

The Challenges of Interactive Science Planning

David E. Smith
NASA Ames Research Center
Moffett Field, CA 94035
david.smith@nasa.gov

At the dawn of time ...

Spirit



Opportunity



Rover SOWG

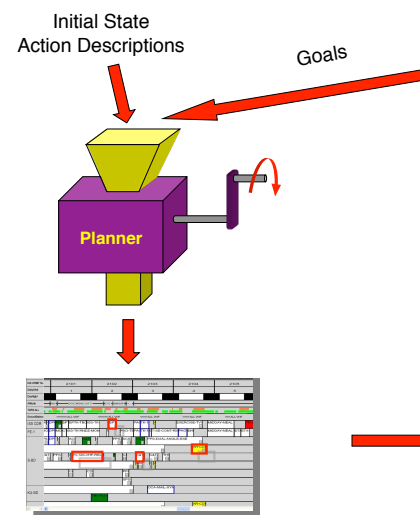


Planetary Geologists
Atmospheric Scientists
Biologists

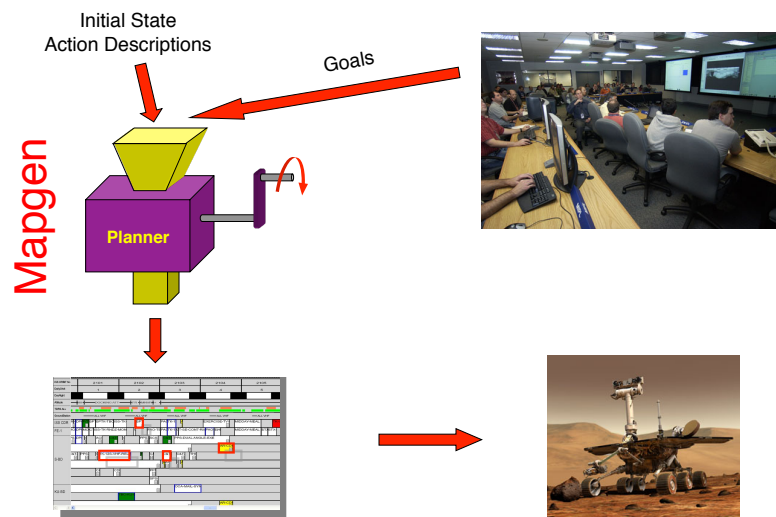
Engineering specialists:
rover mobility
arm placement
instruments
power system
thermal



Let's do Planning!

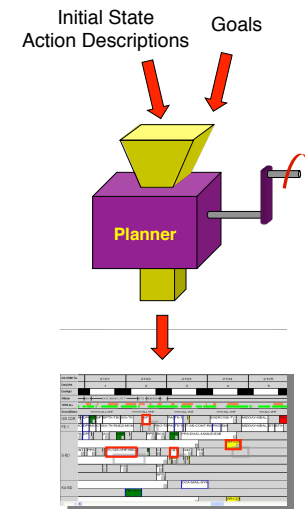


Mapgen



How did it work?

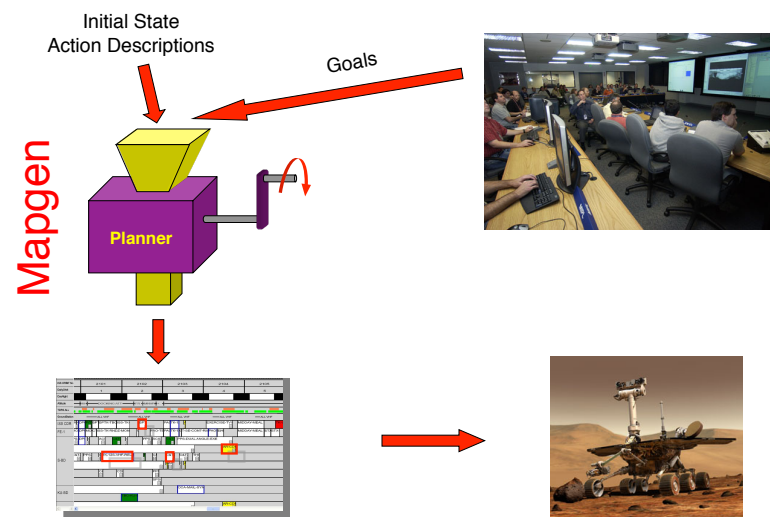
- Planner: EUROPA
 - timelines
 - activities/constraints (NDDL)
 - constraint engine
 - simple temporal network
- UI
 - plan editing: add, delete, fix, move
 - constraint/temporal propagation
 - display violations
 - auto-plan button



