OHB System AG
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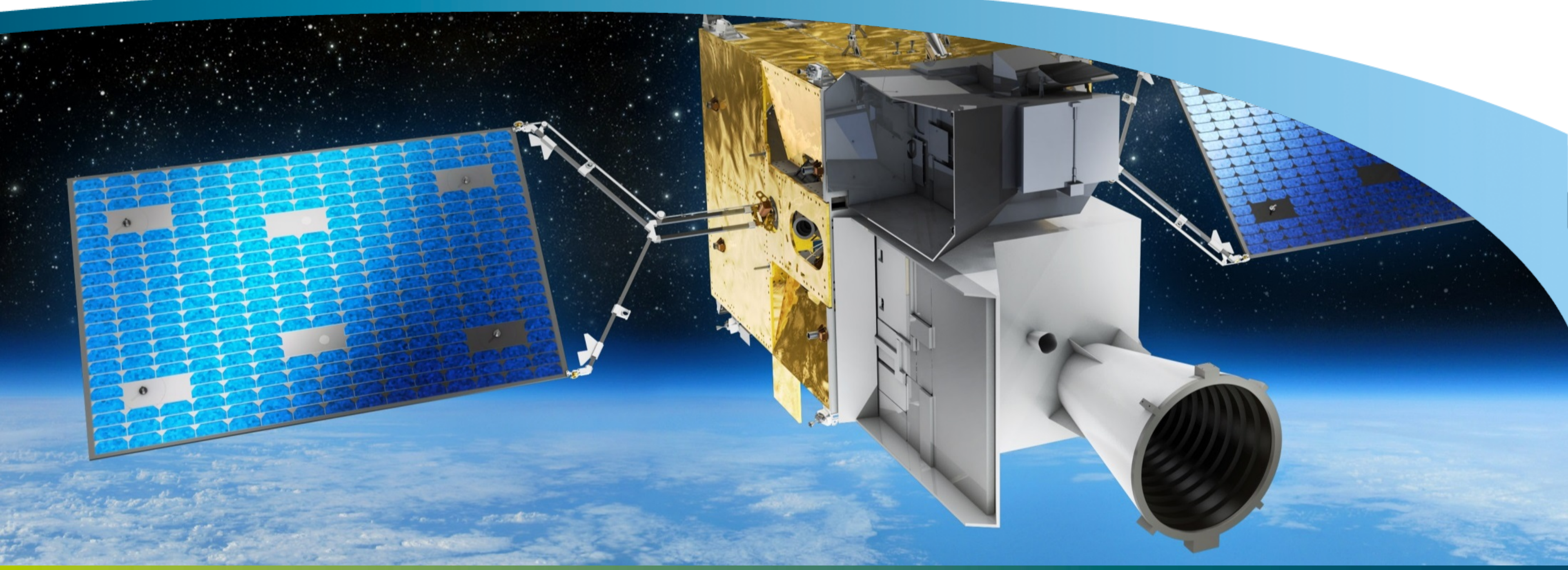


SPACE SYSTEMS

State Aggregation Approximate Dynamic Programming for Model-based Spacecraft Autonomy

We. Create. Space.

Agenda

- Background:
  - Spacecraft Autonomy, Markov Decision Process (MDP) & Approximate Dynamic Programming (ADP)
- MDP formulation for spacecraft autonomy
- A case study
  - Results and remarks
- Conclusion and future work

