Experiments with a Parallel Multi-Objective Evolutionary Algorithm for Scheduling

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Outline

- NASA's Deep Space Network (DSN)
  - Overview
  - Long Range Planning & Scheduling
- Loading Analysis and Planning Software (LAPS)
  - Evolutionary Multi-Objective Algorithm
  - Parallelizing for multiple core hardware
- Results and Conclusions

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

Complex	GDSCC	CDSCC	MDSCC
Location	Goldstone, California, USA	Canberra, Australia	Madrid, Spain
Longitude	117° W	149° E	4° W
Latitude	35° N	35° S	40° N
Antennas	1 - 70m 5 - 34m	1 - 70m 2 - 34m	1 - 70m 3 - 34m
Capabilities	S, X, Ka	S, X Ka downlink only	S, X Ka downlink only

- DSN scheduling problem:

  - ~500 tracks (communications contacts) per week for ~37 DSN users, with wide variation in types of scheduling requirements
  - 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

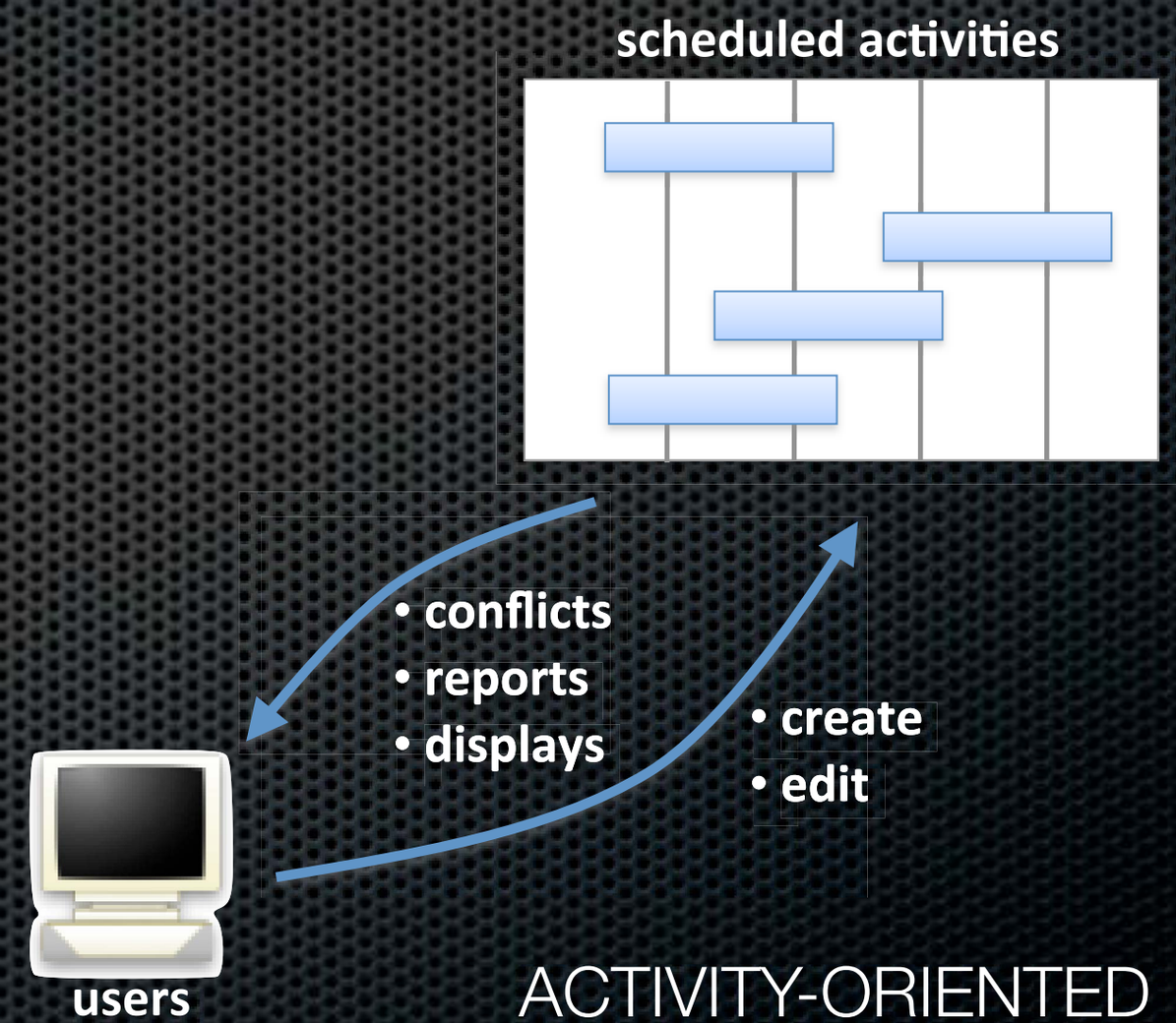
DSN Scheduling Process Phases

Process Phase	Time frame relative to execution	Software tools (software/database)	Characteristic activities
Long-range	≳ 6 months	TIGRAS (RAP version) + MADB database	• identify and resolve periods of contention • plan for extended downtime • assess proposed missions • assess long range asset options
Mid-range	few weeks out to 6 months	S^3 webapp/database	• schedule normal science operations • schedule pre-planned s/c activities (maneuvers, unique science opportunities) • generate negotiated schedules for s/c sequencing • schedule network maintenance
Near Real-time	closer than a few weeks	TIGRAS (SPS version) + Service Preparation System (SPS) database	• predict generation for execution • reschedule due to unplanned resource unavailability • respond to spacecraft emergencies • activate pre-planned launch contingencies

Service Scheduling Software (S^3)

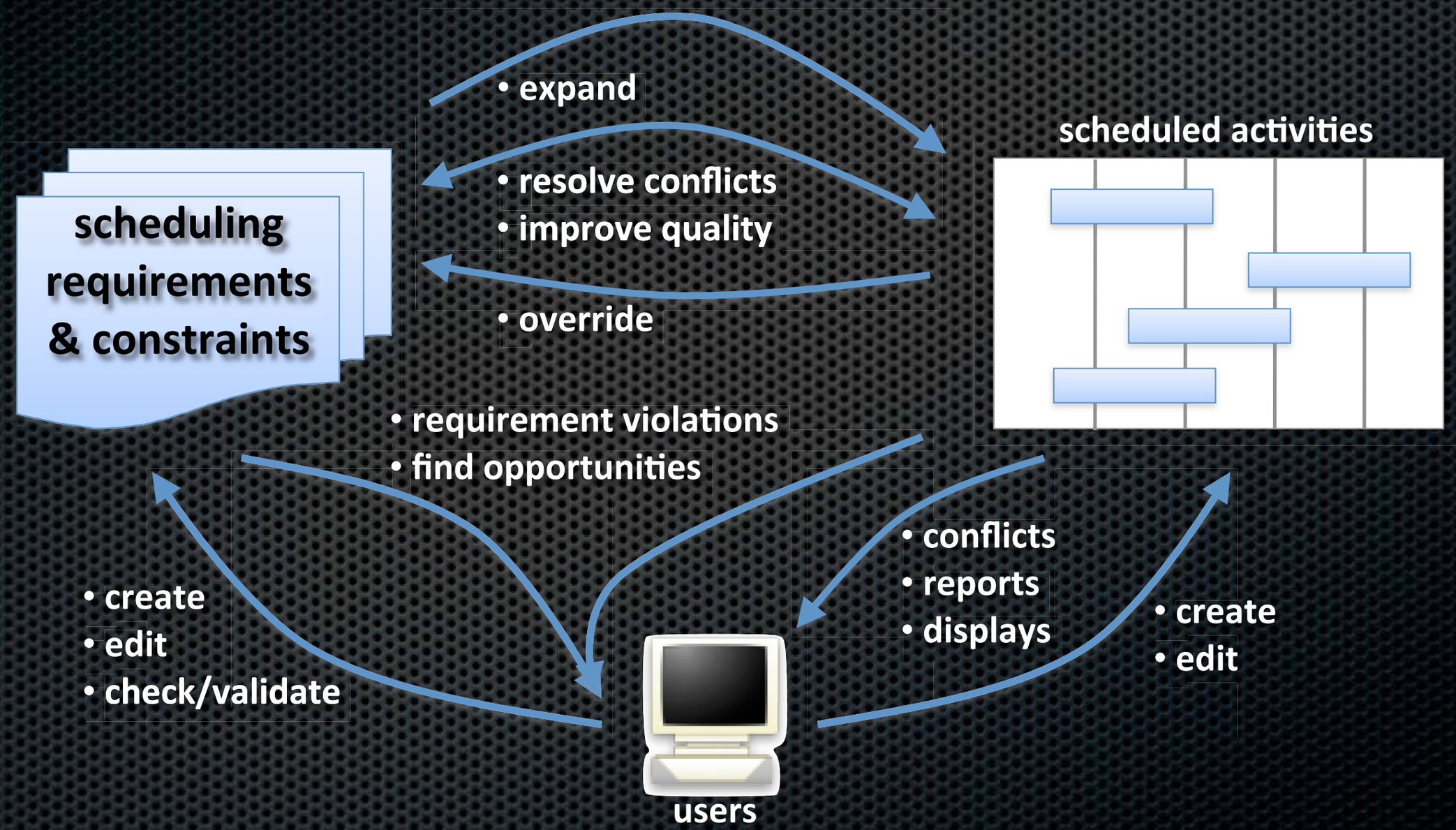
- DSN has undertaken a major implementation of scheduling automation called the Service Scheduling Software (S^3) system
- Major goals are:
  - unify the scheduling software and databases into a single integrated suite covering realtime out through as much as several years into the future
  - adopt a 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