Results

- Good!
 - significant improvement in science return
 - plan editing, constraint propagation useful
- Bad
 - automated planning rarely used

Wha' Happened?



Characteristics



- Over-subscription
 - multiple competing goals
 - dependent goal utilities
 - limited resources

Characteristics



- Over-subscription
 - multiple competing goals
 - compilation
 - net-benefit planners
 - dependent goal utilities
 - net-benefit planners
 - limited resources
 - delete relaxation heuristics poor

Characteristics



- Temporal
 - actions have durations
 - time constraints
 - concurrency (RC)

Characteristics



- Temporal
 - actions have durations
 - time constraints
 - heuristics?
 - concurrency (RC)
 - very few planners

Characteristics



- Resources
 - battery charge
 - data storage
 - duty cycles



Characteristics



- Resources
 - battery charge
 - charging continuous, non-linear
 - data storage
 - duty cycles



Characteristics



- Preferences
 - goals, times



Characteristics



- Uncertainty
 - pose
 - terrain
 - resource levels
 - action durations
 - resource usage



Characteristics

- Uncertainty

- pose
- terrain
- resource levels
- action durations
- resource usage



Continuous, not discrete!
Big trouble for MDPs!

Characteristics

- Uncertainty

- pose rover is bigger
- terrain obstacles bigger
- resource levels lower
- action durations longer
- resource usage larger



Conservative planning

Characteristics

- Over-subscription

- multiple competing goals & limited resources

- Temporal

- concurrency, durations, time constraints

- Resources

- battery charge, data storage, duty cycles

- Uncertainty

- pose, terrain, resource levels, action durations, ...

- Preferences

- goals, times

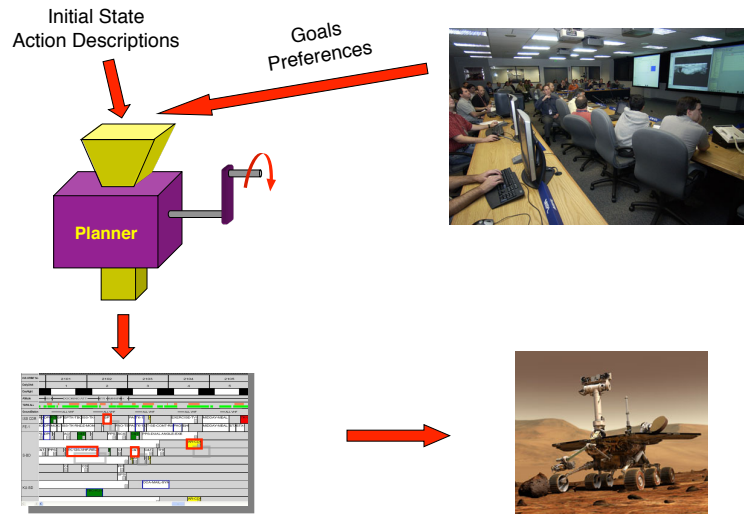


All these together!

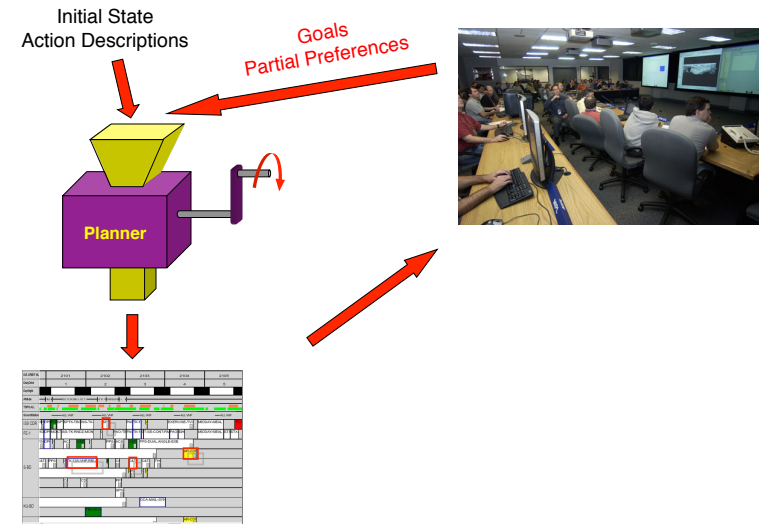
Can we do this?