Background

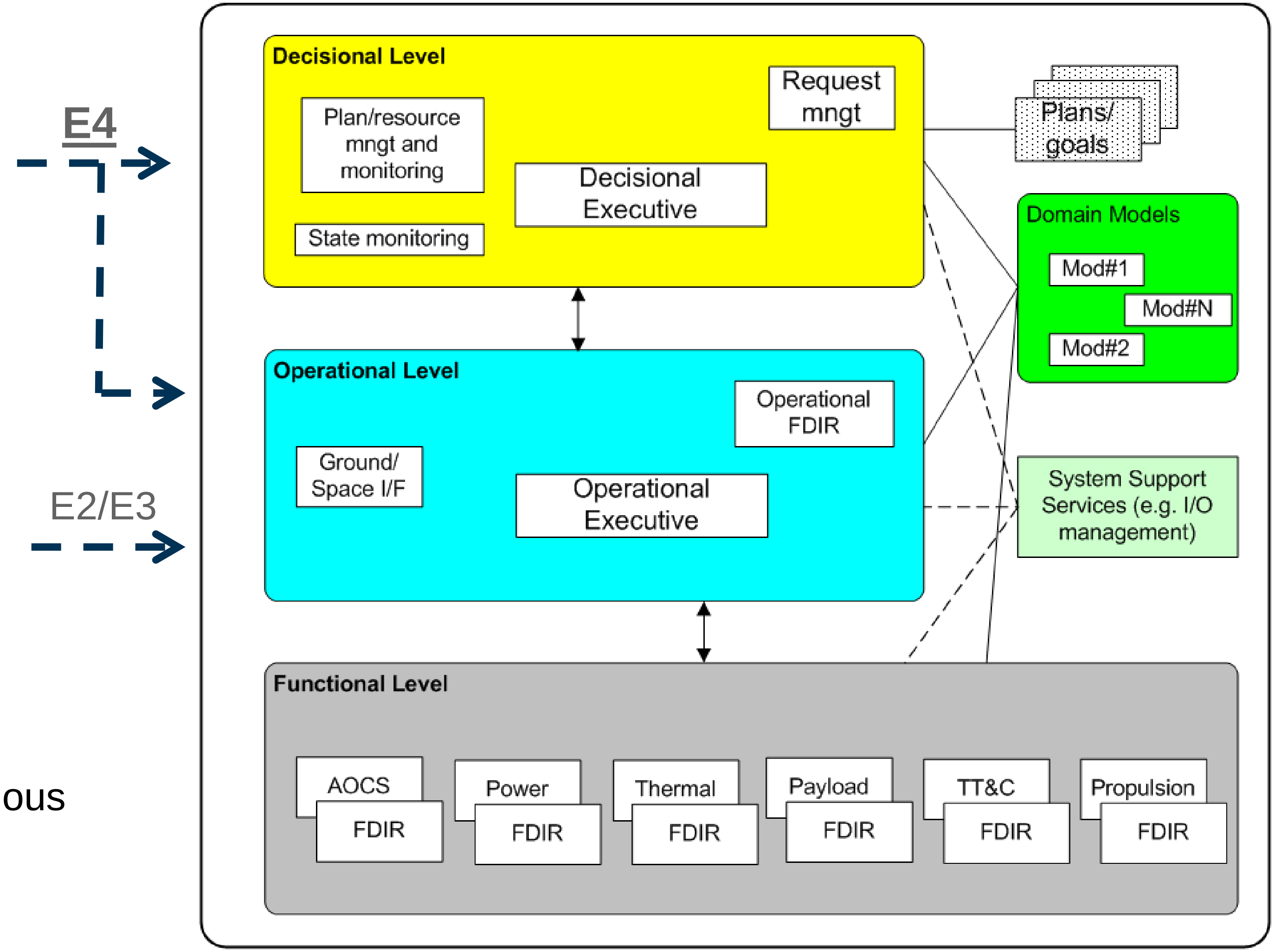
- Spacecraft autonomy: migration of functionality from the ground segment to the flight segment.

- Main drivers/benefits for spacecraft autonomy:
  - reliability improvement, operation cost reduction, context unpredictability

- Spacecraft autonomy applications:
  - Intelligent Sensing
  - Planning & execution (high-level goals processing) ← – –
  - Autonomous fault detection, isolation & recovery
  - Distributed decision making

Background

Autonomy level definition: ECSS-E-ST-70-11C – Space Segment Operability



Model-based OBSW architecture of autonomous space systems

Background

- MPD as a mathematical framework for representing complex multi-stage stochastic decision problems
  - MDP is a 4-tuple $< X, U, T, R >$
  - To maximize the value function J → Optimal policy
- Optimal Policy $u = \pi^{*}(i)$ over the whole state space:
  - Value Iteration & Policy Iteration algorithms
- Approximate Dynamic Programming (ADP) as a way to solve the curse of dimensionality and modelling
  - Compact representation of the value function
  - Feature-based state aggregation ADP

