Hybrid *AI : Integration of Rule-Driven and Data-Driven Approaches for Enhanced Autonomous Robotics*

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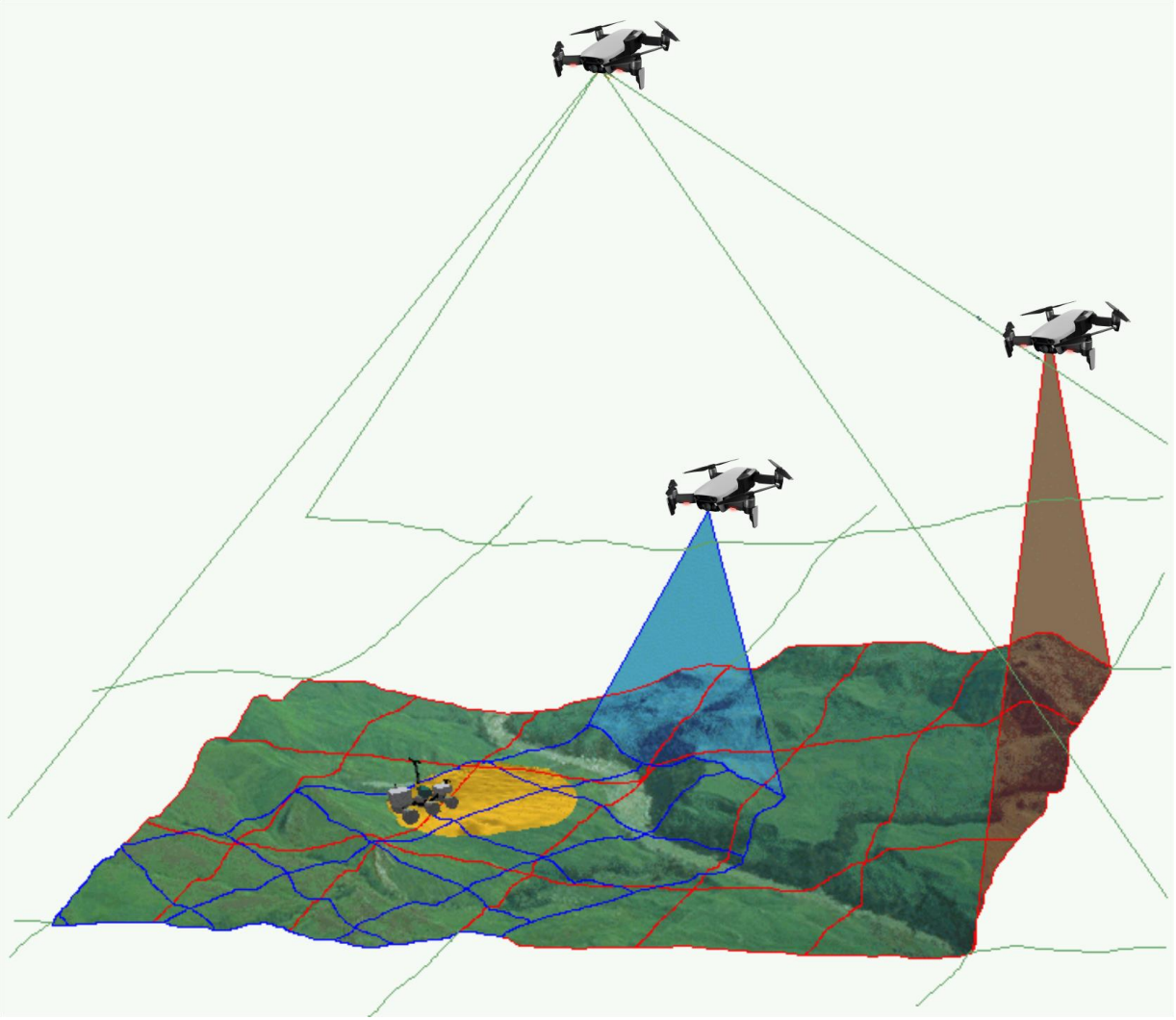
SCIENTIFIC OBJECTIVES

