



# Automated Scheduling for NASA's Deep Space Network

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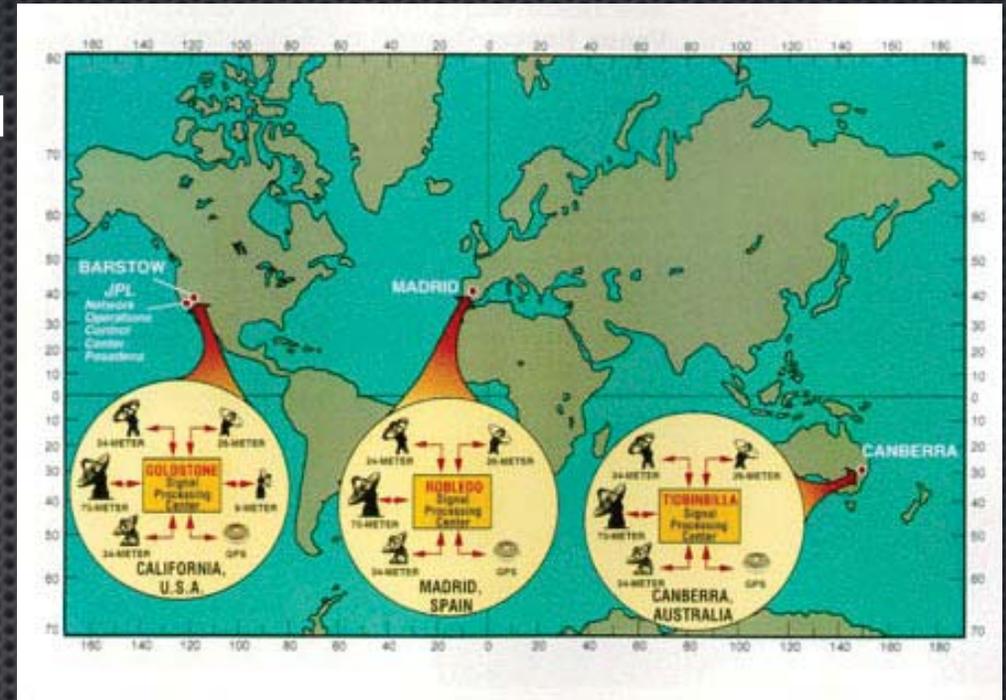
# Outline

- NASA's Deep Space Network (DSN)
  - Overview
  - Scheduling
- Service Scheduling Software (S<sup>3</sup>) and the DSN Scheduling Engine (DSE)
- Deployment
- Future plans



# The Deep Space Network (DSN)

- Current DSN comprises
  - 3 sites roughly equally spaced in longitude
  - one 70m + multiple 34m antennas at each site
- DSN supports all planetary missions + some earth orbiters + radio science/astronomy
- DSN scheduling problem:



- ~500 tracks (communications contacts) per week for ~35 DSN users
- Goal is to have a negotiated schedule about 16 weeks ahead of realtime, and be conflict free about 8 weeks ahead
  - driven by need to sequence spacecraft well in advance
  - rarely met in practice
- Previous scheduling process was labor intensive and based on aging heterogeneous tools

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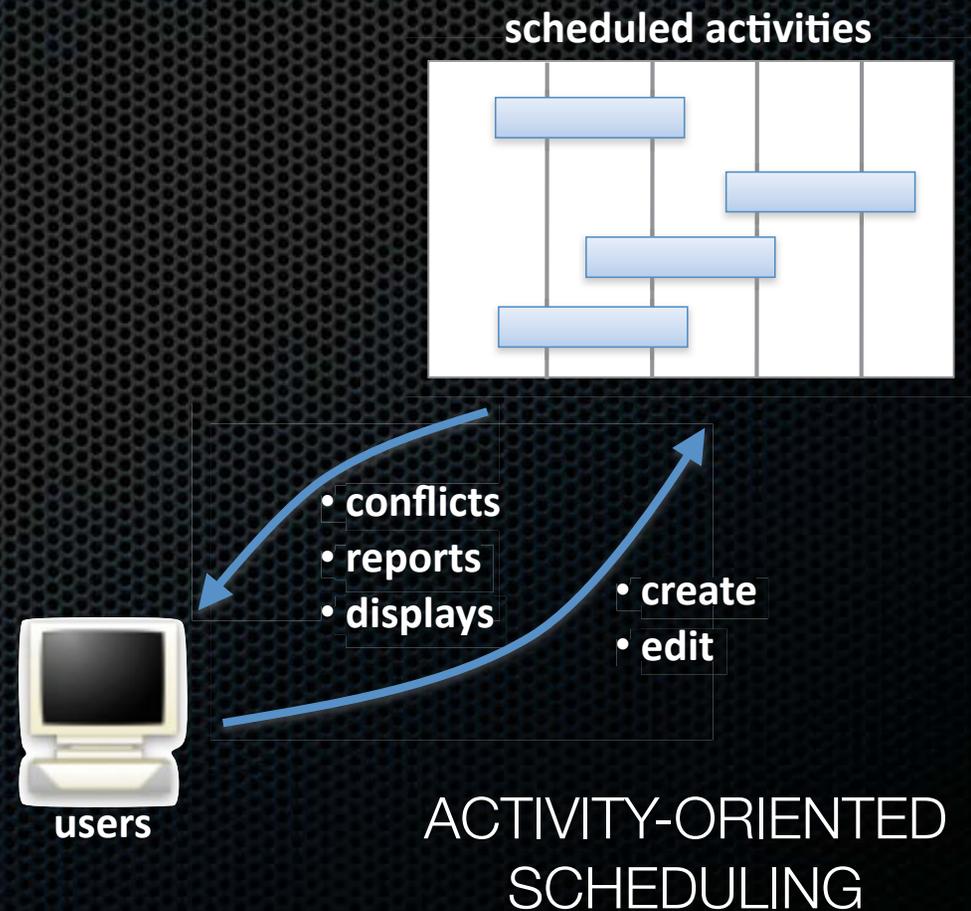
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  - **adopt a request-driven approach to scheduling** (as contrasted with the current activity-oriented scheduling)

