	-	0	0	0	0	0	0	0	0	0	0.01	0.01	0.03	0.05	0.08	0.13	0.2	0.29	0.41	0.55	0.72	0.92	1.15	1.41	1.68	1.98	2.3	2.63	2.98	3.33	3.69	3.69			
388	180	24	10LCI	-	28.79	0	0	0	0	0	0	0.01	0.04	0.09	0.19	0.35	0.6	0.97	1.49	2.18	3.08	4.2	5.54	7.11	8.9	10.9	13.1	15.48	18	20.66	23.41	26.24	29.11	32.02	32.02	32.02			
389	180	ALL	-	ALL	-	0	0	0	0	0	0	0	0	0.01	0.03	0.05	0.1	0.17	0.28	0.43	0.63	0.89	1.21	1.59	2.05	2.56	3.14	3.77	4.46	5.18	5.95	6.74	7.55	8.38	9.22	9.22			
390	181	24	10LCI	-	51.1	0	0	0	0	0	0.01	0.04	0.08	0.17	0.32	0.55	0.89	1.38	2.04	2.89	3.94	5.19	6.64	8.26	10.04	11.94	13.92	15.95	18	20.03	22.02	23.94	25.78						



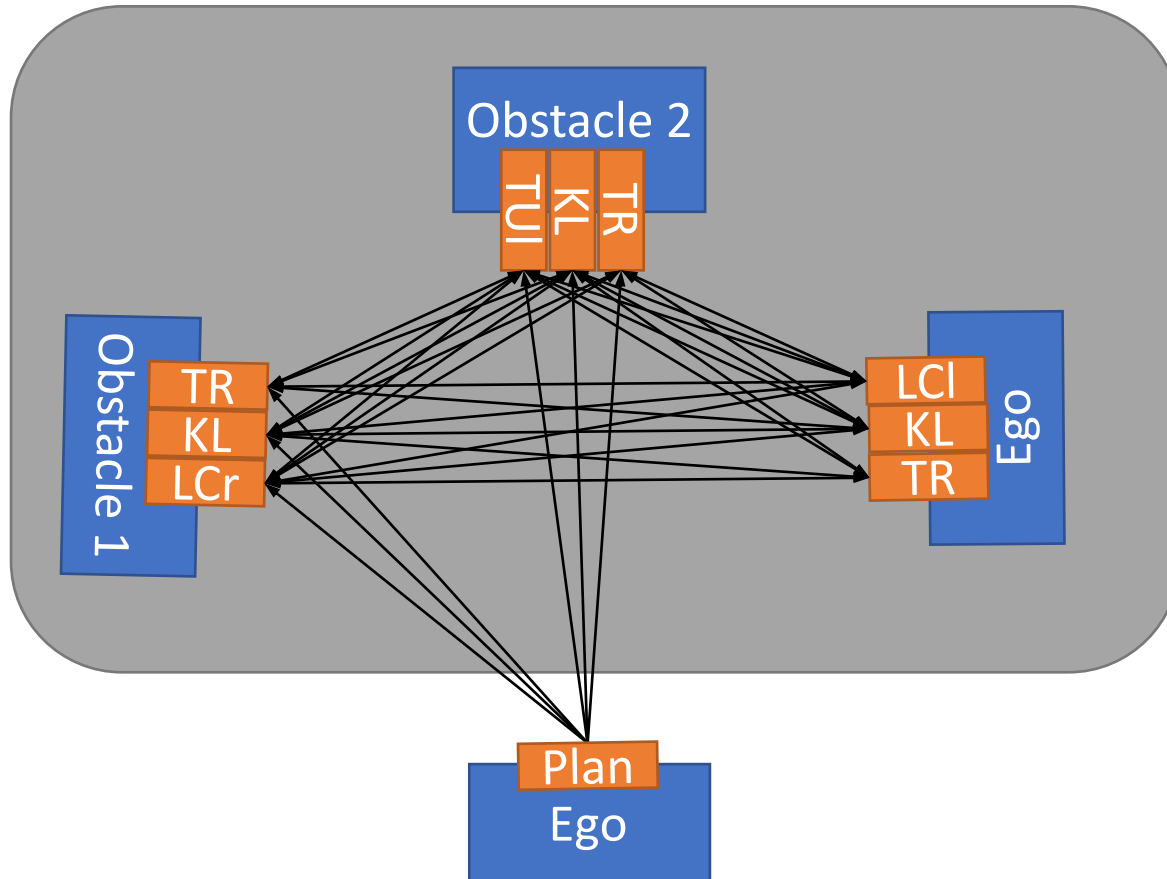