- Develop **real-time perception of complex and dynamic environments** in order to build large scale semantic representations that can be shared to other robots

- Develop **intelligent robots** able to
  i. decide their actions in real-time
  ii. manage uncertainty
  iii. predict in real-time the future states
  iv. acquire new capacities

- Develop **autonomous collaborative robots** able to accomplish complex task taking high-level cognitive-based decisions without human intervention



A definition of intelligence

- Intelligence is the ability to acquire, understand, and apply knowledge and skills.
- Intelligence allows to adapt to new situations, think abstractly, comprehend complex ideas, and learn from experience.
- Intelligence is often considered a combination of both a priori knowledge and experiences.
- It may not be limited to academic or theoretical knowledge but may also includes practical and emotional aspects, such as social understanding and empathy (interaction with humans).

KNOWLEDGE SOURCE

A priori knowledge

- Well known rules / relationships
- Scientific knowledge
- Expert knowledge

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- Indirect perception (metadata, …)
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- Correlation between observations

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RULE-BASED METHODS

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DATA-BASED METHODS

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Actual knowledge from perception	- Indirect perception (metadata, …) - Direct perception
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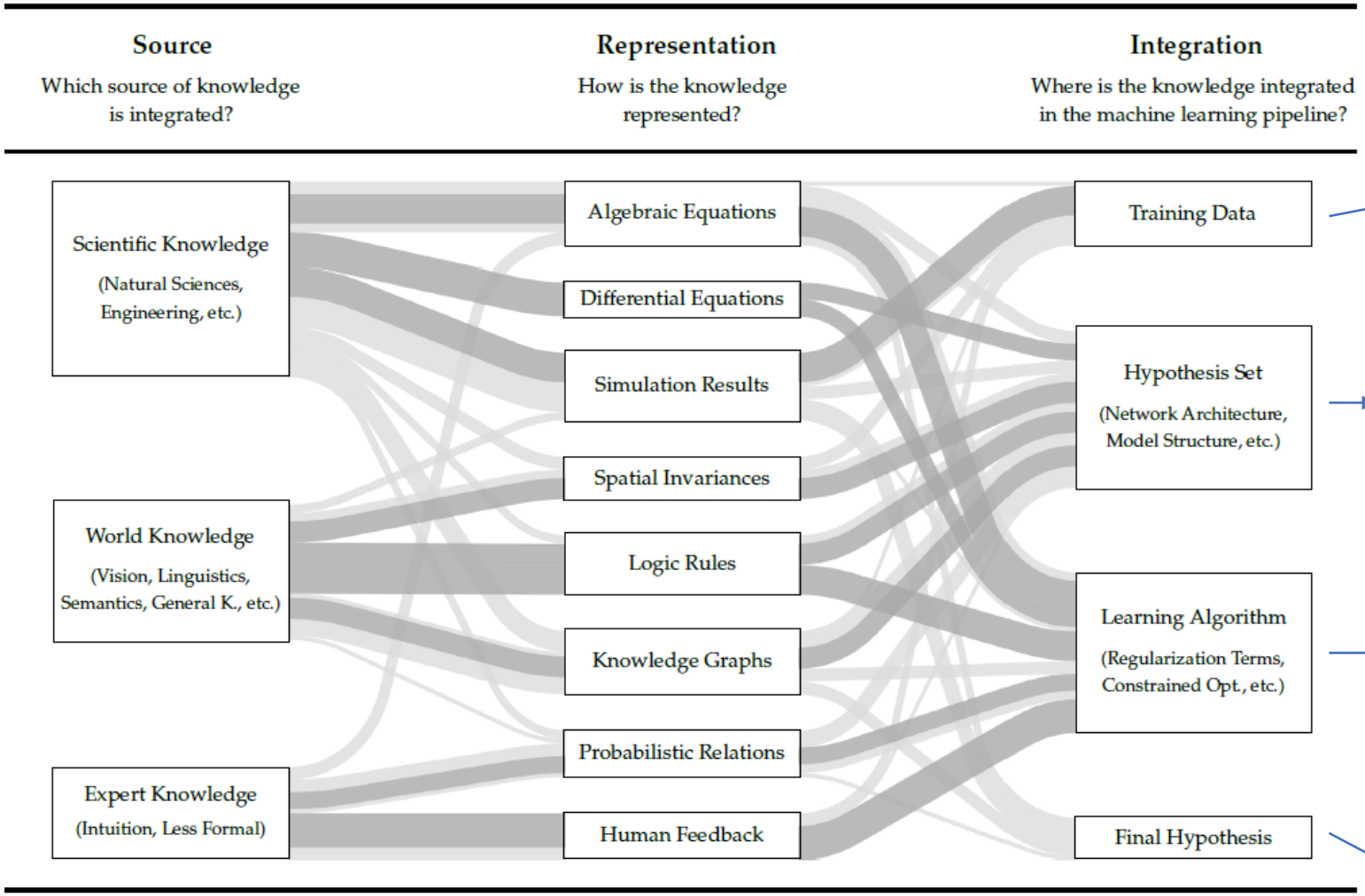
HYBRID AI METHODS

