Activity Planning with Resources for the Exploration of Space

Introducing APRES 2.0

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- 1988 – 1998: NASA Contractor
- !998 – present: NASA Civil Servant
- Mission Involvement
  - **MER:** GDS/MOS Tactical Activity Planner
  - **MSL:** GDS only
  - **LCROSS:** GDS/MOS Activity Planning & Sequencing Lead
  - **LADEE:** GDS/MOS Activity Planning & Sequencing Lead
  - **HelioSwarm**: GDS/MOS since Proposal/Phase A

APRES Project Intro

- *Parent Project:* The AES Autonomous Systems and Operations (ASO) Project
- ASO Organizational Responsibility
  - *Responsible Mission Directorate:* Exploration Systems Development Mission Directorate (ESDMD)
  - *Lead Center:* Ames Research Center (ARC)
  - *Responsible Program:* Mars Campaign Office
- ASO Program Management
  - *Program Director:* Christopher L Moore
  - *Program Manager:* Greg Chavers
  - *Project Manager:* Jeremy D. Frank
- APRES Systems
  - **APRES Prototype:** Available in the NASA Software Catalog (entry ARC-18869-1) since August 2023
  - **APRES 2.0:** Started work at beginning of November 2022, and is still a work in progress
    - **In use on HelioSwarm Mission (Phase A & B)**
- Objectives
  - Design and implement the Ames Intelligent Systems Division's next generation mixed-initiative mission planner for ground operations
  - Design to support all missions, and in particular, multi-spacecraft missions; e.g., swarm missions
- APRES 2.0 Team
  - *Project Lead & Design Lead:* John Bresina
  - *Software Development Manager:* Hassan Eslami
  - *APRES Service Team:* David Smith, Elif Kurklu, Vijayakumar Baskaran; *along with support from J Benton*
  - *APRES User Interface Team:* Deep Tailor, Hassan Eslami

APRES 2.0 Architecture

APRES 2.0 Interface
Browser-based, using the REACT framework

Spring Boot API with JSON content

APRES 2.0 Data Store
Directory structure with JSON and ANML files

APRES 2.0 Service

- ANML Parser
- Project Validator
- Episodic Plan Simulator (EpSim)
- Constraint Checker
- STN Violation Resolver
- Mutex & Threat Analyzer
- File Manager

ANML Editor
Browser-based

Service Components

- ANML Parser
  - Validates model and creates parse data structure used by Service components
  - Creates Activity Dictionary used by User Interface and supports the creation of initial assignments and default configuration files.
- Project Validator
  - Determines if loaded projects have valid syntax and if all associated files are compatible with the domain model
  - Also performs semantic checks (e.g., activities must be contained within the plan boundaries)
- Constraint Checker
  - Detects if user's temporal constraints are inconsistent
  - Detects temporal constraints that are not satisfied in the plan
- Episodic Plan Simulator (EpSim)
  - Simulates plan, creating numeric and state chronicles
  - Detects and reports violations
  - Determines process triggering and termination
- STN Violation Resolver
  - Determines action rescheduling resolutions, using a Simple Temporal Network & greedy search
- Mutex & Threat Analyzer
  - Supports STN construction
- File Manager
  - Retrieves and saves files in the APRES Data Store
  - Maintains integrity of the APRES Data Store

Planning Project

- Project information
  - Author
  - Last modified timestamp and last valid timestamp
  - Plan start and end timestamps
  - Action start time precision (Milliseconds, seconds, or minutes)
  - Associated file references (model, initial & timed assignments, configuration)
- Activity Plan
  - Actions and processes
  - User-defined temporal constraint (unary and binary)
- Simulation Information
  - Violations detected
    - variable-bounds
    - unsatisfied-condition
    - violated-condition
    - inconsistent-effect
    - duplicate actions
    - temporal-constraint
    - inconsistent-constraints
  - Numeric chronicles
  - State chronicles
- Resolution Suggestions
  - Rescheduling of action instances