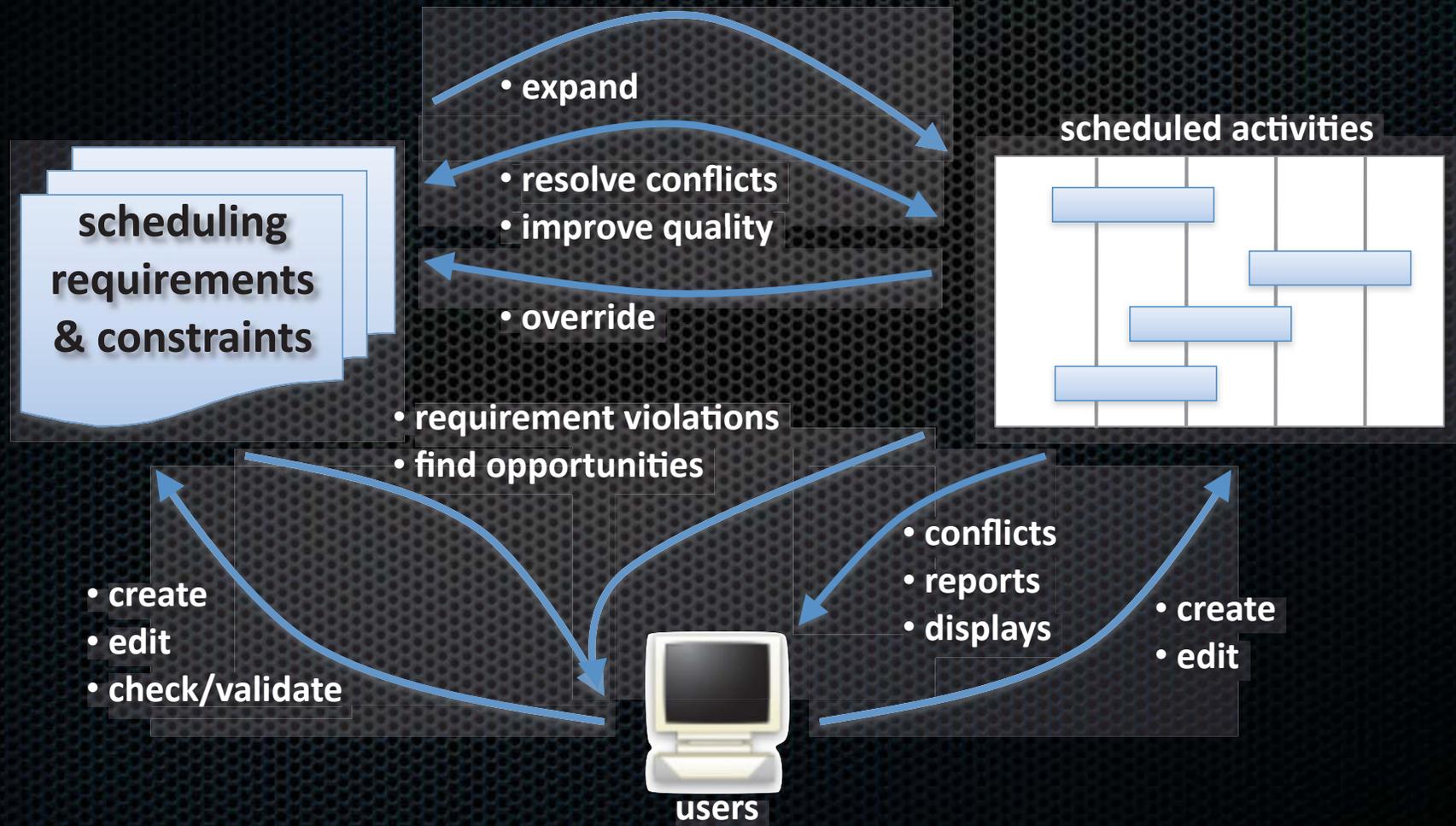
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  - adopt a request-driven approach to scheduling (as contrasted with the current activity-oriented scheduling)
  - **develop a peer-to-peer collaboration environment** for DSN users to view, edit, and negotiate schedule changes and conflict resolutions

# Request-Driven vs. Activity-Oriented Scheduling



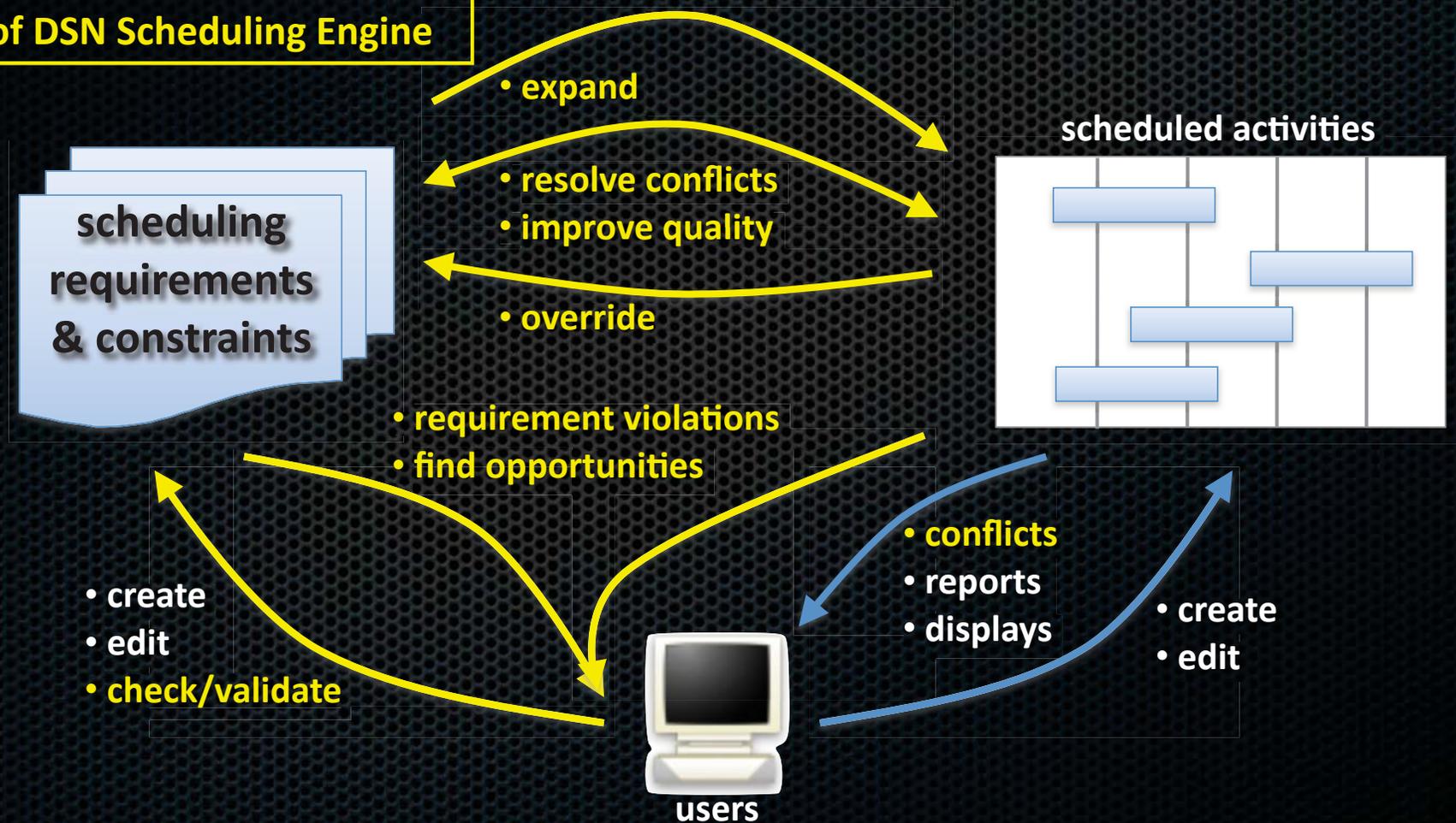
# Request-Driven vs. Activity-Oriented Scheduling



