CODEI: Co-Design of Embodied Intelligence

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1 Introduction

Designing mobile robots involves **hardware and software integration**, exploring **design options**, and handling **trade-offs**. We automate this process to meet **task requirements** while **minimizing resource** use.

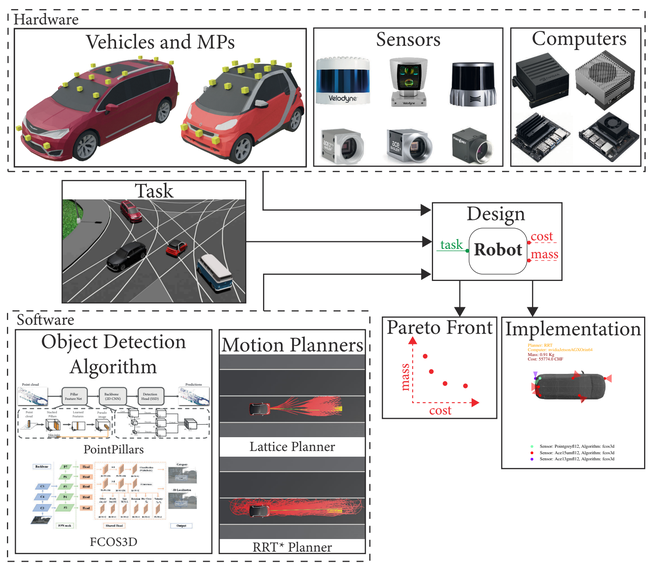

Figure 1: Illustration of the AV design problem for urban driving, using hardware and software catalogs [1].

2 Perception Requirements for Agents

Sampling-based planners generate **occupancy queries**: collision checks at a **configuration** and future **time**. Different planners have different **information needs**, creating trade-offs with **optimality**. We simulate the agent, record each query, and **trace back what the perception must observe**, based on **prior knowledge** of obstacle locations and motion.

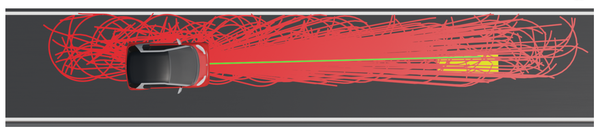

Figure 2: RRT* planner [1].

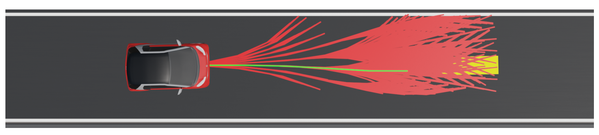

Figure 3: A* search lattice planner with motion primitives [1].

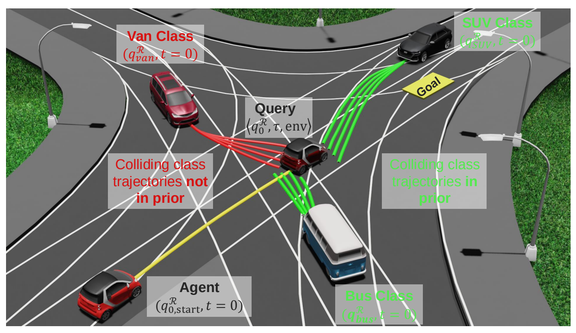

Figure 4: The perception requirements are the green configurations $q^{\mathcal{R}}_{\text{suv}}$ and $q^{\mathcal{R}}_{\text{bus}}$ [1].

3 Benchmarking Perception Pipelines

Perception performance is **benchmarked** using **real sensor data** and **off-the-shelf object detection models** and abstracted as **FNR** and **FPR**.

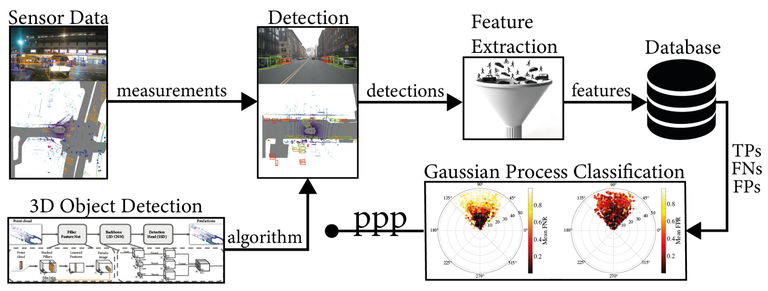

Figure 5: Data flow for the entire benchmarking process [1].