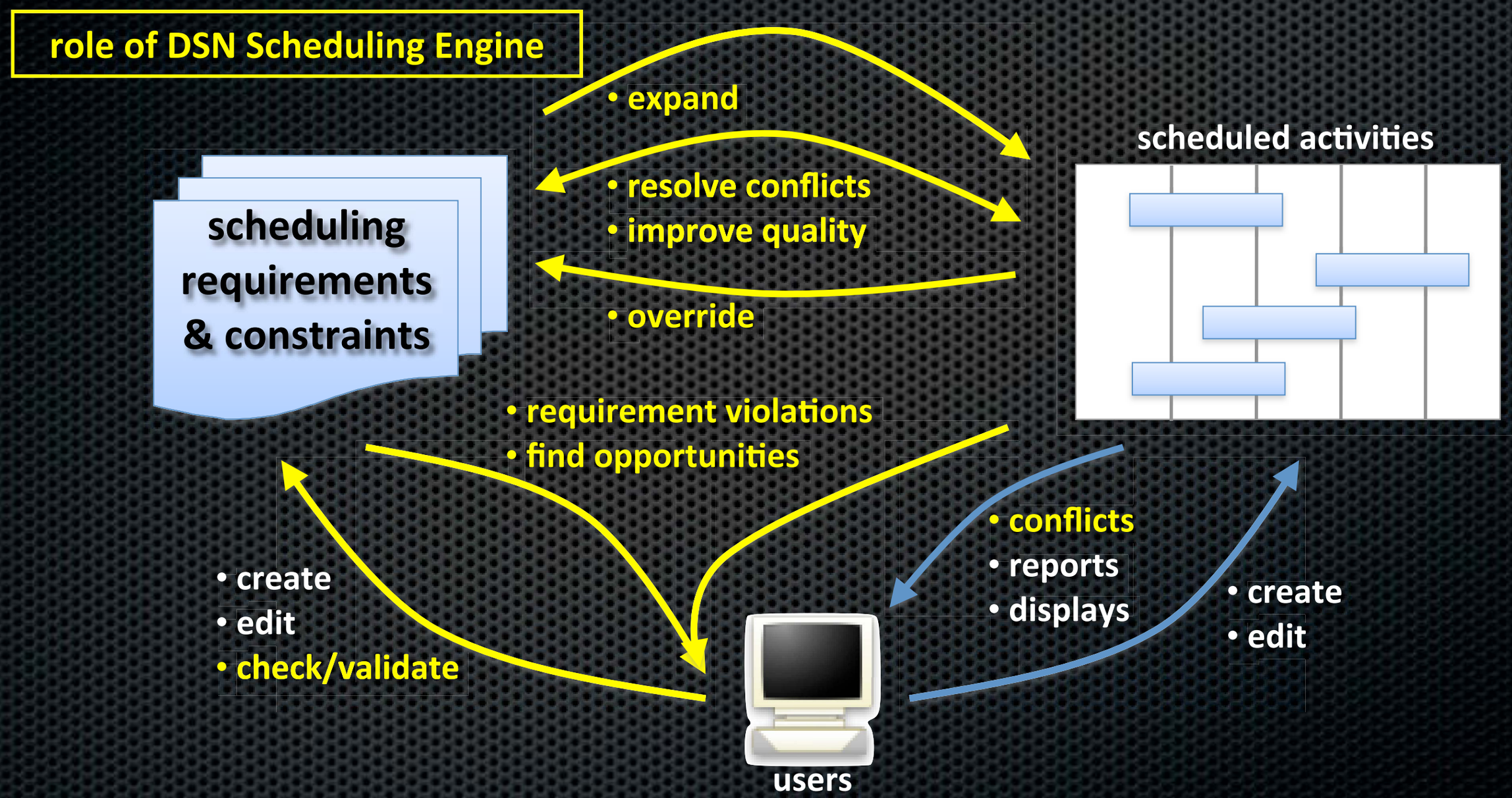
ACTIVITY-ORIENTED SCHEDULING

Request-Driven vs. Activity-Oriented Scheduling



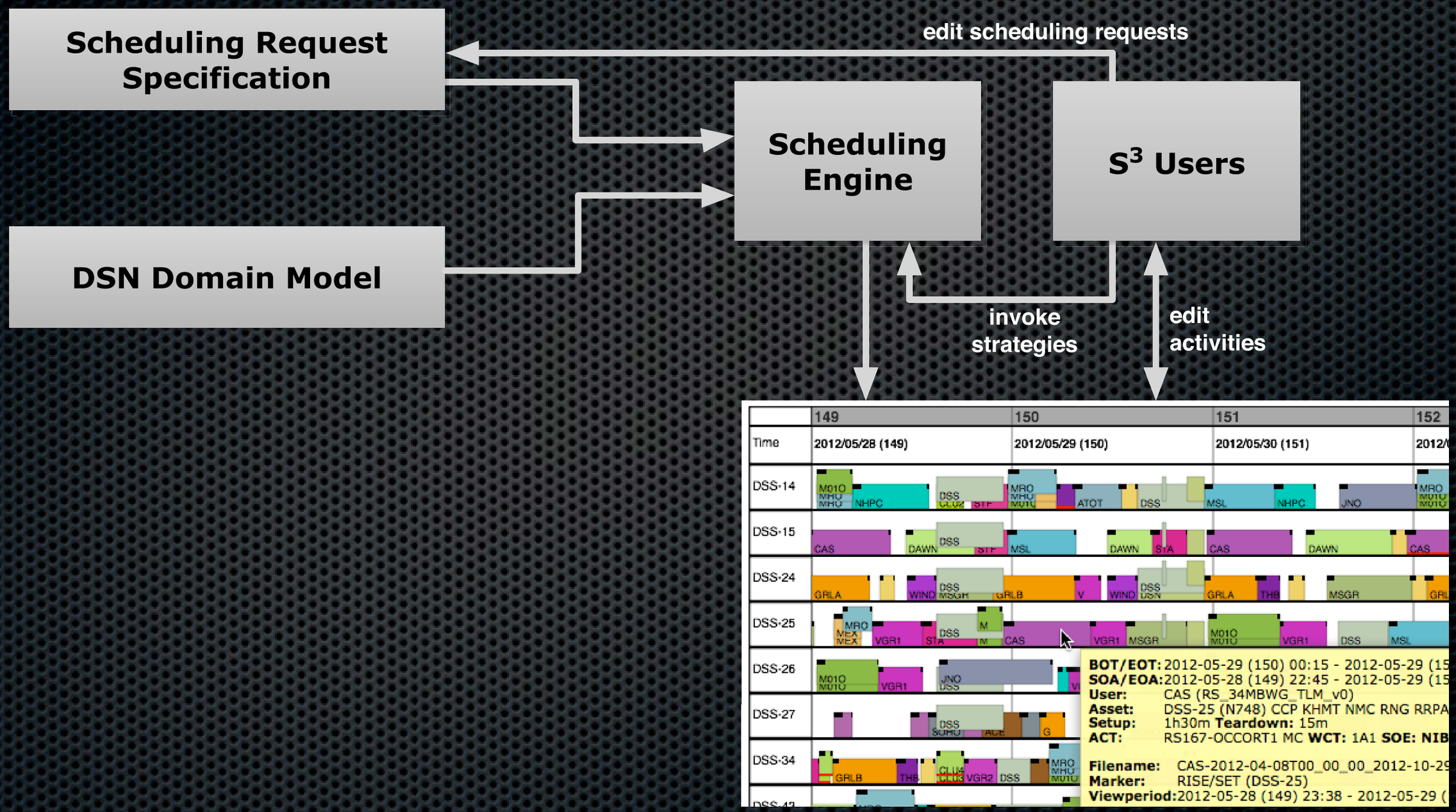
REQUIREMENTS-DRIVEN SCHEDULING

Request-Driven vs. Activity-Oriented Scheduling



REQUIREMENTS-DRIVEN SCHEDULING

S^3 Data Flows...



S^3 Data Model – Key Elements

Scheduling Request Specification

Service Configuration Req'ts
DSN asset options (antennas and equipment)

Timing requirements
Duration (min/max)
splittable? overlap, contiguous, gaps
min split duration, max # split segments

Priority

Viewperiod Requirements
Visibility from various DSN antennas

Event Intervals
Non-visibility based timing constraints

Timing Relationships
To other tracks/requests
including min/max nominal gaps

DSN Domain Model

DSN Assets
Antennas including time-phased availability
Complexes
Equipment (antenna-specific and shared)
Downtime

Mission Service Configurations
Legal configuration choices
Default track attributes

Viewperiods
Computed visibility intervals

Network Parameters
MSPA mission groups and rules
Constellations
Conflict parameters, RFI rules