REQUIREMENTS-DRIVEN SCHEDULING

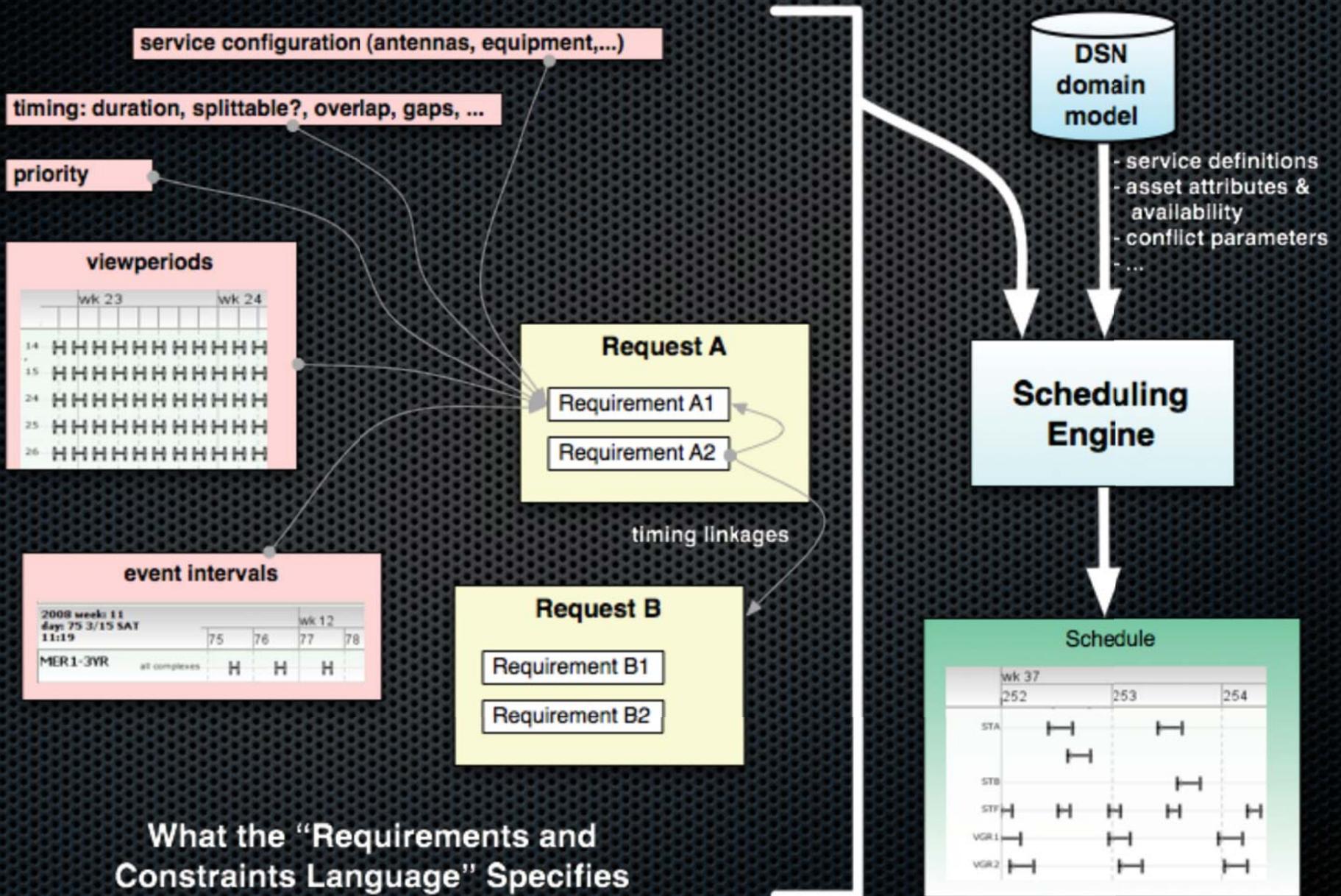
# Request-Driven vs. Activity-Oriented Scheduling

