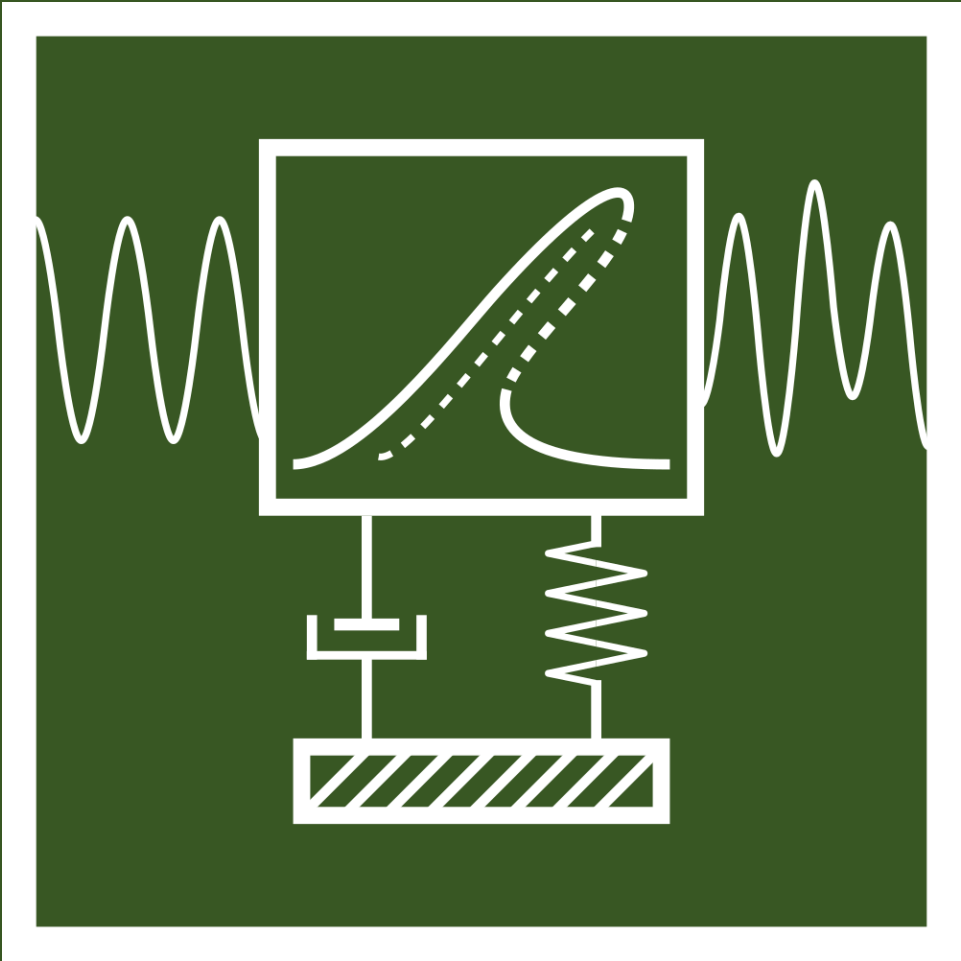


Towards Semantic Risk-Aware Control for Autonomous Robots

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A Abstract

Mobile robots are increasingly expected to work alongside people, yet most navigation systems still treat their surroundings as either occupied or free space, so a pedestrian, a chair and a wall are effectively the same obstacle. In dynamic environments this leads to behaviour that is either overly cautious or unsafe. Introducing semantic information into the control loop is an obvious solution, however, semantic perception is slow, its output can be outdated by the time it is used, and the models are often too resource-intensive to run on small robots.

This early-stage research aims to address three questions: how the timing mismatch between perception and control can be modelled and compensated; how an object's class, motion and context can shape a risk field that determines clearance; and whether such a system can run in real time on resource-limited hardware.

01 Problem statement

Classical planners such as artificial potential fields and the dynamic window approach [1] reason about geometry alone: every obstacle is simply occupied space (Fig. 1). Clearance alone cannot reflect what an obstacle is or how it may move, therefore, it is a core limitation in human-shared spaces [2].

