Consiglio Nazionale delle Ricerche

CNR ISTC
ISTITUTO DI SCIENZE E TECNOLOGIE DELLA COGNIZIONE

Integrated Planning and Scheduling Capabilities to Support Space Robotics

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PST Planning & Scheduling Team

Planning & Scheduling *team*

Outline

- Motivations
- **Timeline-based Planning and Space**
  - The APSI-TRF Framework
- Two emerging timeline-based systems: **EPSL and J-Tre**
- The Knowledge Engineering Environment (**KEEN**)
- Application to the **GOAC Domain**

Motivations

- Many **space applications** rely on **timeline-based** planning systems

  [HSTS, EUROPA, ASPEN, APSI-TRF]

- But which is the role for research centers?
  - To propose **innovation**
  - To **foster the use of timeline-based approach**
  - To create more **robust user-oriented tools**

- We provide a report about **three recent research initiatives**: EPSL, J-Tre and KEEN

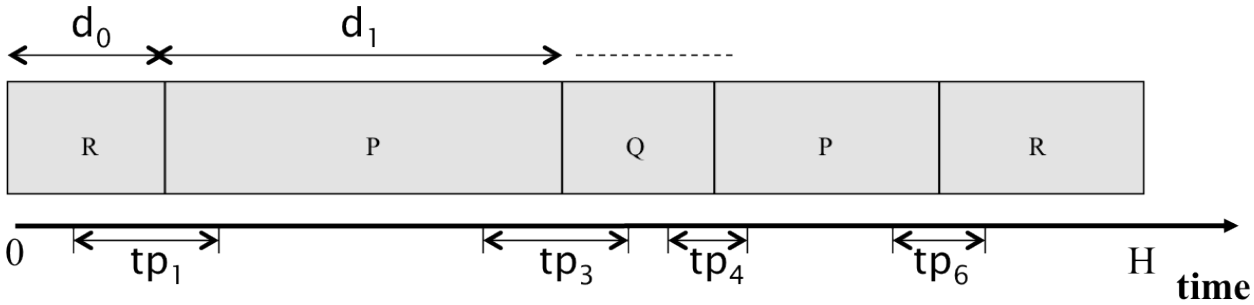
  [De Benedictis & Cesta 2012, Cesta et al 2013, Bernardi et al 2013]

Timeline-based Planning

- Plans are set of ***Timelines***
  - A timeline denotes the temporal evolution of a particular feature (*State Variable*, *Resources*, *etc…*)

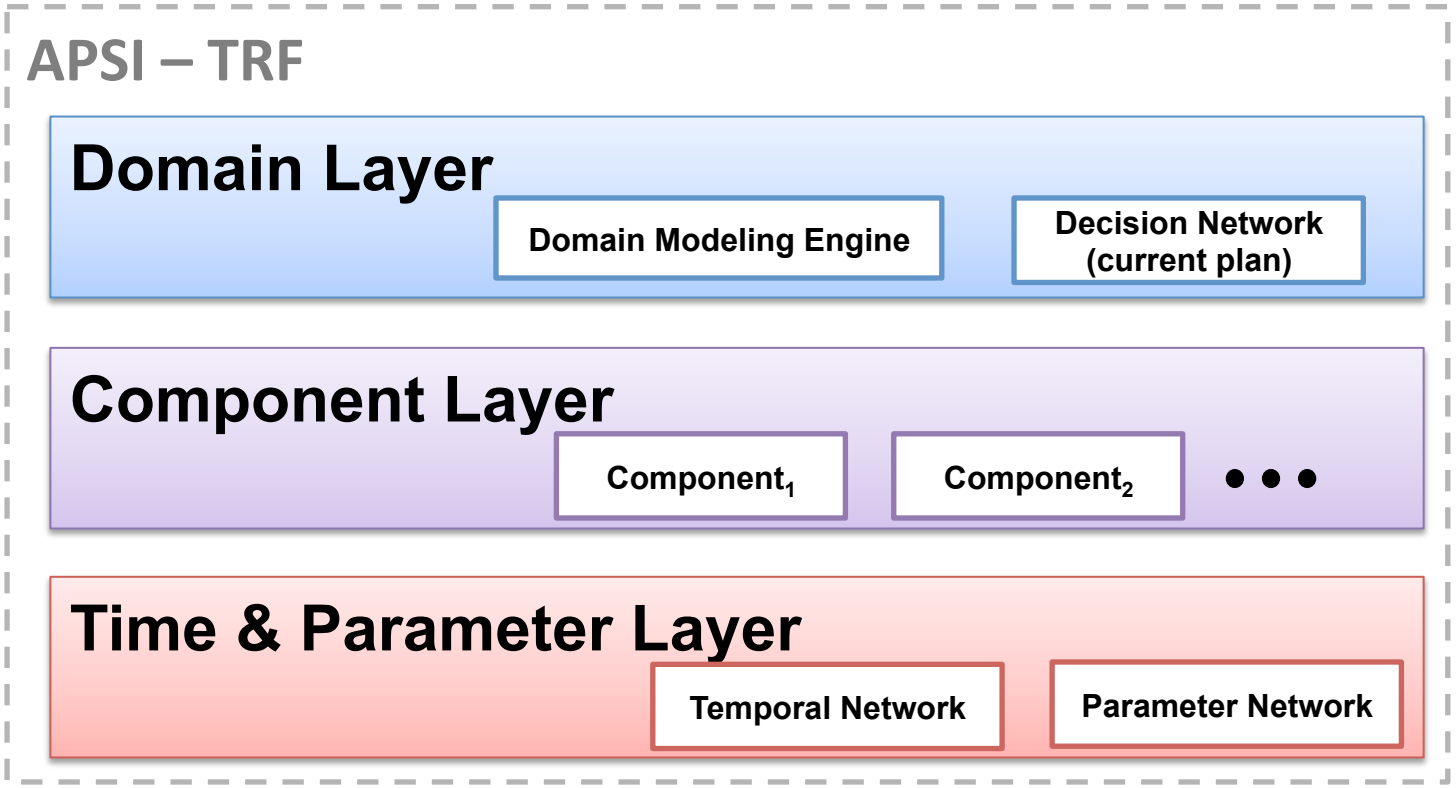
- A ***Domain Theory*** describes a planning domain defined over a set of timelines by means of **Causal and Temporal Constraints**

- Time-flexible plan: at least one timeline is time-flexible



- Planning process should build a ***valid plan*** (w.r.t. a Domain Theory) achieving desired Goals