## role of DSN Scheduling Engine

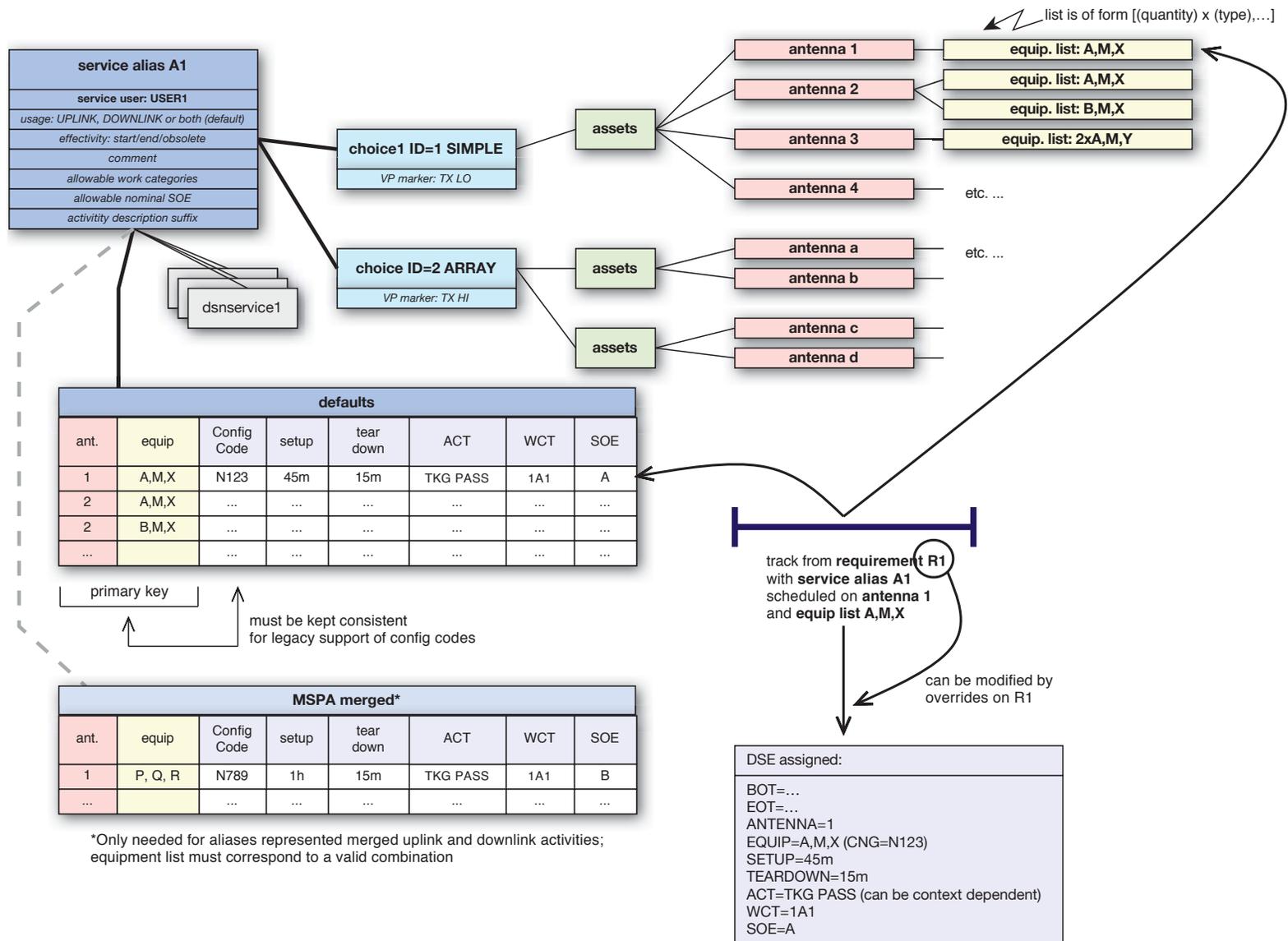


REQUIREMENTS-DRIVEN SCHEDULING

# What Scheduling Requests Specify...



# Service aliases represent resource flexibilities and constraints



# Request-Driven Scheduling

- Challenges

- **request complexity:**

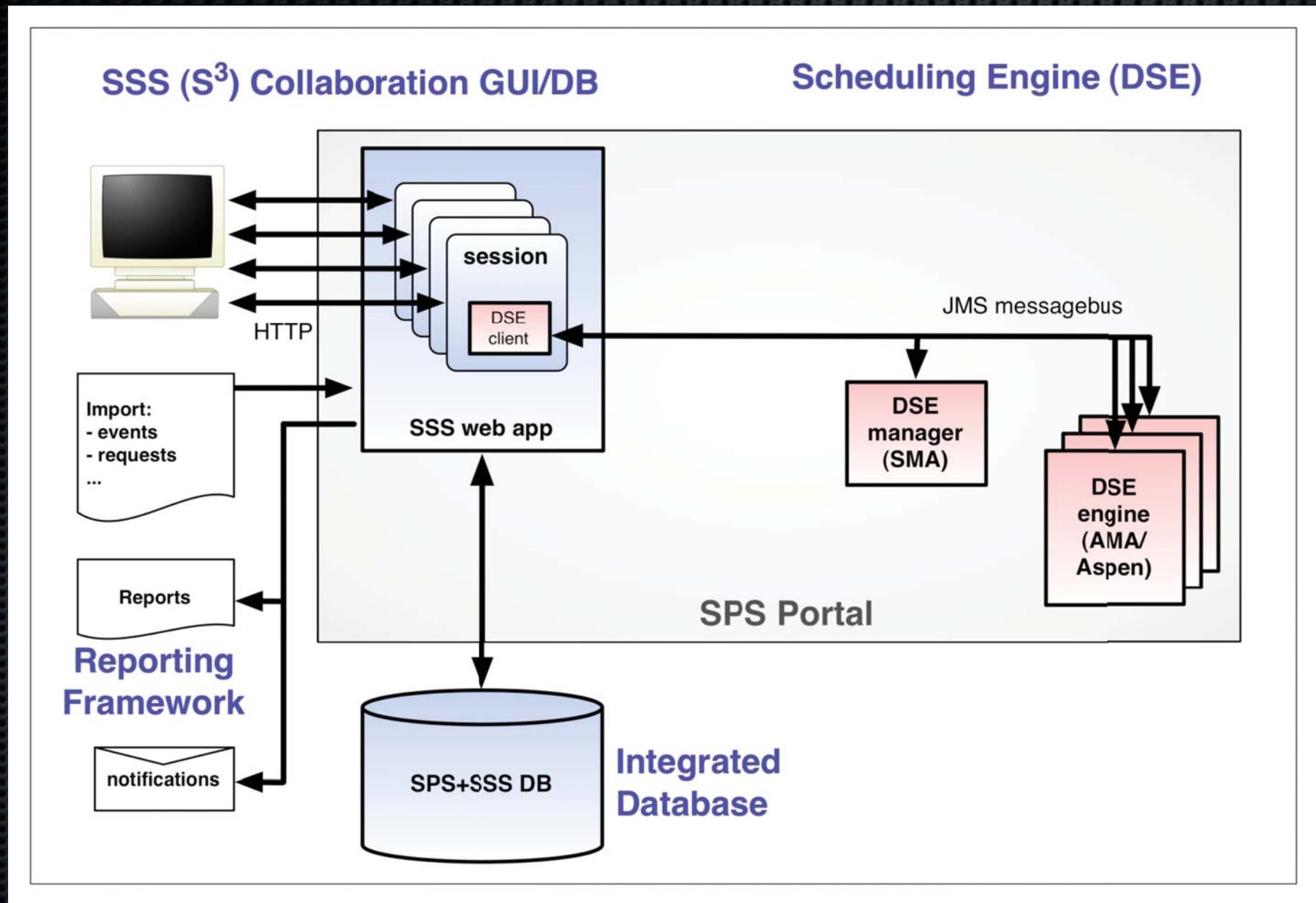
- ▶ even apparently simple requests can have complex options
    - ▶ detail can become overwhelming

