HUMAN-ON-THE-LOOP AUTONOMY ARCHITECTURE FOR RESIDENT-AUV UNDERSEA SUPPORT INFRASTRUCTURE

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About the Presenter

IARIA

Pedro A. Forero received his Diploma in Electronics Engineering from Pontificia Universidad Javeriana, Bogota, Colombia in 2003, M.Sc. degree in Electrical Engineering from Loyola Marymount University, Los Angeles, in 2006, and Ph.D. degree in Electrical Engineering from the University of Minnesota, Minneapolis, in 2012. His broad research interests lie in the areas of statistical signal processing, machine learning, autonomy and underwater networking.

Since Fall 2012, Dr. Forero has been with the Autonomous Technologies Division at the Naval Information Warfare Center (NIWC) Pacific, San Diego, CA.

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Motivation

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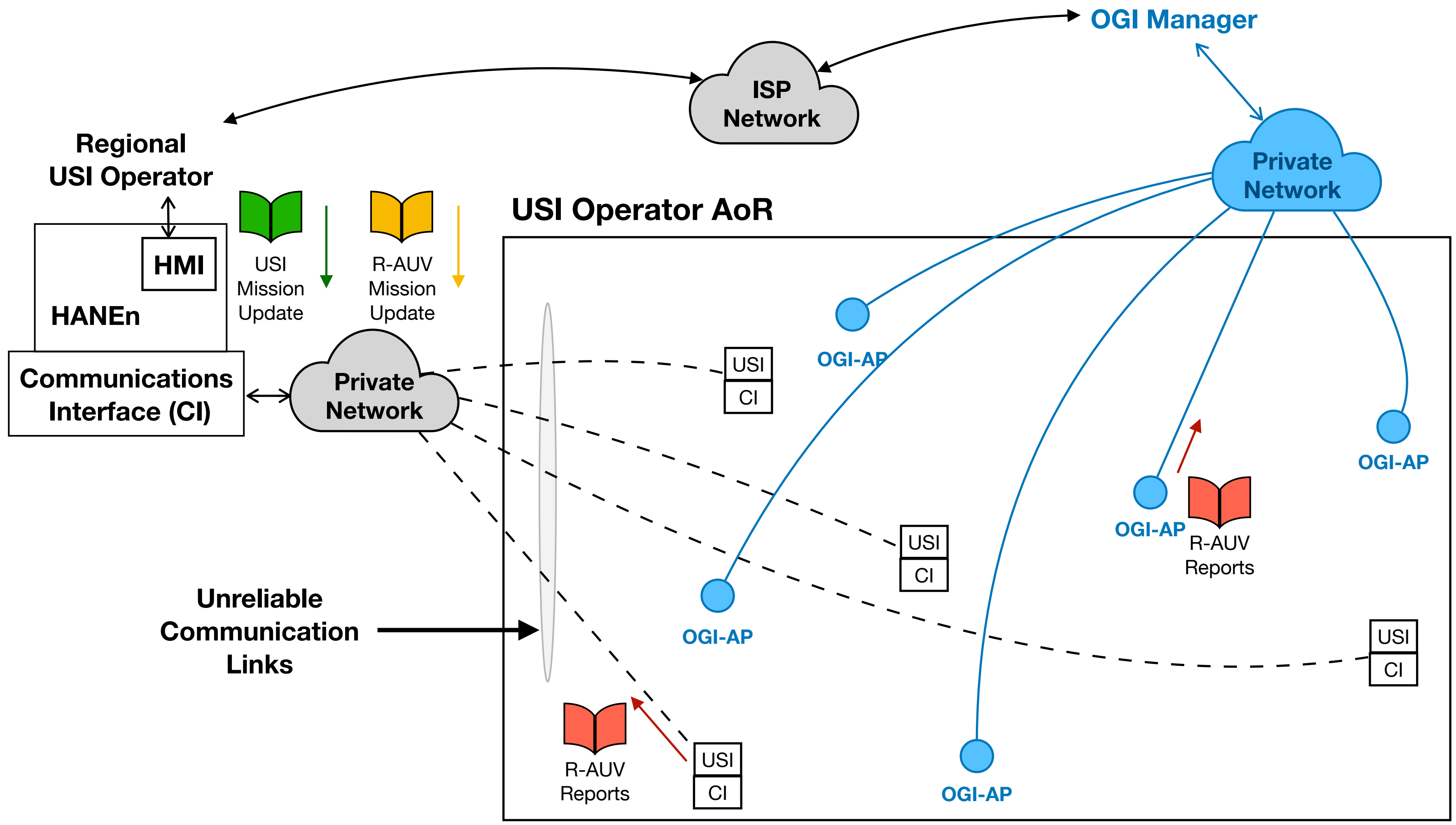
- Long-endurance operations for underwater autonomous vehicles (AUVs)
  - Emphasis on vehicle autonomy: actuation and navigation
- Long deployments require support infrastructure
  - Human support drives operations cycle due to AUV power limitations
  - Very expensive
- Nascent undersea applications for AUVs -> Resident AUVs (R-AUVs)
  - Continual inspection, maintenance and repair (IMR)
  - Persistent environmental monitoring
  - Extended under-ice exploration
- Undersea support infrastructure (USI) for AUVs must have autonomy embedded
  - Focused on scheduling, resource allocation and reliability
  - Able to operate disconnected from the human infrastructure operator