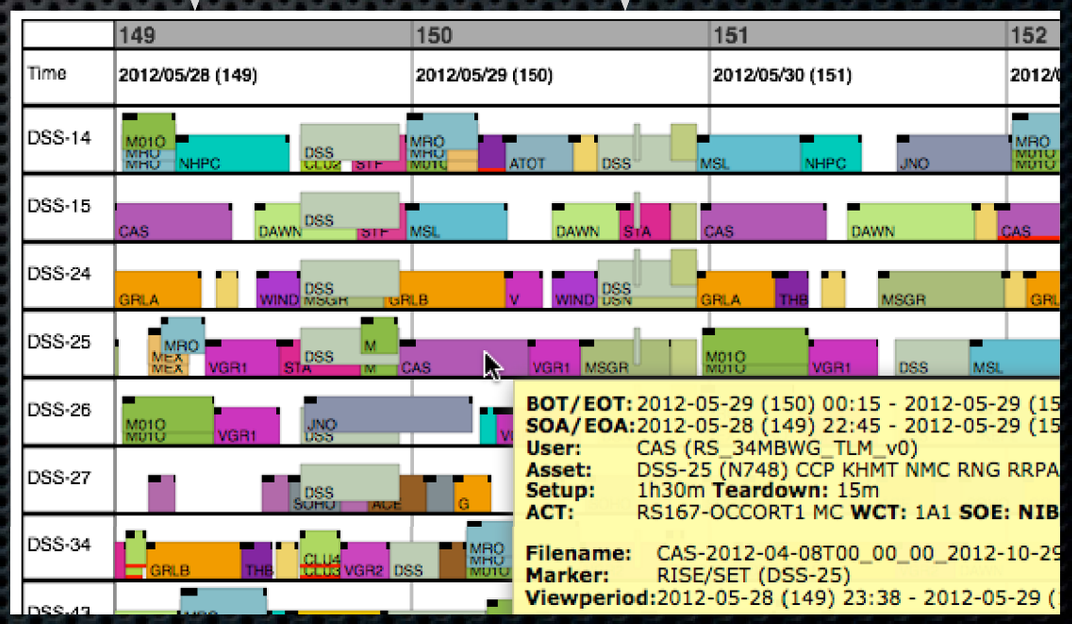
Scheduling Engine

S^3 Users

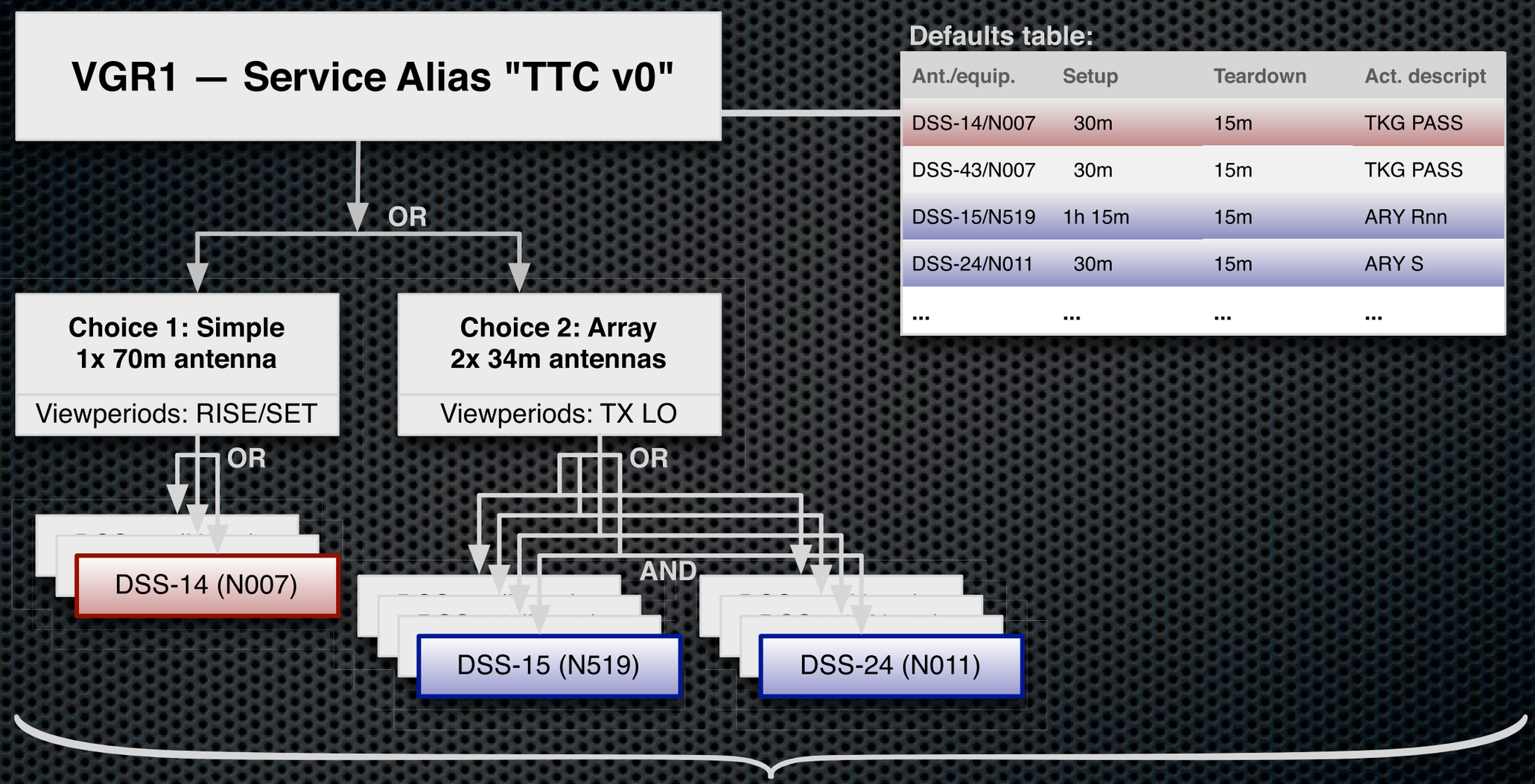
edit scheduling requests

invoke strategies

edit activities



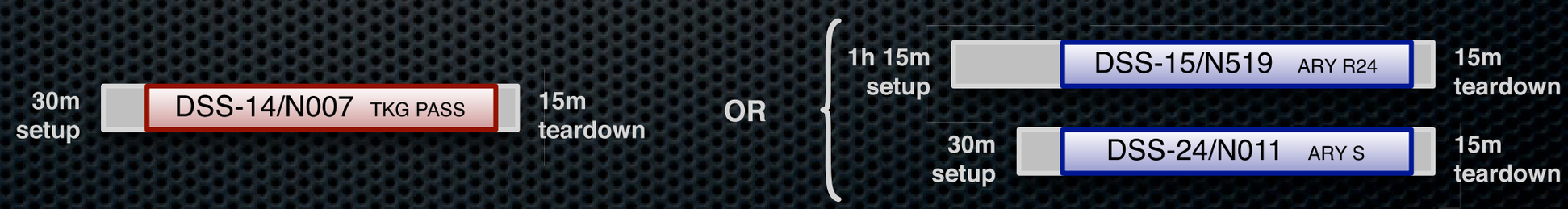
Service configurations (“aliases”) represent DSN resource flexibilities and constraints



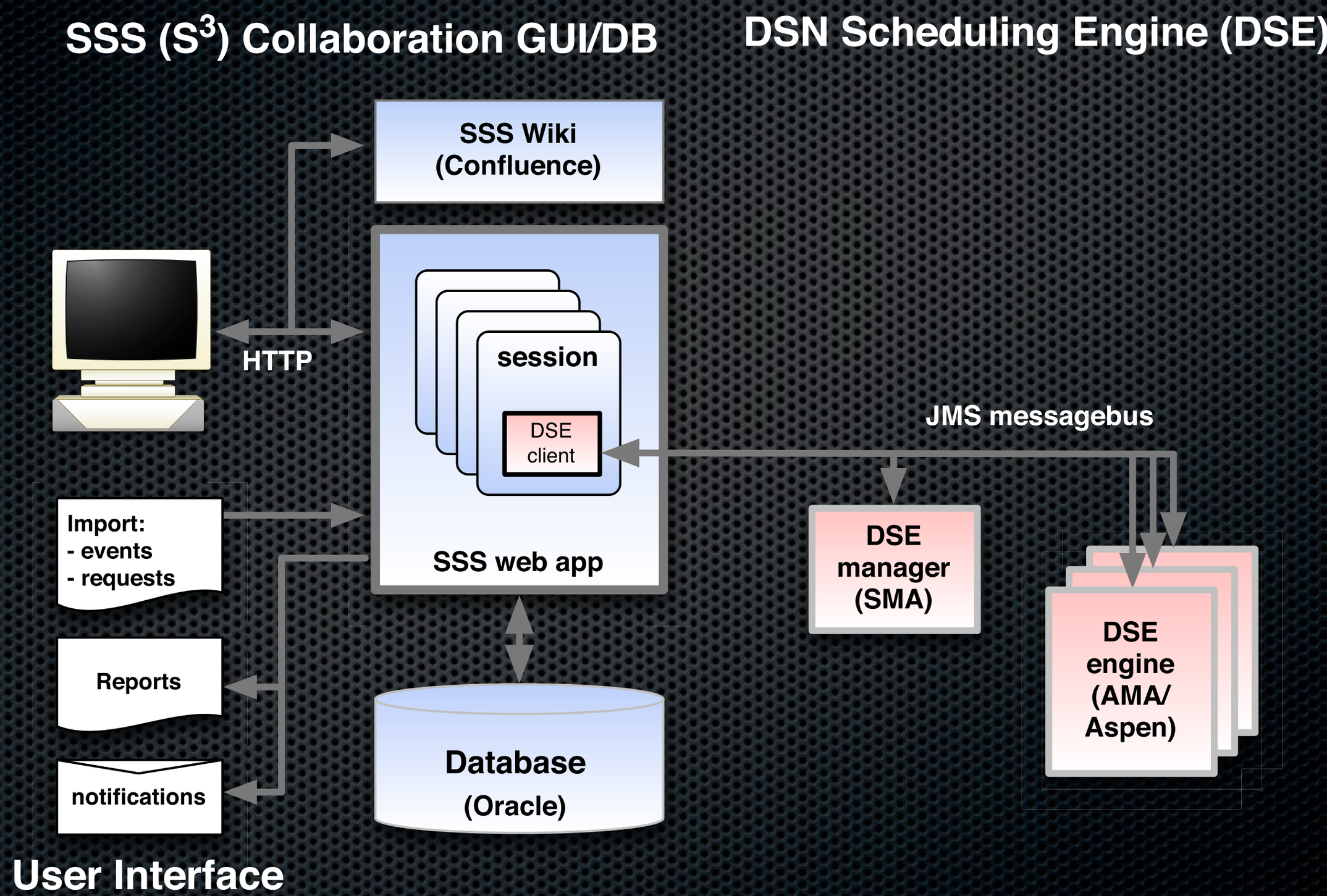
Defaults table:

Ant./equip.	Setup	Teardown	Act. descript
DSS-14/N007	30m	15m	TKG PASS
DSS-43/N007	30m	15m	TKG PASS
DSS-15/N519	1h 15m	15m	ARY Rnn
DSS-24/N011	30m	15m	ARY S
...	...	...	...