- **complexity makes it hard to check for feasibility**

- ▶ interactions of timing constraints with scheduling windows can easily make a request unschedulable

- **accurate representation of scheduling flexibility**

# Architectural Overview of S<sup>3</sup> and the DSE



# S<sup>3</sup> Definitions



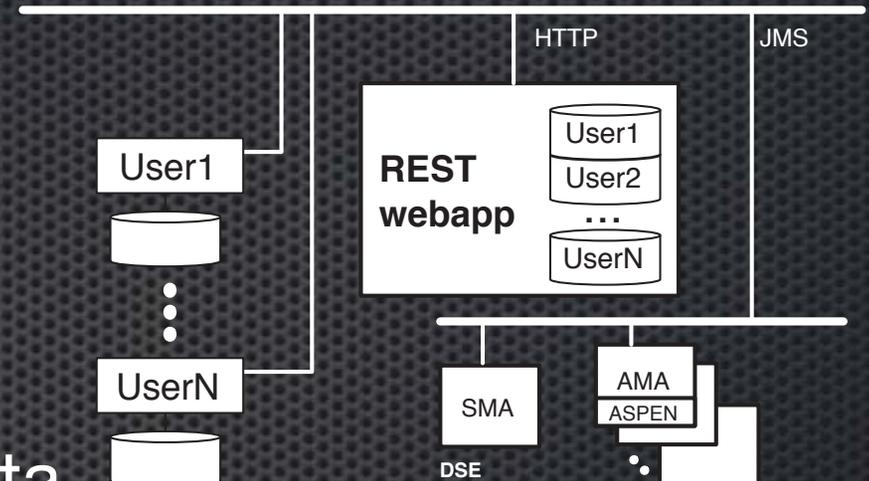
- **Master Schedule** is the current baseline DSN schedule, including tracks, scheduling requests, and events, over a conceptually unbounded time frame; in practice some portions of the schedule could be very firm from months to over a year in advance
- **Workspace** is a user-defined, time-bounded schedule including tracks, scheduling requests, and events. A workspace could be a subset of the master or initially an empty schedule, to be used for what-if analysis
- **Scheduling Requests** are specifications created by service users of their tracking requirements, including constraints and flexibilities
- **Activity** or **Track** represents the actual time allocation on the DSN antennas and are the result of expanding scheduling requests
- **Pull** is the action of bringing activities and requests into a Workspace from the Master Schedule
- **Push** is the action of putting activities and requests into the Master Schedule from a Workspace

# DSE Design Principles

- No unexpected schedule changes
  - all changes to the schedule must be requested either explicitly or implicitly by the user
  - the same sequence of operations on the same data must yield the same schedule
- Even for *infeasible* schedule requests, attempt to return something “reasonable” in response
  - possibly by relaxing aspects of the request, along with a diagnosis of the sources of infeasibility
  - provides a starting point for users to handle the problem

# DSE Implementation

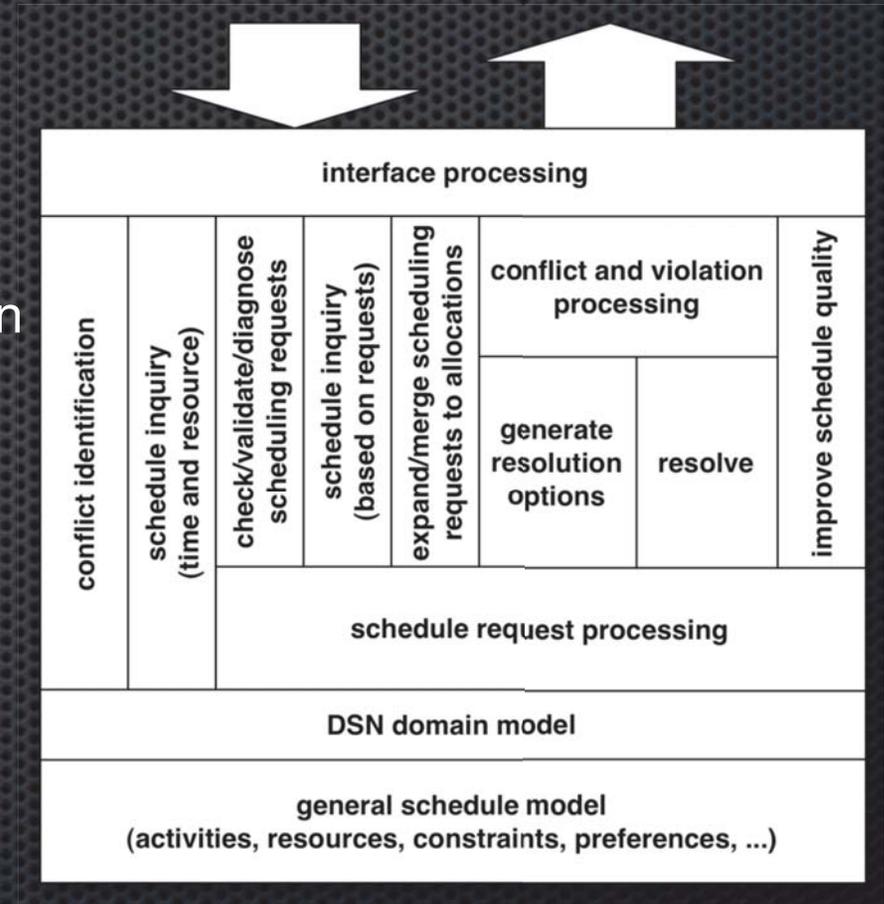
- Distributed client/server
  - JMS XML messaging API between client and DSE
  - REST webapp for storing and sharing scheduling data



- DSE provides scheduling strategies for expanding requirements, repairing conflicts, resolving violations
  - built on ASPEN
- DSE GUI allows entry/editing requirements and associated data, and creating and working with schedules for test purposes

# DSN Scheduling Engine

- Key functionality:
  - Scheduling request interpretation and track generation
  - Conflict identification and resolution
  - Requirement validation/violation detection and resolution
- Implementation
  - Based on ASPEN
  - distributed high-availability server infrastructure
  - user interaction managed transparently by web application GUI