	O-S	Temporal	Resources	Prefs	Uncertainty
Over-Subscription	Y			?	
Temporal		Y	Y		
Resources		Y	Y		
Preferences	?			Y	
Uncertainty					

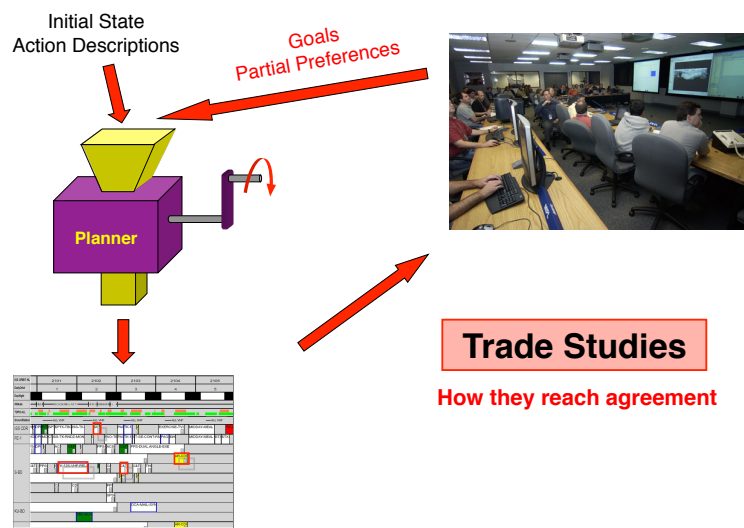
The Paradigm



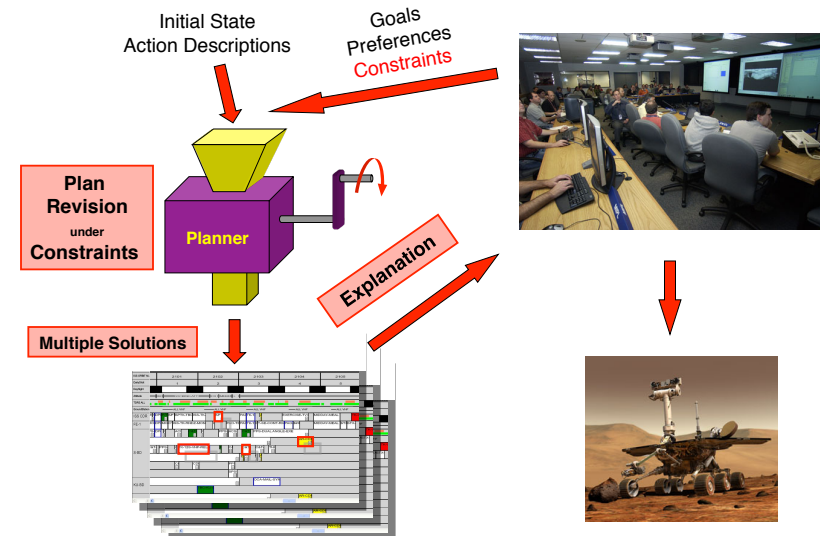
Another Problem



The Process



Implications

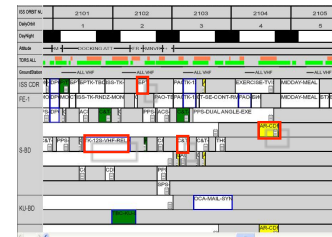


Challenges

- ➔ Plan revision under constraints
- Multiple, qualitatively different plans
- Explanation