The APSI-TRF Framework



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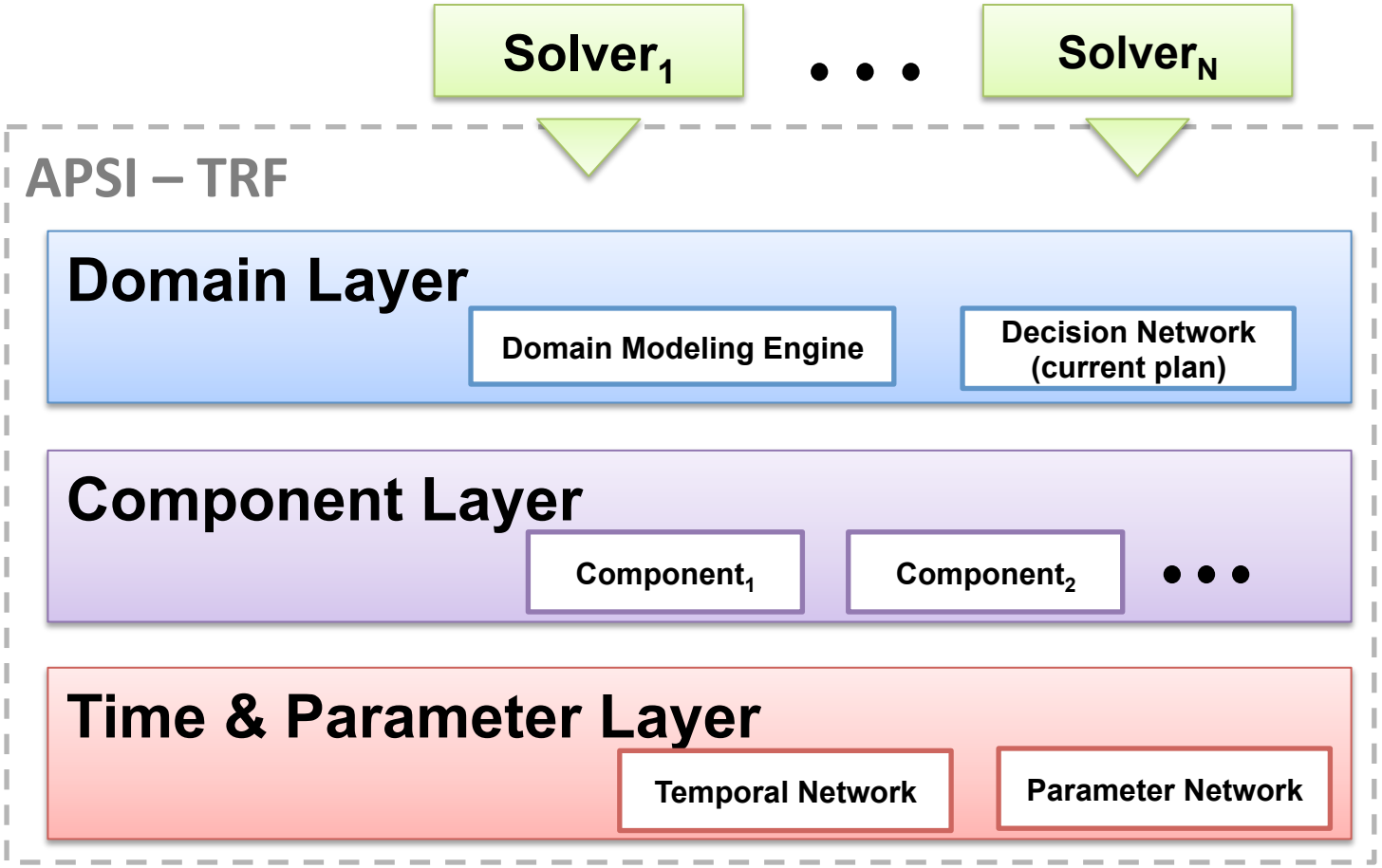
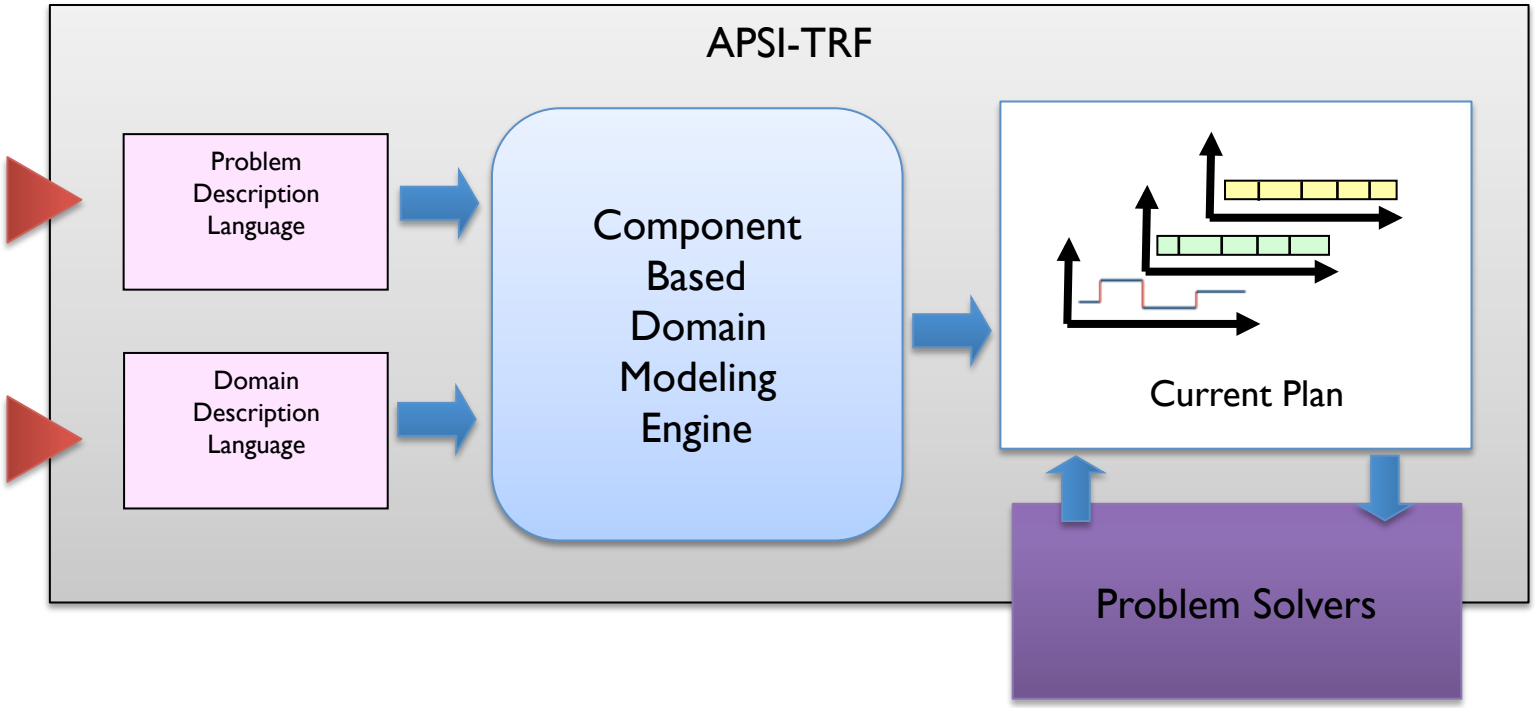


How to use APSI-TRF for Planning



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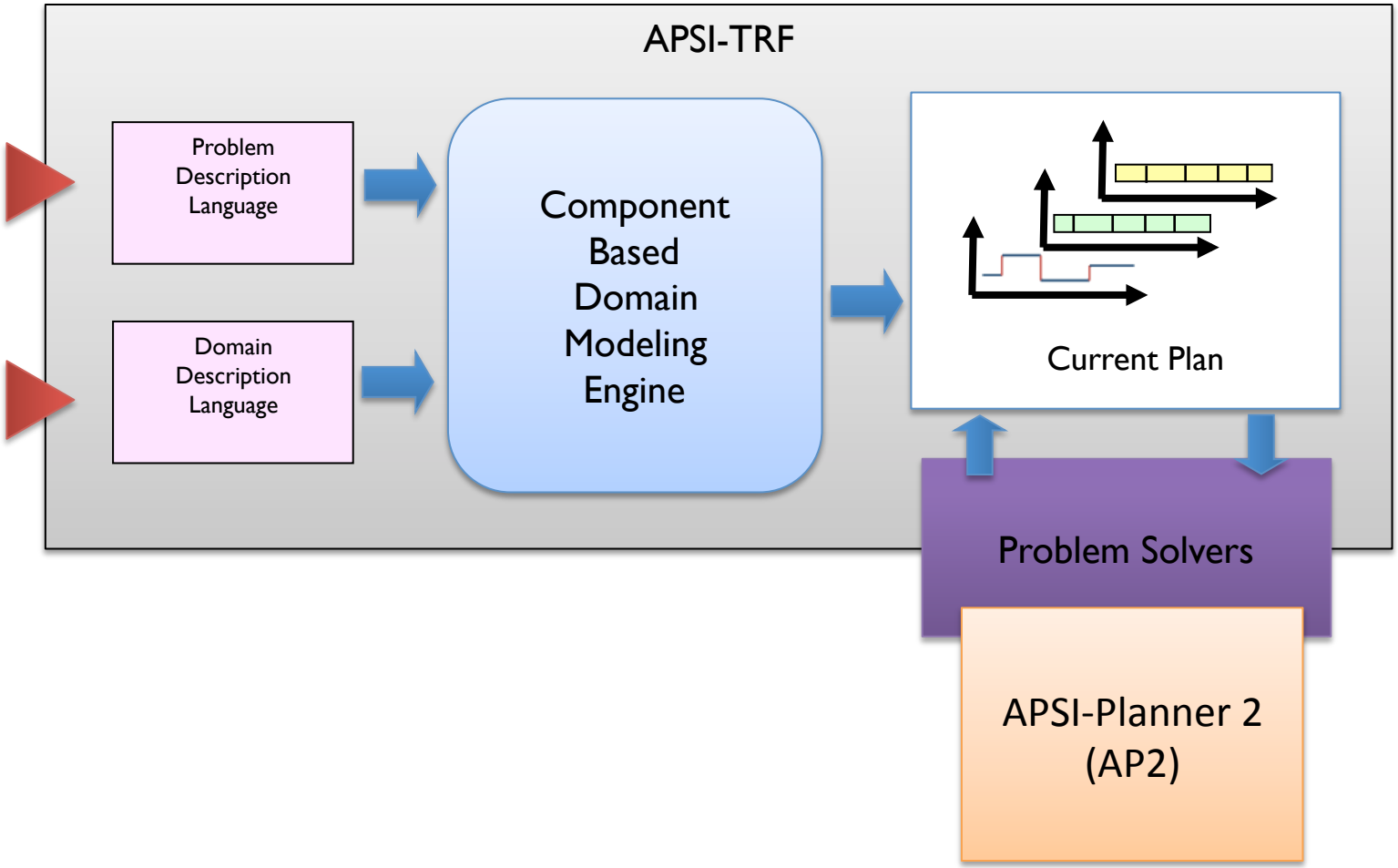

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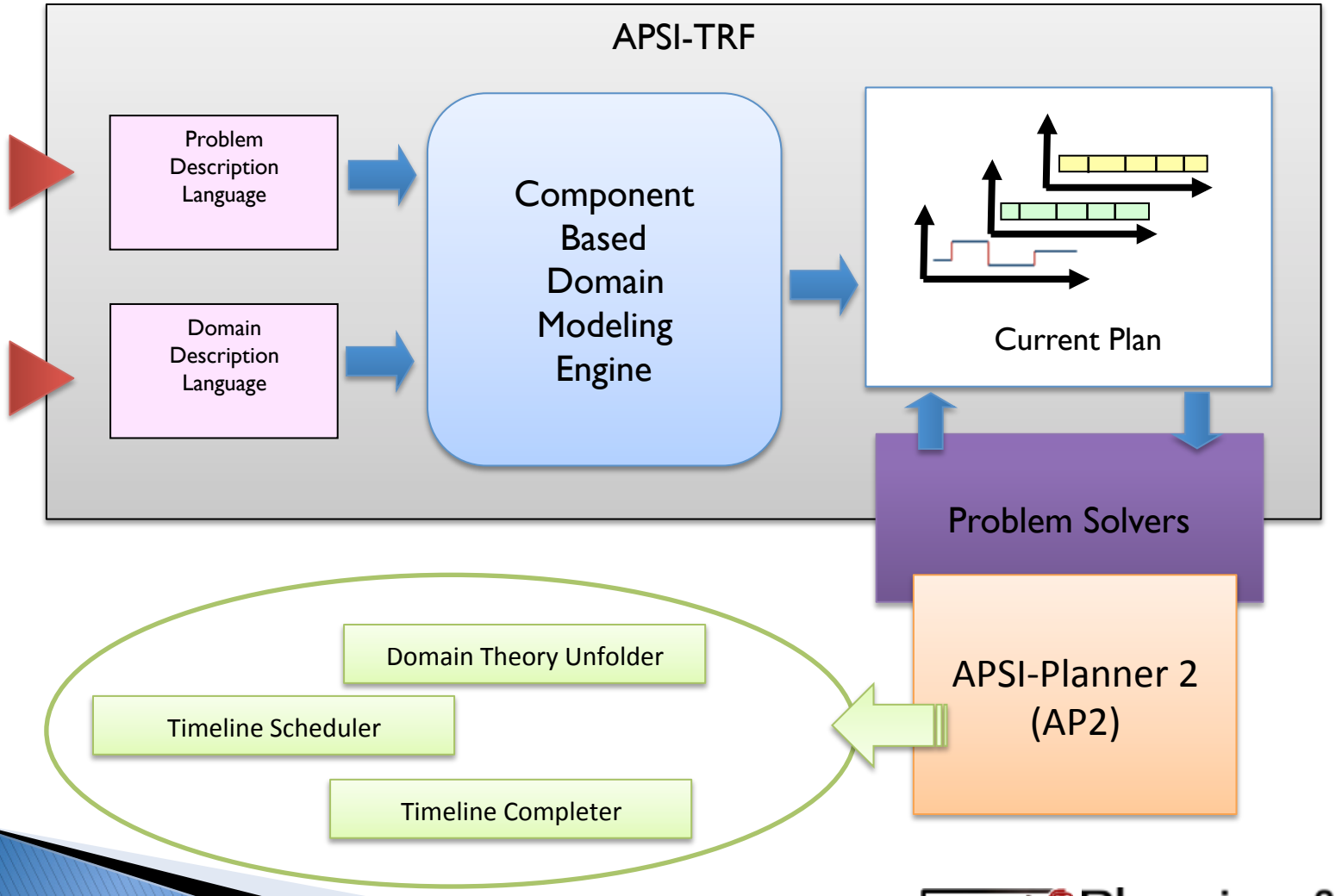