# DSE Usage



- Starting in May 2009, DSE was adopted as the **first step of the scheduling process for all DSN users**
  - For most missions/users, DSE scheduling requests were built by one of the scheduling teams to capture user requirements/constraints
    - ▶ For a few, imported fixed tracks were used
    - ▶ DSE-generated schedules were treated in a legacy tool after DSE conflict resolution and before negotiation

# DSE Usage



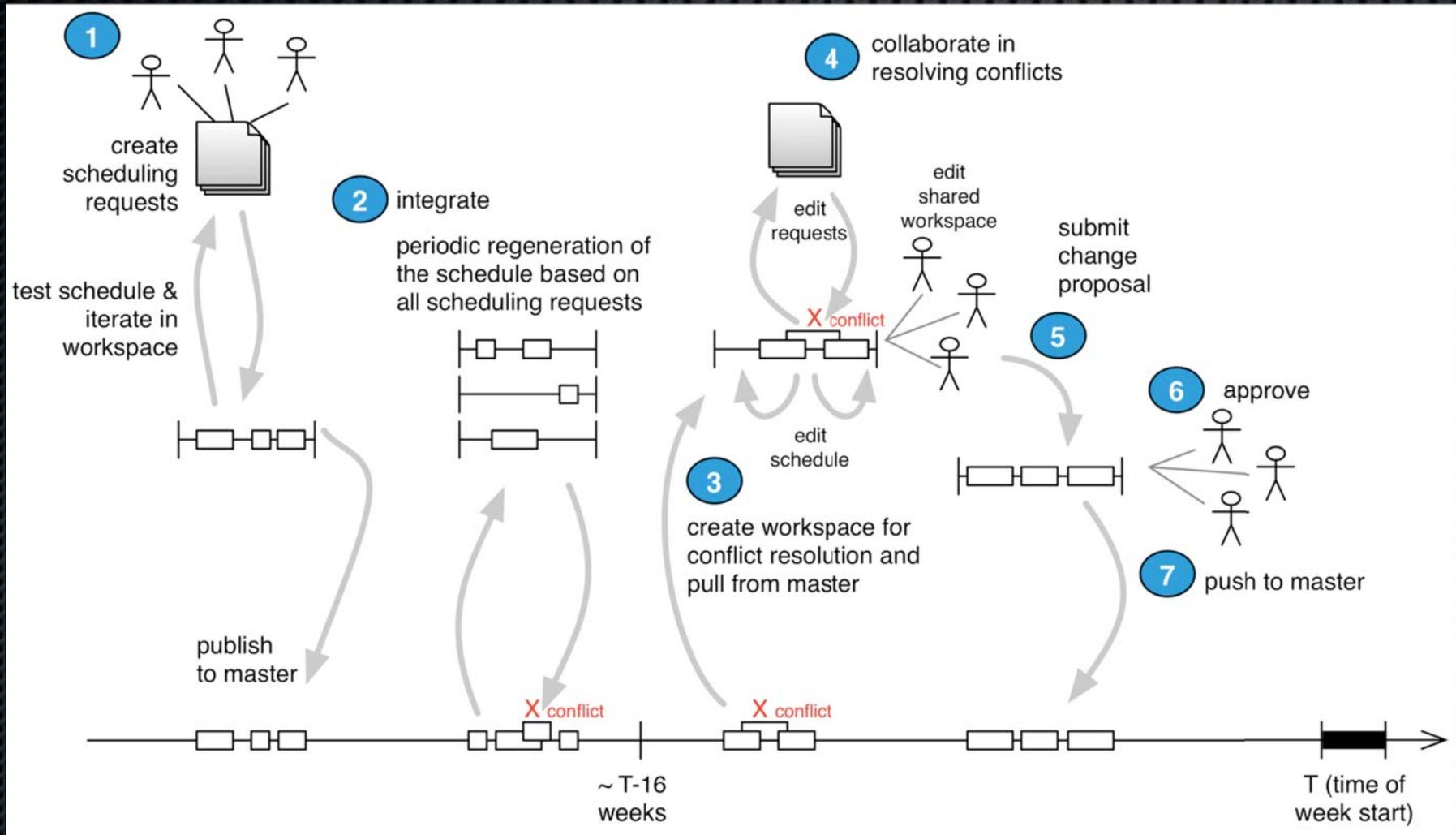
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  - **Every DSN schedule since week 35 of 2009 (late Aug) has started out as generated from scheduling requests by the DSE**

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    - ▶ For a few, imported fixed tracks were used
    - ▶ DSE-generated schedules were tweaked in a legacy tool after DSE conflict resolution and before negotiation
  - Every DSN schedule since week 35 of 2009 (late Aug) has started out as generated from scheduling requests by the DSE
  - **Caught up from ~5 weeks to ~16 weeks of schedule lead time by Nov 2009** (but lost some of this gain in 2010 due to launches and other critical events)