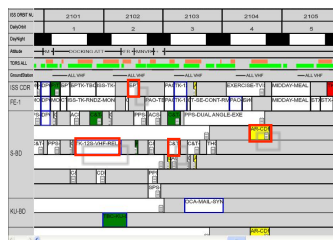
Plan Revision under Constraints

- Inclusion/Exclusion
- Temporal constraints
- Preferences/Utilities
- Complex/conditional
- Solving advice



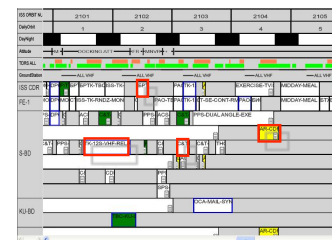
Plan Revision under Constraints

- Inclusion/Exclusion
 - keep A, B, & C
 - get rid of D
 - don't do both E & F



Plan Revision under Constraints

- Inclusion/Exclusion
 - keep A, B, & C
 - force A, B, C into plan
 - get rid of D
 - remove goal/action D
 - don't do both E & F
 - make E & F dependent on a common resource



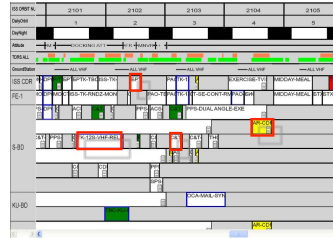


Plan Revision under Constraints



Temporal constraints

- do A between 4pm and 6pm
- do B before C

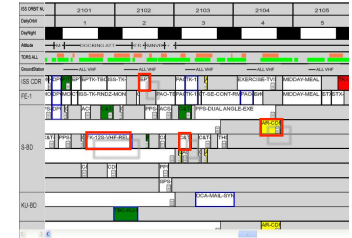


Plan Revision under Constraints



Temporal constraints

- do A between 4pm and 6pm
- do B before C
- timed initial literals
- ordering constraints
- LTL
- introduce linking condition

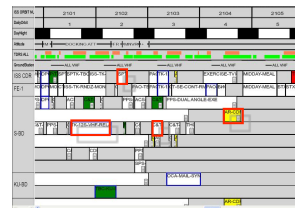


Plan Revision under Constraints



Preferences/Values

- G_1 is more important than G_2
- G_1 is of no value unless G_2 is done first
- prefer using A_1 to A_2 to achieve C



Plan Revision under Constraints



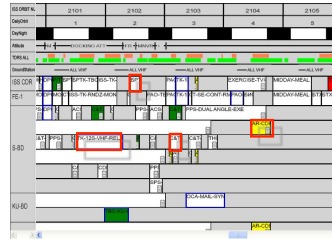
Preferences/Values

- G_1 is more important than G_2
- preference
- G_1 is of no value unless G_2 is done first
- LTL
- add precondition to G_1 that requires G_2
- prefer using A_1 instead of A_2 to achieve C
- ??



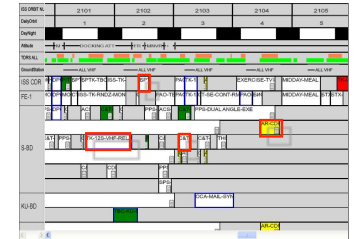
Complex/conditional

- don't do E unless there is 20 units energy available after including all the other geology goals



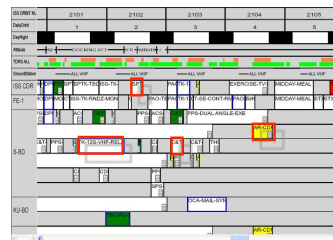
Complex/conditional

- don't do E unless there is 20 units energy available after including all the other geology goals
- preferences between E and other geology goals
- + phantom action required at end that uses 20-x units energy



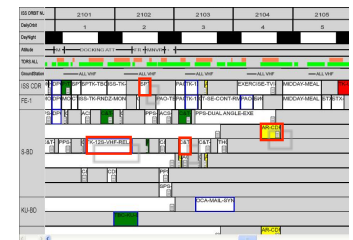
Solving advice

- plan for all geology goals before considering atmospheric science goals
- prefer moving atmospheric goals to moving geology goals



Solving advice

- plan for all geology goals before considering atmospheric science goals
- flaw ordering
- only possible in certain types of planners
- prefer moving atmospheric goals to moving geology goals
- ??