Examples of alternative track instantiations
for the same total tracking duration



Architectural Overview of S^3 and the DSE

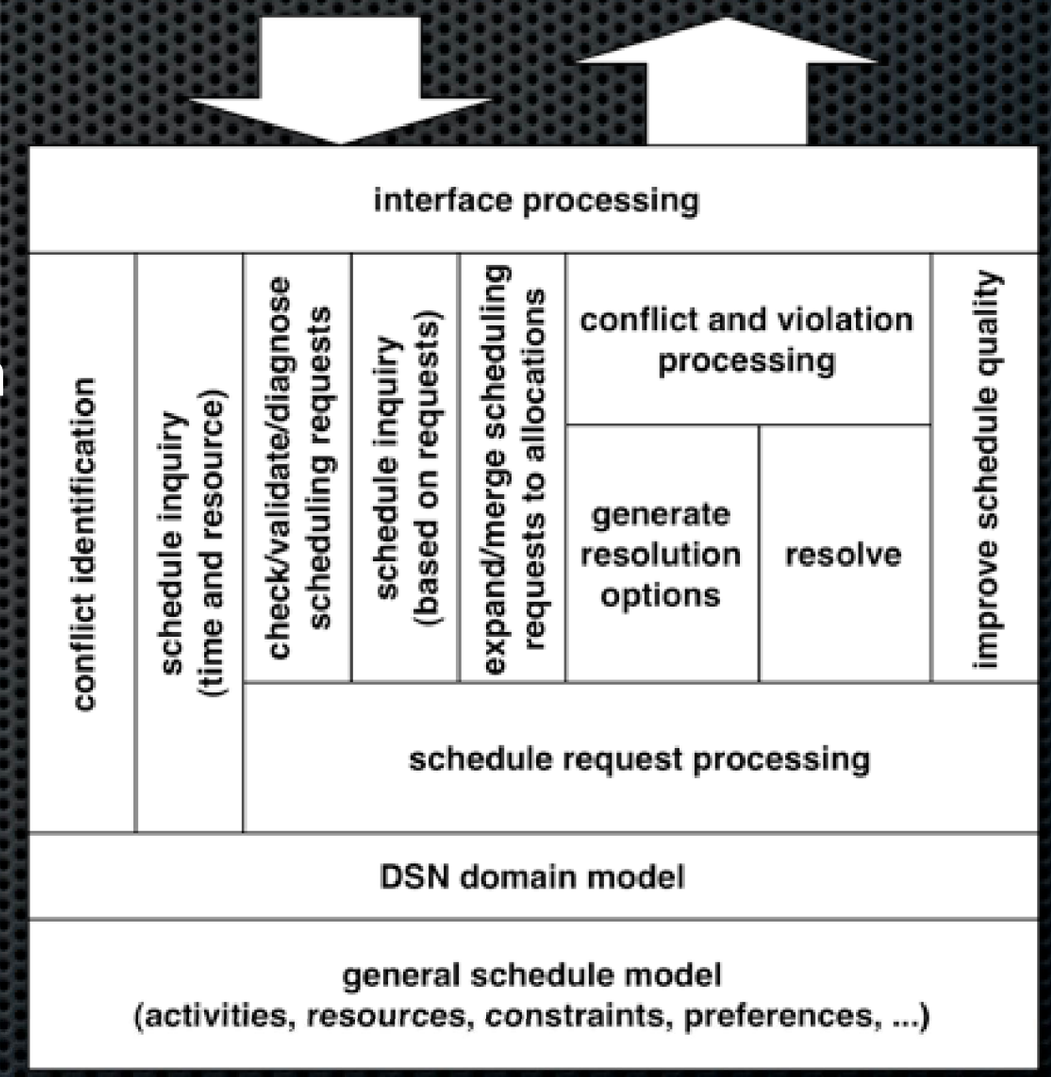


S^3 Definitions

- **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

DSN Scheduling Engine

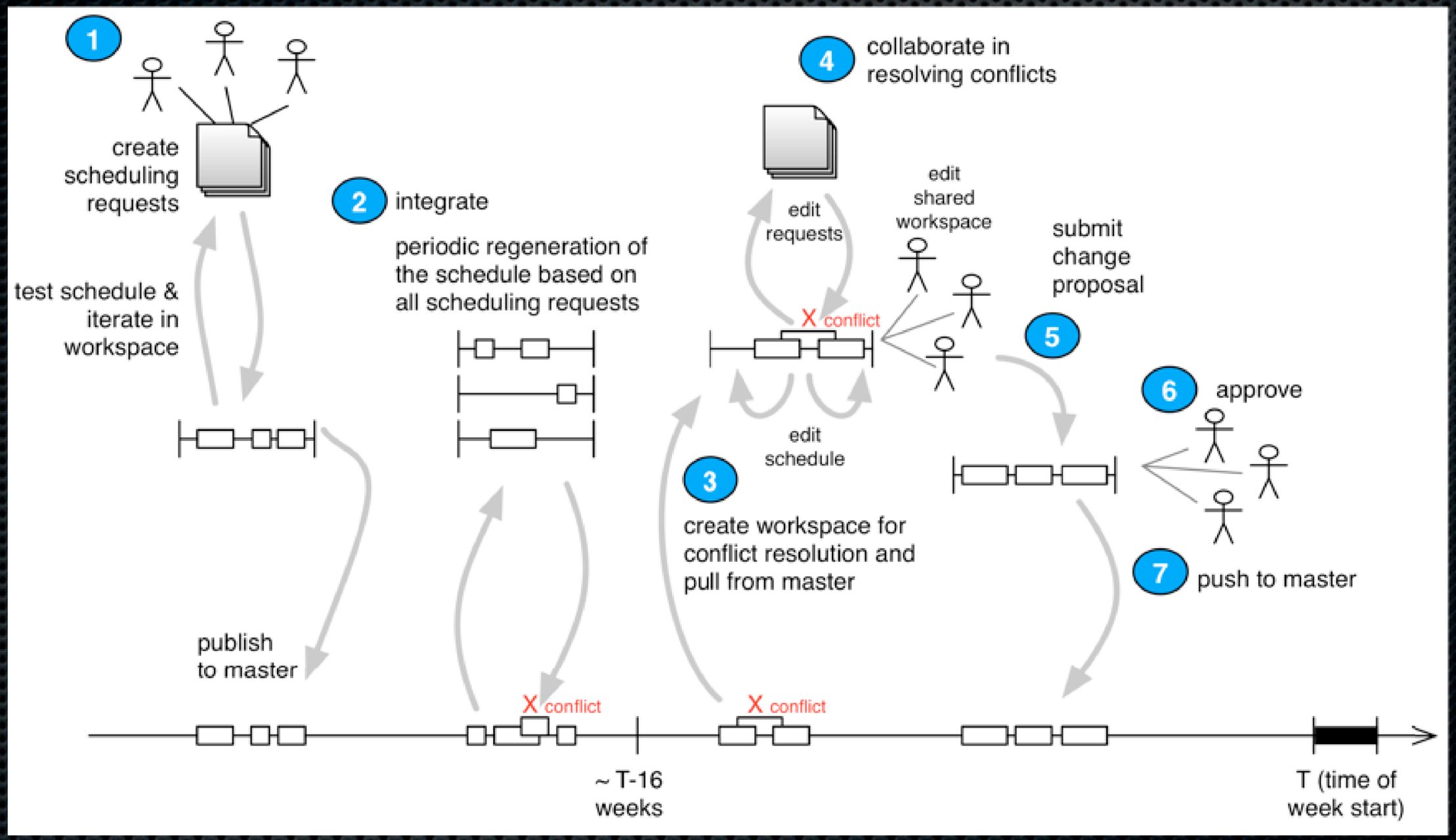
- Key functionality:
  - Scheduling request interpretation and track generation
  - Conflict identification and resolution
  - Requirement validation/violation detection and resolution
- Implementation
  - Based on ASPEN
  - distributed high-availability server infrastructure
  - user interaction managed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



DSE 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

S^3 High-Level Activity Flow during mid-range scheduling



S^3 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
  - S3 keeps track of concurrences required, with due dates

S^3 Status

- S^3 was deployed operationally in June 2011 and has been operational since that date
- Over one year of DSN schedules have been created and negotiated in S^3, since 2011 week 29
  - includes baseline schedules for 3 launching missions in late 2011
  - includes Mars Science Laboratory Entry/Descent/Landing in early August 2012