IMR Use Case



OGI: Oil and gas industry manager
HMI: Human machine interface
AP: Access point

Oil and gas industry contracts continual IMR services for specify areas of responsibility (AoR) from third party

Challenge:

USIs must coordinate and manage all R-AUV activities to support predefined quality-of-service guarantees for the costumer while ensuring the safety of its infrastructure

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Background

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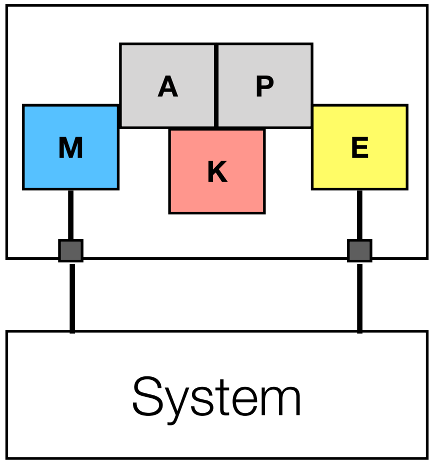
- Lots of work on the definition of Autonomy architectures
- Three layer-architecture [Gat‘98]
  - Captures timeliness of decision making at various scales
- Separation between configuration and behavior decisions [Braverman’15]
- Variable autonomy [Luck’03], [Calefato’08]
- Autonomy over cloud computing infrastructure [Ahmad’16], [Saha'22]
  - Control and automation implemented on resource-constrained systems
  - Planning instantiated over cloud computing infrastructure
  - Relies on reliable and persistent access to cloud computing environments