Inclusion/Exclusion

- keep A, B, & C
- get rid of D
- don't do both E & F

Temporal constraints

- do A between 4pm and 6pm
- do B before C

Preferences/Values

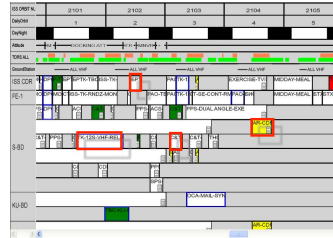
- G_1 is more important than G_2
- G_1 is of no value unless G_2 is done first

Complex/conditional

- don't do E unless there is extra energy available after including all the more important goals

Solving advice

- put in all the geology goals before considering atmospheric science goals



Plan Revision under Constraints

Inclusion/Exclusion

- keep A, B, & C
- get rid of D
- don't do both E & F

Temporal constraints

- do A between 4pm and 6pm
- do B before C

Preferences/Values

- G_1 is more important than G_2
- G_1 is of no value unless G_2 is done first

Complex/conditional

- don't do E unless there is extra energy available after including all the more important goals

Solving advice

- plan for all geology goals before considering atmospheric science goals

Compile into planning problem.

How does this information affect search heuristics?

Can we take advantage of this information to improve search?

Challenges

Plan revision under constraints



Multiple, qualitatively different plans

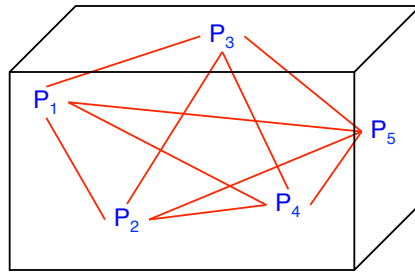
Explanation

Multiple Qualitatively Different Plans

What could this mean?

- Multiple objectives
pareto frontier
- Single objective, secondary criteria
different plans of similar utility

Plans of similar utility



of actions different

of objectives different

differences in time/resource usage

differences in *risk*

of actions different

of objectives different

differences in time/resource usage

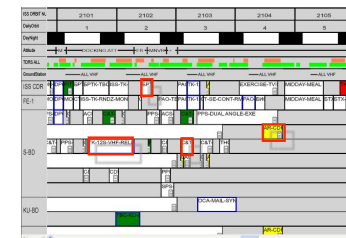
differences in *risk*

How do we take advantage of this
information in search?

Plan revision under constraints

Multiple, qualitatively different plans

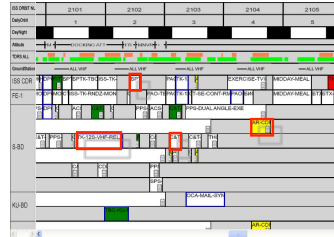
➡ Explanation



Answering Questions

Why is activity A_1 in the plan?

A_1 achieves condition C_1 which is needed for $A_2 \dots$
which is needed for G

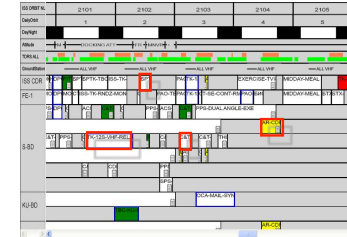


Answering Questions

Why is activity A_1 in the plan?

A_1 achieves condition C_1 which is needed for $A_2 \dots$

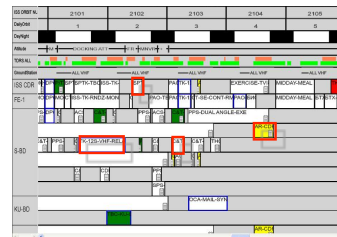
extract causal chain for A_1
 $A_1 \xrightarrow{C_1} A_2 \xrightarrow{C_2} \dots \rightarrow G$
might be multiple chains



Answering Questions

Why is activity A_1 before A_2 ?