4 Sensor Selection and Placement Problem

The **match** what **perception provides** and what **planners require** is framed as a **set cover problem** and solved via **ILP**.

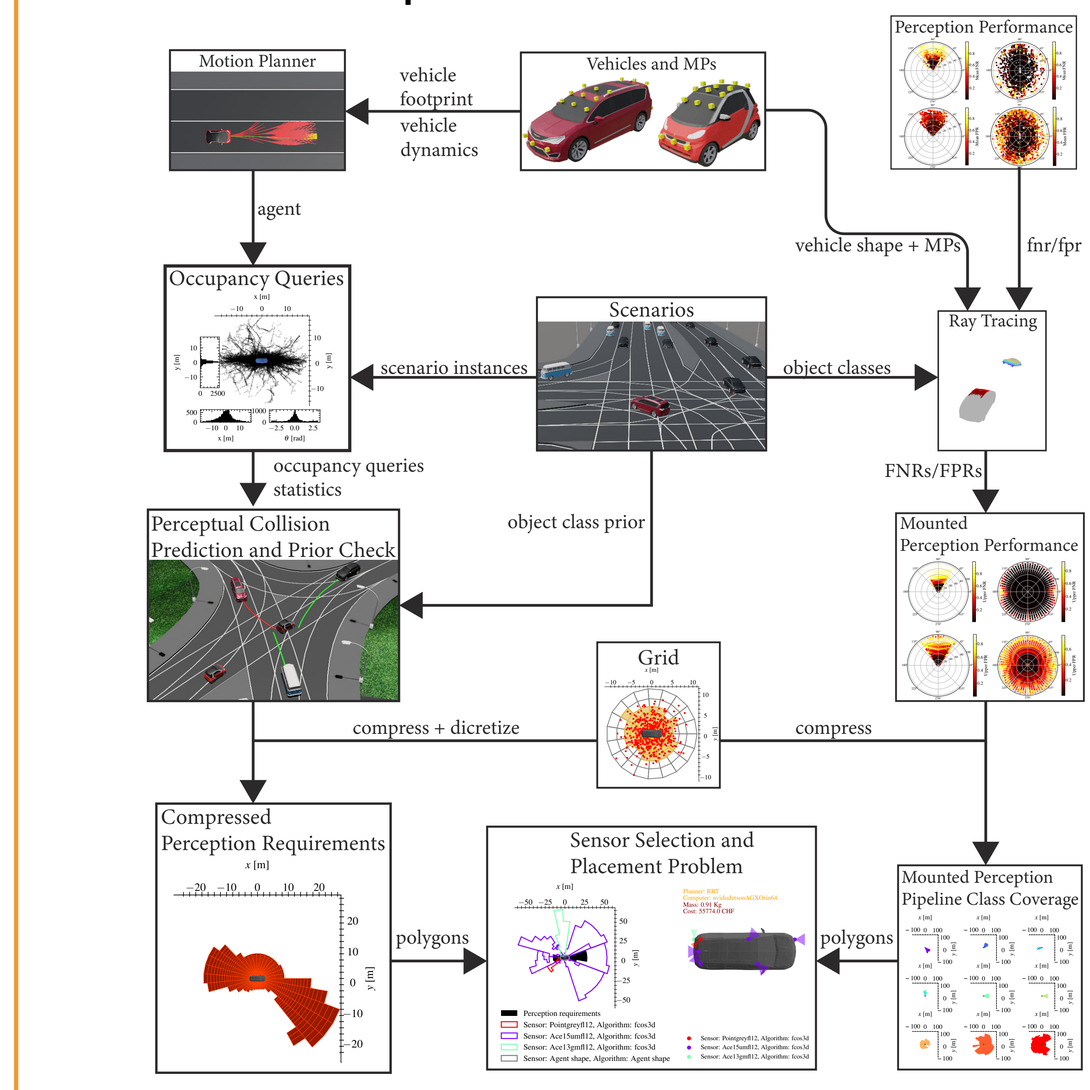

Figure 6: Overview of the sensor selection and placement process [1].

