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# OPERATIONS MISSION PLANNER

## Beyond the Baseline


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# Operations Mission Planner

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Abstract

The scheduling of Space Station Freedom must satisfy four major requirements. It must ensure efficient housekeeping operations, maximize the collection of science, respond to changes in tasking and available resources, and accommodate the above changes in a manner that minimizes disruption of the ongoing operations of the station. While meeting these requirements the scheduler must cope with the complexity, scope, and flexibility of Space Station Freedom operations. This requires the scheduler to deal with an astronomical number of possible schedules.

JPL has been researching advanced software scheduling systems for several years (DEVISER, SWITCH, PLAN-IT, RALPH, PLANNER, and OMP). Our current research, the Operations Mission Planner (OMP), is centered around minimally disruptive (non-nervous) replanning and the use of heuristics limit search in scheduling. OMP has already demonstrated several new AI-based scheduling techniques such as Interleaved Iterative Refinement and Bottleneck Identification using Process Chronologies.

We are currently delivering these techniques to JSC for integration into the COMPASS scheduling tool. The first test case will by the Shuttle Systems Engineering Simulator (SES)

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# BACKGROUND

- Space Station Requires Advance Scheduling Techniques
  - Large Complex Ongoing Operations
  - Non-Nervous Replanning
  - Maximize Science Collection
- Leverages off of Current Research at JPL
  - DEVISER, SWITCH, PLAN-IT, RALPH, and OMP

## Background

The scheduling of Space Station Freedom must satisfy four major requirements. It must ensure efficient housekeeping operations, maximize the collection of science, respond to changes in tasking and available resources, and accommodate the above changes in a manner that minimizes disruption of the ongoing operations of the station. While meeting these requirements the scheduler must cope with the complexity, scope, and flexibility of Space Station Freedom operations. This requires the scheduler to deal with an astronomical number of possible schedules.

JPL has been researching advanced software scheduling systems for several years (DEVISER, SWITCH, PLAN-IT, RALPH, PLANNER, and OMP). Our current research, the Operations Mission Planner (OMP), is centered around minimally disruptive (non-nervous) replanning and the use of heuristics limit search in scheduling. OMP has already demonstrated several new AI-based scheduling techniques such as Interleaved Iterative Refinement and Bottleneck Identification using Process Chronologies.

Concurrently, JSC and McDonnell-Douglas (MDAC) are performing work on developing interactive scheduling tools for use by ground personnel and astronauts on the Space Shuttle and for Space Station Freedom (SSF). This task is led by Dr. Barry Fox of MDAC, Houston and is sponsored by NASA Codes M and ST and contracted from the Software Technology Branch under Robert Savely at JSC.

These two efforts complement one another. The usefulness of interactive tools for scheduling will be enhanced by removing some of the burden from ground-based and astronaut users by automating aspects of the scheduling process.

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# OBJECTIVE

- Develop and Demonstrate Advanced Automated Scheduling Techniques Suitable for Space Station Freedom

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## Objective

Deliver software implementing functional capabilities for automated scheduling from JPL to Mr. Savely's and Dr. Fox's effort at JSC/MDAC to support SSF scheduling needs.

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# WHY?

Scheduling problem is intractable

Existing NASA scheduling is manually intensive

SSF will require continuous scheduling over extended lifetime

→

SSF Cannot afford the cost or non-responsiveness of existing scheduling philosophies

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## Why?

Scheduling and resource allocation needs for NASA are manifold: Maximizing science data collection, ensuring efficient routine operations, minimal disruption of ongoing activities during timely responses to unexpected events like transient science opportunities and resource disruptions. Currently most flight projects' schedules are largely built and maintained manually.

Future flight projects like SSF, EOS, or CRAF/Cassini, will demand a higher level of complex scheduling extended over large continuous periods of time. These flight projects may also require distribution of the scheduling task through out the various science communities. This will place exorbitant demands on the current style of highly manual scheduling. Emerging AI-based technology can provide automated assistance in the form of human/machine cooperative scheduling tools.

JSC with McDonnell-Douglas (MDSSC) is performing work on developing interactive scheduling tools (COMPASS) for the Space Shuttle and for Space Station Freedom (SSF). This task is led by Dr. Barry Fox of MDSSC, Houston, is sponsored by NASA Code MD. Our work on OMP complements the COMPASS work. The usefulness of interactive tools for scheduling will be enhanced by removing some of the burden from users by automating aspects of the scheduling process. A Code MT funded task exists to transfer OMP automated scheduling techniques to COMPASS.

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# BENEFITS

- Increase Mission Operations Productivity
  - Less Manual Effort in Producing and Maintaining Schedules
- Increase Station Utilization
  - Optimization of Schedule
- Increase Station Responsiveness
  - Reduce Time to Modify Schedule

## Benefits

OMP will reduce the time and effort necessary in both generating and maintaining a mission plan.

Performance Enhancement:

OMP will allow the schedulers to spend more of their time in optimizing the schedule. This will lead to an increase in the science return of a mission. Also since the time to modify a schedule can be reduced it will become feasible to change the science request in response to earlier science observations.

Cost Reduction:

Automated scheduling will enable the creation of schedules in significantly less time and with substantially less human involvement. This can lead to a direct reduction in the size and numbers of the scheduling teams.