ANML II Summary

- ANML II is a very expressive language, enabling more **accurate domain models** and **plans**
  - APRES 2.0 is only using a subset of the ANML II language; e.g., we currently do not support decomposition, conditional effects, quantification, existential temporal qualifiers
- ANML II allows the definition of **processes** which autonomously occur due to world states.
  - *For example, charging of the battery from the solar panels, or the operation of survival heaters that automatically power on and off based on temperature sensor readings.*
- ANML II allows the specification of a rich set of **flight rules**
  - *For example, the battery state-of-charge must remain above a specified minimum, or the instantaneous power draw must remain below a specified maximum.*
- ANML II allows the specification of **predicted behaviors** over time
  - *For example, eclipse periods, periods when a spacecraft is in view of a particular Deep Space Network Station, and range of spacecraft from Earth*
- ANML II allows the specification of a rich variety of activity/resource effects, including the following:
  - Absolute or incremental
  - Discrete or **continuous**
  - Resource consumption or production of reusable or consumable resources
- ANML II allows functional fluents; e.g., thrustersActive(sc) where sc is a variable whose value is a member of the set of spacecraft
  - Greatly reduces the size of the domain model, especially for multi-spacecraft missions

Demonstration Model

- Small, simplified model based on a *swarm mission*
- *Multi-spacecraft:* one hub s/c and three node s/c (n1, n2, n3)
- *Communication Policy:*
  - The nodes only communicate with the hub
  - The Ground only communicates with the hub
  - The hub can only communicate with one node at a time
  - The hub can communicate with the Ground and a node simultaneously
- *Two science instruments per spacecraft:* MAGa and MAGb
- *Five telemetry sources per spacecraft: s/c bus HK, MAGa HK, MAGa Sci, MAGb HK, MAGb Sci*
- *Three DSN stations (one per complex):* DSS34, DSS45, DSS55
- *Numeric resources modeled:*
  - Total (instantaneous) Power
  - Data to be downloaded on each spacecraft
  - Data received on the ground
- *Resource Flight Rule:* Total Power must not exceed 400 Watts
- There are a number of mutual exclusion flight rules, including:
  - The hub cannot communicate to a node or the Ground when its thrusters are active
  - A node cannot communicate to the hub when its thrusters are active

Demo Activity Types

- Action Types
  - Hub_Unload_Momentum
  - Node_Unload_Momentum
  - **Ground_Comm**
  - **Crosslink**
  - Node_Maneuver
  - Hub_MAGa_PwrOff
  - Hub_MAGa_PwrOn
  - Hub_MAGb_PwrOff
  - Hub_MAGb_PwrOn
  - Node_MAGa_PwrOff
  - Node _MAGa_PwrOn
  - Node _MAGb_PwrOff
  - Node _MAGb_PwrOn
- Process Types
  - Hub_MAGa_Operate
  - Hub_MAGb_Operate
  - Node_MAGa_Operate
  - Node_MAGb_Operate
  - **Comm_Xmit**
  - **CL_Xmit**
  - nodeDevData
  - hubDevData

ANML Action Example


```
action Ground_Comm (Station dss, PosReal commDur ::("default", "14400.0"), PosReal
            GCSdataRate ::("default", 100.0) ::("units", "kbps")  )
            ::("legend", "Ground Comm") :("keyParams", "dss")
{       duration := commDur ;
        [start] DLrate := GCSdataRate ;
        [all] {  TotalPower :uses GCSpwr ;
              GroundComm_Active == false := true ==> := false ;
              inview(dss) == true ;
              allocated(dss) == true ;
               hubThrust_Active == false ;
               radioGCS == Rx := RxTx ==> := Rx ;
             }
}
```

Annotations (in blue) are used by the UI

[start] TotalPower :+= GCSpwr;
[end] TotalPower :-= GCSpwr ;

radioGCS must initially equal Rx; at the action start it is set to RxTx and this value must be maintained until the action end; at which point it is set to Rx.