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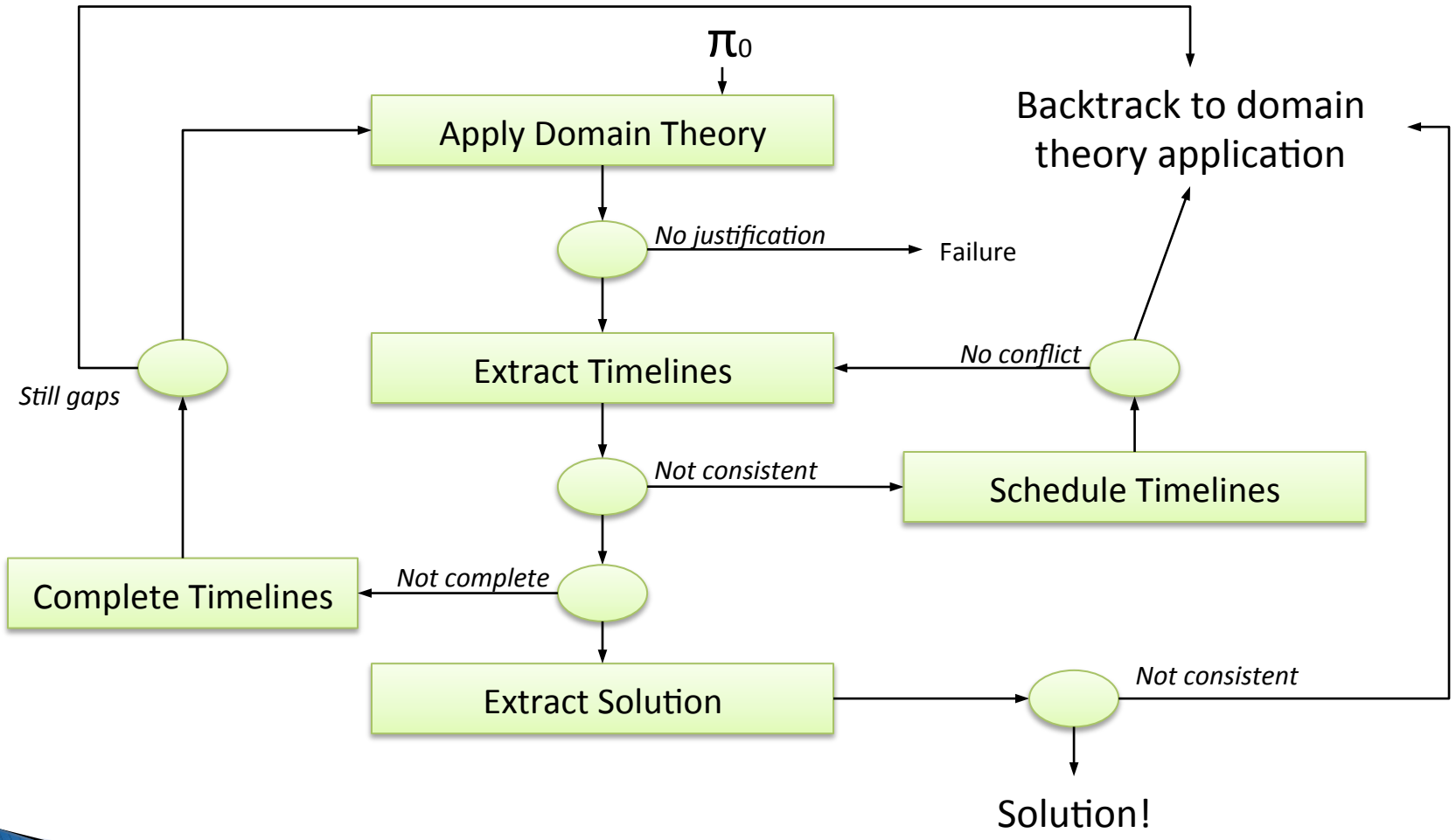
APSI-Planner 2



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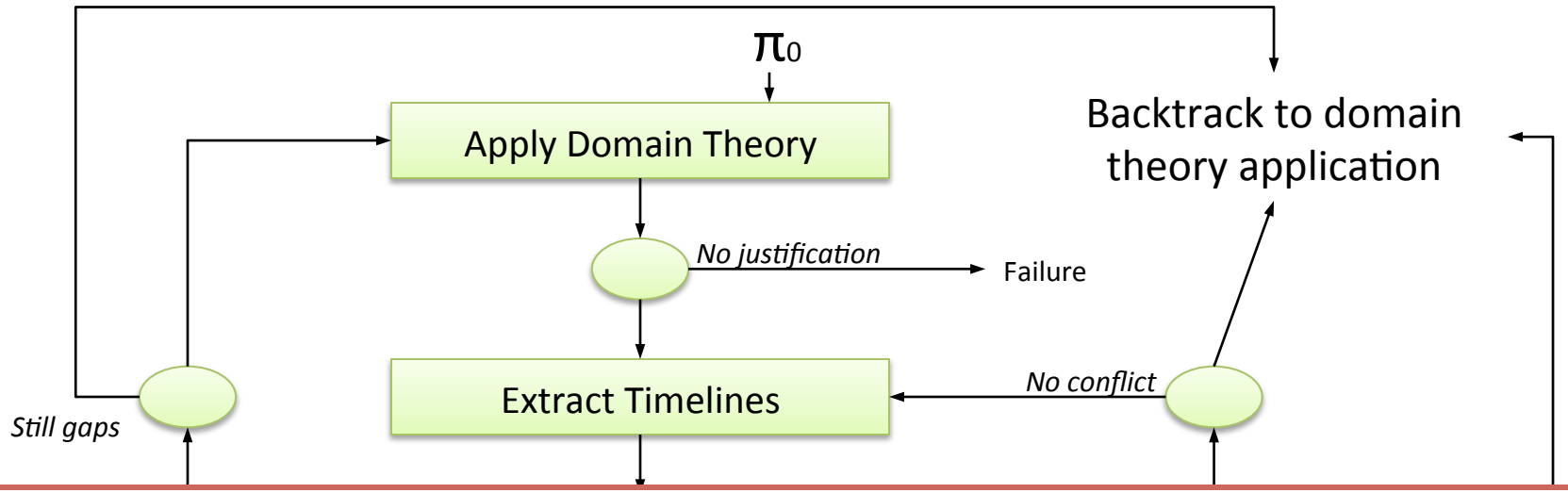

-- fully integrated in GOAC

-- continuous planning on a dynamic evolving solution database

-- flexibility could be improved

-- backtracking to domain theory application forbids early detection of inconsistency

The Extensible Planning and Scheduling Library: EPSL

- A planner is composed by a set of **independent elements**:
  - **Engine**, is responsible for flaw resolution
  - **Heuristic**, is responsible for flaw detection
  - **Strategy**, is responsible for managing the search space fringe

- A planner instance implements the **solving process** making all these elements **working together**

[Cesta et al 2013]