HYBRID METHODS CLASSIFICATION



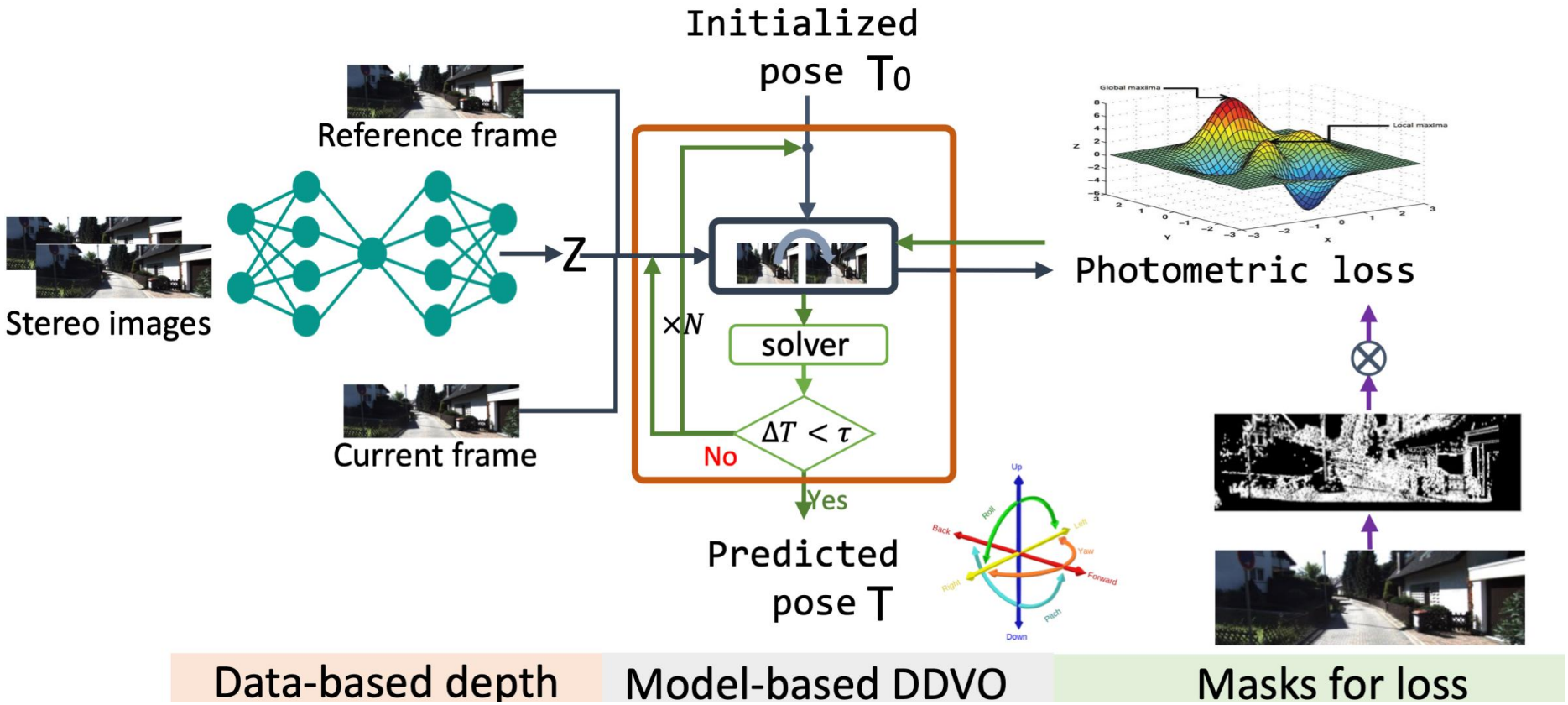
Use simulation to augment the training data