5 Co-design of Mobile Robots

To **optimize** the **full robot design** we apply **monotone co-design theory**. **Design problems** are modeled as **feasibility relations** between **functionalities** and **resources**, linked by a **monotone map**.

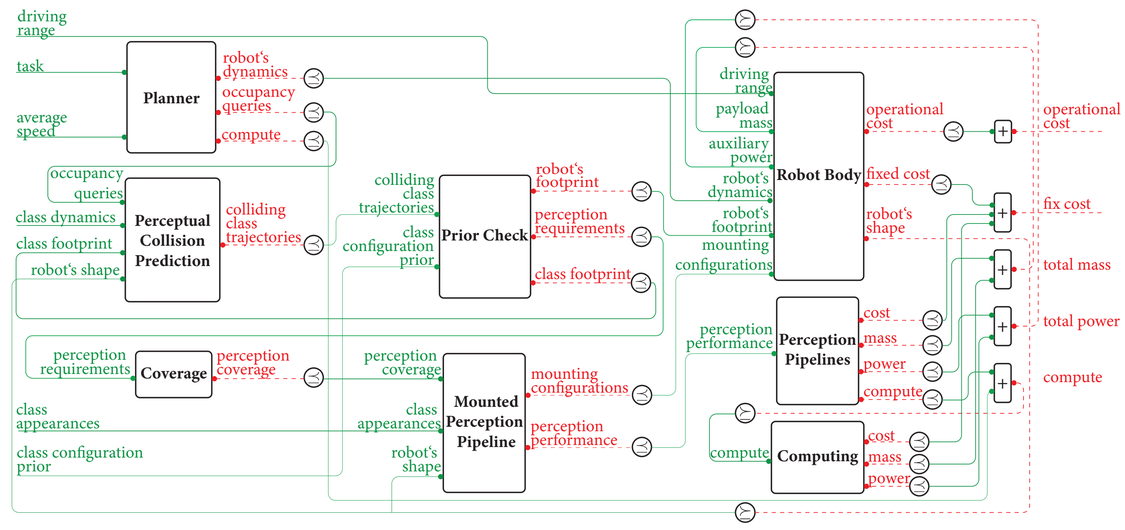

Figure 7: The co-design diagram for the design of a mobile robot tailored to accomplish a task [1].

6 Case Study on Autonomous Vehicle Design

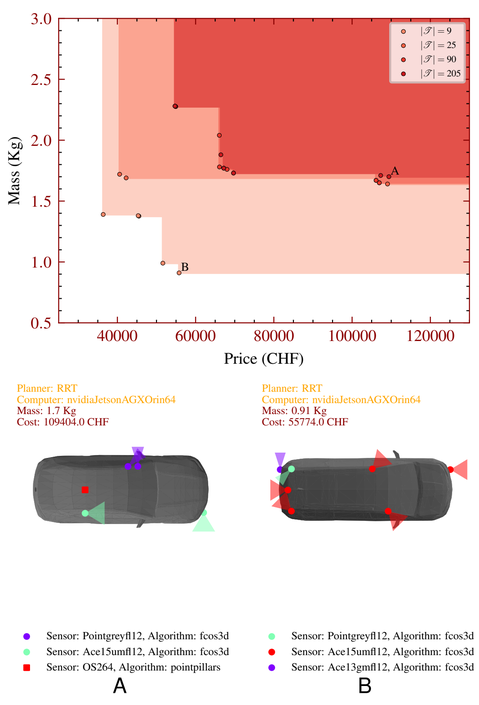

Figure 8: More task scenarios increase resource demands [1].