S3 Lessons Learned: Request-Driven Scheduling

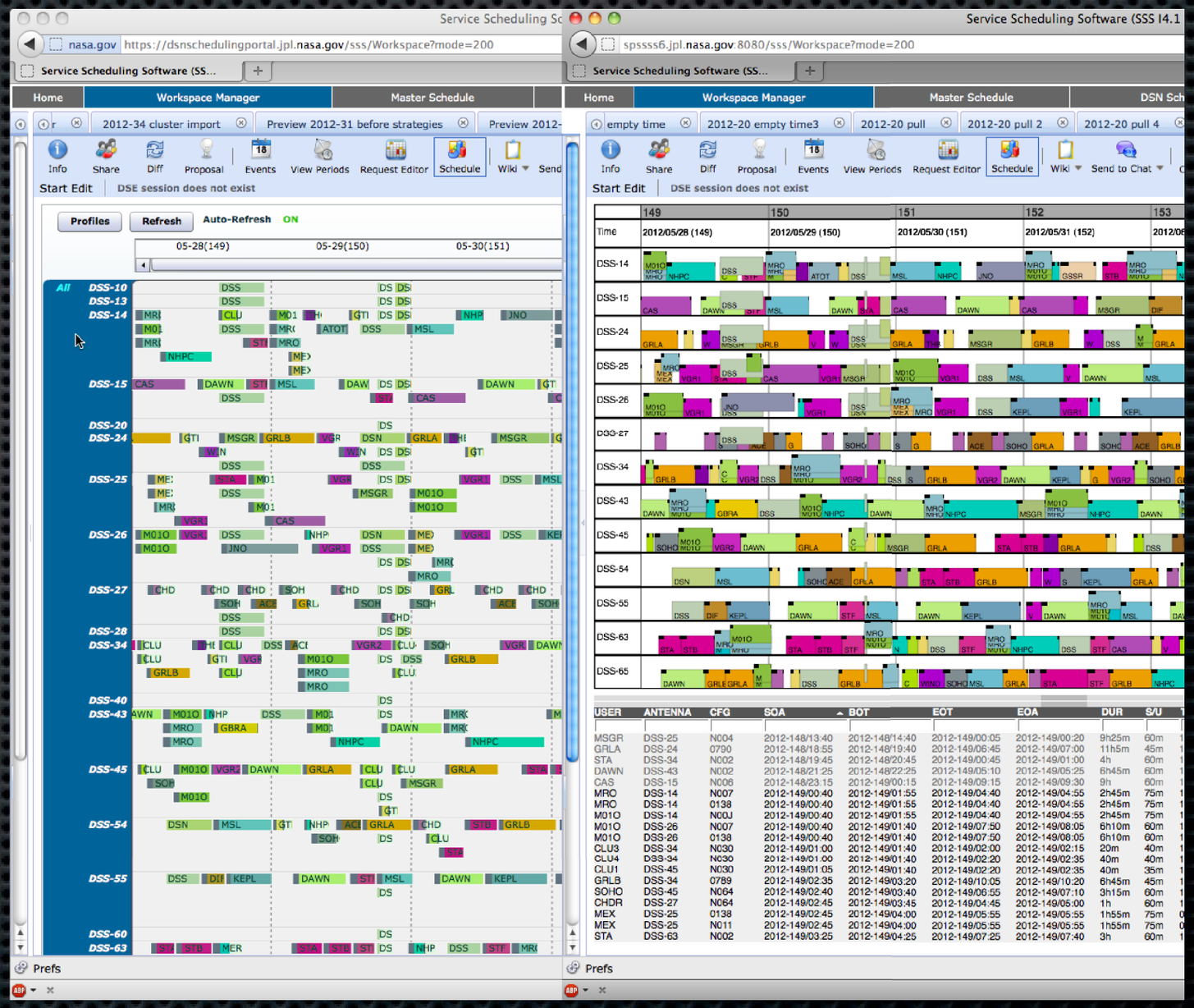
- Challenges
  - hidden request complexity:
    - even apparently simple requests can have complex options
    - detail can become daunting to enter/manage
  - complexity makes it hard to check for feasibility
    - interactions of timing constraints with scheduling windows can easily make a request unschedulable
  - accurate representation of scheduling flexibility

S3 Lessons Learned: Implementation and Usability

- Technical challenges of web/database application included:
  - performance
    - database + user interface
  - “undo” functionality
  - traceability/change visualization

S3 Lessons Learned (cont.)

- Replacement of Adobe Flash by HTML5 canvas provided an enormous performance and usability improvement
  - 10x schedule faster editing/ visualization



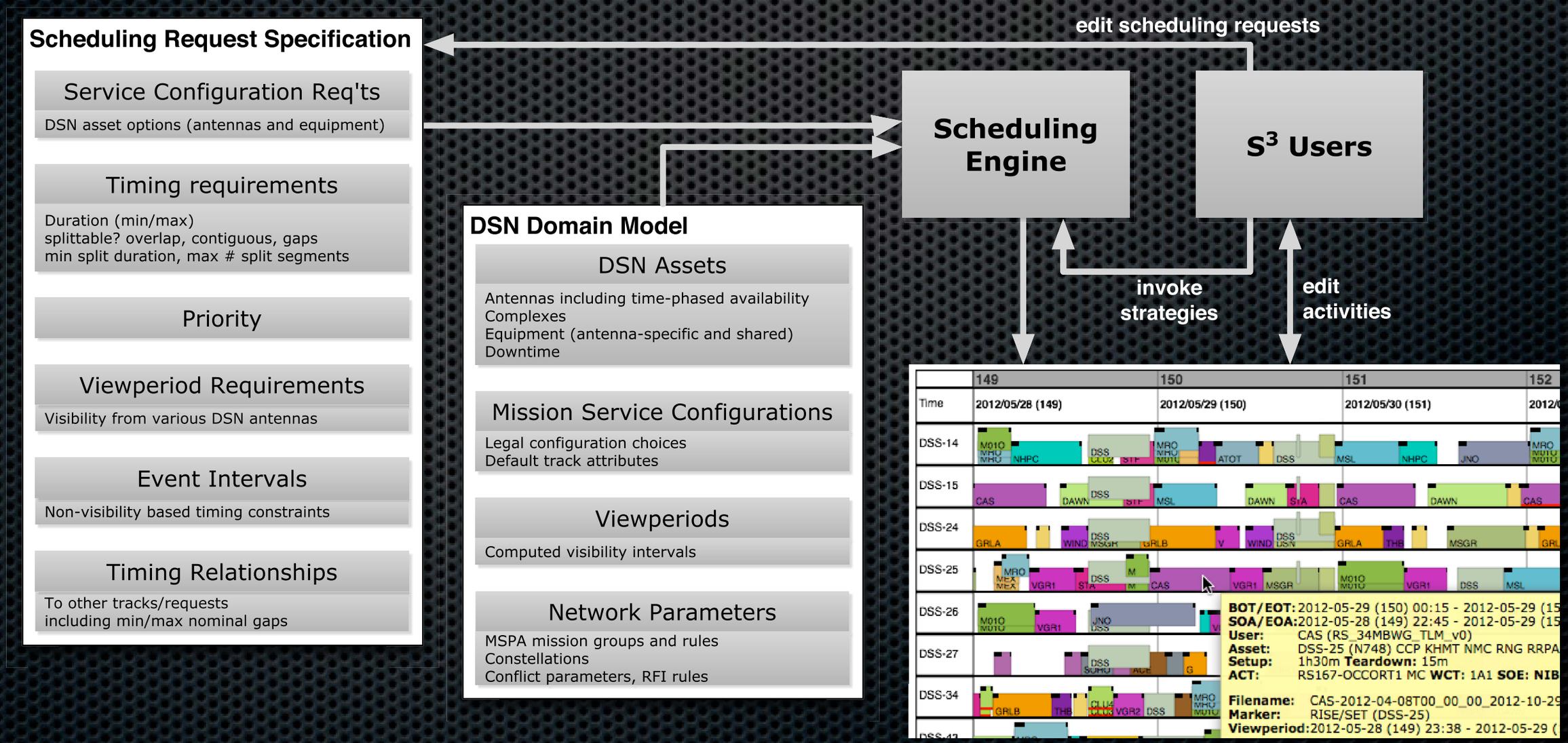
Before: Flash

After: HTML5 canvas

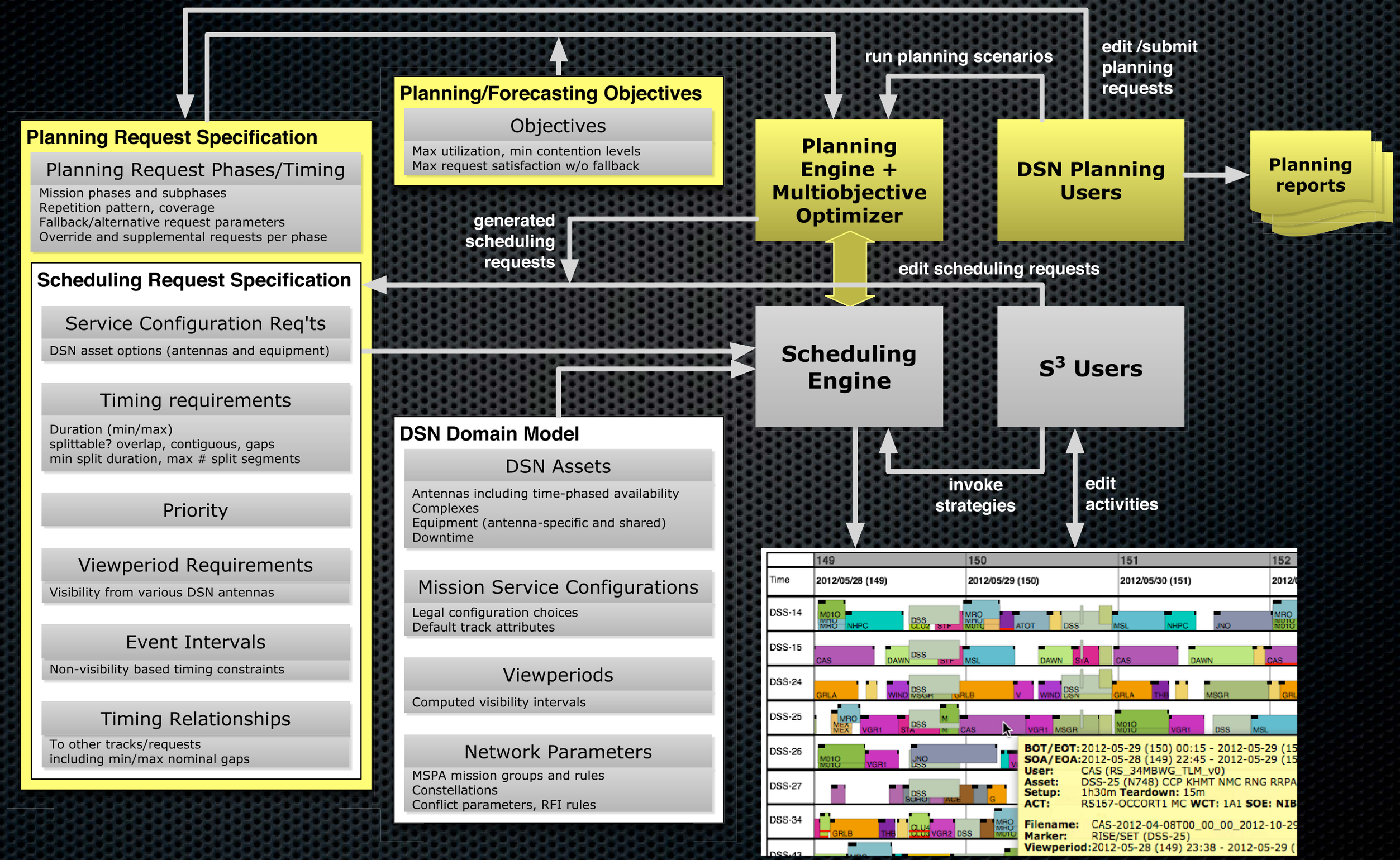
Extension of S^3 to long-range planning and forecasting

- DSN is extending S^3 functionality to long-range process
- Leverage S^3 data model and infrastructure
- Additional development is required for
  - modeling uncertainty
  - different optimization criteria
  - simplified planning request interfaces for users
  - new reporting functionality
- Optimization will explicitly use multiobjective algorithms to provide insight into tradeoffs among competing objectives

Extending the S^3 baseline...