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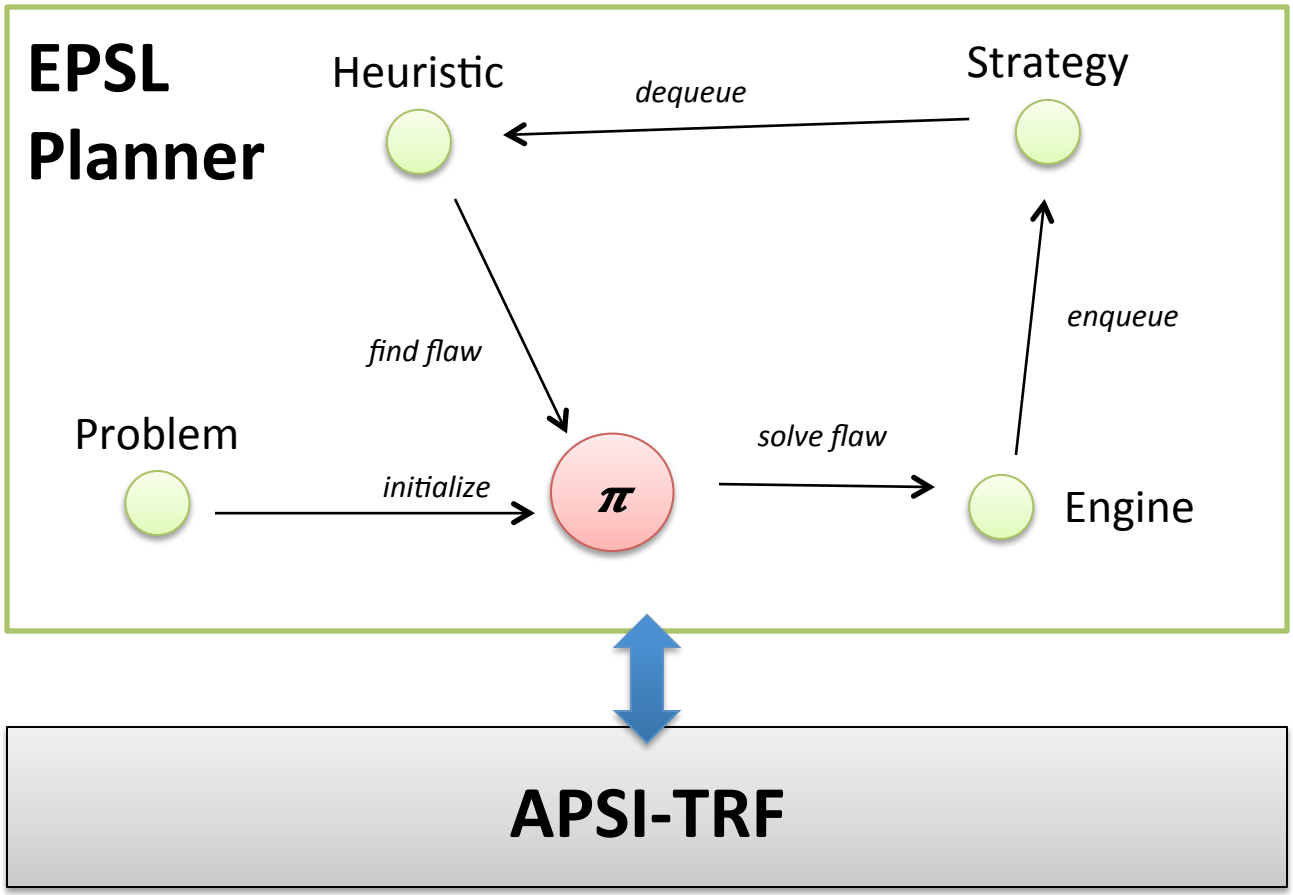

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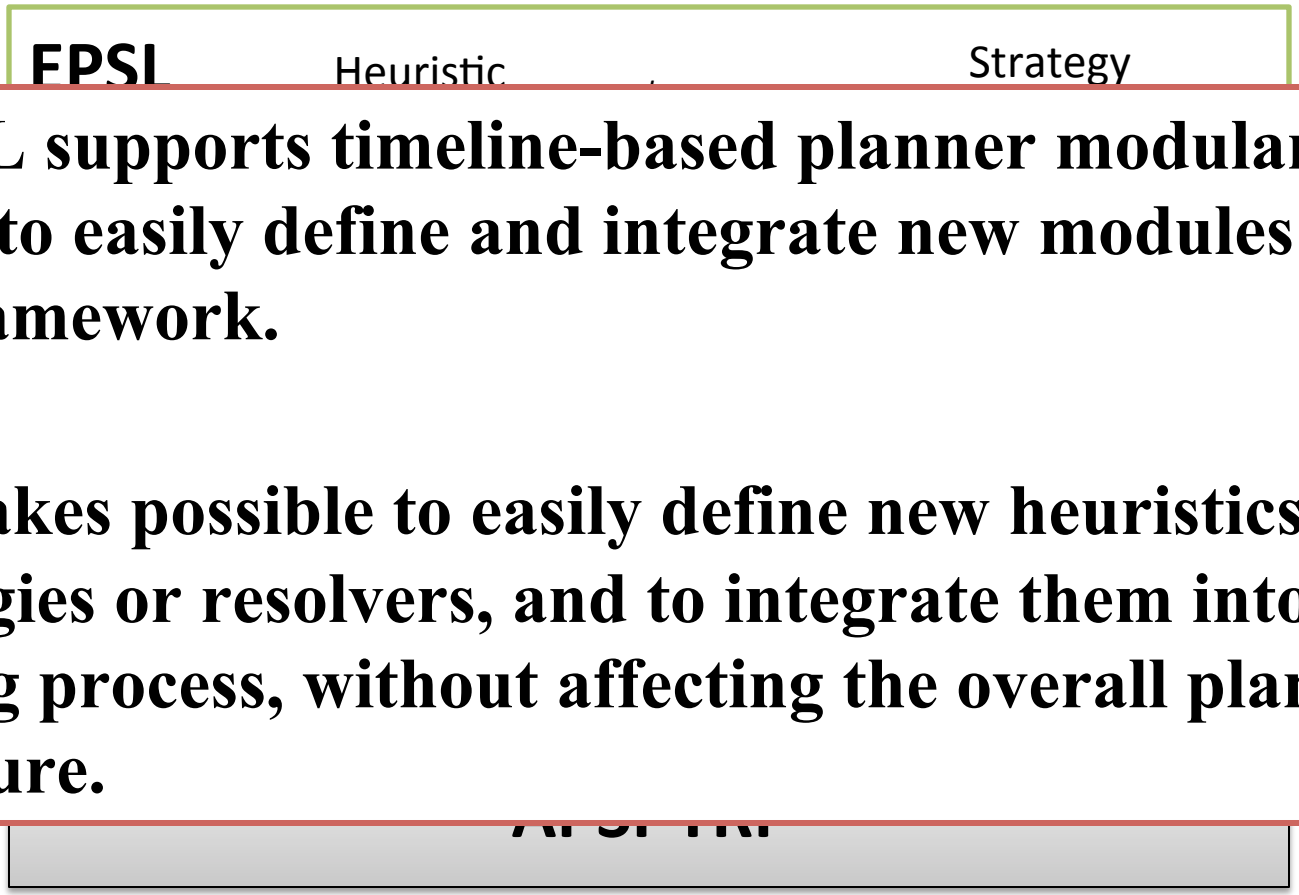

- EPSL supports timeline-based planner modularity in order to easily define and integrate new modules into the framework.

- It makes possible to easily define new heuristics, strategies or resolvers, and to integrate them into the solving process, without affecting the overall planning structure.

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One solver many flaws!
J-Tre

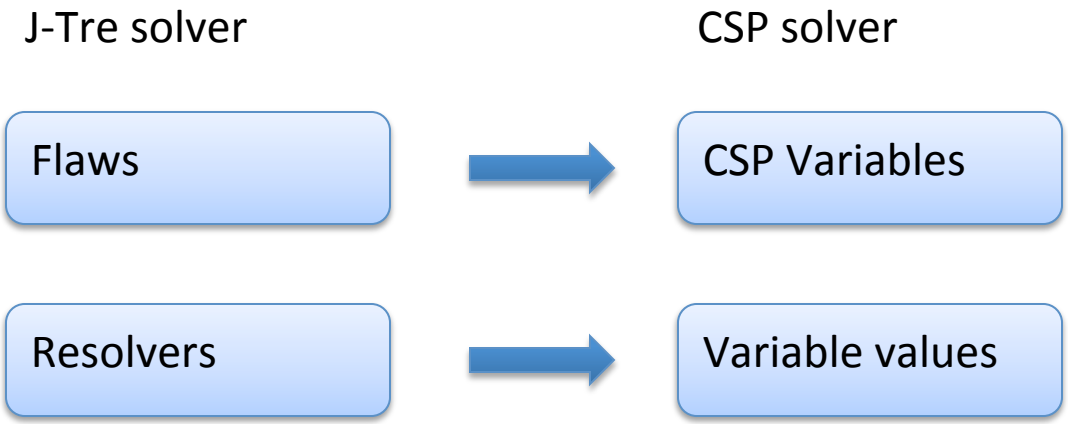
- Standard **refinement search** algorithm
  - **Identify** a set of flaws
  - **Select a flaw** according to a *selection strategy*
  - **Solve the flaw** by using a *resolution strategy*

- Different kind of flaws
  - Goals, MCSs, disjunctions, preferences, etc...

- Each flaw has a **set of resolvers**
  - All possible ways to resolve the flaw

[De Benedictis et al 2013]

A meta-CSP approach



A meta-CSP approach

J-Tre solver		CSP solver	**CSP Heuristics!**
Flaws	→	CSP Variables	*Most constraining variable* *(lowest number of resolvers)*
Resolvers	→	Variable values	*Least constraining value* *(min-slack heuristic, etc...)*

1) The flaw cannot be solved by any resolver

Early detection of inconsistency!

2) The flaw can be resolved in only one way

Unavoidable decision!
Could provide additional explicit constraints on other flaws

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A meta-CSP approach

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Resolvers	→	Variable values	*Least constraining value* *(min-slack heuristic, etc...)*