From Prediction to Planning

Scenario Prediction: Hypothesis about the Plans of the Others

-> Trajectory Planning Based on Same Method as Prediction

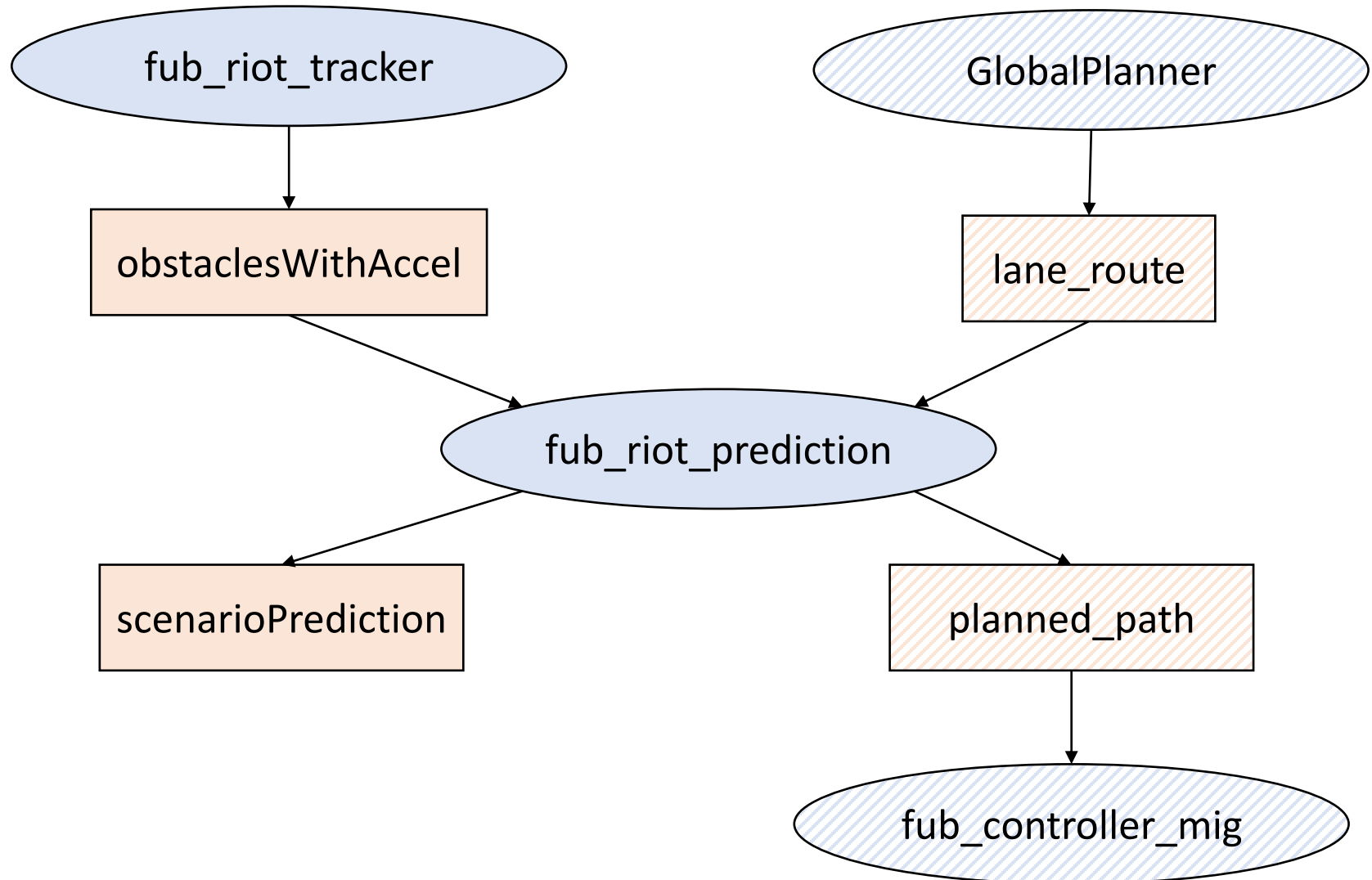
Differences	Prediction	Planning
Spatial Decisions	Multi-Modal	Mainly given by Route
Temporal Decisions	Uncertainty about Pass/Yield	Pass/Yield is Decision of the Planner
Continous Decisions	High Variance of Predicted Trajectory	Low Variance of Planned Trajector
Decision Persistence	Correction on Every Iteration Possible	Correction Dangerous after Start of Realisation
Smoothness	Incidental	Important
Traffic Rule Compliance	Mostly	Mandatory