Choose the network based on known properties of the data (i.e. CNN for images, RNN for time sequences, …)

The loss function is designed specifically for the problem

We can validate the result of the network checking it's conformity to the knowledge we have

EXAMPLE: HYBRID STEREO ODOMETRY



Z. Liu, E. Malis, P. Martinet: "A new dense hybrid stereo visual odometry approach", IROS 2022.

Z. Liu, E. Malis, P. Martinet: "Multi-masks Generation for Increasing Robustness of Dense Direct Methods", ITSC 2023.

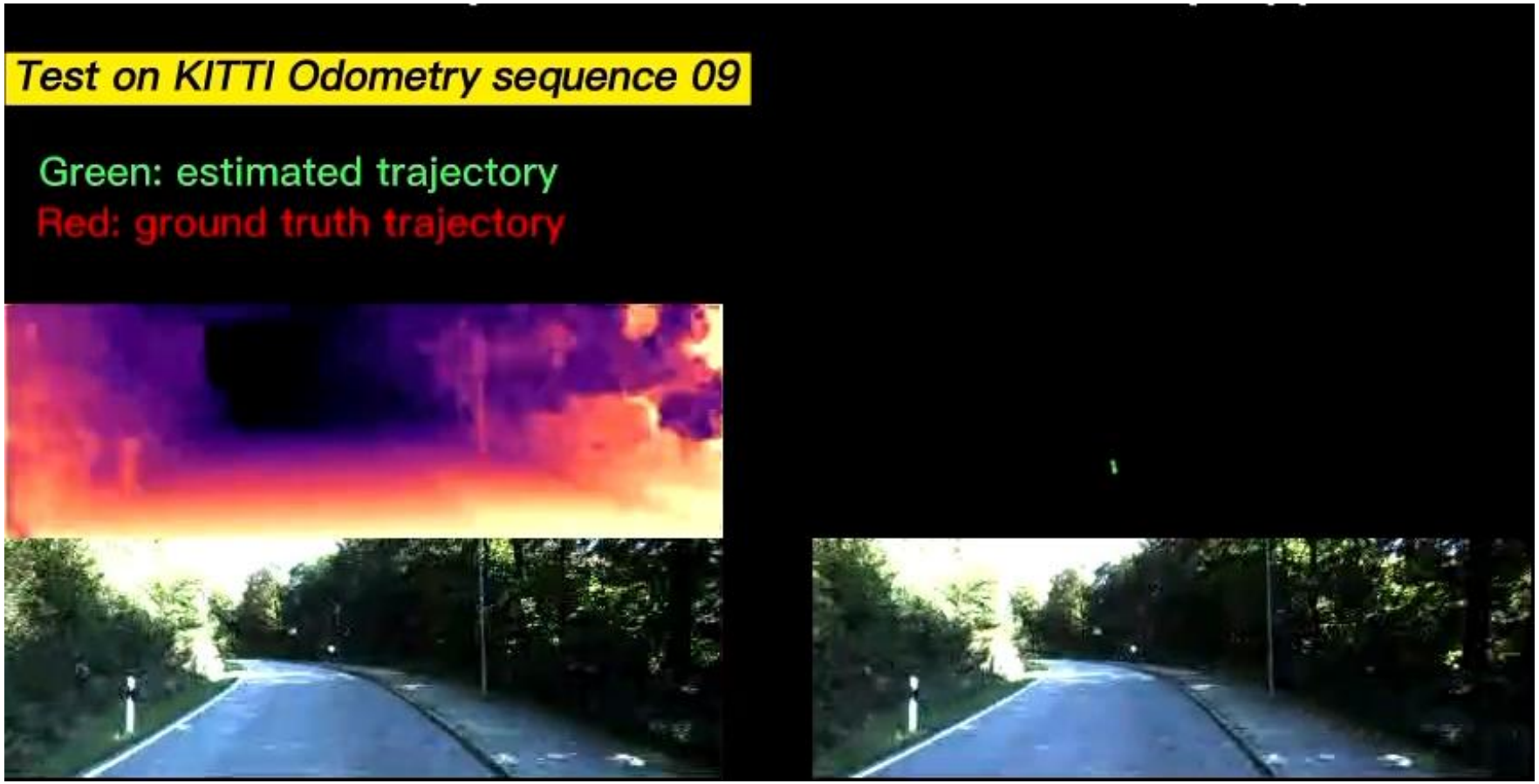
Z. Liu, E. Malis, P. Martinet: "One-stage deep stereo network", ICASSP 2024.