... to incorporate long-range planning functionality



Workspace Manager

Home | Workspace Manager | Master Schedule | DSN Scheduling Wiki | User's Guide | Administration | Log Out

Workspace | Shared | Proposals

Refresh

Workspace Filter

Workspace: NWS

Tags:

Filter

Shared

Workspace	Owner	Info
NWS-045-046-DI	[illegible]	
2012-07-NWS-DAWN-048	[illegible]	
2012-07-NWS-MRO-DOY047&048	[illegible]	
2012-07-NWS-MSGR-044&046	[illegible]	
2012-07-NWS-MSGR-045&049	[illegible]	
2012-07-NWS-SPO-049-050	[illegible]	
2012-08-NWS-DAWN-057	[illegible]	
2012-08-NWS-GRLA/GRLB	[illegible]	

2012-22-NWS

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

Start Edit | DSE session does not exist

Workspace Info

Owner: [illegible]
Name: 2012-22-NWS
Start Time: 2012-05-28 (149) 00:00
End Time: 2012-06-04 (156) 00:00
Create Filter: -
Activities: 510
Requests: 355

Wiki

Selected	Title
☐	2012-22-NWS
☐	2012-22-NHPC Counter

Delete | Send Wiki to Chat

Tags

2012-22

Save Points

Restore	Delete	Copy	Create Time	Name	Filter Name	Start Time	End Time	Description
			2012-03-22 (082) 18:53	Proposal 2845 [illegible] 2012-03-22 (082) 18:53	-	2012-05-28 (149) 00:00	2012-06-04 (156) 00:00	Do not want to hold up Wk22 process. MRO clears KEPL right now and will work outside negotiation dependent on DSN project response.
			2012-03-22 (082) 17:26	Proposal 2842 [illegible] 2012-03-22 (082) 17:26	-	2012-05-28 (149) 00:00	2012-06-04 (156) 00:00	Clearing a GSSR/VGR1 BOT conflict. No impact.
			2012-03-22 (082) 12:49	Proposal 2836 [illegible] 2012-03-22 (082) 12:49	-	2012-05-28 (149) 00:00	2012-06-04 (156) 00:00	STB cannot accommodate the 5m on DOY151 at DSS45. STB is extremely short on DOY151-152 so STB asks GRLB for 5m on STB's previous pass at

send workspace reference to chat session

Integrated wiki links

Negotiation workspace

Proposals and counter proposals as part of peer-to-peer process

Workspace Sharing

Home | Workspace Manager | Master Schedule | DSN Scheduling Wiki | User's Guid

Workspace | Shared | Proposals

Refresh

Workspace Filter

Workspace: NWS

Tags:

Filter

Shared

Workspace	Owner	Info
NWS-045-046-DI	[illegible]	
2012-07-NWS-DAWN-048	[illegible]	
2012-07-NWS-MRO-DOY047&048	[illegible]	
2012-07-NWS-MSGR-044&046	[illegible]	
2012-07-NWS-MSGR-045&049	[illegible]	
2012-07-NWS-SPO-049-050	[illegible]	

2012-22-NWS

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

Start Edit | DSE session does not exist

Share to groups or users with various permission levels

Groups

Grant Permissions to Group - Add Search

Default Group Permissions ☑ Read ☐ Write ☐ Publish

Group	Read	Write	Publish	Delete
ALL SCHEDULERS	✓	✓	✗	⊗

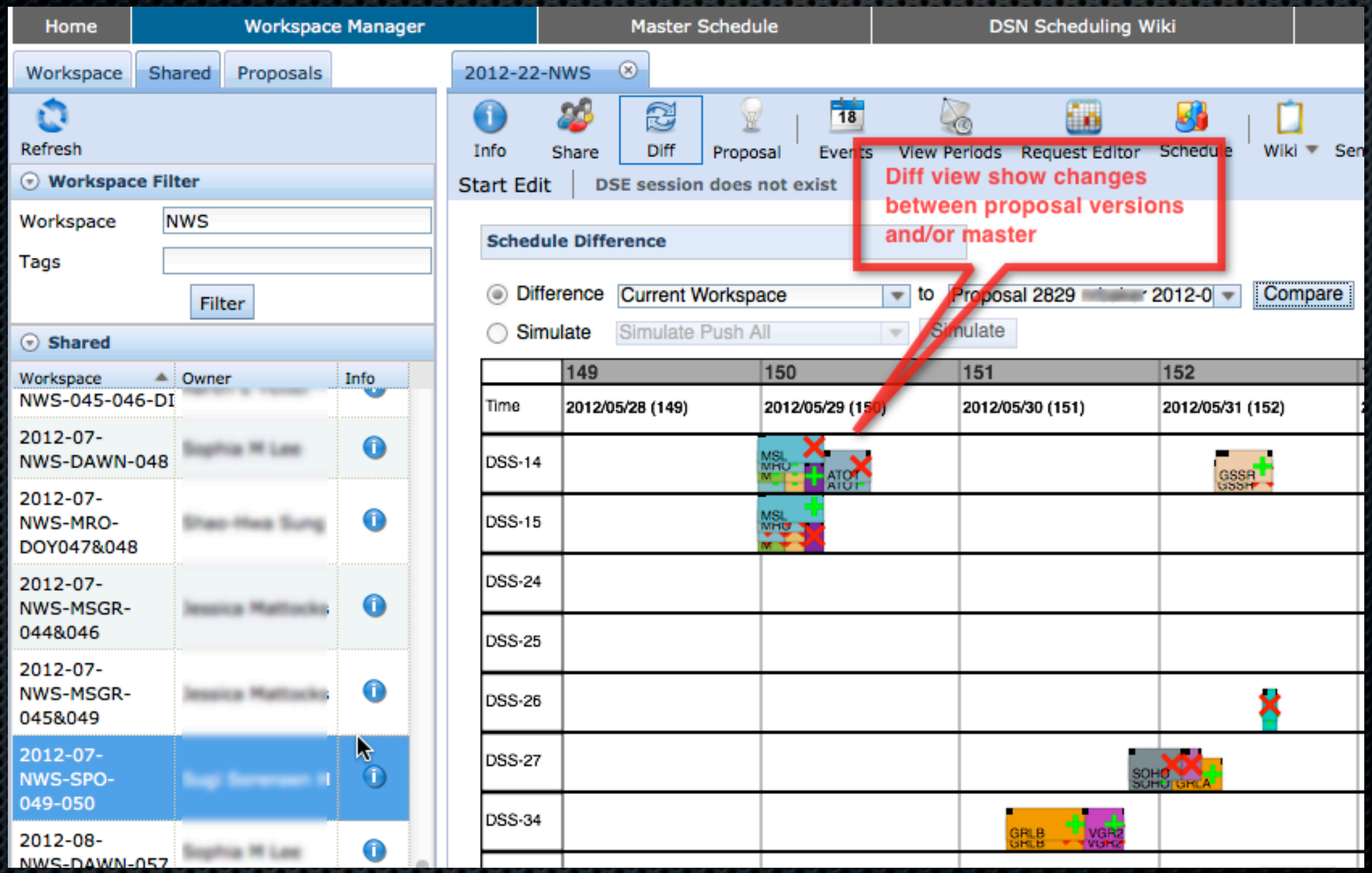
Users

Grant Permissions to User Add Search

Default User Permissions ☑ Read ☐ Write ☐ Publish

First	Last	Login	Read	Write	Publish	Delete
[illegible]	[illegible]	[illegible]	✓	✓	✗	⊗
[illegible]	[illegible]	[illegible]	✓	✓	✗	⊗
[illegible]	[illegible]	[illegible]	✓	✓	✗	⊗
[illegible]	[illegible]	[illegible]	✓	✓	✗	⊗
[illegible]	[illegible]	[illegible]	✓	✓	✗	⊗

Workspace/Proposal Differences



Request Editor

2012-22-NWS

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

Start Edit | DSE session does not exist

Scheduling request list for workspace

Request Filter

Request List (355)

Active

Edit	Lock	Errors	Sync	Service User	Name	Criticality	Priority	Start Time	End Time
				MSGR	Nominal#7	4	7	2012-06-02 (154) 06:00	2012-06-0
				MSGR	Nominal#8	4	7	2012-06-02 (154) 15:40	2012-06-0
				MSGR	Nominal#9	4	7	2012-06-03 (155) 15:40	2012-06-0
				MSL	Nominal Tracking	4	7	2012-05-28 (149) 15:00	2012-05-2
				MSL	Nominal Tracking	4	7	2012-05-29 (150) 15:00	2012-05-3

Request Status: Nominal Tracking

Requirement Management

Edit	Ignored	Name
		60421R001

Scheduling requirement editor

Requirement Detail. Request: Nominal Tracking

Ignore this Requirement

Name 60421R001

Description

Service Alias TTC v0

Expand All

Duration & Splitting duration 16h, resolution 5m, splittable into unlimited tracks of m

Duration 16h at 5 minute resolution

can be reduced to 8h can be extended to 8h

splittable?