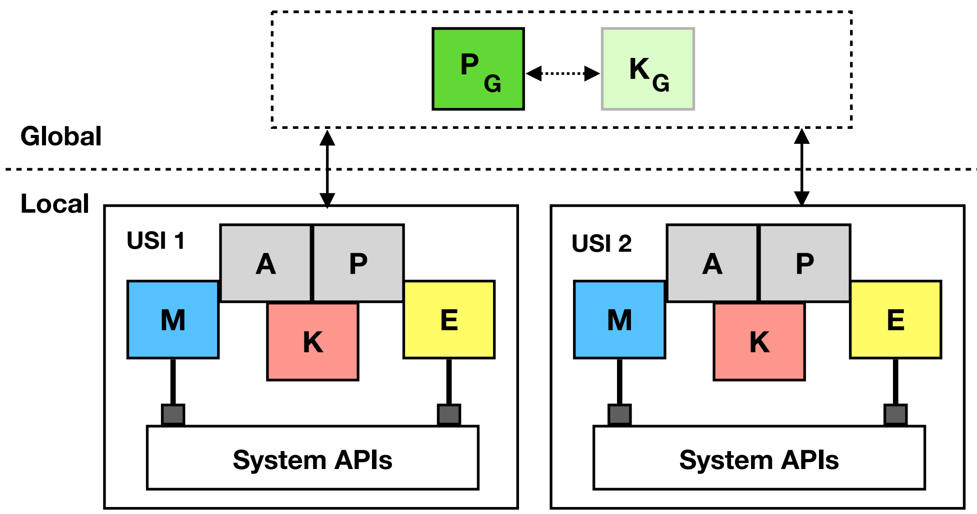
Our Contribution:
Human-on-the-loop Autonomy in Austere Networking Environments (HANEn) architecture that enables autonomous, resource-constrained systems to coordinate with and autonomous coordinating-system with high computational resources

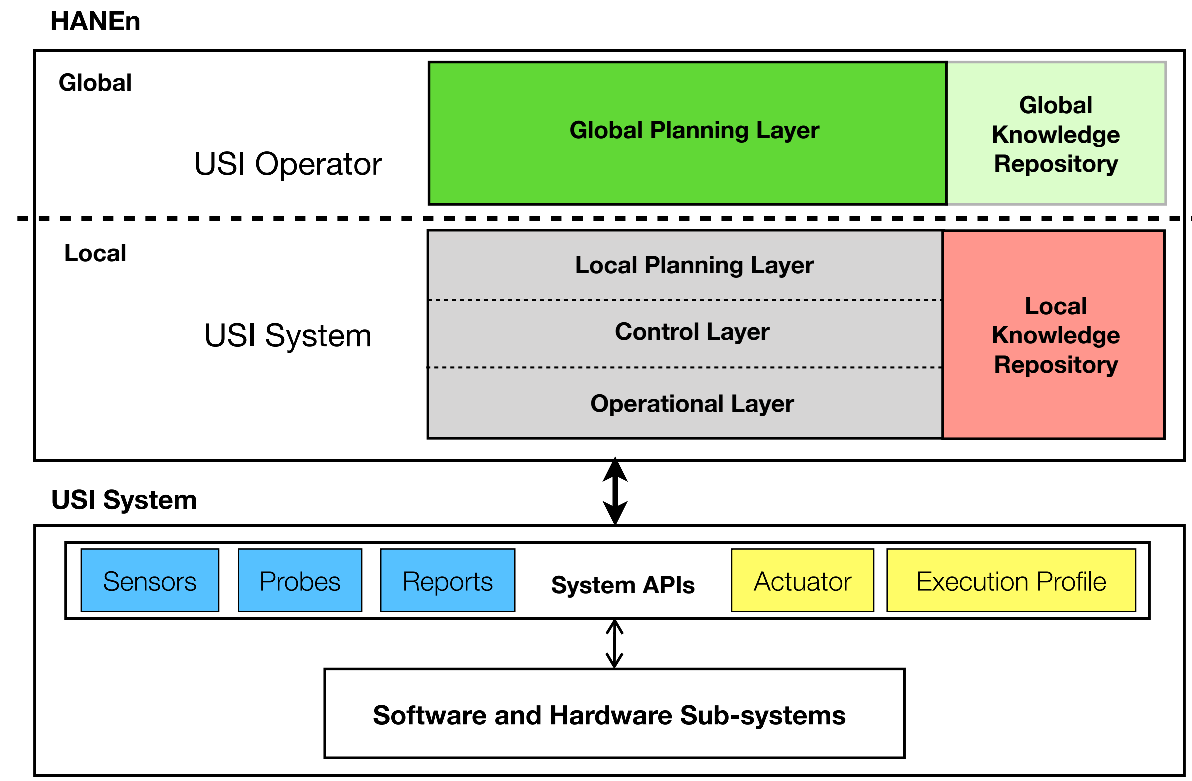
MAPE-K Model [Kephart'03]