# S<sup>3</sup> High-Level Activity Flow



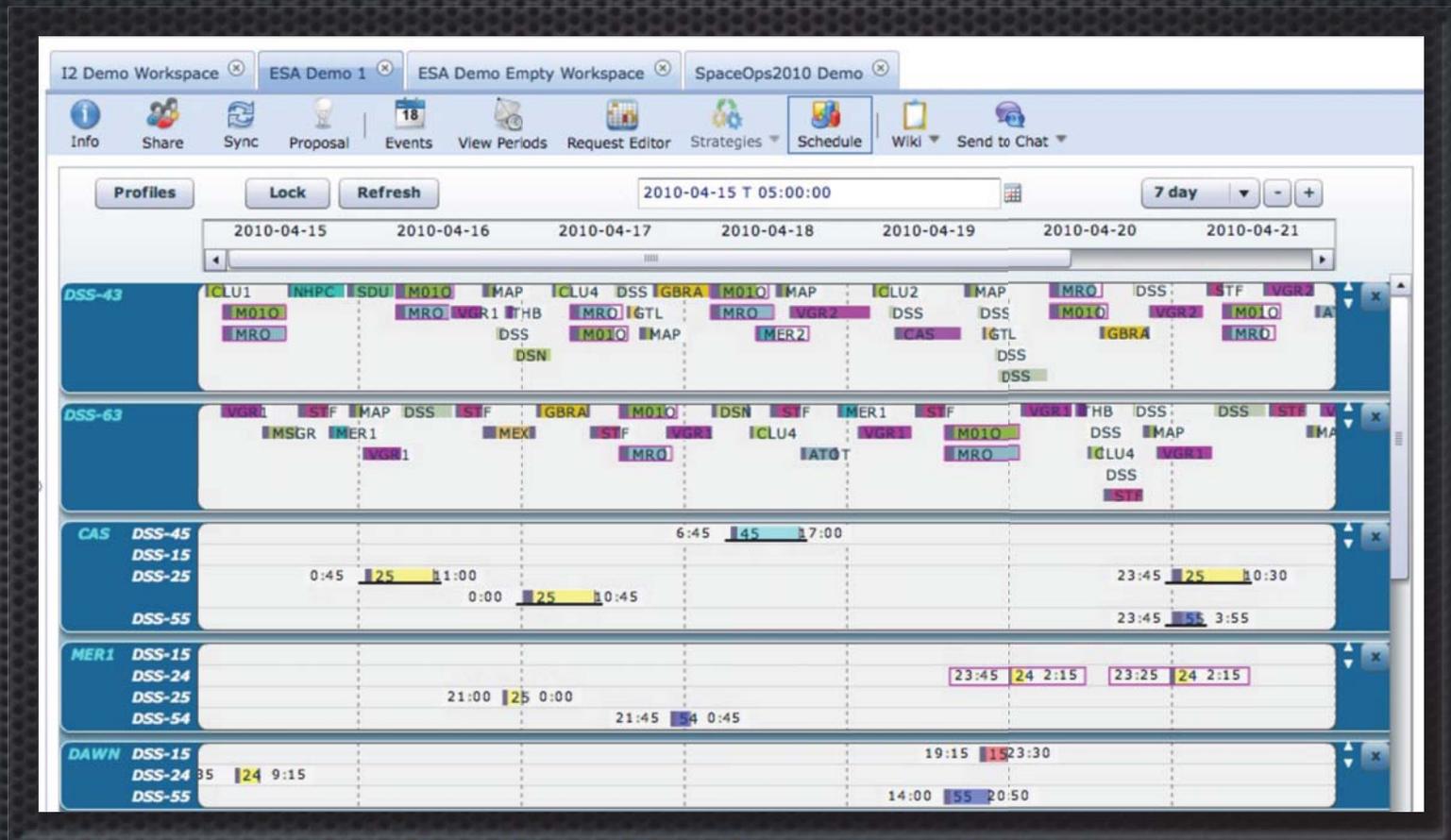
# DSE User Feedback



- Early access of DSE to users has been an invaluable source of feedback to the development team for over 2 years
  - dramatically reduced the risk of deployment of the full S<sup>3</sup> system
- Most useful features:
  - Easy to use “repeat” and “clone” functionality
  - Graphical visualization of request timing constraints
  - Rapid creation of day of week/time of day constraint intervals

# Status

- DSE has been integrated with the S<sup>3</sup> browser-based collaboration framework and is currently in final stages of deployment



# Workspace Manager

Home **Workspace Manager** Master Schedule SSS Report Portal User's Guide

Workspace Shared Proposals

Add Refresh

Workspace Filter

Current

Workspace	Info	Sync	Coll
Preview 2011-17			
Preview 2011-18			
Preview 2011-20			
Preview 2011-20 before CLU run (no CAS)			
Preview 2011-20 for edit timing			
Preview 2011-21			
Preview 2011-21 after CLU run			
Preview 2011-21 before CLU run			
Preview 2011-22			
Preview 2011-23			
Preview 2011-24			
Preview 2011-25			
WK20-MASTER-RAP copy			

Preview 2011-25

Info Share Diff Proposal Events View Periods Request Editor Schedule Wiki Send to Chat

Start Edit | DSE session does not exist

**Workspace Info**

Owner: **Mark Johnston (mdj)**  
 Name: **Preview 2011-25**  
 Start Time: **2011-06-20 (171) 00:00**  
 End Time: **2011-06-27 (178) 00:00**  
 Create Filter: -  
 Activities: **428**  
 Requests: **257**

**Wiki**

Selected Title  
 Delete Send Wiki to Chat

**Tags**

**Save Points**

Restore	Delete	Create Time	Name	Filter Name	Start Time	End T
		2011-02-20 (051) 00:53	after CLU push, strategies plus split/unsplt	-	2011-06-20 (171) 00:00	2011

# Scheduling Request Editor

The screenshot displays the Scheduling Request Editor interface. At the top, there is a 'Request List (257)' table with columns for Edit, Lock, Errors, Sync, Service User, Name, Criticality, Priority, Start Time, End Time, and Comment. Below the table, the 'Request Status' is shown as 'MEX-WK25-NOM OCC'. The 'Requirement Management' section on the left shows a list of requirements, with '37852R001' selected. The 'Requirement Detail' section for 'MEX-WK25-NOM OCC' includes fields for Name (37852R001), Description (MEX-WK25-NOM OCC), and Service Alias (34M/70M v0). The 'Expand All' section shows 'Duration & Splitting' details, including a duration range of [6h,12h], resolution of 5m, and options for track splitting. The 'Preview Requirement' section at the bottom shows a Gantt chart with a 'Show' checkbox and a time range of 2011-171 to 2011-177. The Gantt chart displays several green bars representing tasks, with a legend on the left listing DSS-14, DSS-15, DSS-63, and DSS-65.

Edit	Lock	Errors	Sync	Service User	Name	Criticality	Priority	Start Time	End Time	Comment
				MEX	MEX-WK24-NOM OCC#6	4	7	2011-06-19 (170) 04:00	2011-06-20 (171) 03:59	
				MEX	MEX-WK25-NOM OCC	4	7	2011-06-20 (171) 03:59	2011-06-21 (172) 03:57	
				MEX	MEX-WK25-NOM OCC#1	4	7	2011-06-21 (172) 03:57	2011-06-22 (173) 03:56	
				MEX	MEX-WK25-NOM OCC#2	4	7	2011-06-22 (173) 03:56	2011-06-23 (174) 03:54	

Request Status: MEX-WK25-NOM OCC

**Requirement Management**

Edit Name

37852R001

**Requirement Detail. Request: MEX-WK25-NOM OCC**

Ignore this Requirement

Name: 37852R001

Description: MEX-WK25-NOM OCC

Service Alias: 34M/70M v0

Expand All

**Duration & Splitting**

duration 8h range: [6h,12h], resolution 5m, splittable into unlimited tracks of min duration 6h, gap range: [5m,10m]

Duration: 8h at 5 minute resolution

can be reduced to 6h  can be extended to 12h

splittable?