MDP formulation for spacecraft autonomy

- Autonomous spacecraft reconfiguration in the decisional layer.
- Assumptions:
  - Mission featured by a set of objectives (low, nominal, relevant) and phases (stand-by, attitude manovre , science data collection)
  - Event report service: low, medium & high severity
  - Reconfiguration actions: safe, nominal & high performance
- MDP Reward Definition:
  - $r(X_i) = \lambda \exp\left[-\beta\left(MisPh_i\right)H\left(MisOb_i, SCCon_i\right) - F\left(SCCon_i, Sev\mathrm{Re}\,p_i\right)\right]$

Aggregate state

Mission objective achievement

Spacecraft safety

A case study

Report Severity	Mission Objective	Current Spacecraft Configuration	Action selected in STAND_BY	Action selected in ATT_MAN	Action selected in SCI_DATA_COL
LOW_SEV_REP	MIN_OBJ	SAFE_CONF	NO_ACT	NO_ACT	NO_ACT
LOW_SEV_REP	MIN_OBJ	NOM_CONF	1	1	1
LOW_SEV_REP	MIN_OBJ	HIGH_PERF_CONF	1	1	1
LOW_SEV_REP	NOM_OBJ	SAFE_CONF	2	2	2
LOW_SEV_REP	NOM_OBJ	NOM_CONF	NO_ACT	NO_ACT	NO_ACT
LOW_SEV_REP	NOM_OBJ	HIGH_PERF_CONF	2	2	2
LOW_SEV_REP	REL_OBJ	SAFE_CONF	3	3	3
LOW_SEV_REP	REL_OBJ	NOM_CONF	3	3	3
LOW_SEV_REP	REL_OBJ	HIGH_PERF_CONF	NO_ACT	NO_ACT	NO_ACT
MED_SEV_REP	MIN_OBJ	SAFE_CONF	NO_ACT	NO_ACT	NO_ACT
MED_SEV_REP	MIN_OBJ	NOM_CONF	1	1	1
MED_SEV_REP	MIN_OBJ	HIGH_PERF_CONF	1	1	1
MED_SEV_REP	NOM_OBJ	SAFE_CONF	NO_ACT	2	2
MED_SEV_REP	NOM_OBJ	NOM_CONF	1	NO_ACT	NO_ACT
MED_SEV_REP	NOM_OBJ	HIGH_PERF_CONF	1	*1*	2
MED_SEV_REP	REL_OBJ	SAFE_CONF	NO_ACT	3	3
MED_SEV_REP	REL_OBJ	NOM_CONF	1	*1*	3
MED_SEV_REP	REL_OBJ	HIGH_PERF_CONF	1	NO_ACT	NO_ACT
HIGH_SEV_REP	MIN_OBJ	SAFE_CONF	NO_ACT	NO_ACT	NO_ACT
HIGH_SEV_REP	MIN_OBJ	NOM_CONF	1	1	1
HIGH_SEV_REP	MIN_OBJ	HIGH_PERF_CONF	1	1	1
HIGH_SEV_REP	NOM_OBJ	SAFE_CONF	NO_ACT	2	2
HIGH_SEV_REP	NOM_OBJ	NOM_CONF	1	NO_ACT	NO_ACT
HIGH_SEV_REP	NOM_OBJ	HIGH_PERF_CONF	1	*1*	2
HIGH_SEV_REP	REL_OBJ	SAFE_CONF	NO_ACT	3	3
HIGH_SEV_REP	REL_OBJ	NOM_CONF	1	*1*	3
HIGH_SEV_REP	REL_OBJ	HIGH_PERF_CONF	1	NO_ACT	NO_ACT

Aggregate State (col. #1,#2.#3)