- Model for decision-making process as a control loop over a system
  - Monitor (M): Collect and aggregate data
  - Analyze (A): Complex analysis of data
  - Plan (P): Structure actions to achieve goals
  - Execute (E): Change behavior of the system
- Acknowledges dependency of decision making process on a Knowledge Repository (K)
- It can model nested control loops operating at different time scales



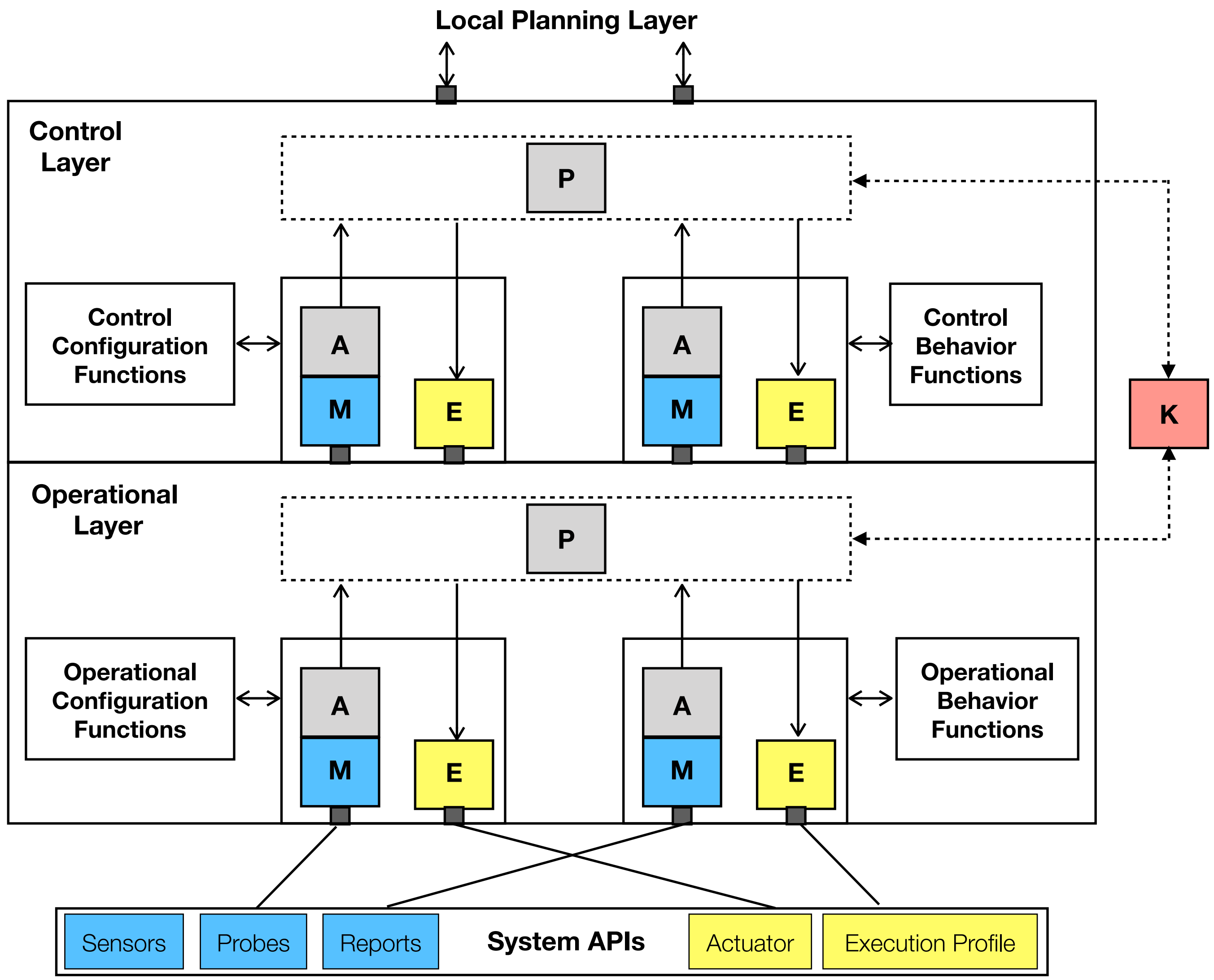
HANEN Architecture Overview





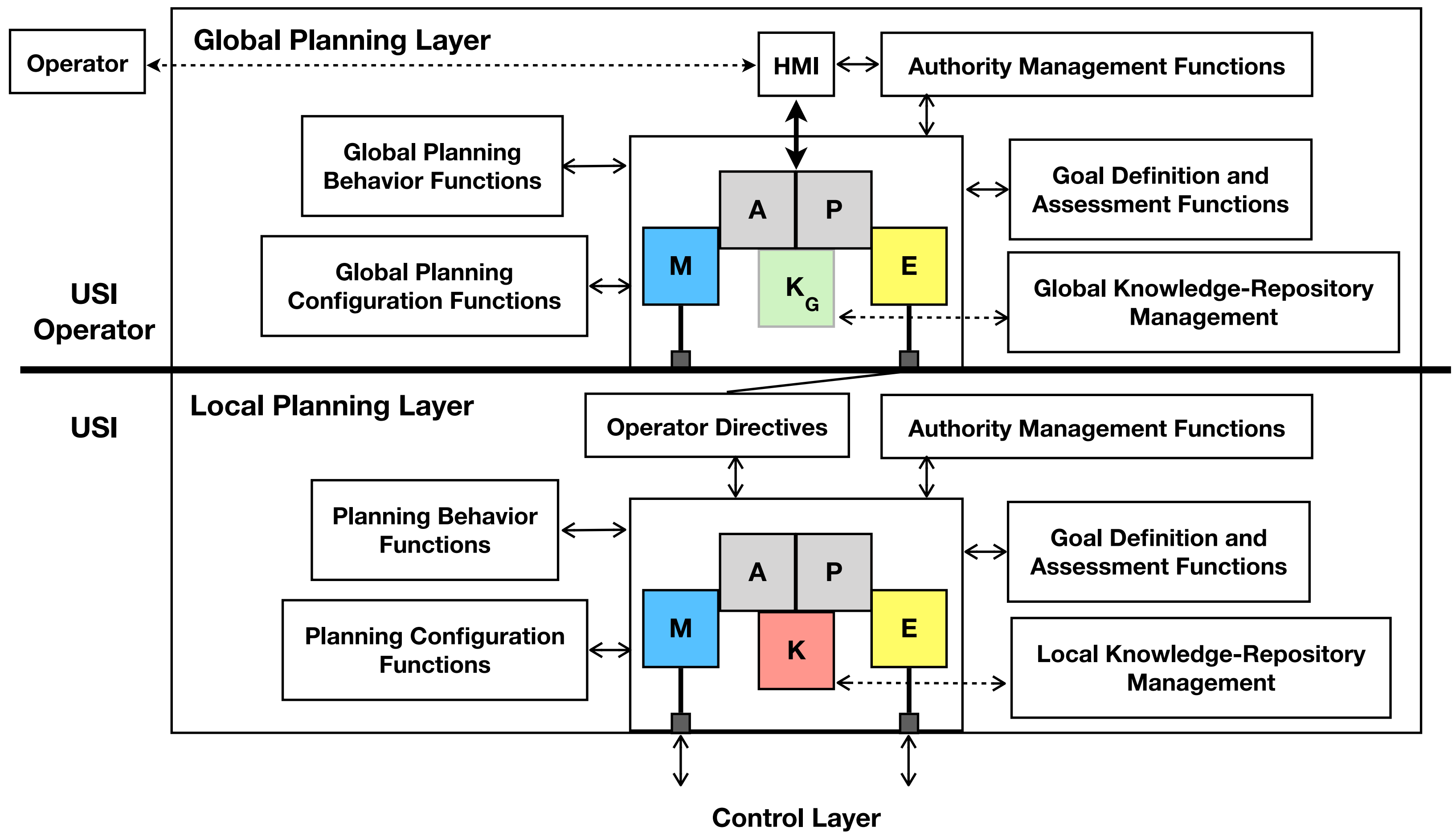
- Multiple decision-making systems modeled by local MAPE-K models
- Three-layer architectures used as basis for development of local autonomy
- Global Plan and Global Knowledge Repository computational blocks are common to all systems
    - Global computational block implementations are not colocated with the systems