max # tracks  unlimited, or 1, of minimum duration: 6h

split pieces must  Overlap  be contiguous  be separated

**Priority/Criticality** from parent Requirement

**View Periods**

**Events**

**Timing Relationships**

**Overrides**

**Other**

**Preview Requirement**

Show

2011-171 T 07:00:00 7 day

2011-171 2011-172 2011-173 2011-174 2011-175 2011-176 2011-177

DSS-14  
DSS-15  
DSS-63  
DSS-65

# Schedule View/Edit

Preview 2011-25

Info Share Diff Proposal Events View Periods Request Editor Schedule Wiki Send to Chat

Stop Edit All Requests 0 0 1 257 requests (10 with violations), 286 requirements, 411 activities (222 with conflicts)

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Profiles Refresh Auto-Refresh ON 2011-171 T 07:00:00 7 day

2011-171 2011-172 2011-173 2011-174 2011-175 2011-176

All DSS-10 DSS-13 DSS-14 DSS-15 DSS-20 DSS-24 DSS-25 DSS-26 DSS-27 DSS-34

Track Time: 2011-173 T 14:40:00 - 2011-173 T 16:07:00  
Activity Time: 2011-173 T 14:10:00 - 2011-173 T 16:22:00  
Description: WBD

Mission: CLU4  
Antenna: DSS-15 (34M HEF - GOLDSTONE)  
Setup: 00:30  
Track: 01:27  
Teardown: 00:15  
SOE: A  
Work Cat: 1A1  
Config Code: N030  
Service Alias: WBD v0  
Equipment: NMC RPPA SHMT TLPA

Relevant ViewPeriod  
Time: 2011-173 T 12:17:38 - 2011-173 T 16:07:09  
File: CLU4-2011-01-23T00\_00\_00\_2011-08-16T10\_30\_09.xml\_V0.1

Conflict: antenna  
- antenna:DSS-15  
- subType:pose

Debug Info (Ignore)  
Act ID/Rev: 487587/1  
Rep/Bgmt Name: CLU4\_AK81\_2011-173-14-40\_WK25/48001

# Invoking the Scheduling Engine

The screenshot displays a software interface for scheduling, likely a radio frequency management system. The main window shows a Gantt-style chart with various tracks (activities) plotted against time for different DSS (Deep Space Station) units. A context menu is open over the chart, listing several strategies for execution:

- initialLayout
- initialLayout (preferred)
- optimizeLayout
- relayout
- relayout (no equip/soa/bot)
- repairConflicts
- repairViolations
- x Delete All Tracks

The interface also shows a toolbar with options like 'Info', 'Share', 'Diff', 'Proposal', 'Events', 'View Periods', 'Request Editor', 'Schedule', 'Wiki', and 'Send to Chat'. A status bar at the top indicates '257 requests (10 with violations), 286 requirements, 411 activities (222 with conflicts)'. A date range of '2011-171 T 07:00:00' to '2011-173 T 16:07:00' is visible, along with a '7 day' view selector.

A detailed view of a track conflict is shown in a blue box:

Track Time: 2011-173 T 14:40:00 - 2011-173 T 16:07:00  
Activity Time: 2011-173 T 14:10:00 - 2011-173 T 16:22:00  
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- subType: pose

Debug Info (Ignore)  
Act ID/Rev: 487587/1  
Req/Reqmt Name: CLU4\_AK81\_2011-173-14-40\_WK25/48001

# Schedule Metrics

Preview 2011-25

Info Share Diff Proposal Events View Periods Request Editor Schedule Wiki Send to Chat

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Profiles

Export as [.XLS](#)

- + number of activities 407
- + tracking gaps by user
- utilization by user
  - + summed track duration (BOT to EOT)
  - + total time tracking (BOT to EOT, overlaps not counted)
- + tracking gaps by antenna
- + utilization by antenna and subnet
- + conflicts 134
- conflicted antenna time
  - + by antenna
  - by antenna group
    - 34BWG 5d22h26m 14.1%
    - 34BWG1 4d13h16m 21.7%
    - 34BWG2 1d2h5m 7.8%
    - 34BWG3 7h5m 4.2%
    - 34HEF 3d17h17m 17.7%
    - 34HSB 8h30m 5.1%
    - 34M 10d13m 14.3%

Close

# S<sup>3</sup> Collaboration Features

- Fully web-based application
- Shared workspaces
  - with groups or with individual users
  - read, write, and/or publish-to-master permissions
  - live updates as changes are made
- Notification framework
  - toaster (pop-up), recent, and all
  - workspace shares, change proposals, track/conflict changes, and more
- Integrated wiki (Confluence)
- Online users
  - presence and status
- Custom chat interface
  - one-to-one and multi-user text chat
  - share files, workspaces, and wikis
  - integrated chat + wiki
- Create and manage change proposals
  - S<sup>3</sup> keeps track of concurrences required, with due dates



# Future Plans

- Next steps
  - Complete the deployment of S3
  - Integration of forecasting functionality based on the same description language as for detailed scheduling
  - Multi-objective scheduling
  - Cross-network scheduling



# S<sup>3</sup> – ESA interface feasibility test

Event Import File  
provided by ESA  
of usable MEX intervals

```

<scheduleEventIntervalSets>
- <scheduleEventIntervalSet>
  <spacecraft_abbrev>MEX</spacecraft_abbrev>
  - <ID>
    PLNVIEW_20110315T000000_20120101T000000_20110317T142306_v01-00.PASS-O
  </ID>
  - <characterization>
    <tag>MEX</tag>
  </characterization>
  <description>times that can be used by MEX</description>
  - <intervals>
    - <absoluteTimeIntervals>
      - <absoluteTimeInterval>
        <start>2011-03-10T12:00:00Z</start>
        <end>2011-03-14T22:58:39Z</end>
      </absoluteTimeInterval>
      - <absoluteTimeInterval>
        <start>2011-03-15T09:23:39Z</start>
        <end>2011-03-15T13:20:00Z</end>
      </absoluteTimeInterval>
    </absoluteTimeIntervals>
  </intervals>
  </scheduleEventIntervalSet>
</scheduleEventIntervalSets>
  
```



All	FIX	REC	C	V	SOA	EOA	User	Ant	Description	Setup	BDOY	BOT	EDOY	EOT
					0625	1540	MEX	54	TKG PASS	60	206	0725	206	1525
					0625	1540	MEX	54	TKG PASS	60	207	0725	207	1525
					0625	1540	MEX	55	TKG PASS	60	208	0725	208	1525



MEX tracks scheduled with respect to usable intervals



**Thank you!**