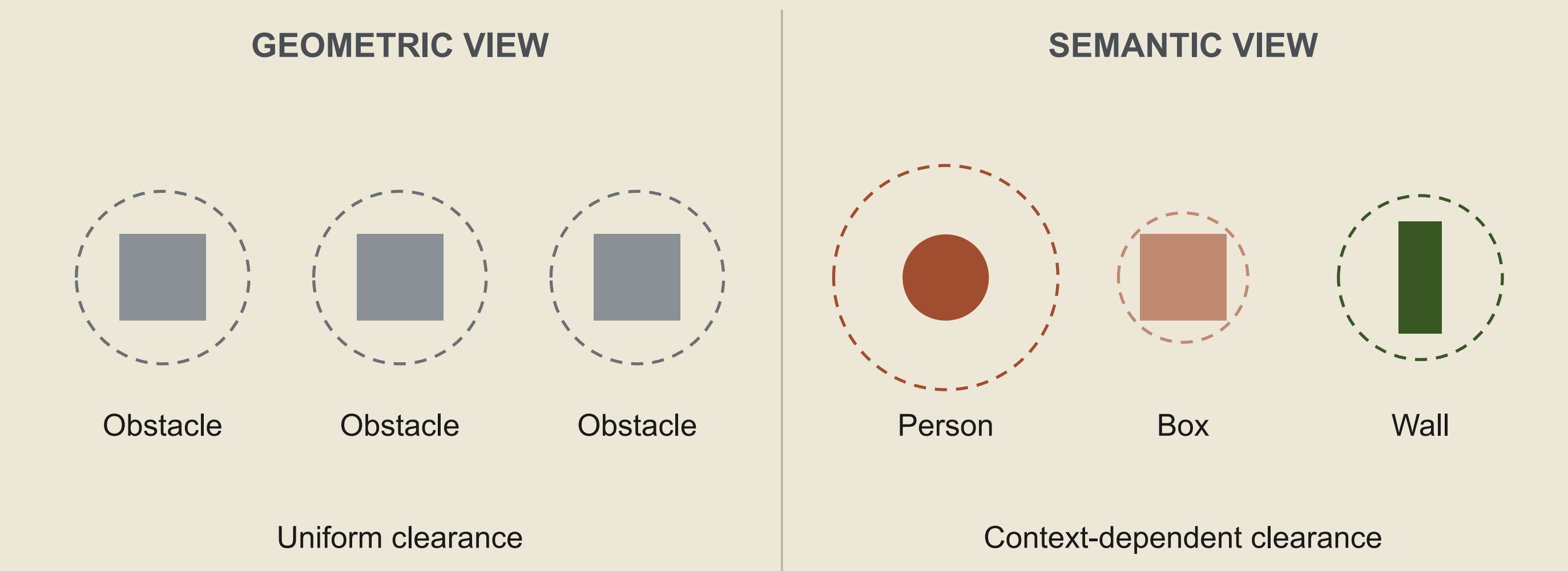


Fig 1. The same scene perceived geometrically (left) and semantically (right).

02 Proposed approach

A semantic layer is added to a conventional navigation pipeline (Fig. 2). Three pillars address its main weaknesses:

- **P1: Asynchronous compatibility.** Modelling the perception to control delay and treating the freshness of semantic information as a design variable.
- **P2: Semantic risk field.** Encoding object class, motion and context as a continuous field that sets the clearance kept by the controller (Fig. 3).
- **P3: Limited-resource deployment.** Running the full navigation pipeline in real time on low-cost sensors and embedded computing.