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

split pieces must Overlap be contiguous be separated

Priority/Criticality

View Periods

Events

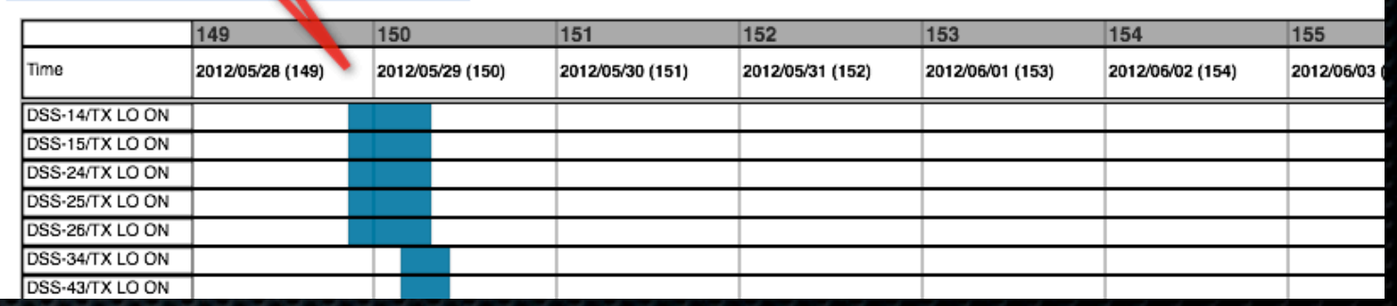
Timing Relationships

Overrides

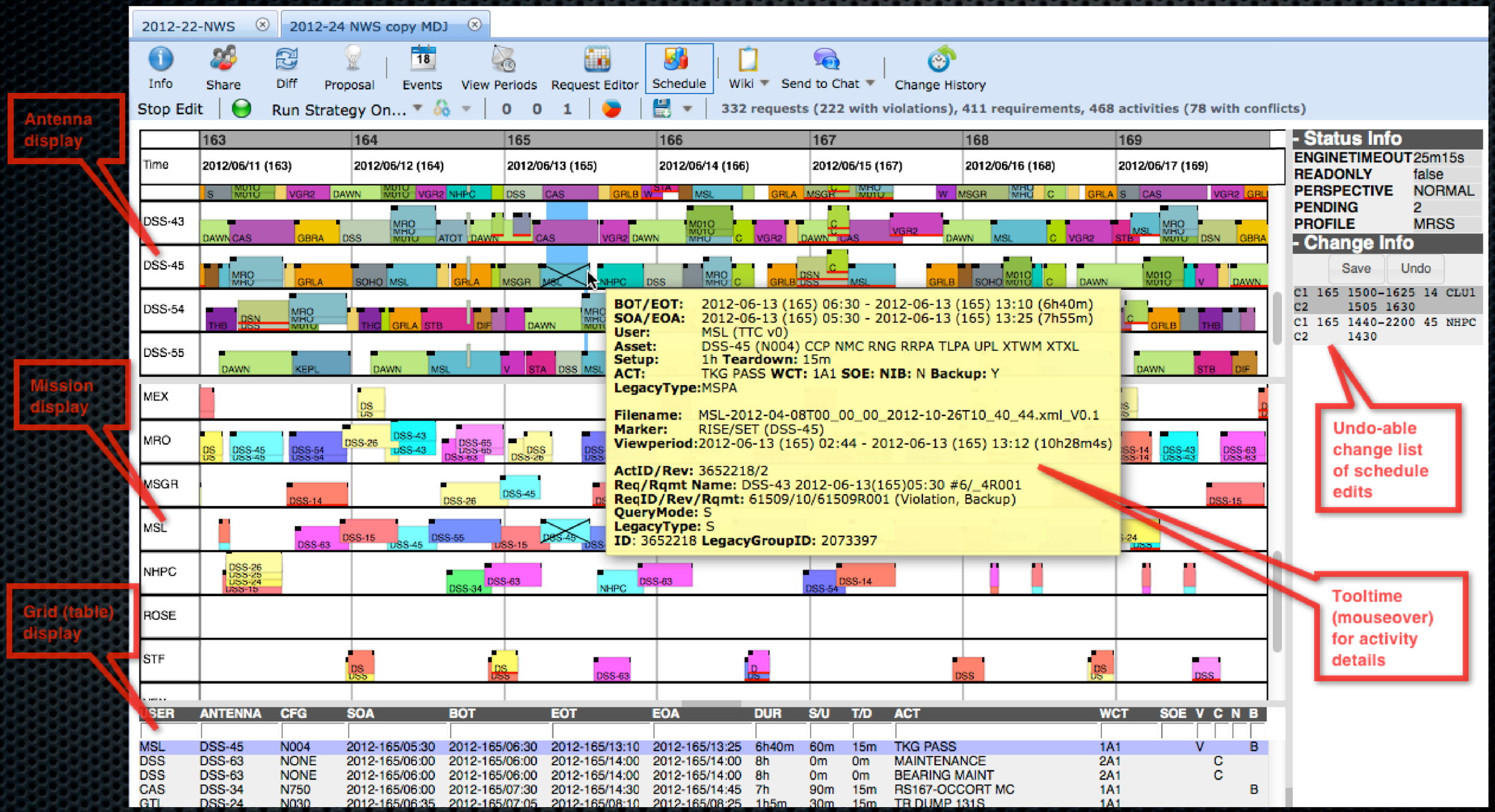
Other

Preview schedulable intervals on all legal antennas

Preview Requirement



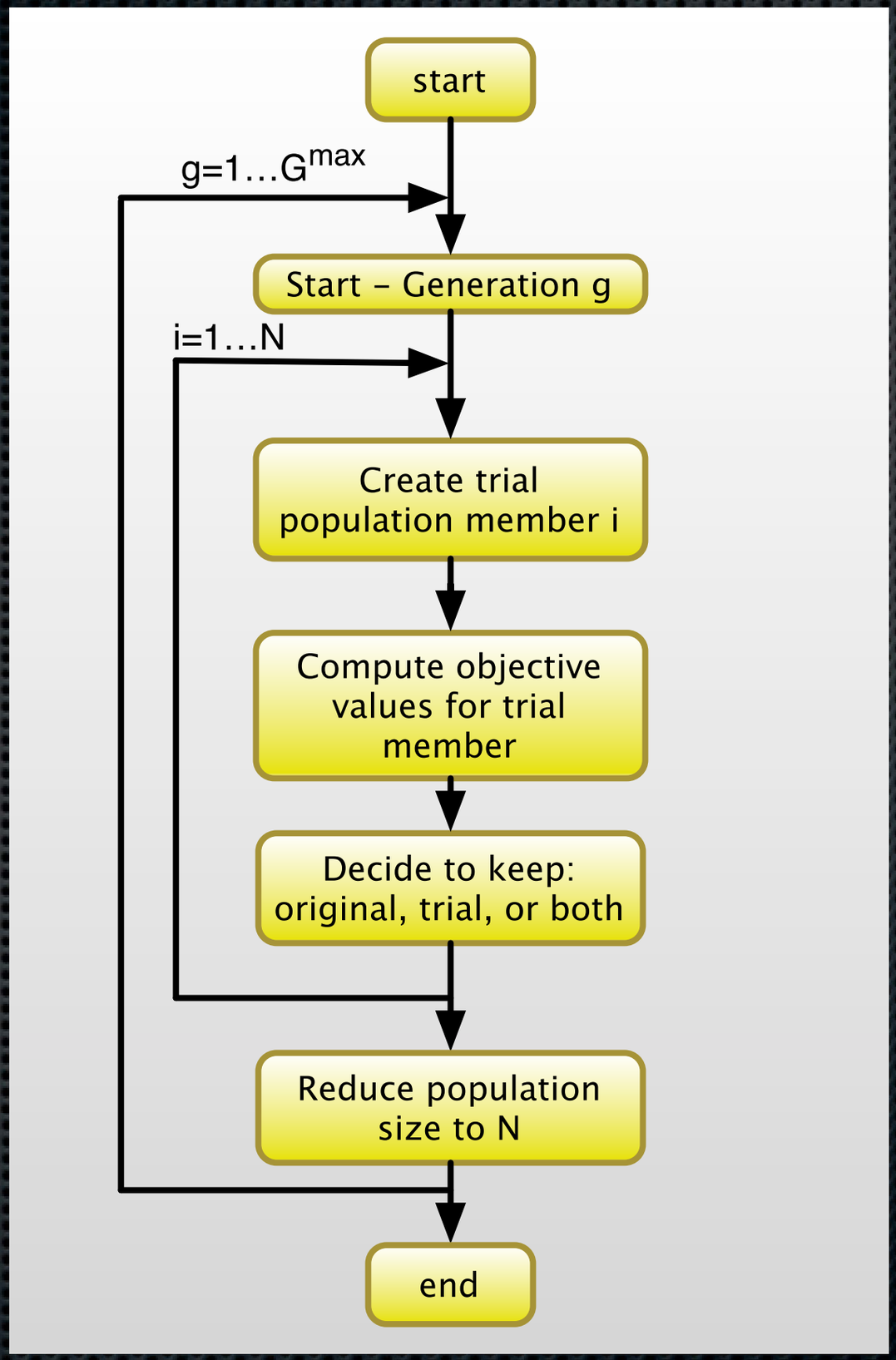
Schedule Visualization and Editing



Loading Analysis & Planning Software (LAPS)

- Algorithm: GDE3 (Generalized Differential Evolution 3, Kukkonen and Lampinen 2005)
  - maintains population of real-valued decision vectors
- Decision variables:
  - per time interval (nominally weekly)
    - mission relative priority
    - fallback potential (nominal, reduced, minimal)
- Objectives (minimization):
  - unscheduled requirement time (all missions)
  - total track duration scheduled on all antennas
- Sample problem: 16 weeks, all DSN missions, slightly (10%) oversubscribed