Prediction Based Planning

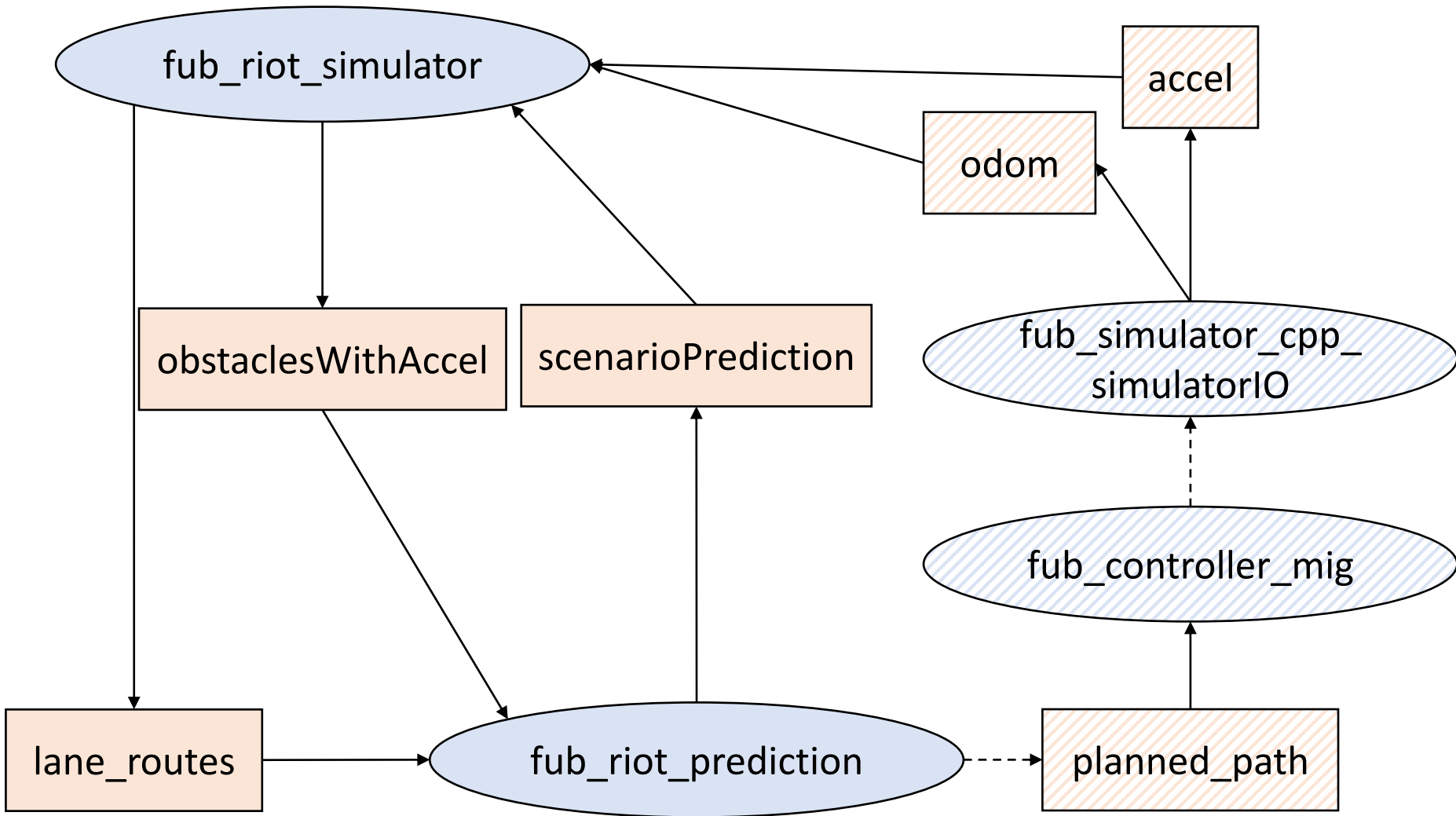


$$I = \frac{(M^2 - 1) \cdot N \cdot (N - 1)}{2} + M \cdot (N - 1)$$

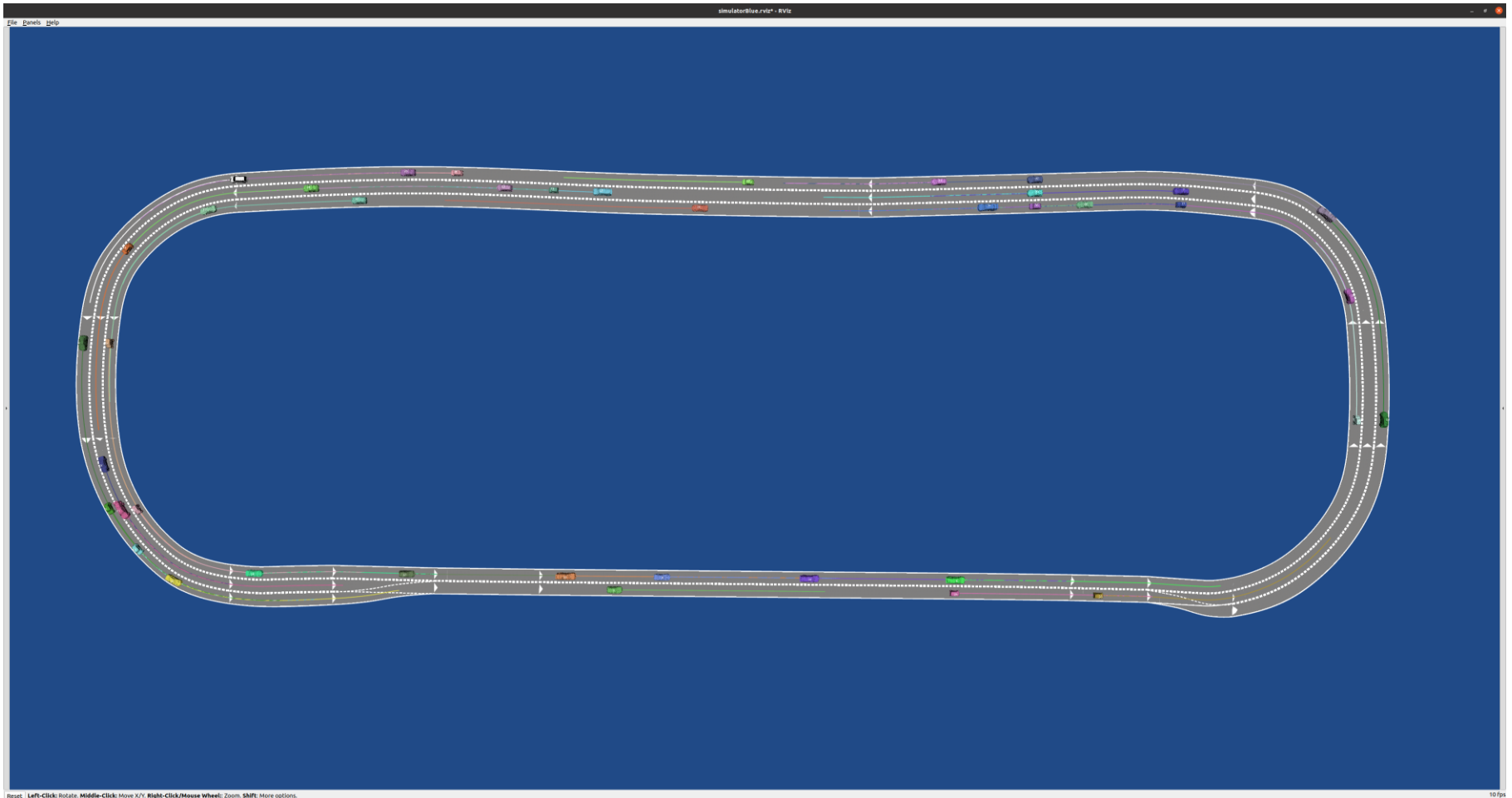