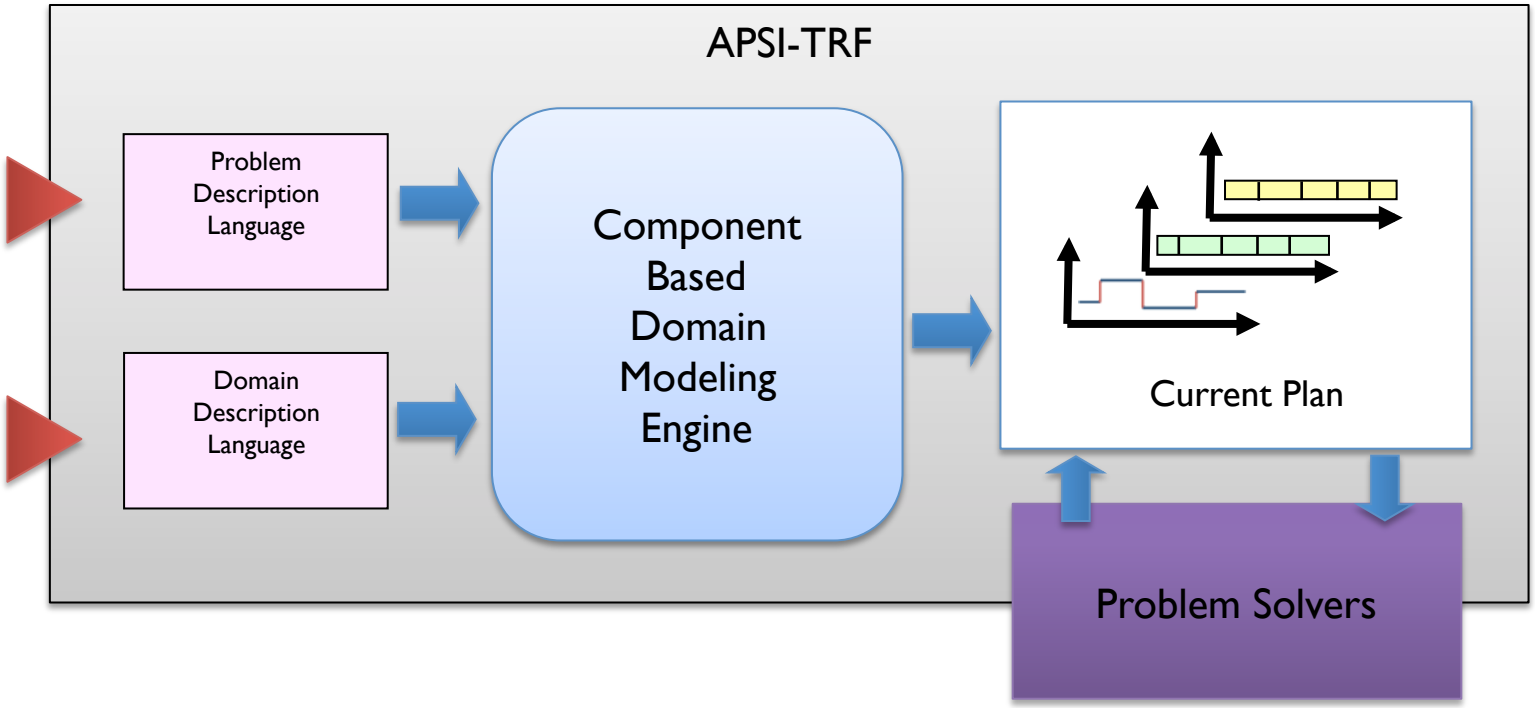
1) The flaw cannot be solved by any resolver

2) The flaw can be resolved in only one way

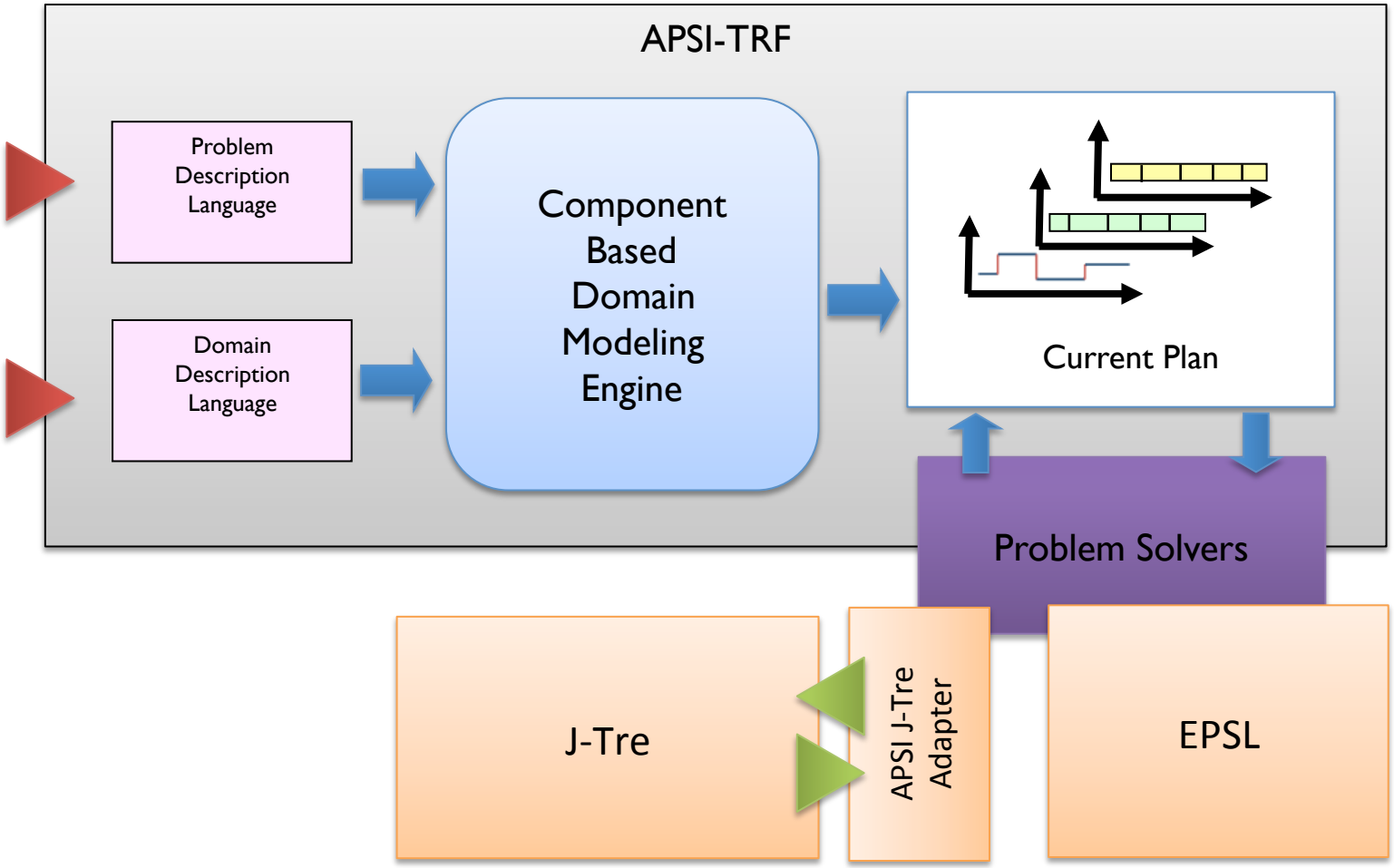
-- seamless integration of planning and scheduling concepts

-- early detection of inconsistency

Extending the APSI-TRF planners portfolio



Extending the APSI-TRF planners portfolio



A Knowledge Engineering Environment (KEEN)

- Exploring **interactions** between V&V and plan generation and execution [Cesta et al 2010]
- Focus on flexible temporal **plan verification** and **robust plan execution** [Cesta et al . 2011. Orlandini et al. 2011.]
- A **Knowledge Engineering ENvironment** (KEEN) design support system for P&S applications
  - Domain/Problem Definition and Visualization
  - Plan Editing and Visualization
  - V&V Tools

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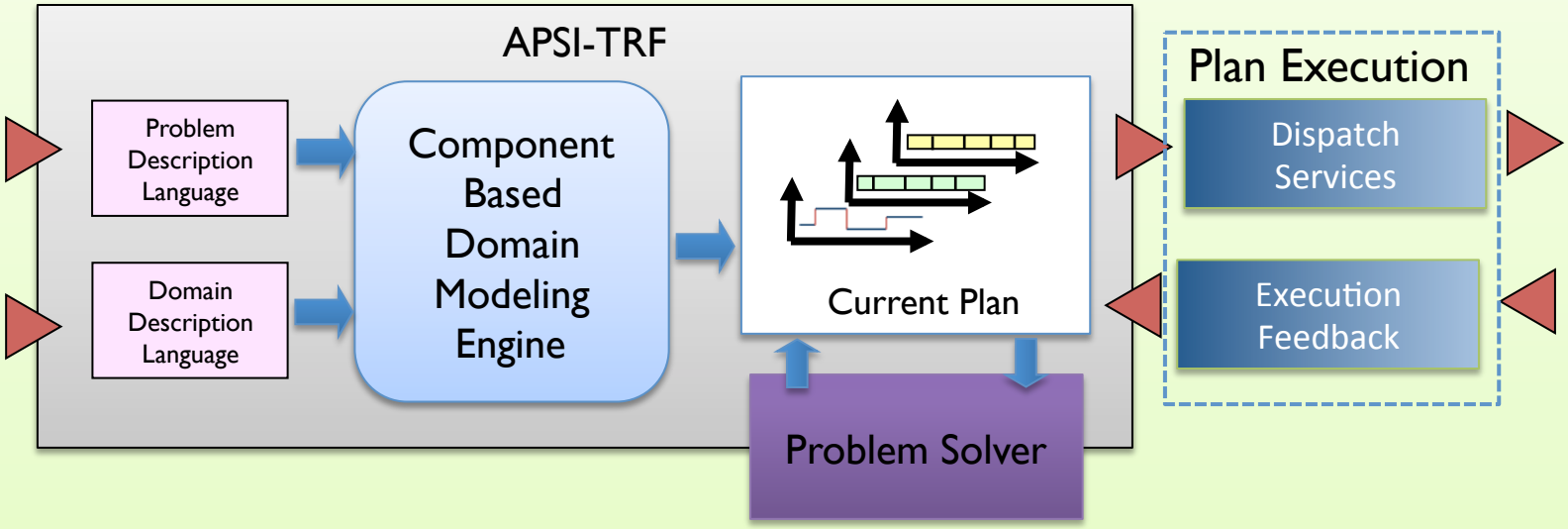
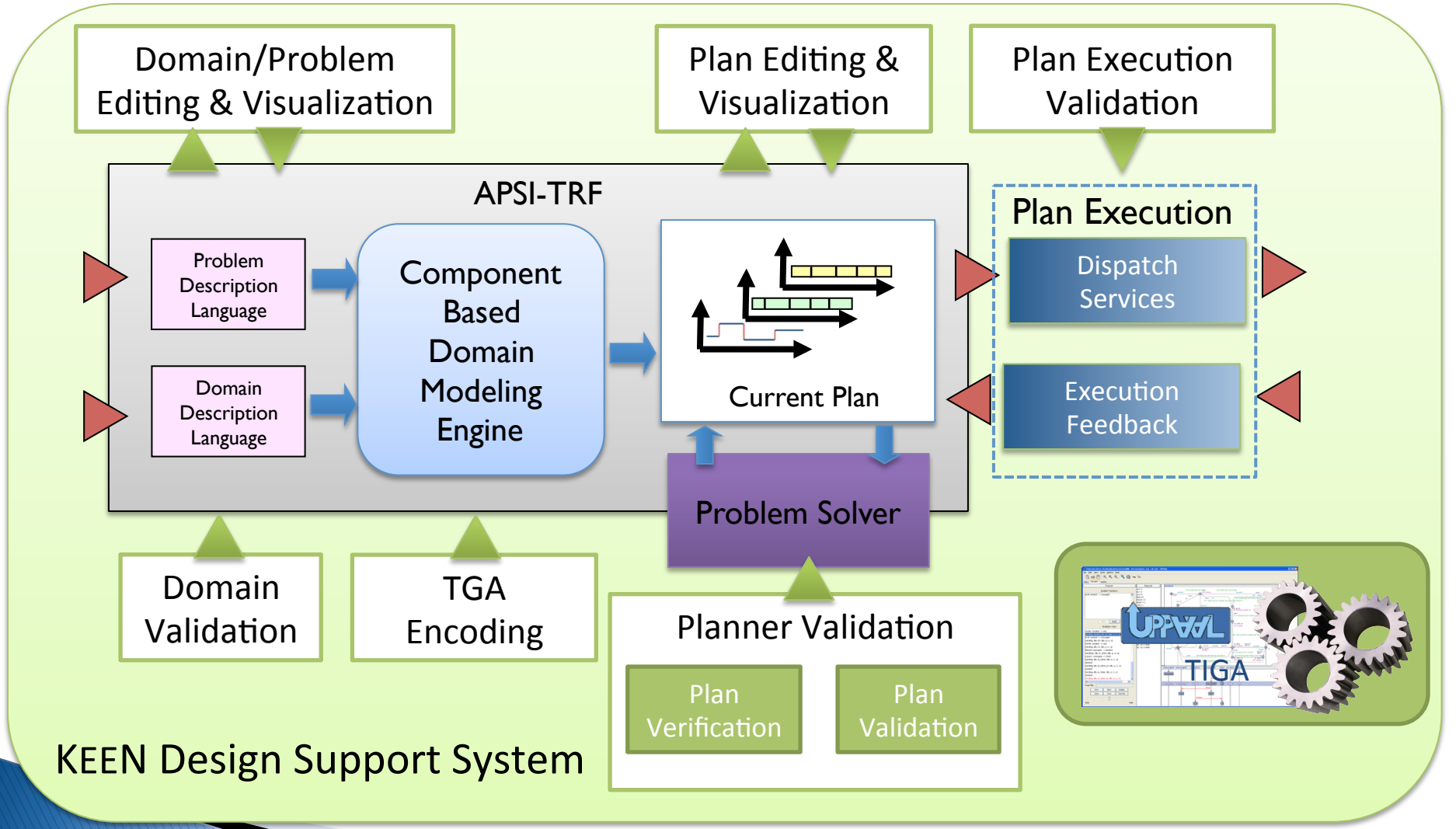
The KEEN to support APSI-TRF