ANML Process Example


```
process Comm_Xmit () ::("legend", "Data Xmit")
  {
  [start] {
            GroundComm_Active == true;
            hubDataTBDL >= DLrate * minXmitDur ;
             }
  [all] {
            hubDataTBDL :-= #t * DLrate ;
            receivedData :+= #t * DLrate ;
             }
 (all] {
            GroundComm_Active == true;
            hubDataTBDL >= 0.0 ;
            }

  }
```

Process is **triggered** when all of these start conditions are **true**

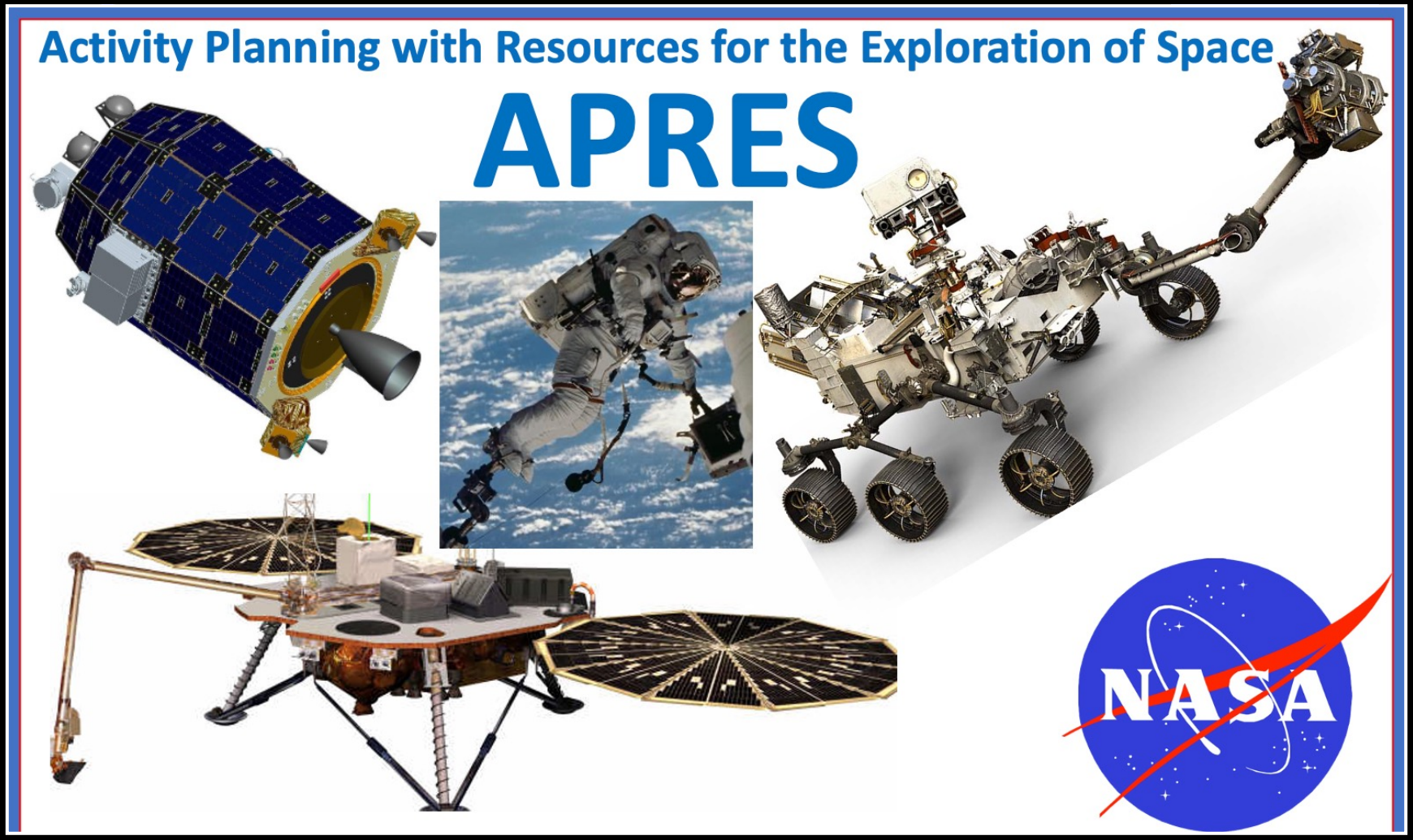
Continuous effects

Process is **terminated** when any of these conditions is **false**

Data Generation Process


```
process hubDevData () ::("legend", "Data Generate")

{

   [all] { hubDataGen(hubBus, HK) + hubDataGen(MAGa, HK) + hubDataGen(MAGa, SCI)
            + hubDataGen(MAGb, HK) + hubDataGen(MAGb, SCI) > 0;

          hubDataTBDL :+= #t * ( (hubDataGen(hubBus, HK) * DataRate(hubBus, HK)) +
            (hubDataGen(MAGa, HK) * DataRate(MAGa, HK)) + (hubDataGen(MAGa, SCI) *
            DataRate(MAGa, SCI)) + (hubDataGen(MAGb, SCI) * DataRate(MAGb, SCI)) ) ;

            }
}
```

- *This process determines the data generated on the Hub s/c based on all of its active telemetry streams (housekeeping, HK, and science, SCI)*
- *The hubDataGen functional fluent has the value 1 when the specified telemetry stream is active and 0 if it is inactive.*



Demonstration of APRES 2.0

Configurable aspects of UI

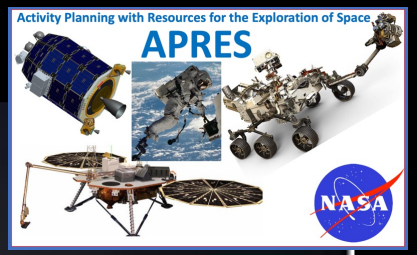
- Defaults for aspects not explicitly specified
- Color of action/process
  - Index: AD type or reusable Color Function w.r.t. **key** parameters
    - One or more action/process parameters can be designated as "**key**" parameters
  - Color for each **key** parameter value
  - Example: nodeColor(nx), where nx is the name of the node parameter in model, with values n1, n2, n3
- Colors for a state chronicle
  - Index: Fluent name or Regular Expression
  - Color for each state value