Operational and Control Layers



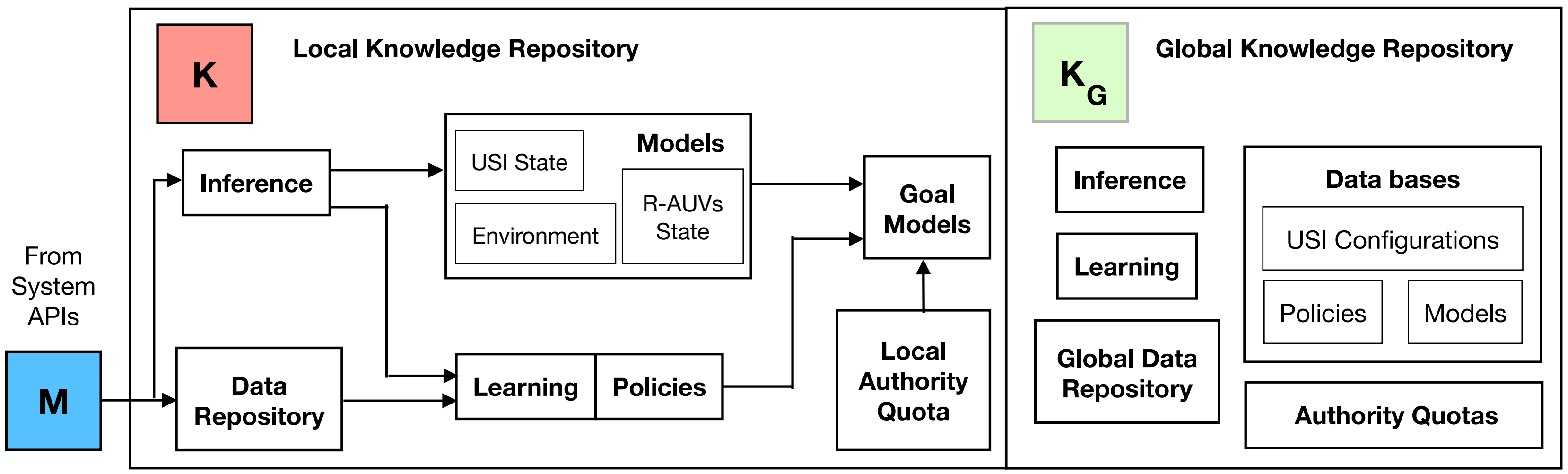
- Horizontal separation allows for configuration strategies and behavior policies to be defined, selected, executed and monitored by loosely coupled planning modules acting as arbitrators
- Vertical separation enables decision making components to be grouped according to the timeliness of the decisions they must make

Planning Layers



- Planning layers are responsible for long-term planning and adaptation functions
- Local Planning Layer:
  - Active when USI is disconnected from the operator or when operator is in supervisory role only
- Global Planning Layer:
  - Access to the Global Knowledge Repository
  - Interacts with the operator via an human-machine interface