KEEN Design Support System

The KEEN to support APSI-TRF



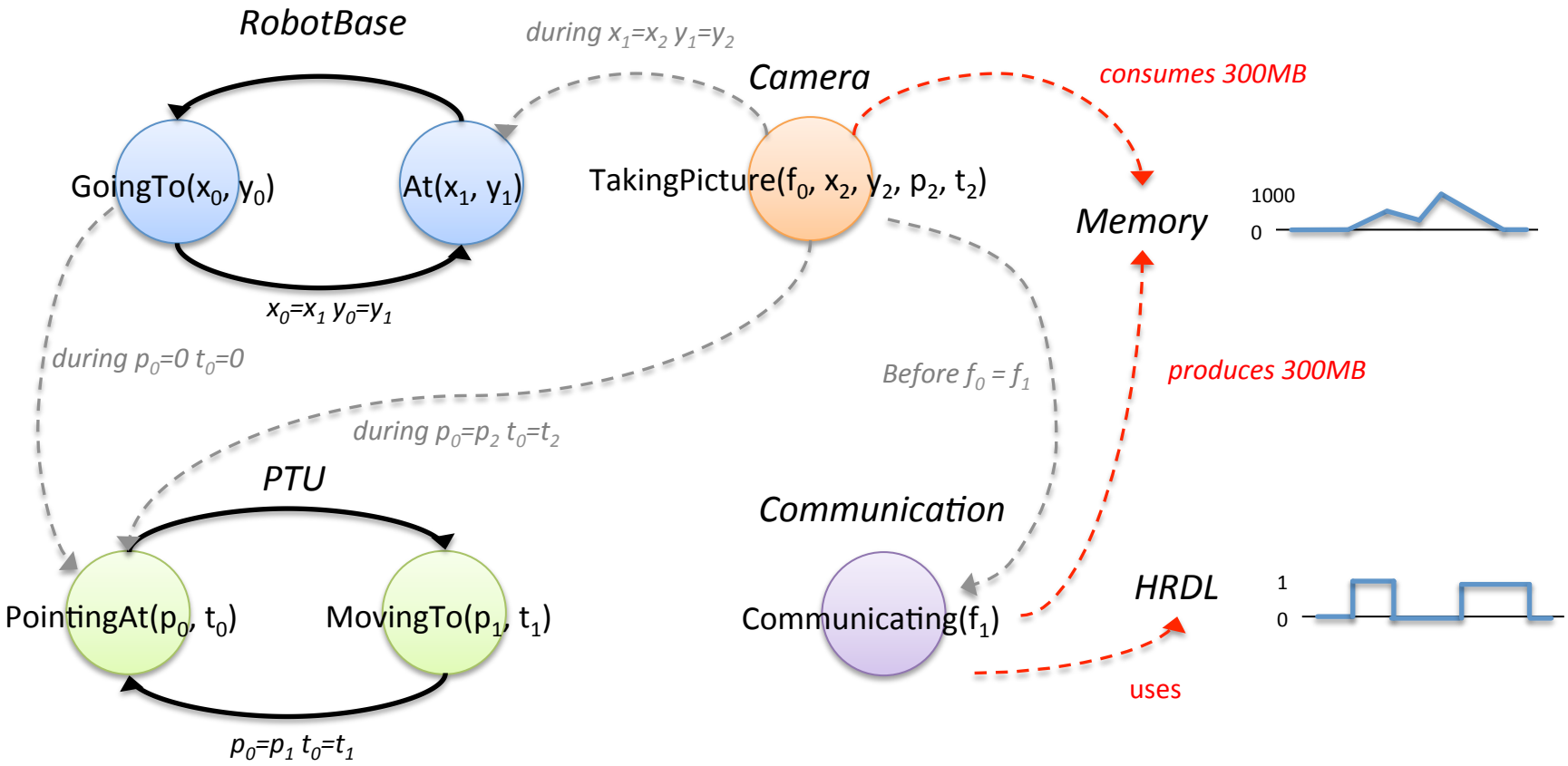
A Robotic Domain…

- A robotic platform equipped with
  - A pan-tilt unit (PTU)
  - Two stereo cameras
  - A communication facility
  - On-board Memory

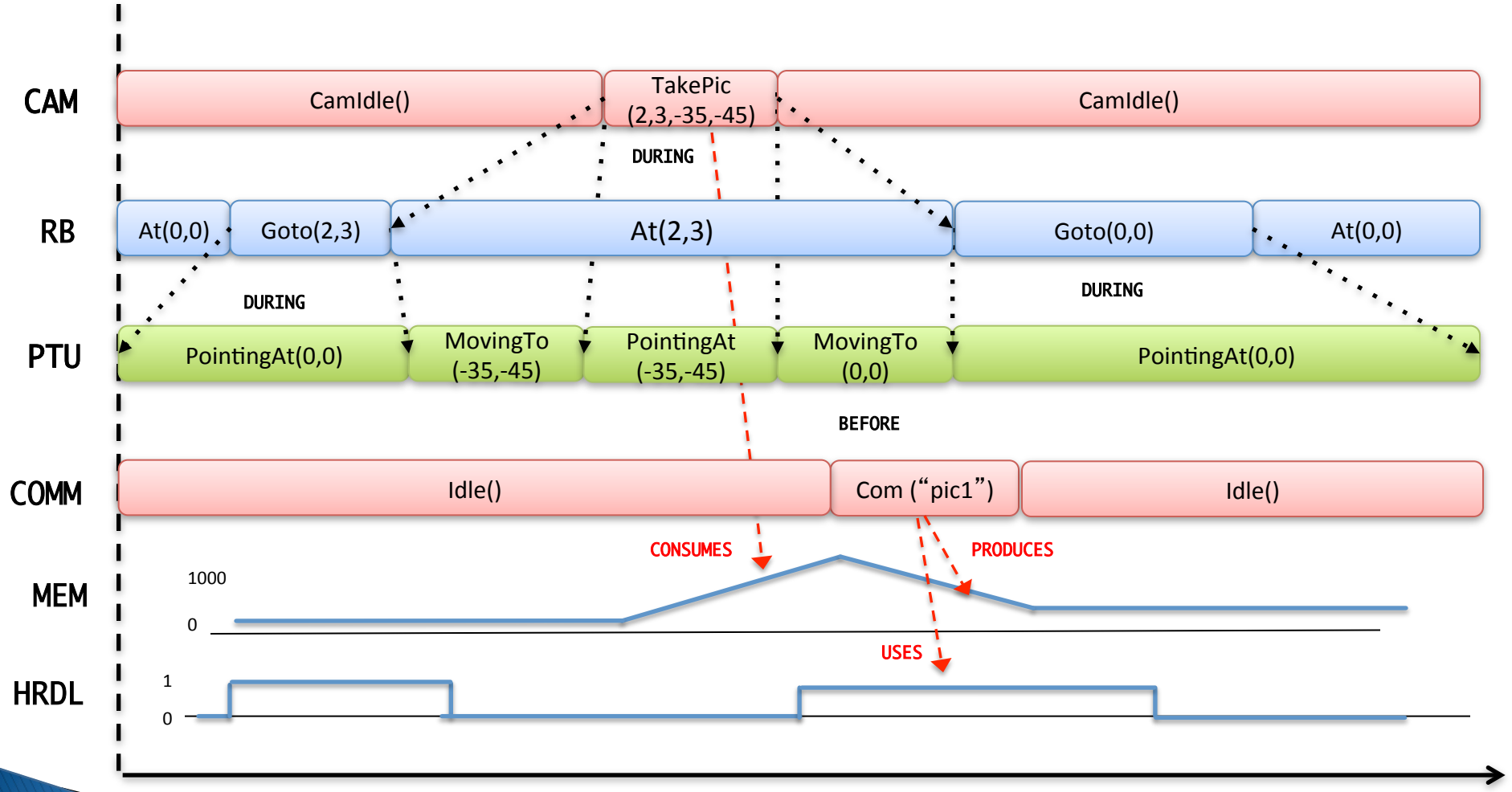
- Robot has to:
  - Autonomously navigate the environment
  - Move the PTU
  - Take a set of required pictures
  - Communicate taken pictures