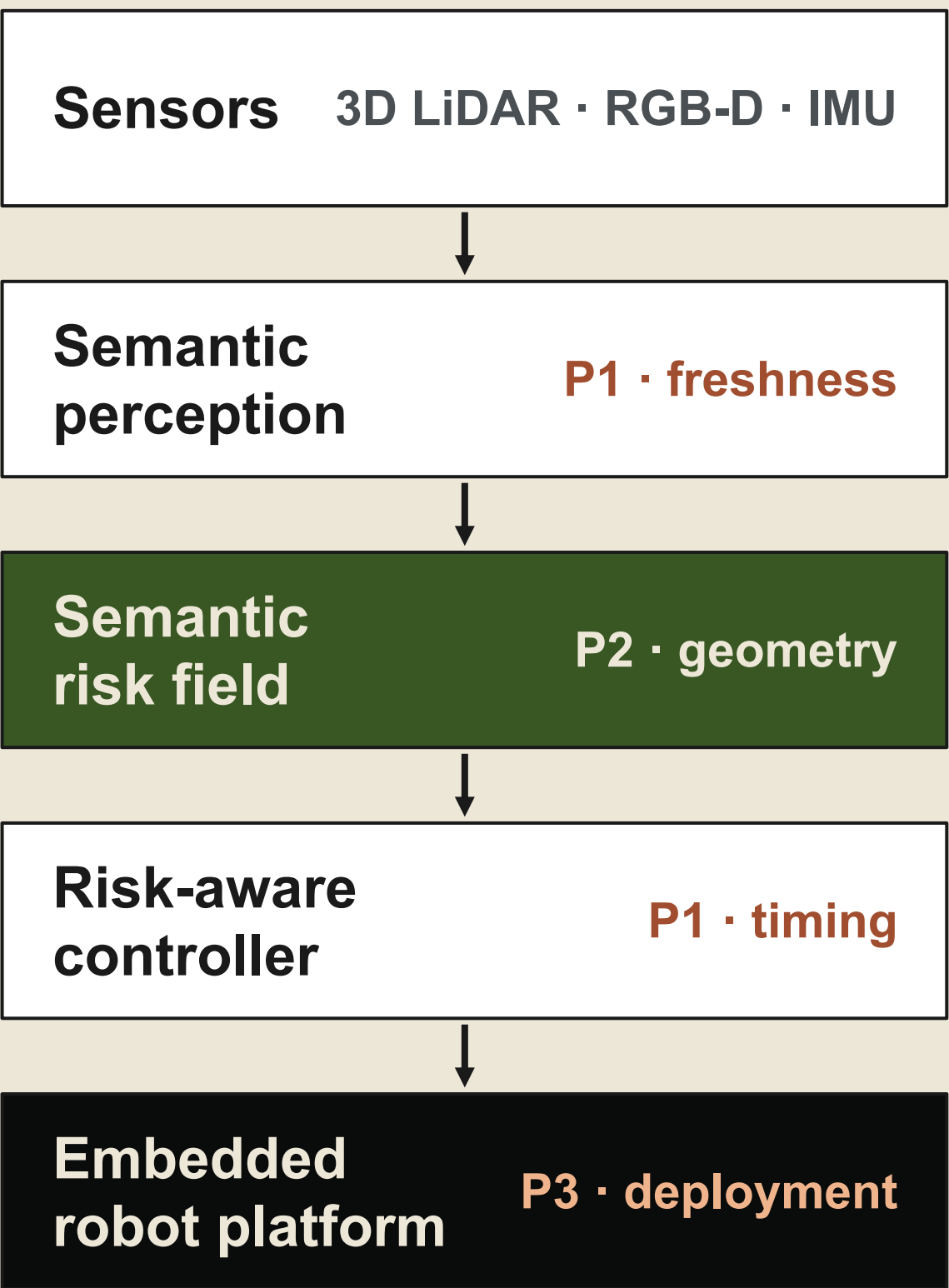


Fig 2. Proposed architecture.