- Color of numeric chronicle
  - Index: Fluent name or Regular Expression
- Whether to show labels for a state chronicle
- Legend of action/process
  - Index: AD type or Regular Expression
- Hide Boolean
  - Legends
  - Numeric Chronicles
  - State Chronicles
- Layout Order
  - Legends
  - Numeric Chronicles
  - State Chronicles

Enhancements Since Demo

- Developed new concept of “observations”
  - Used in place of “Initial/Final Assignments”
  - The effect of an observation occurs immediately and not an epsilon later as for assignments
- Integration of Plan Transition
  - Supports transition between successive overlapping tactical plans
  - Transition time is the end time of last Ground Contact before next planning session
  - Currently, telemetry values for model variables are based on the observations from simulation
  - Initializes the new planning projects with suffix of previous plan
- Import of externally generated Timed Data, used for automatic generation of Timed Assignments
- Import of externally generated subplan (actions and constraints)
- Plan Table View (an alternative to the timeline view)

Future Enhancements

- Multi-user capabilities
  - Enforces user roles (e.g., Manager, Editor, User)
  - Enforces that a plan can only be edited by one authorized user at a time
  - Allows multiple users to watch a plan editing session
  - *Capabilities have been designed and partially implemented*
- Violation resolution based on mathematical programming/optimization
  - Exploring different approaches, but currently focusing on Mixed-Integer Linear Programming employing the open-source SCIP s/w
  - This approach will resolve a wider scope of violations due to its larger (and more disjunctive) solution space
  - It can be extended to handle **numeric** (e.g., resource) violations
  - We plan to investigate its use in some limited plan optimization
  - *Design and implementation are in progress*



Questions?
Thank you!