GOAC [2009-2011]
ESA Space Robotics

… a Timeline-based Specification…



… and a Timeline-based Plan Example



Experimental Results

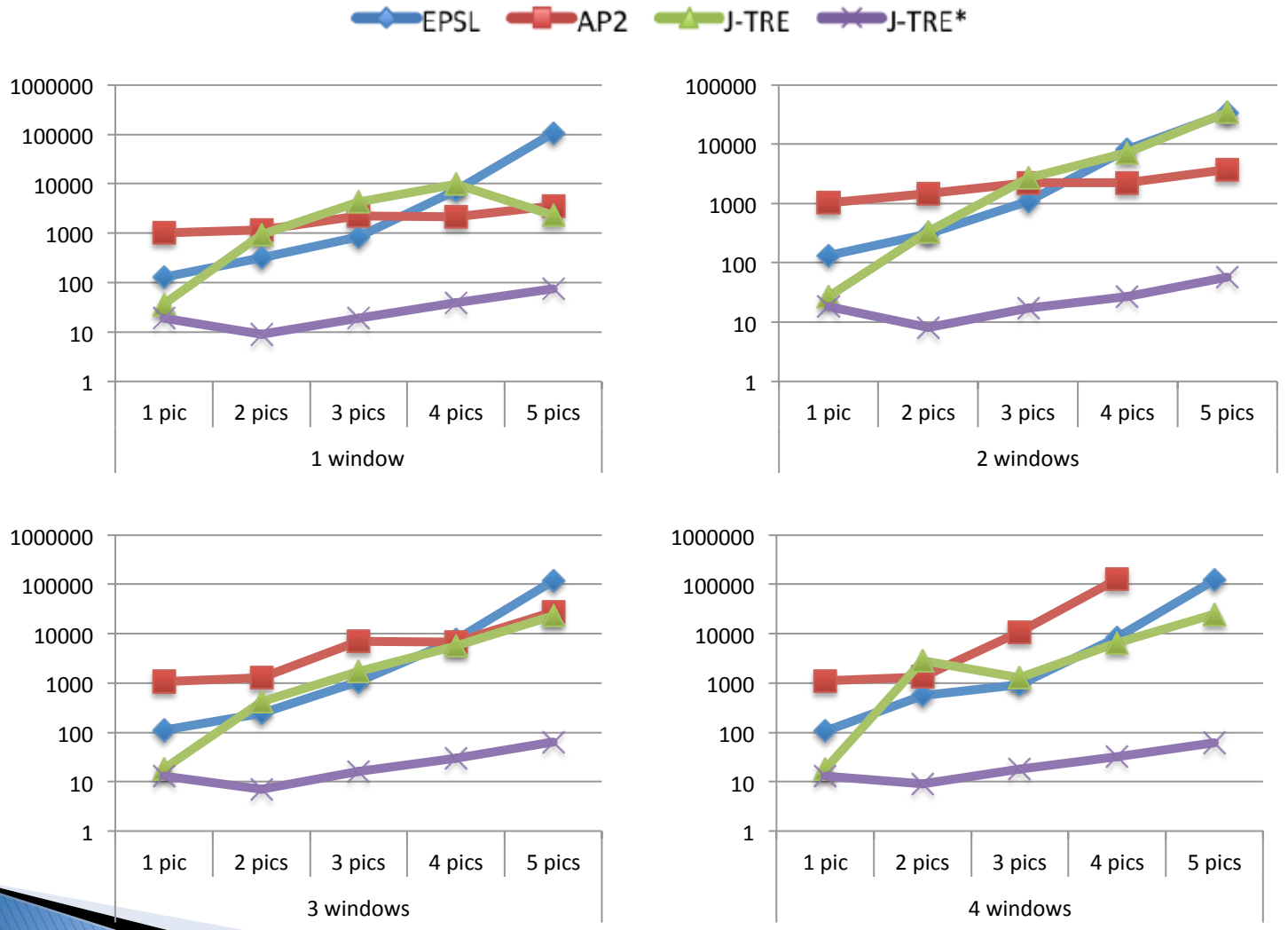
- We deploy the Planners in different GOAC scenarios
  - Set A: AP2 vs EPSL vs J-TRE vs J-TRE*(No Resources)
  - Set B: EPSL vs J-TRE vs J-TRE* (With Resources)

  - For J-TRE we consider the average performance on ten runs
  - For J-TRE* we consider the best result out of ten J-TRE runs

- Performances analyzed varying the:
  - **Horizon dimension**
  - **Temporal flexibility** for uncontrollable actions
  - **Number of visibility windows**

Experiments on Intel Core 2 Duo (2.26GHz) 2GB RAM – Timings in msecs

Experimental results (Set A)



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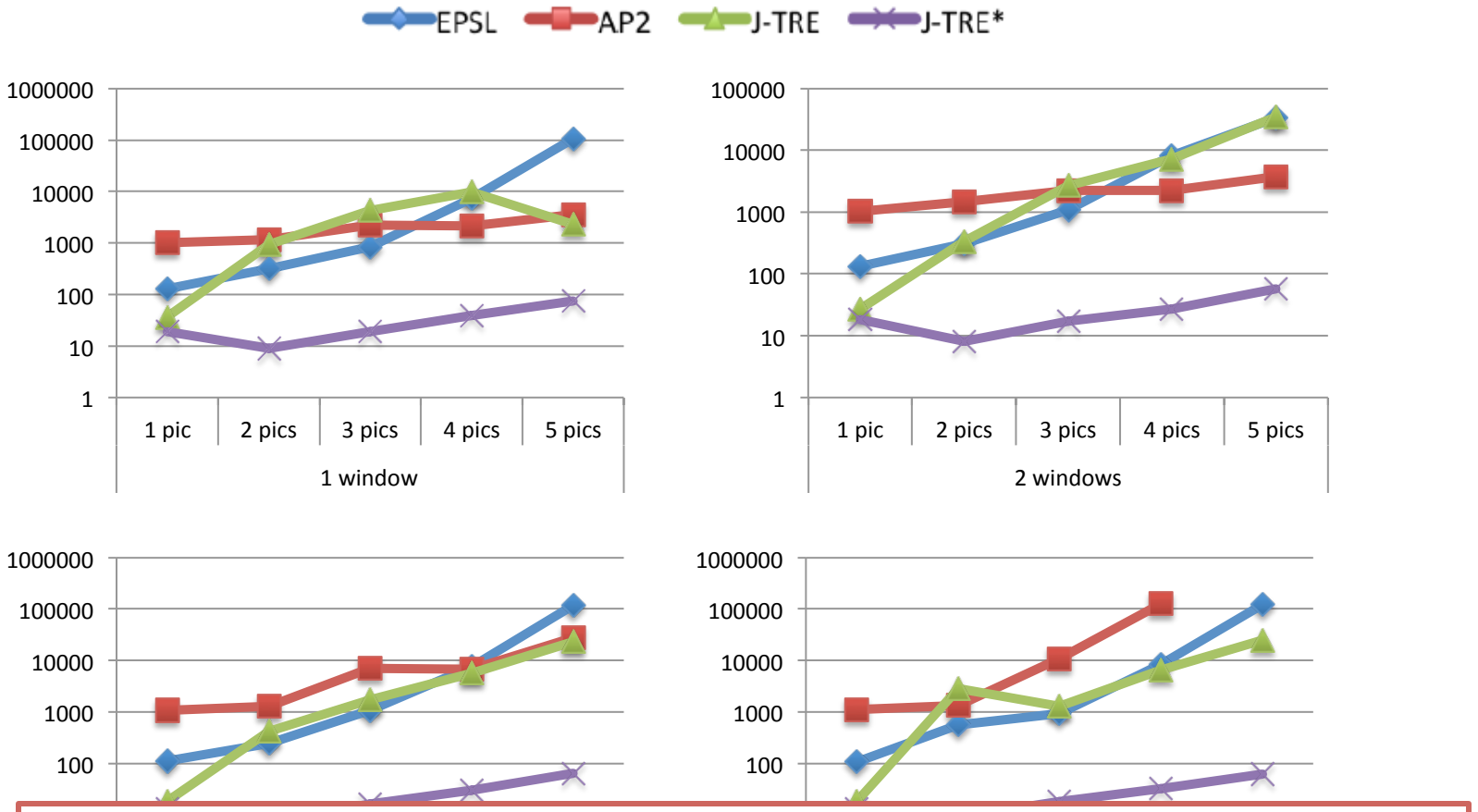
Experimental results (Set A)