Knowledge Repositories



- Resource shared by all computational blocks at each layer
- Decouples data aggregation and management from decision-making process
- Global repository does not necessarily have access to all data stored in the local repositories due to communication constraints between the operator and the USI
- Global repository has access to more information, thus it is able to support more informed decision-making functionality

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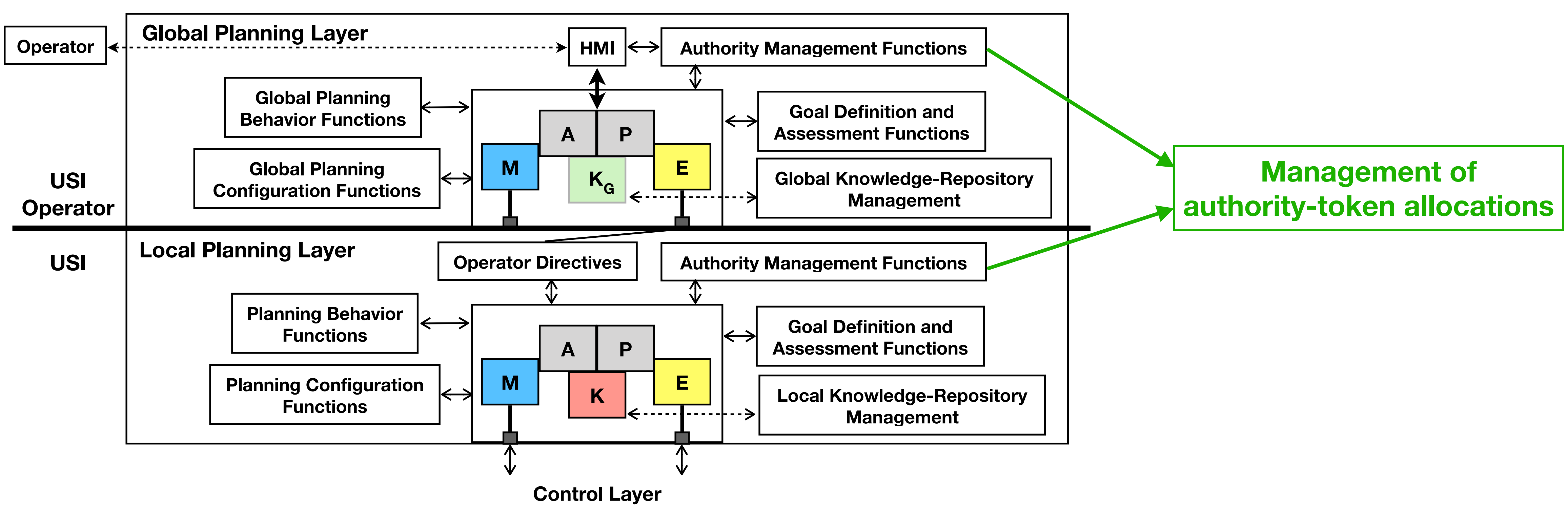
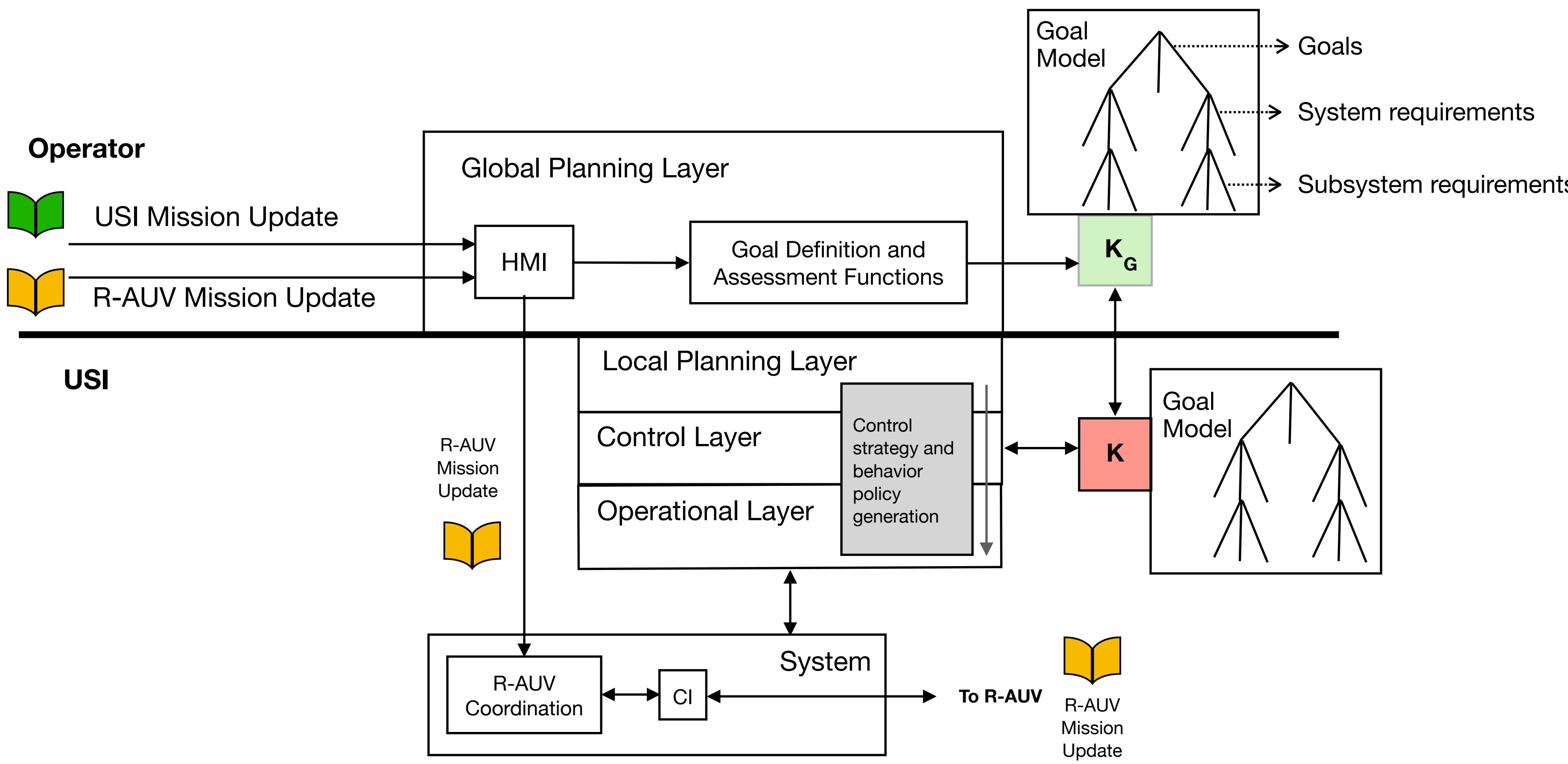
Authority Transfers

- Authority allocation managed via authority tokens
  - Define who has authority over specific USI functionality
- Resolution of authority management is configurable
  - Full authority
  - Authority allocation to specific decision-making processes
- By default USI has all authority tokens allocated to it
- Operator can request and maintain authority over the USI
- When operator is disconnected from the USI, the USI regains authority over all decision-making process taking place at the USI



Goal Model Generation



- Goal Model developed based on mission objectives defined by the operator
- Maintained by the Knowledge Repositories
- Maps goals to verifiable system-requirements to enable goal-feasibility assessment

Summary

- Proposed new autonomy architecture, named HANEn, for R-AUV USI
- HANEn supports human-on-the-loop autonomy
- Four-layer autonomy architecture appropriate for undersea operations where USI's have limited communication capabilities with centralized coordination system
- Extends classical three-layer autonomy architectures to capture coordination of autonomous systems in communication challenged environments
- Implementation plans as part of notional IMR use case are ongoing

Thanks !