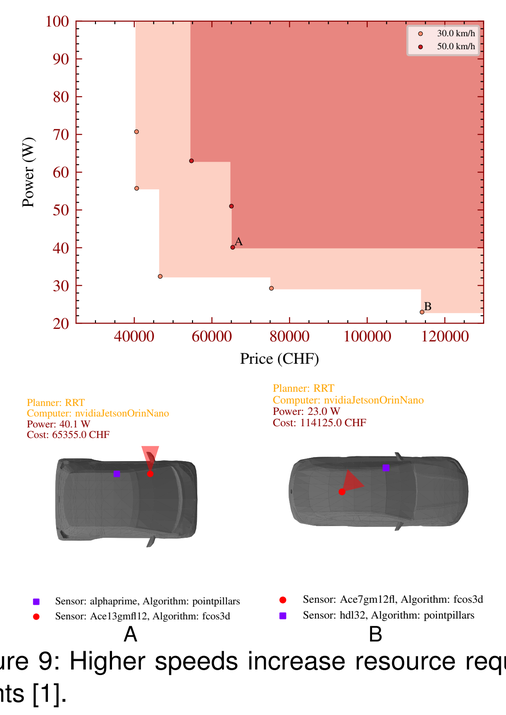

Figure 9: Higher speeds increase resource requirements [1].

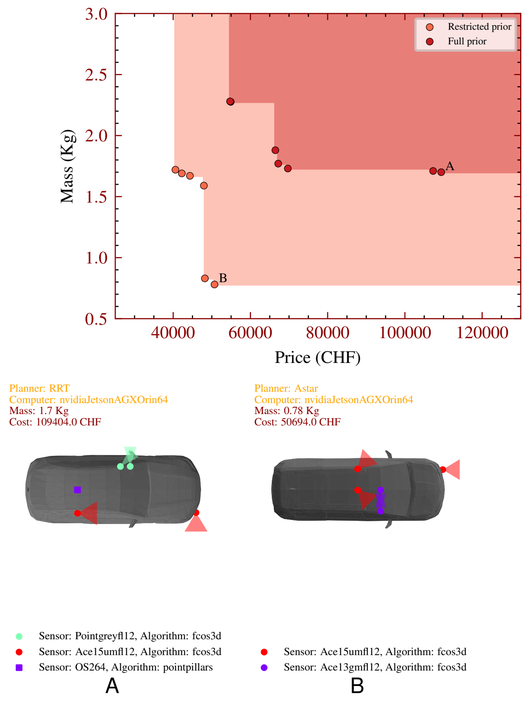

Figure 10: More expected obstacle configurations in a task increase resource requirements [1].

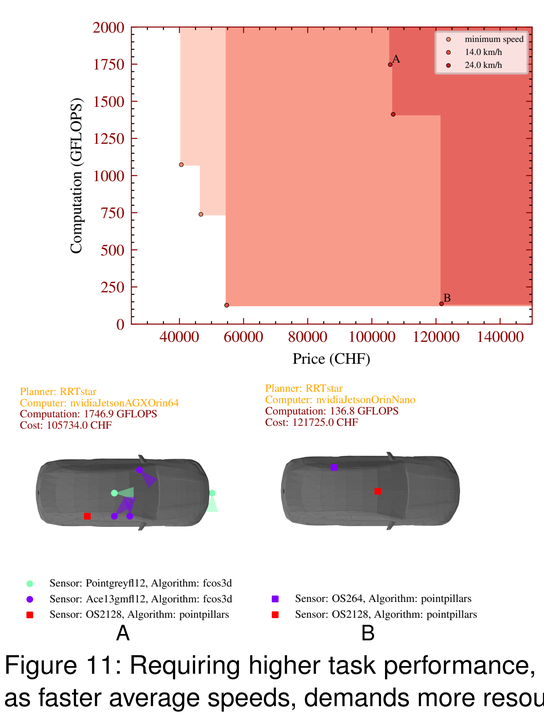

Figure 11: Requiring higher task performance, such as faster average speeds, demands more resources, including faster vehicles and optimal planners [1].

References

[1] Dejan Milojevic, Gioele Zardini, Miriam Elser, Andrea Censi, and Emilio Frazzoli. CODEI: Resource-efficient task-driven co-design of perception and decision making for mobile robots applied to autonomous vehicles. *IEEE Transactions on Robotics*, 41:2727–2748, 2025.