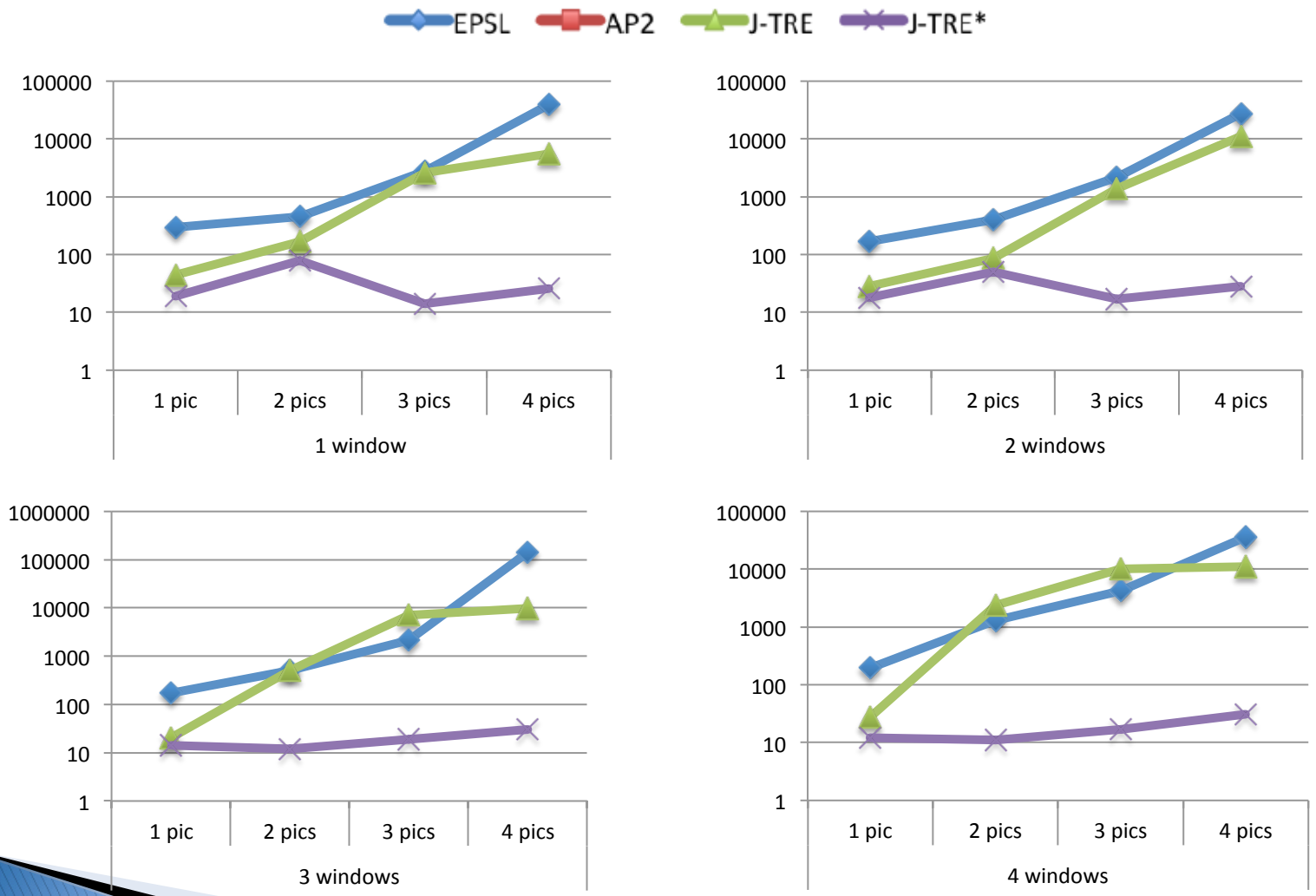


-- AP2 is tailored for solving GOAC problems

-- scalability problems appear in the 4-time-windows

-- J-Tre solves the problem quickly but sometimes the heuristics fails

Experimental results (Set B)



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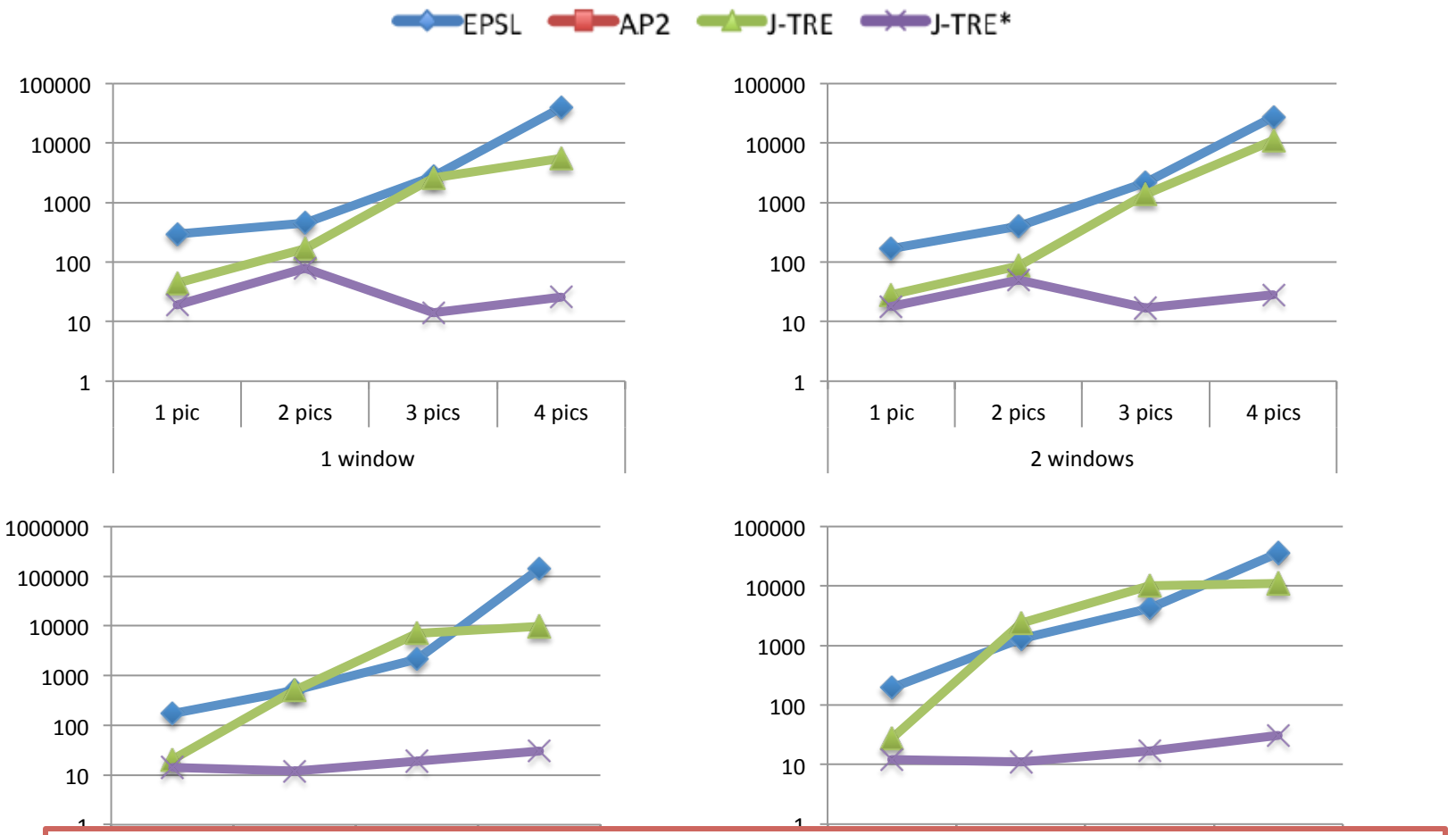
Experimental results (Set B)



Both EPSL and J-Tre solve problems with resources coping well with the scalability

Conclusions

- ESA investments for P&S have been important in the recent past

- The agency is currently involved in
  - Standardization efforts on timeline-based P&S [Chien etal 2012]
  - Enlarging the use of APSI (es. [Policella etal 2013])

- Which is the role of research groups **outside** the Agency?
  - Develop some new ideas in an APSI-compliant environment
  - Recent advancements
    - New planners for combined causal and resource reasoning
    - A comprehensive environment for Planning, Scheduling, Validation & Verification (to support space robotics plan deliberation)

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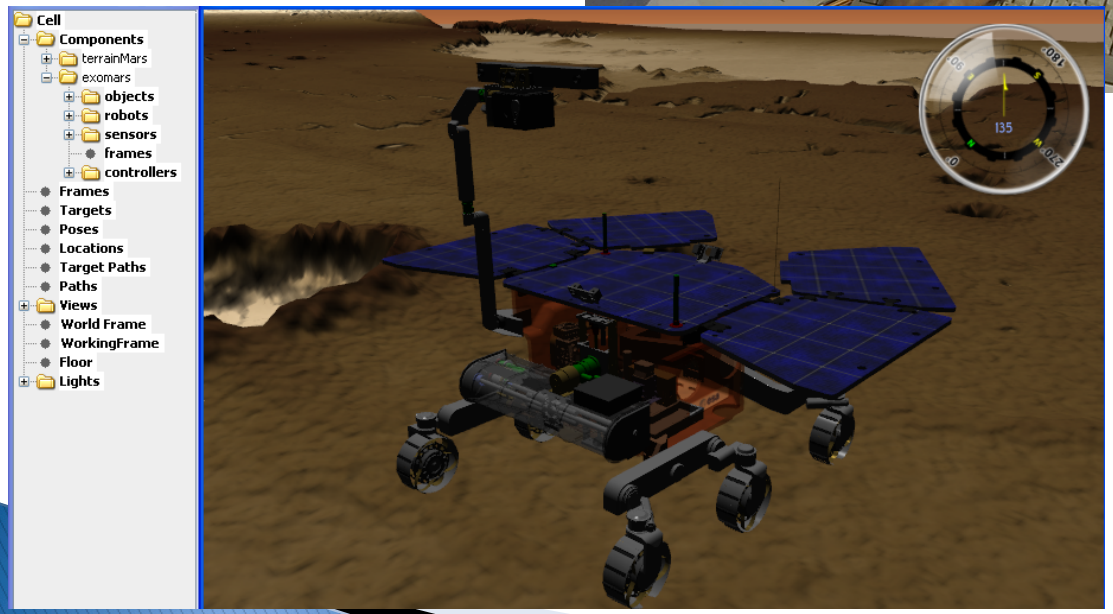
Thanks!



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