It will be faster, less expensive, and less disruptive to modify a schedule. The OMP approach, allows modification of an executing schedule while also maximizing the return received from that schedule and minimizing disruption.

The subsequent costs of using the schedule will be reduced because changes in the schedule will be automatically tracked. The use of a standardized, computer-based medium for schedule representation will enable the automated use of the schedule as input to other processes.

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# APPROACH

- Automated Scheduling
  - Iterative Refinement
  - Chronology
  - Search Paradigms
- Common Graphics Substrate
  - Support Multiple Styles
  - Portable
- OMP - COMPASS Integration
  - Initial data exchange
  - OMP as a COMPASS Button
  - Recode OMP Modules in ADA for COMPASS

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## Approach

The approach to automated scheduling developed in OMP is based on the process used by expert human schedulers in planning the use of scientific instruments for Voyager planetary encounters This approach highlights several new AI-based scheduling techniques. The major innovation is the incorporation of multi-pass scheduling -- Interleaved Iterative Refinement -- where the scheduling system builds and refines a schedule over a series of passes. During the passes OMP constructs chronologies to assess progress and effort expended during the evolution of a schedule. The chronologies are used to identify schedule bottlenecks and focus the search process. This approach allows the same system to be used for both schedule construction and dynamic replanning. Details are in "Operations Mission Planner Final Report", JPL Publication 89-48, by E. Biefeld and L. Cooper.

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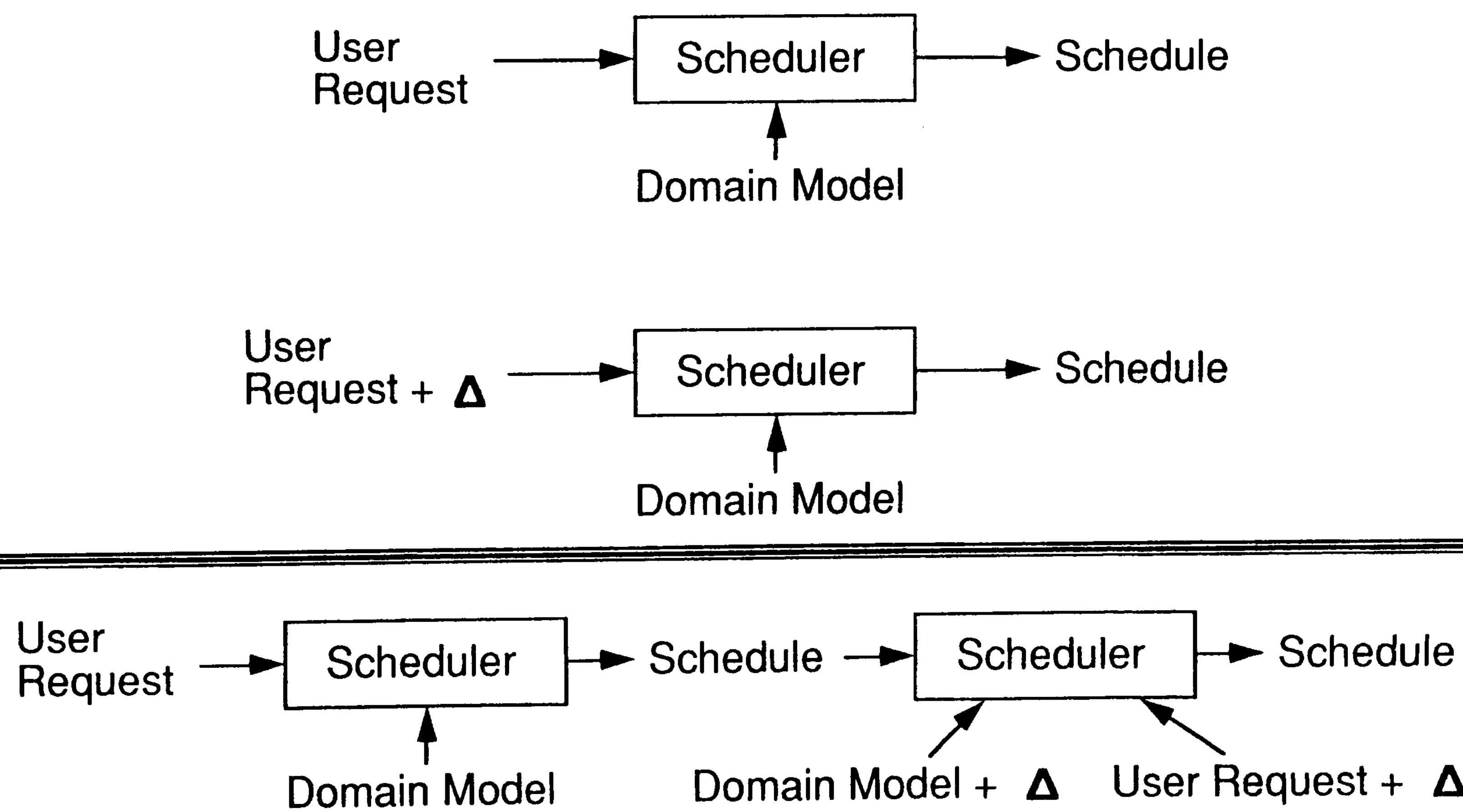
# REACTIVE SCHEDULING