A_1 must be done before 11:00,
but A_2 can't be done until after 12:00

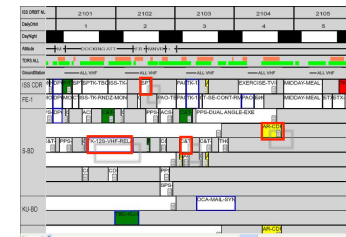


Answering Questions

Why is activity A_1 before A_2 ?

A_1 must be done before 11:00,
but A_2 can't be done until after 12:00

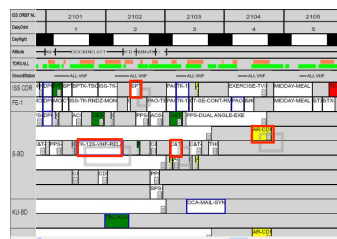
Easy:
direct consequence of given
temporal constraints.



Answering Questions

Why is activity A_1 before A_2 ?

A_1 achieves a condition needed for A_2



Answering Questions

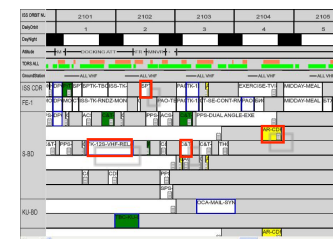
Why is activity A_1 before A_2 ?

A_1 achieves a condition needed for A_2

extract causal structure for A_1

$$A_1 \xrightarrow{C_1} \dots \xrightarrow{C_2} A_2$$

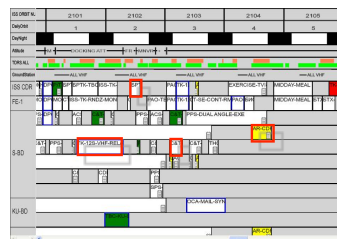
might be multiple chains



Answering Questions

Why is activity A_1 before A_2 ?

A_1 must be done before 11:00,
but A_2 needs resource R which isn't available until after 12:00



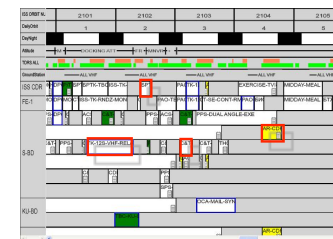
Answering Questions

Why is activity A_1 before A_2 ?

A_1 must be done before 11:00,
but A_2 needs resource R which isn't available until after 12:00

extract causal structure for A_2

$$[12, \dots] \xrightarrow{R} A_2$$



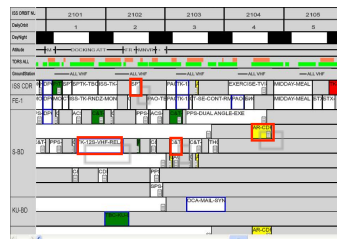
Answering Questions

Why is activity A_1 before A_2 ?

extract chain of temporal constraints connecting A_1 and A_2



proof that A_1 must come before A_2
given the other decisions



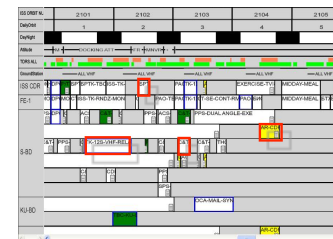
Answering Questions

Why is activity A_1 before A_2 ?

extract chain of temporal constraints connecting A_1 and A_2



proof that A_1 must come before A_2
given the other decisions

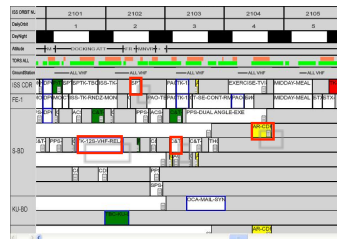


doesn't show that A_1 must come
before A_2 in every possible plan

Hypothetical Questions

What would happen if you delayed A_1 until 13:00?

Delaying this action until 13:00 would mean delaying action A_2 , so the goal of photographing Rock13 could no longer be completed by 16:00, violating preference P_2



Hypothetical Questions

What would happen if you delayed A_1 until 13:00?