1→ Safe_Conf
2→ Nom_Conf
3→ High_Perf_Conf

Spacecraft safety

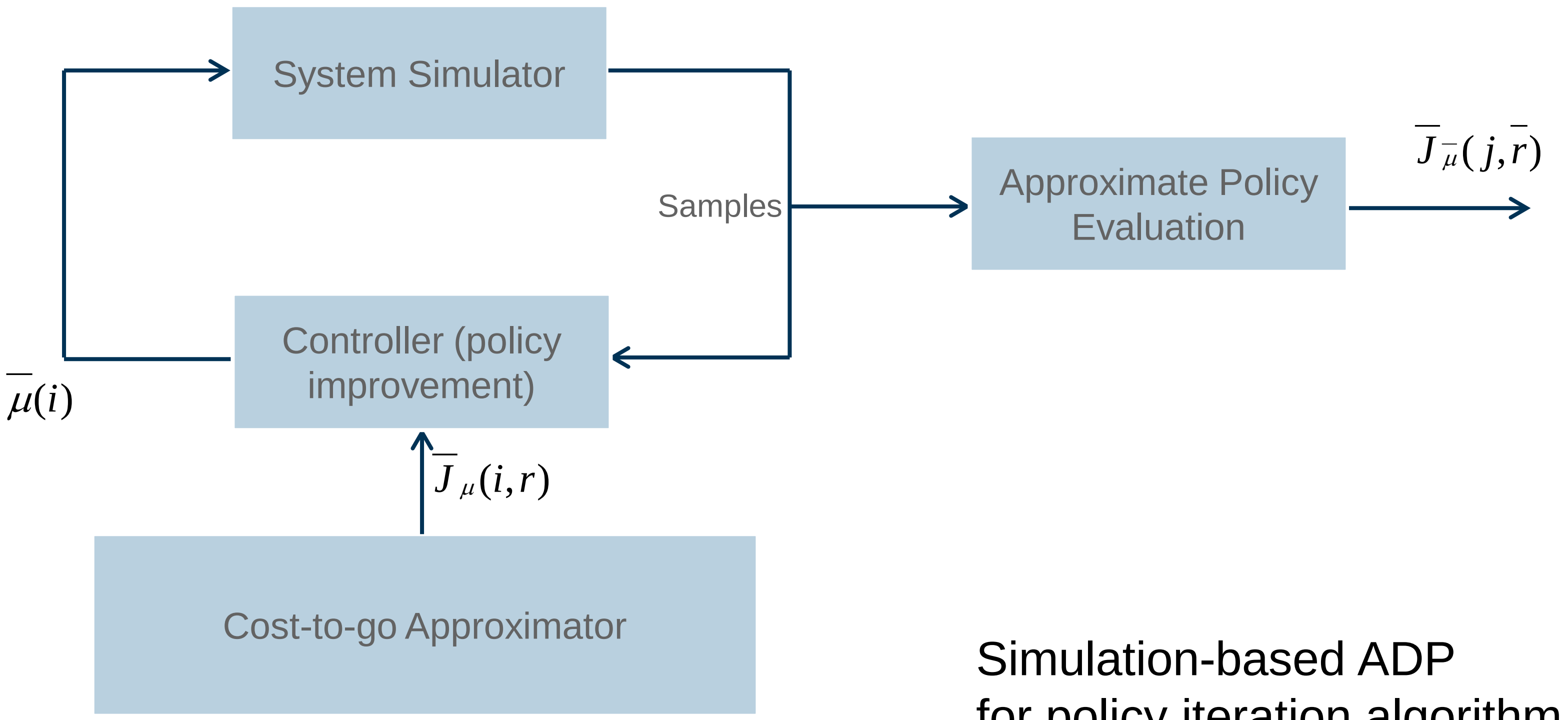
Low success probability in spacecraft reconfiguration

Objective achievement

Conclusion & future work

- MDP framework for autonomous spacecraft reconfiguration (decisional layer)
- Featured-based state aggregation ADP to calculate the optimal policy
- Future work:
  - Simulation-based ADP for the operational layer → optimizing simulator (see next slide)
  - Prototyping & operational concepts

Conclusion & future work



Simulation-based ADP
for policy iteration algorithm

Thanks for your attention
Questions?

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