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## Reactive Scheduling

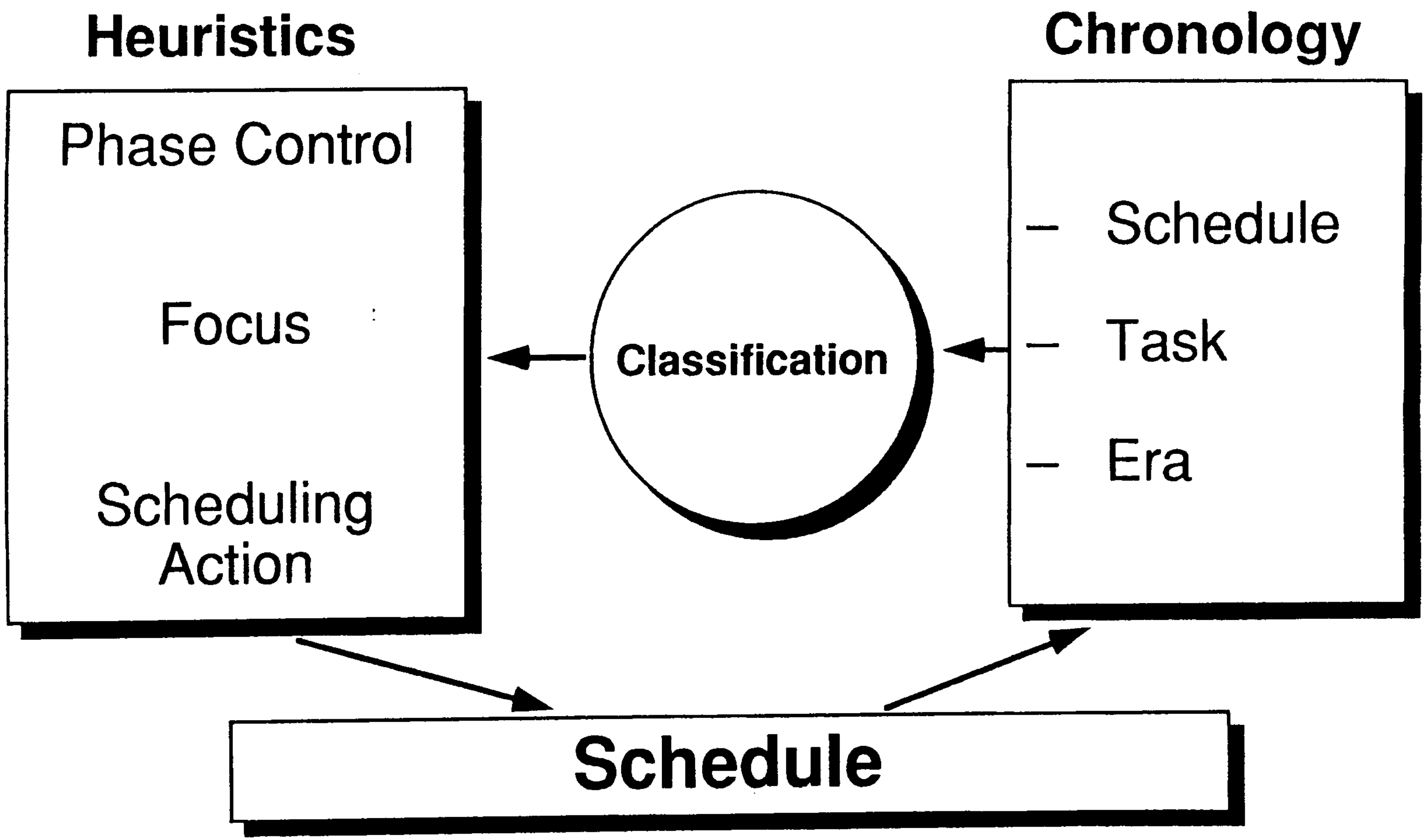
Since the world is not a static place, replanning is a functional requirement for scheduling. Events in the real world change the assumptions upon which a plan is based. These events can be spectacular. For example, the first pictures returned by Voyager of Jupiter's moon, Io, showed a volcanic eruption. The mission scientists immediately requested changes in Voyager's schedule to obtain more information on this totally unexpected event. Most events are, however, more mundane and happen well in advance of the encounter.

A currently popular approach to automated replanning is to simply plan again. The knowledge base and input tasks are updated and the software scheduler is rerun. The software scheduler then produces a new schedule which accomplishes the new tasks using the modified resources. Each time the scheduler runs, however, a radically new schedule is produced.

This approach leads to nervous replanning. This nervous behavior arises due to the underconstrained nature of the scheduling problem. For any mission scheduling-type problem, there exist many acceptable solutions that are radically different. Any change, however slight, in the planner's inputs may cause the planner to explore an entirely different section of the solution space. This change in the search will, most likely, lead to a schedule radically different from the original schedule. Mission planning is known to be extremely input-sensitive.

For a scheduler to survive in an operational environment it must be capable of making small changes to an existing schedule. If the inference engine must do extensive backtracking in order to change a task, then the scheduler is destined to exhibit nervous replanning. The old schedule must therefore be an input to the scheduler. The scheduler knowledge base must include the operational cost of making a change to the existing schedule, and the scheduling inference engine must accommodate this operational requirement for non-nervous replanning.