Delaying this action until 13:00 would mean delaying action A_2 , so the goal of photographing Rock13 could no longer be completed by 16:00, violating preference P_2

Requires:

- 1) Modifying the objectives and preferences
- 2) Replanning
- 3) Examining the new plan to see what goals & preferences are no longer satisfied



Hypothetical Questions



Why wasn't goal G_1 included?

(G_1 isn't possible)

I cannot find any sequence of actions that will achieve G_1 given the current initial conditions.

Reachability argument



Hypothetical Questions



Why wasn't goal G_1 included?

(G_1 isn't possible)

Landmark L is necessary for achieving G_1 and I cannot find any sequence of actions that will achieve L given the current initial conditions.

L could be disjunctive.



Hypothetical Questions



Why wasn't goal G_1 included?

(G_1 is possible)

If I satisfy G_1 I cannot satisfy goal G_3 or preference P_2 .



Hypothetical Questions



Why wasn't goal G_1 included?

(G_1 is possible)

If I satisfy G_1 I cannot satisfy goal G_3 or preference P_2 .

Requires:

- 1) Modify the constraints to require G_1
- 2) Run the planner again
- 3) Examine the new plan to see what other objectives & preferences were sacrificed that were satisfied in the previous plan

Hypothetical Questions

Why didn't you satisfy preference P?

(P isn't possible)

I cannot find any sequence of actions that will satisfy P given the current initial conditions.

Reachability argument

Hypothetical Questions

Why didn't you satisfy preference P?

(P is possible)

If I satisfy P I cannot satisfy goal G_3 or preference P_2

Requires:

- 1) Modify the constraints to require the preference
- 2) Run the planner again
- 3) Examine the new plan to see what other objectives & preferences in the original plan were sacrificed.

Answering Questions

Why is activity A_1 in the plan?

Why is activity A_1 before A_2 ?

Causal & temporal structure

What would happen if you delayed A_1 until 13:00?

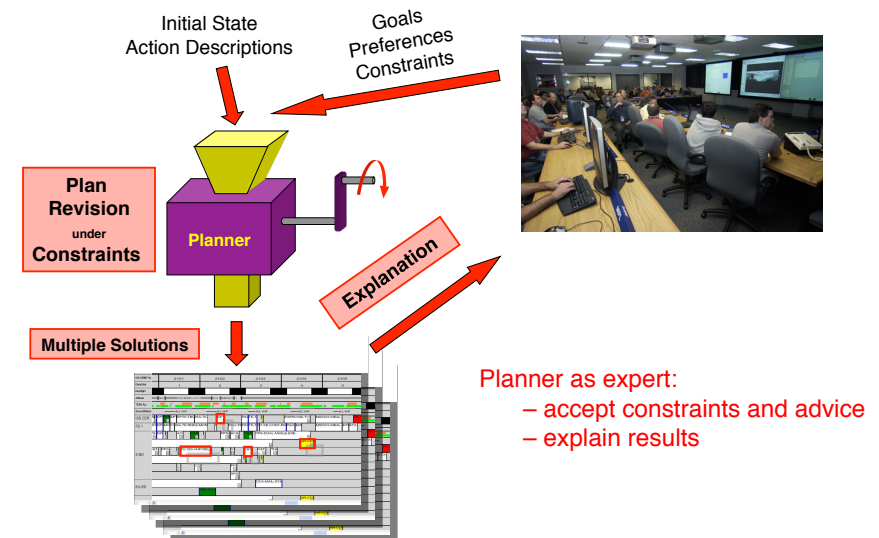
Why wasn't goal G included instead?

Why didn't you satisfy preference P?