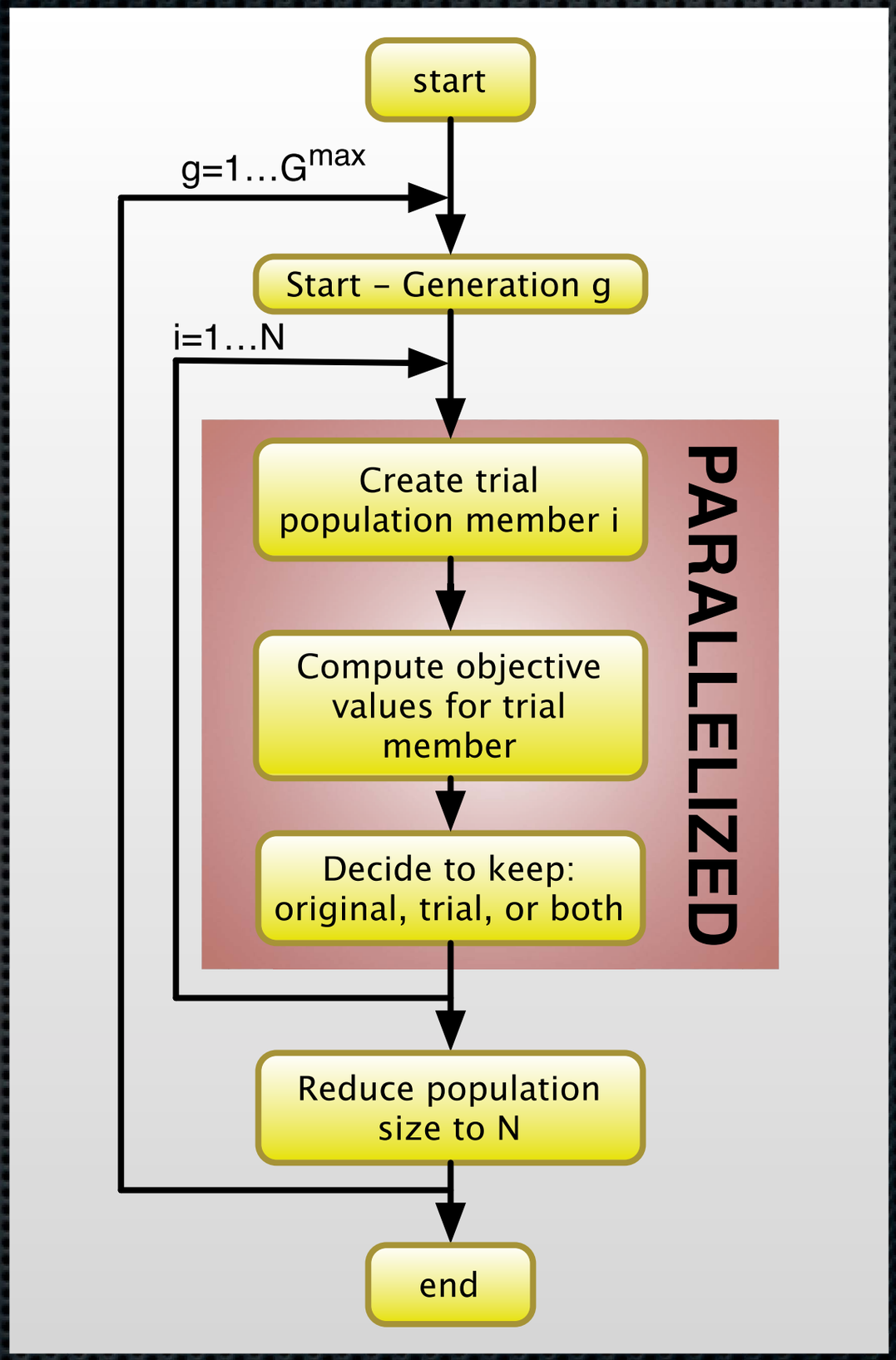
Algorithm


start
g=1…G^max
Start – Generation g
i=1…N
Create trial population member i
Compute objective values for trial member
Decide to keep: original, trial, or both
Reduce population size to N
end

Java 7 ForkJoin functionality

- New with Java 7 is API for easily parallelizing algorithms to use multiple cores
- Applied to GDE3 as follows:
  - (Fork) For each generation, create N Java *Callable* tasks that implement offspring generation, including time-consuming the objective calculation
  - (Join) When all N tasks have completed, perform the population reduction as needed, then prepare for the next generation
- By default ForkJoin uses maximum number of cores supported by hardware

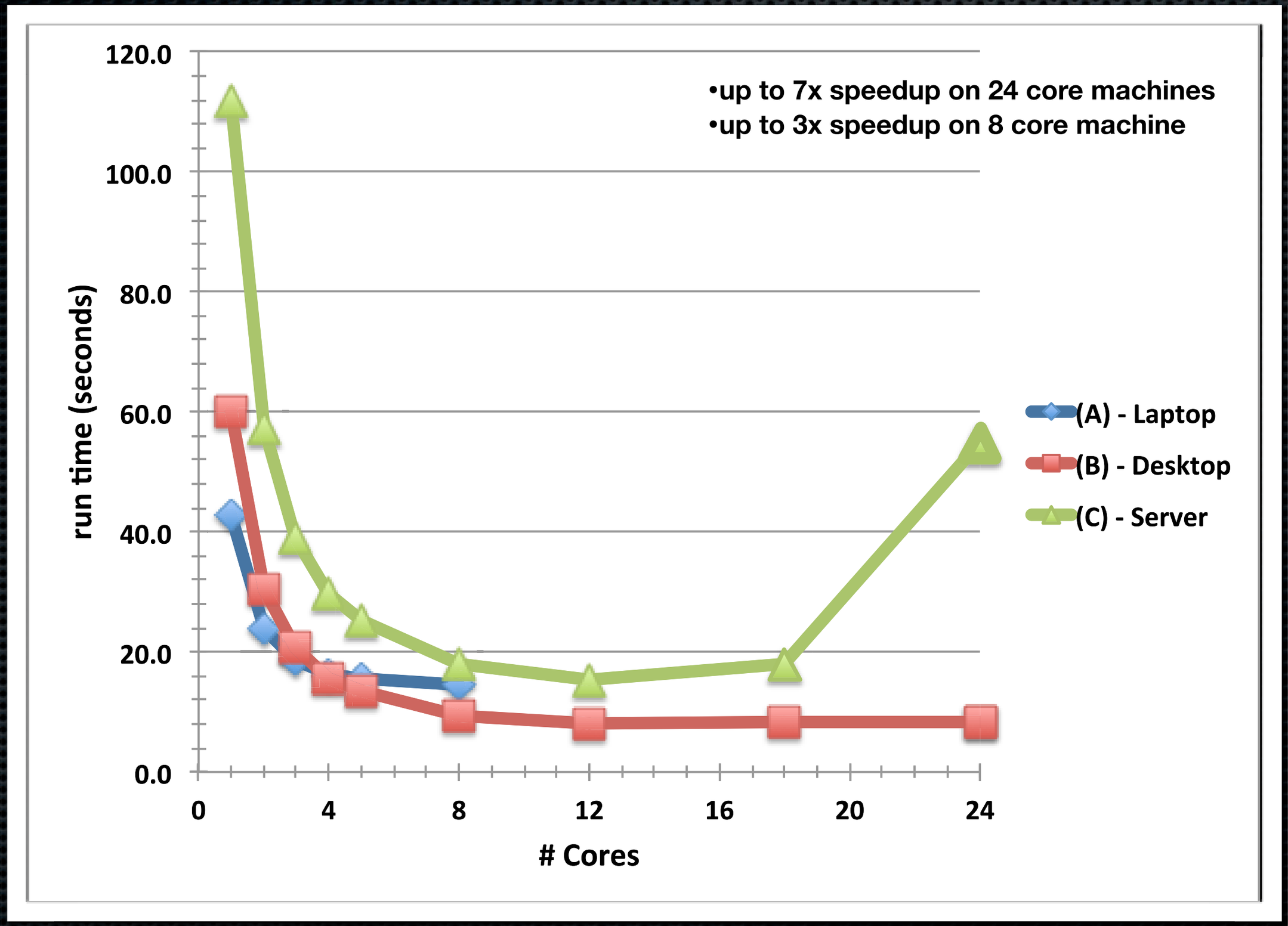
Algorithm


start
g=1…G^max
Start – Generation g
i=1…N
Create trial population member i
Compute objective values for trial member
Decide to keep: original, trial, or both
PARALLELIZED
Reduce population size to N
end

Experimental Hardware

System	Description	Processor	RAM	cores
A	Laptop – MacBook Pro (2012 retina display)	2.7 GHz Core i7	16 GB	8
B	Desktop – Mac Pro (2011)	2x 2.93 GHz Xeon X5670	64 GB	24
C	Linux server Sunfire x4450 (2009)	4x 2.66 GHz Xeon X7460	128 GB	24

Results –


•up to 7x speedup on 24 core machines
•up to 3x speedup on 8 core machine
120.0
100.0
80.0
60.0
40.0
20.0
0.0
run time (seconds)
0
4
8
12
16
20
24
Cores
(A) - Laptop
(B) - Desktop
(C) - Server

Results

- Best speedup is substantial:
  - 3x on 8-core machine
  - 7x on 24-core machine
- Using more than 1/2 the reported # cores is not beneficial
- Why is the Linux server proportionately worse when > 12 cores are used? (using 24 cores is no better than 2, and much worse than 12)
  - Memory bandwidth limitations has been reported as limiting factor in other similar work
  - particularly problematic in older server with slower RAM

Conclusions

- Parallelizing for multi-core hardware via Java 7 library features
  - easy to implement
  - can provide a major performance boost
  - some suggestions included in paper
- We are planning to configure as the default computational mode for the DSN long-range planning engine
- Next stages of LAPS development are less on performance than solution quality and visualization

Thank you!