# AUTOMATED SCHEDULING

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## Automated Scheduling

The scheduling problem devolves into controlling the search through a very large and complicated problem space. Brute-force search mechanisms are incapable of supporting automated scheduling with realistic and acceptable response times. Instead, heuristics are used to determine how to conduct the search.

Heuristics are simply rules of thumb which guide the performance of a given activity. Research at JPL has characterized three types of heuristics: (1) assessment heuristics, which assess the state of the schedule and provide information on how well the scheduler is performing; (2) dispatch heuristics, which perform the actual scheduling actions; and (3) control heuristics, which set and change the focus of attention of the scheduling process . The heuristics are the "brain" of the scheduling system. They determine what areas of the schedule to concentrate on; what types of changes to make; and, based on how well the scheduler is doing, when to change approaches.

In order to control the search, the scheduler must know about the difficulties arising in the particular schedule. The scheduler must identify the problem contention areas, called bottlenecks. Once this information is available, the scheduler can then use that information to direct the search process. This type of use of heuristics has been used in Ralph , a scheduler for the NASA Deep Space Network, and OPT and OPIS for factory scheduling.

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# ITERATIVE REFINEMENT

- After Each Pass
  - More is Known About the Schedule
  - Willing to Perform Deep Search on a Few Items
  - Not Willing to Perform Search on Many Items
- Five Phases
  - Initial Load
    - Resource Centered
      - Bottleneck Centered
        - Optimization
          - Event Handling

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## Iterative Refinement

Iterative planning consists of a series of scheduling phases. Each phase is responsible for a different aspect of the overall planning process. The first of these techniques roughs out the plan and identifies areas of high resource conflicts. The later techniques use the knowledge of the resource conflicts to refine the plan and solve many of the scheduling problems. The final techniques try to solve the last of the conflicts and add a few more tasks. Once the schedule is executing, changes are accomplished by reverting to the appropriate planning phase and making use of the information available on the schedule up to that point. During each phase, the scheduler cycles through its scheduling activities until it determines that a change in phase is appropriate.

By specializing the planning techniques associated with each phase, the techniques can be made more efficient. For example, the first techniques use shallow searches over a broad spectrum of tasks. Later techniques will use deeper searches which are applied to only a limited number of tasks. They will use knowledge about the particular schedule (i.e., the current resource conflicts, which tasks have changed most often in the scheduling process) to constrain the search space. The techniques will employ either a shallow and broad search or a deep and narrow search. If a planner must perform a broad and deep search, it will not be able to generate a schedule in any reasonable time. However, if the planner is always restricted to a shallow search, it will generate a severely suboptimal schedule.

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# CHRONOLOGY

- Limited History of the Scheduling Process
  - Actions Recorded Depend on Focus State
- Used to Guide Search Process
  - Provide Assessment of Scheduling Process
  - Identifies Bottlenecks

## Chronology

A chronology is a limited history of the scheduling activity that has taken place. The chronology does not keep a complete snapshot of the changes taking place during the scheduling process. Rather, it focuses on characteristics which can provide information useful in directing subsequent searches. The chronology is used to identify interactions between time regions across several resources, detect the termination condition of a scheduling phase, and identify tasks that cause problems for the scheduler. Because we use an iterative approach to planning in which the scheduler focuses on either resources or tasks, the chronology keeps either resource or task information, depending upon the phase.

There are two activities associated with the chronology system: (1) collecting the information and (2) analyzing this information to characterize the schedule. During the multiple passes of each scheduling phase, information is collected to help the scheduler identify when the goals for that phase have been accomplished. For example, during the resource-centered phase, the goal is to identify the bottlenecks. Information which enables the scheduler to determine the boundaries of the bottlenecks is collected and analyzed. Once the bottleneck areas have been identified, that phase is complete and the scheduler changes its focus to perform bottleneck-centered scheduling.