ROS Nodes and Topics for Planning



ROS Nodes and Topics for Simulation

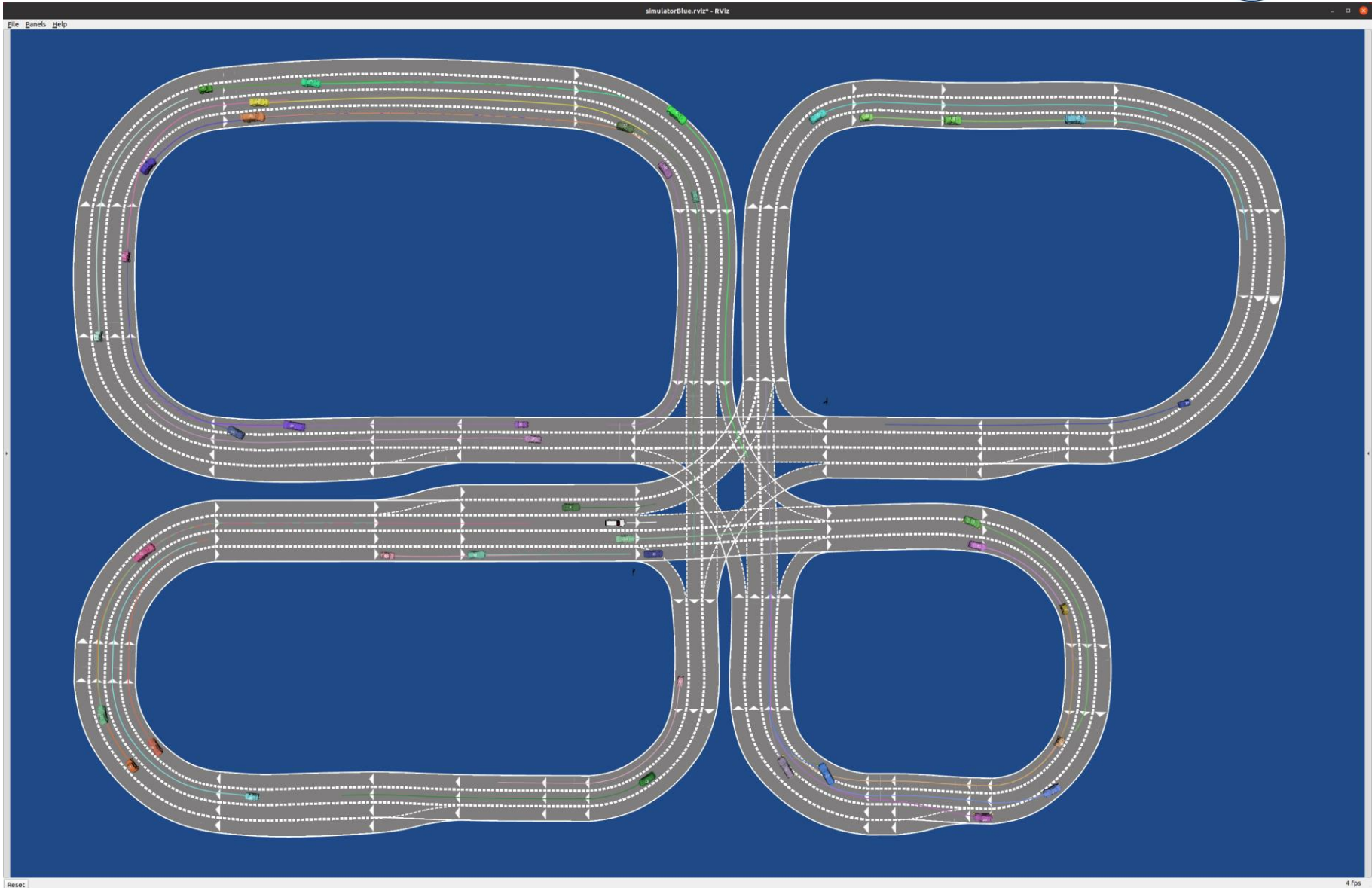


Highway Oval Track Scenario

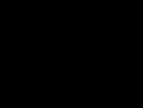


All Vehicles Share the Same Route

Intersection Scenario



11 Different Routes Assigned Randomly to Vehicles



Thank You for Your Attention