COMPARISON WITH OTHER METHODS

Type	Depth Error				Depth Accuracy			Pose Error				Time/ms
	abs rel	rel sqr	rmse	rmse log	1.25	1.25^2	1.25^3	t_{err}	r_{err}	RPE_{tran}	RPE_{rot}	
Soft												
SFMLearner [3] [13]	0.1482	2.7122	5.0126	0.2497	89.59	93.96	96.10	2.32	0.66	0.024	0.039	137.6
Bayesian [39], [20], [7]	0.3186	12.3994	9.1111	0.3943	86.29	90.91	93.40	2.64	0.70	0.024	0.039	154.6
Binary												
Principled [4] [17]	0.3431	14.2719	9.7451	0.4090	85.83	90.46	93.06	2.90	0.74	0.023	0.039	209.8
monodepth2 [5] [12]	0.0781	0.5958	3.6738	0.1747	91.67	95.95	97.76	5.17	1.66	0.026	0.045	121.7
Ours	**0.0665**	**0.4731**	**3.3050**	**0.1460**	**93.37**	**97.20**	**98.65**	**1.54**	**0.45**	**0.021**	**0.032**	209.6

year	model	seq.9	seq.10
		ATE	*ATE*
	model-based		
2015	ORB full [2]	0.0140±0.0080	0.0120±0.0110
2015	ORB short [2]	0.0640±0.1410	0.0640±0.1300
	end-to-end		
2017	SfmLearner [6]	0.0160±0.0090	0.0130±0.0090
2018	Geonet [21]	0.0120±0.0070	0.0120±0.0090
2018	Vid2depth [33]	0.0130±0.0100	0.0120±0.0110
2019	Com Col [22]	0.0120±0.0070	0.0120±0.0080
	hybrid		
2019	UnOS [32]	0.0120±0.0060	0.0130±0.0080
	Ours	**0.0109±0.0068**	**0.0105±0.0088**