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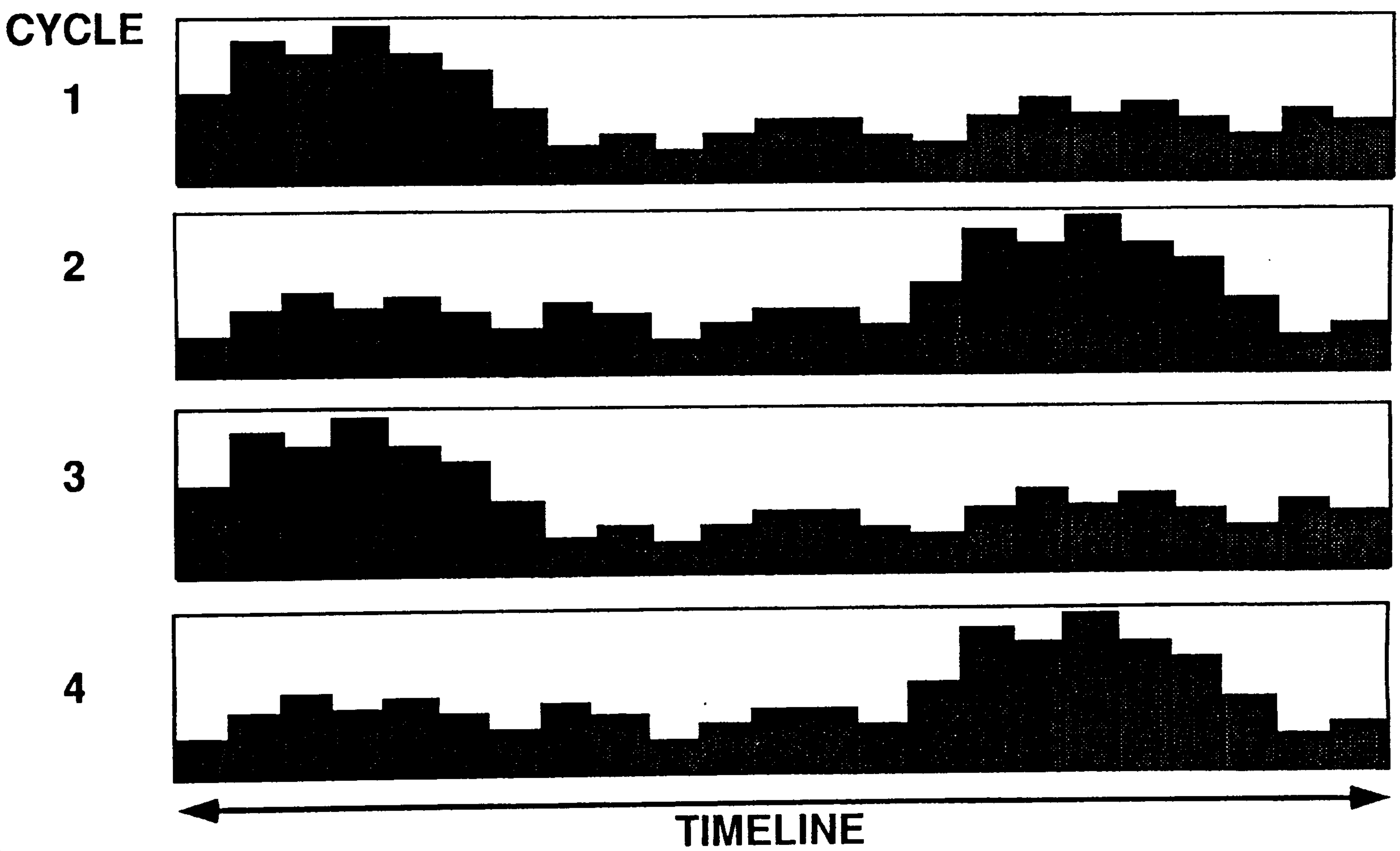
# BOTTLENECK IDENTIFICATION

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## Bottleneck Identification

The identification of bottlenecks is an important and necessary step for effective scheduling. The exact location and extent of the bottlenecks are highly context-dependent. Since the scheduler cannot anticipate where the bottlenecks will be located, the basic approach is to perform a simple exploration of the schedule space and use the information gathered to identify the bottlenecks.

After performing the initial expansion of the tasks into activities, the scheduler focuses on the area in the schedule with the most conflicts The scheduler performs a shallow search, which lowers the number of conflicts in this area. Only the activities that are involved in the conflict are modified. The chronology module records the impact of these modifications on the resources.

While the search tries to avoid creating new conflicts, it will create them if necessary. The magnitude of these new conflicts may be larger than the magnitude of the original conflict that initiated the search. The scheduler will eventually focus on one of the new conflict areas. Solving this area may, in turn, cause other conflicts and so on, until the original conflict spot is once again in conflict. As the search progresses through the oversubscribed resources, the level of conflict in these and other areas oscillates. The conflict areas that continually oscillate in this manner are classified as potential bottlenecks.

As the scheduler focuses on a single conflict area, several other areas will be affected by the subsequent search. Since the conflict level for all these affected areas is modified during the same *focus state*, these areas and the conflict changes are all associated in the system's chronology. This chronological association of the oscillating resource areas allows the chronology module to group these areas into bottleneck regions.