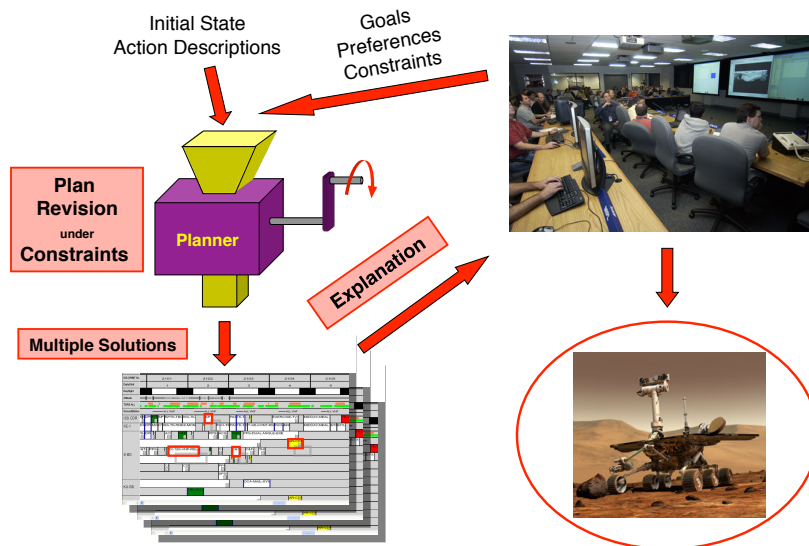
Hypothetical

Re-planning
+
Comparison

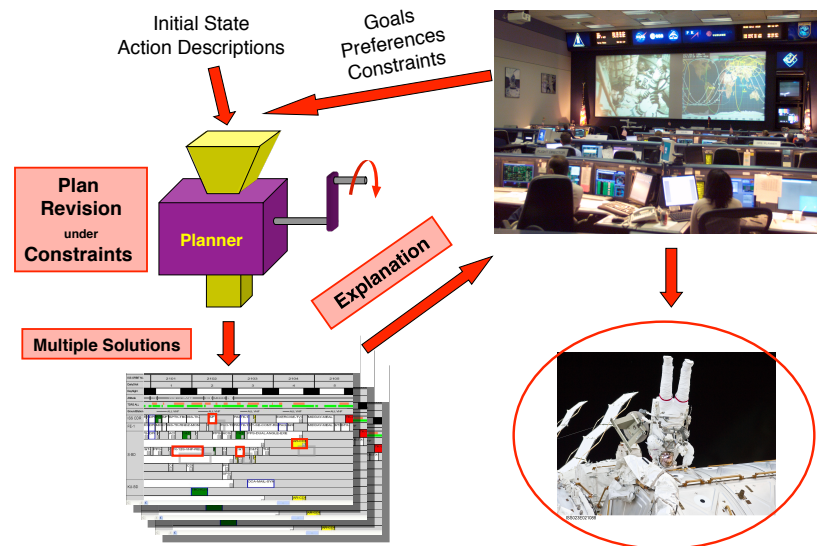
The Overall Picture



The Executive



The Smart Executive



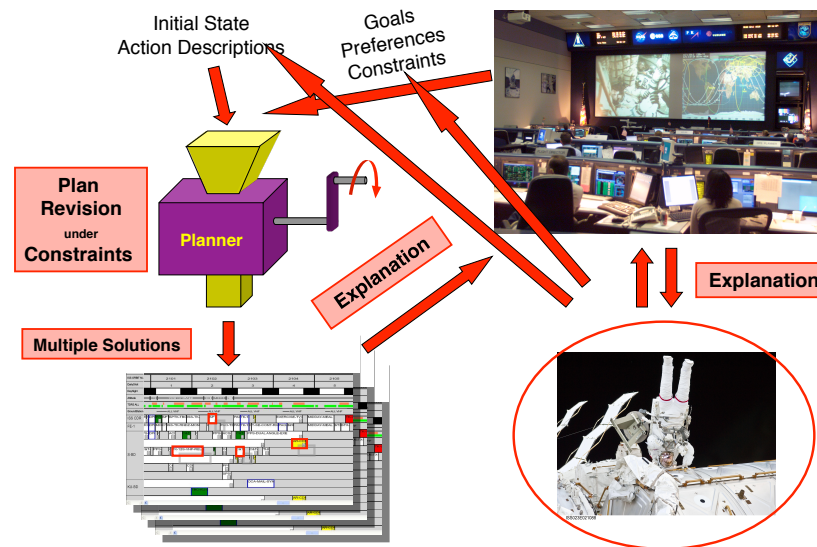
The Curse of the Smart Executive



Explanation
Stupidity not tolerated
Re-ordering
Interleaving
Collaboration
Ingenuity



The Implications



Humans as consumers



Richer representation
Smarter planner
Explanation