RESULTS ON KITTI DATASET



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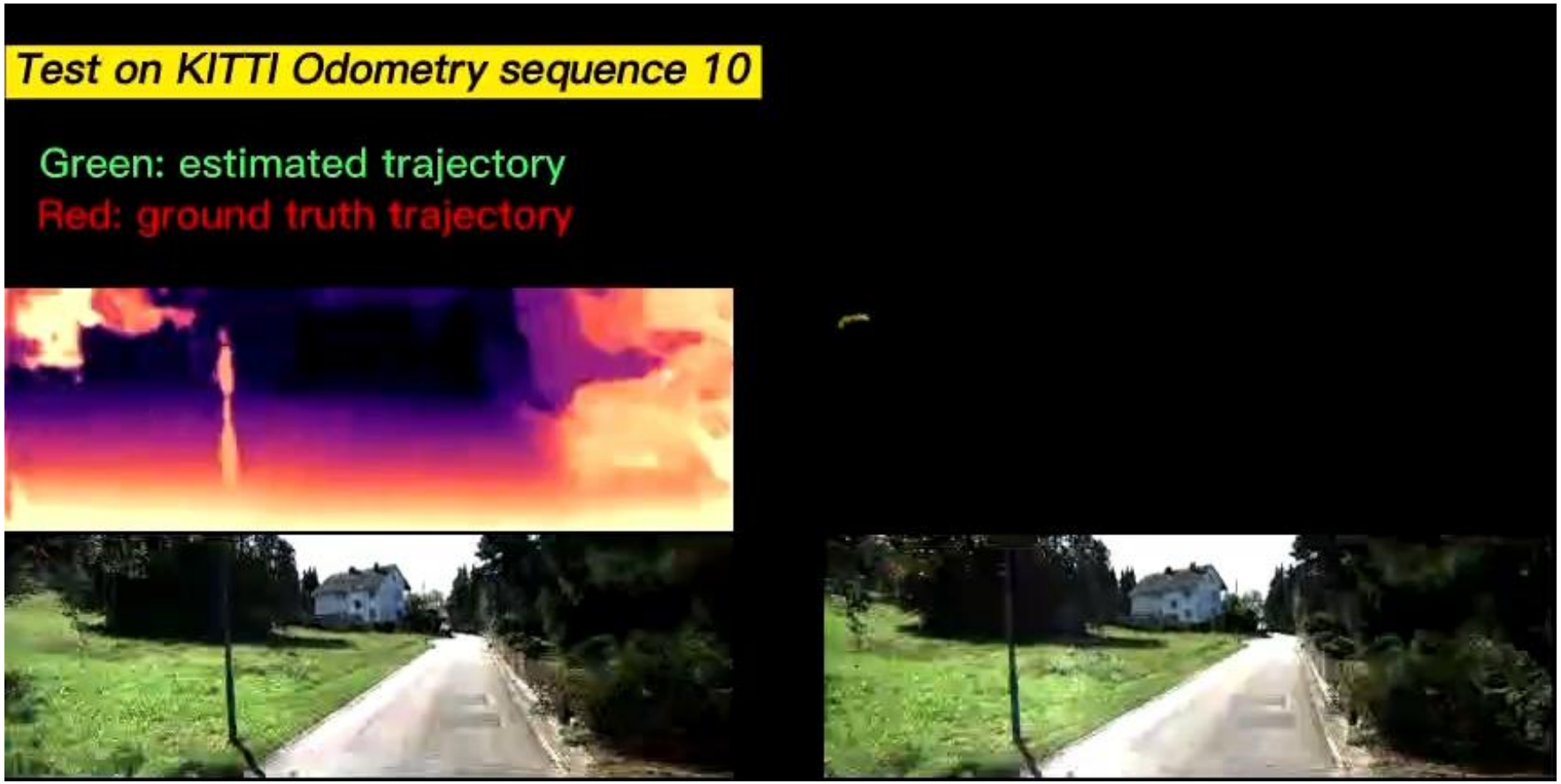