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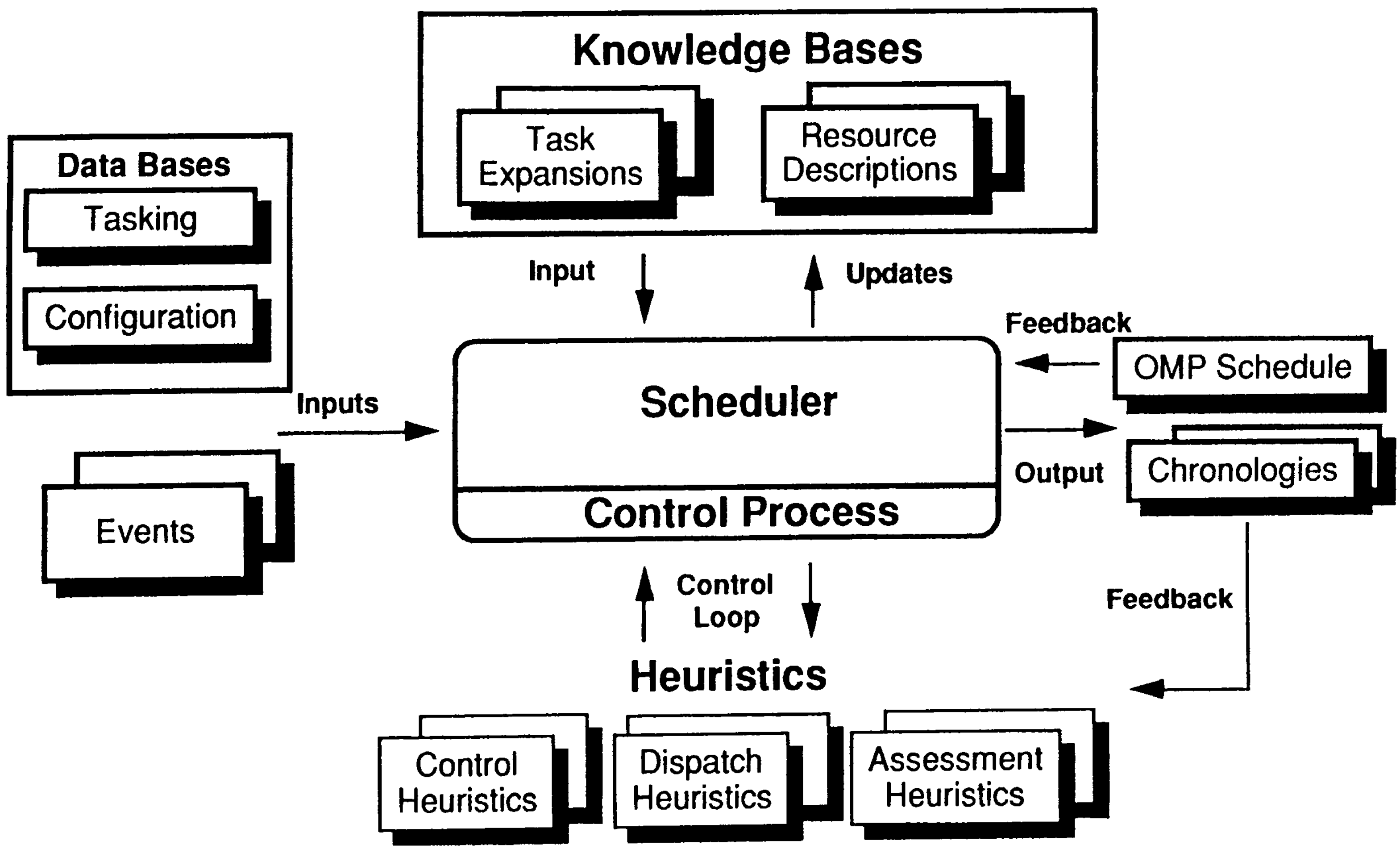
# OMP ARCHITECTURE

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## OMP Architecture

One of the major benefits of the use of AI in automated planning is the decoupling of the schedule model from the scheduling engine. This allows the addition of different types of tasks and resources without requiring changes to the scheduler. A generalized view of an intelligent scheduling system is given in the opposing view graph. The major components of the system are the knowledge bases, the data bases, the heuristics, and the schedule itself. The information in these distinct areas are integrated by the scheduling engine which produces the actual schedule.

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# SEARCH PARADIGMS

- **Hill Climbers**
  - **Quickly Finds a "Good" Schedule**
  - **Not Complete**
  - **Approaches to Local Maximum Problem**
    - Classical: Add Randomness
      Simulated Annealing
      Boltzman Machines (Neural Networks)
      Genetic Algorithms
    - Innovative: Varying Strategies
      Iterative Refinement
      Chronologies

## Search Paradigms

At its highest level of control, OMP is a "Hill Climber." Hill climbing is a search strategy where neighboring nodes are evaluated to identify the best next step to take to improve the schedule. Hill climbers are fast and generally find a "good" schedule, but they don't provide a complete search. The major flaw with hill climbers is that they get caught at local maximums.

The classical approach to solving the local maximum problem is to add randomness to the evaluation function (simulated annealing), thereby allowing the scheduler to move beyond the local maximum.

OMP's approach is to vary search strategies based a characterization of the problem area. Essentially, OMP changes the evaluation functions over the local regions in order to search using the most appropriate strategy.

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# SEARCH PARADIGMS CONT

- Hill Climber With Seven League Boots
  - Keep Speed of Hill Climber
  - Use to Find Non-Shallow Task Interleaving
  - Address Local Maximum Problem
  - Provide Depth Cutoff