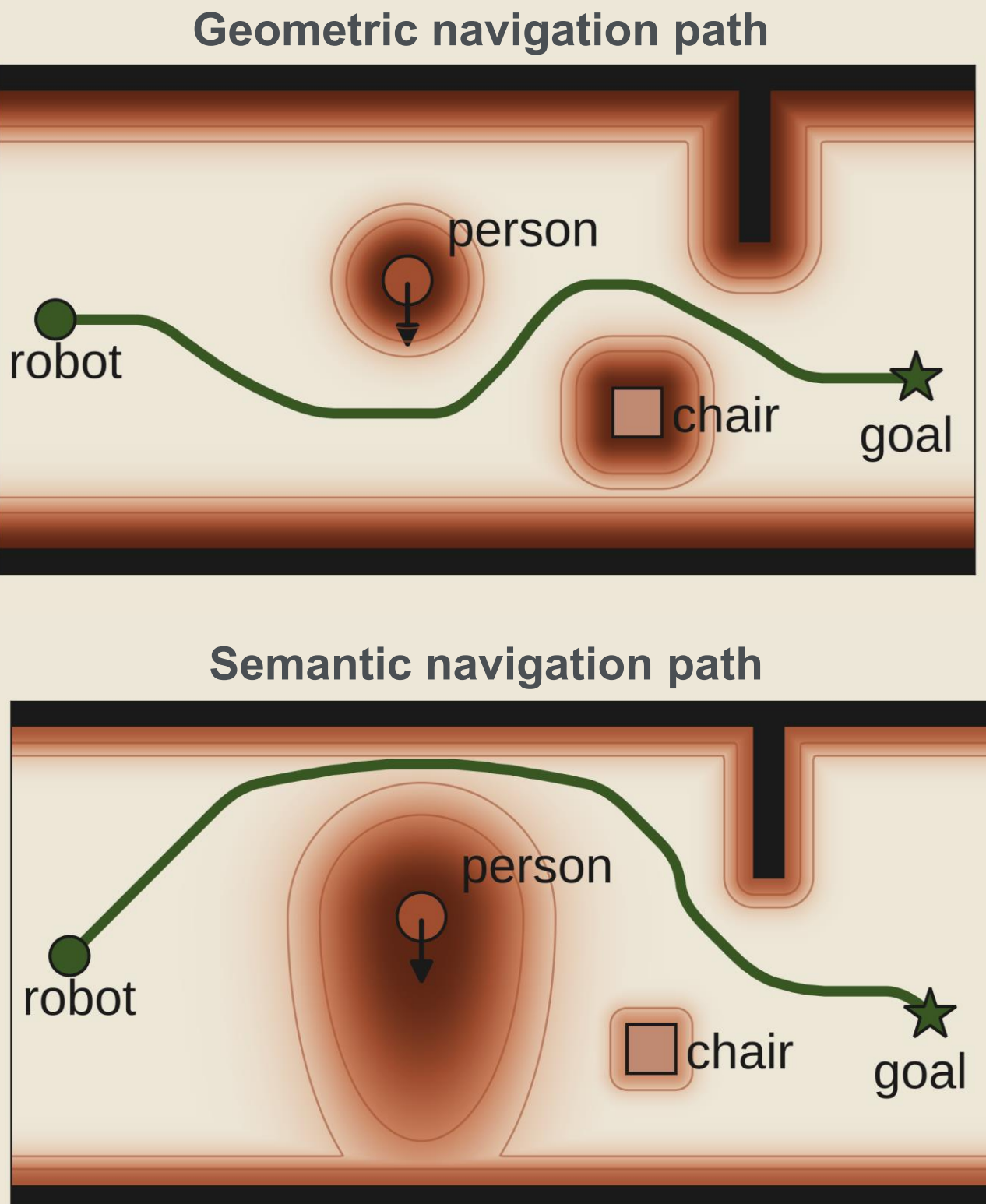


Fig 3. Example of the semantic risk field.

03 Research gap

The literature reviewed so far [1], [3], and [4] suggests that no existing approach combines semantic context, real-time operation and low-cost hardware (Table 1).

Table 1. Indicative comparison.

Approach	Semantic context	Real-time	Low-cost hardware
Geometric planners [1]	—	✓	✓
Semantic mapping, scene graphs [3], [4]	✓	partial	partial
End-to-end learned navigation	implicit	partial	—
Research target	✓	✓	✓

04 Conclusions

- Geometry alone cannot distinguish obstacles whose risk depends on context.
- Semantic perception runs slower than the control loop, so the freshness of semantic information must be modelled, not assumed.
- Safe semantic navigation on small robots requires context, timing and hardware limits to be addressed together rather than separately.

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