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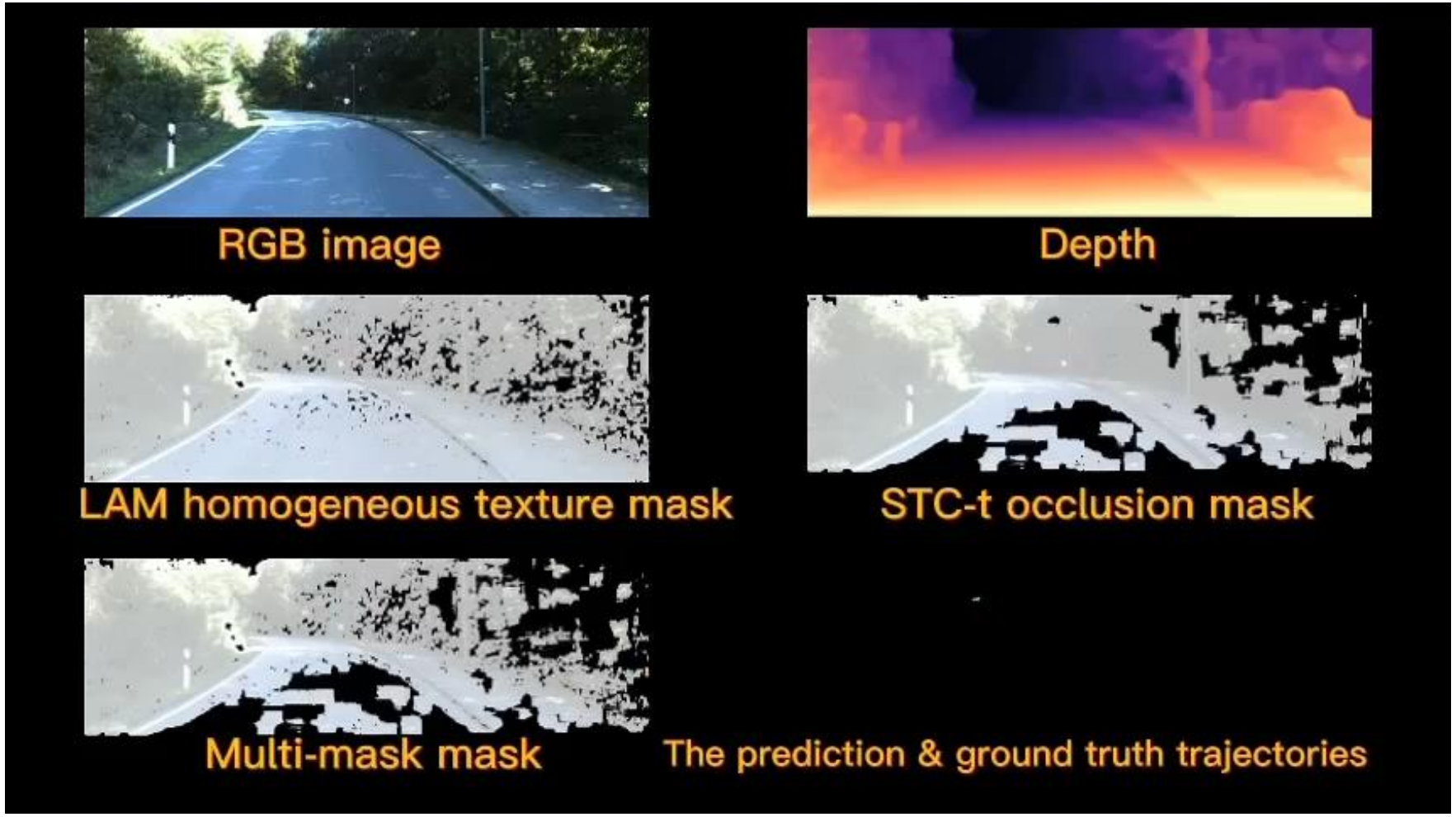

CONCLUSION

- Hybrid AI can overcome the limitations of individual methods. For example, combining rule-driven AI's interpretability with machine learning's data-driven adaptability.
- Hybrid AI is a large field of research since there exists many possible ways to combine rule-based and data-based AI
- Future research directions:
  - Understand if it exists a preferred and systematic way to combine rule-based and data-based AI
  - Apply the methodology at all levels: perception, decision and control