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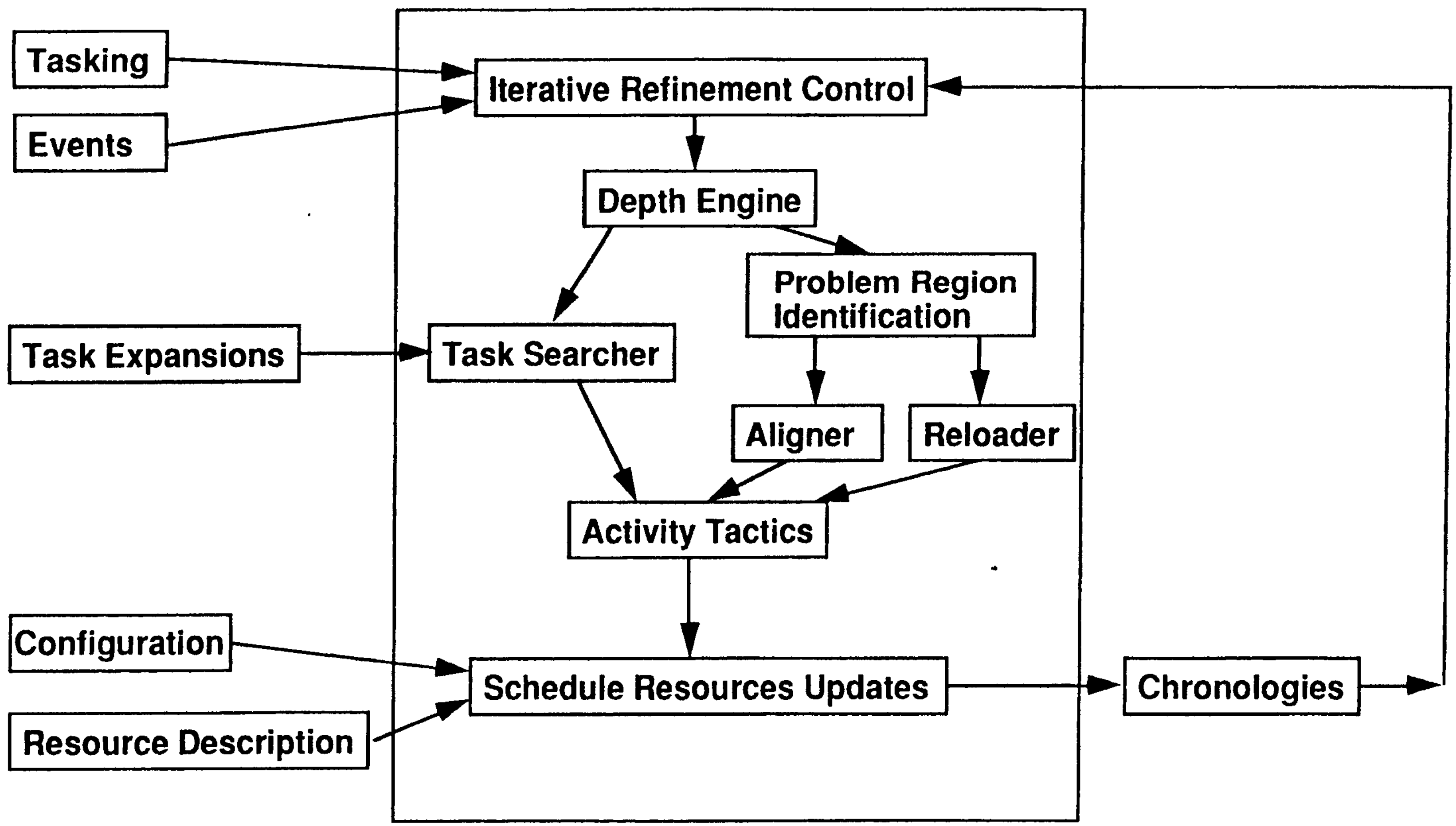
# OMP ARCHITECTURE - 2

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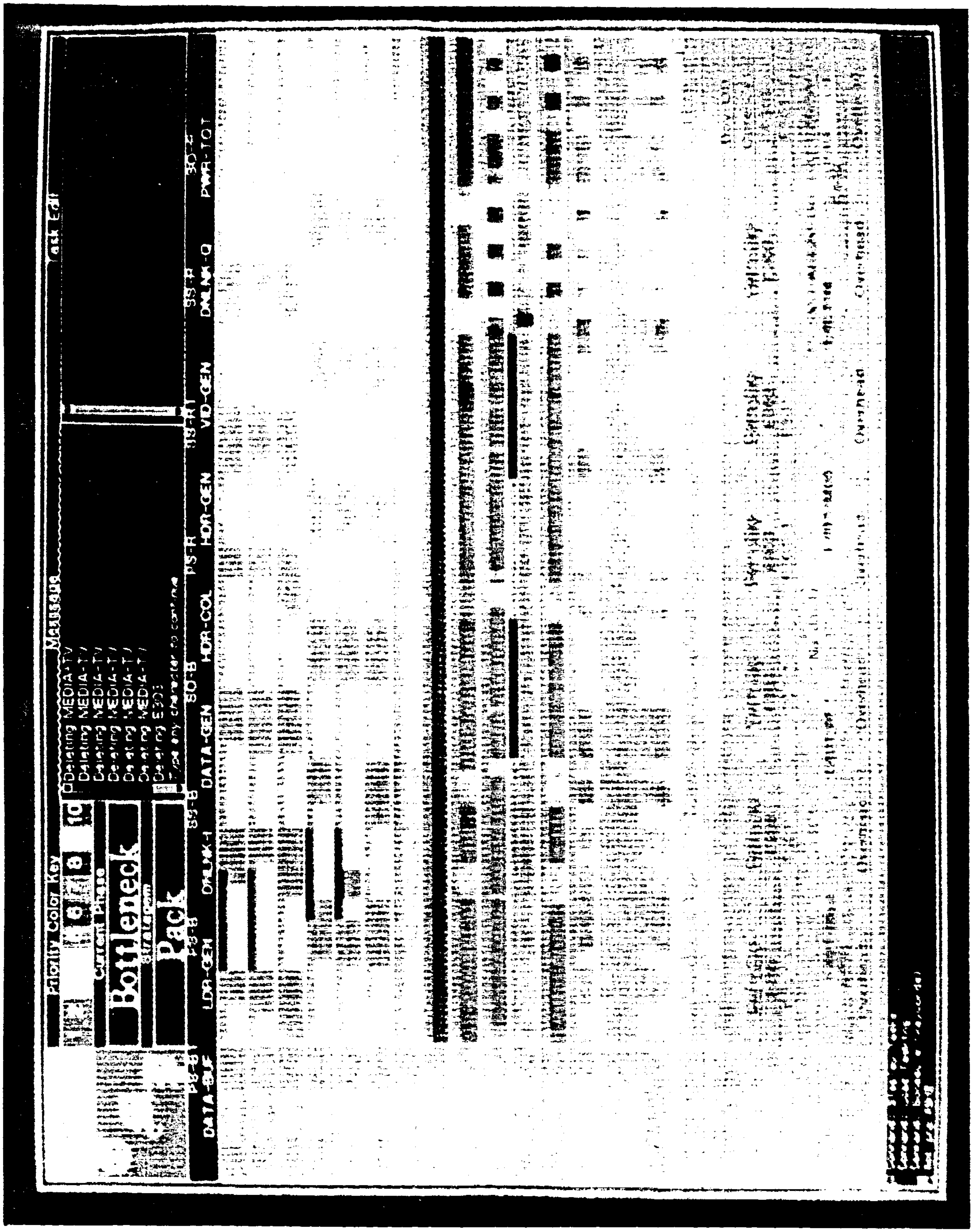
## OMP Architecture - 2

There exist many different scheduling heuristics that focus the search on a particular aspect of the schedule. While these techniques exhibit excellent performance in some cases, they are not universally applicable. Therefore, the scheduler must identify when a particular scheduling heuristic may be appropriate. The iterative refinement approach is based on making the most effective use of the various scheduling heuristics.

In using the search, there is a trade-off between power and time; the deeper the search, the longer the time required. The use of a deep search over the entire schedule is infeasible and unnecessary, but limiting the deep search to limited segments where a less powerful search is ineffective is productive without incurring unreasonable costs.

The chronology system provides the necessary information for the control heuristics to determine which scheduling heuristics to use and where. This provides the scheduler with the flexibility necessary to approach the variety of scheduling problems encountered in the generation of a single schedule. This, in turn, enables the scheduler to expend a greater amount of effort on tightly focused areas, thus producing a more effective schedule.




ORIGINAL PAGE IS
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# COMMON GRAPHICS SUBSTRATE

- Designed to Support Variety of Graphical Styles and Future Enhancements.
  - PLAN-IT
  - COMPASS
  - OMP
  - RALPH
- Portable (C++ & ADA)
  - X-Window
  - Macintosh
  - Microsoft Windows
  - PostScript
- Separates Graphics from Scheduling Engine

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## Common Graphics Substrate

During the past year a group of individuals from various NASA scheduling projects formed an informal working group to address issues in building portable scheduling graphics. The members of this group have built scheduling graphics in support of their research (PLAN-IT, COMPASS, OMP, and RALPH). While on the surface these graphical interfaces are not identical there is much commonality in their components. The results of this working group is an outline of a Scheduling Graphic Substrate. This substrate would support a verity of GUE features and be applicable for all of our different scheduling engines. It would also modularize the windowing system specific code to allow easier porting of the system from platform to platform.

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# OMP - COMPASS INTEGRATION
## Long Term Plan

- COMPASS Produces Request, OMP Generates Schedule, COMPASS Displays Results
  - Standardized I/O Data Representation
- Integrate OMP as COMPASS Button
  - OMP is Background Process of COMPASS
- Recode Selected Modules of OMP and Integrate Code into COMPASS
  - Ada
  - Standardized Internal Data Structures

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## OMP - COMPASS Integration

There are three stages to the OMP - COMPASS integration. In the first stage COMPASS builds a file of the schedule and the changes that need to be made in the schedule. OMP can then read this standardized file and modify the schedule. OMP will then produce a standardized file continuing the new schedule that COMPASS will then read in and display. The advantage of this approach is that it will be easy for other systems other than OMP to use the same techniques to preform joint test and demonstration with COMPASS.

In the second stage both OMP and COMPASS will be closely coupled. COMPASS will invoke the OMP module and pass it the schedule information. OMP will then represent the schedule in its own internal format, modify the schedule and return the results to COMPASS. COMPASS will once again display the results. In this stage OMP will be directly called by COMPASS (as a button or buttons on COMPASS display) and the data transfer will be by directly function call and return.

In the third stage selected modules of OMP are recoded into Ada. This code will directly use the COMPASS internal data structures and will become part of the COMPASS program.

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# INITIAL COMPASS - OMP

- Schedule Data in COMPASS Format
  - Data Sent Electronically to OMP
  - COMPASS to OMP Translator
  - Resulting Schedule Displayed by COMPASS
- Initial Test Case
  - Space Shuttle Simulator
  - One Week Schedule
  - 55 to 75 Request in a Week
  - About 20 Resources
  - Running Time 7 Minutes

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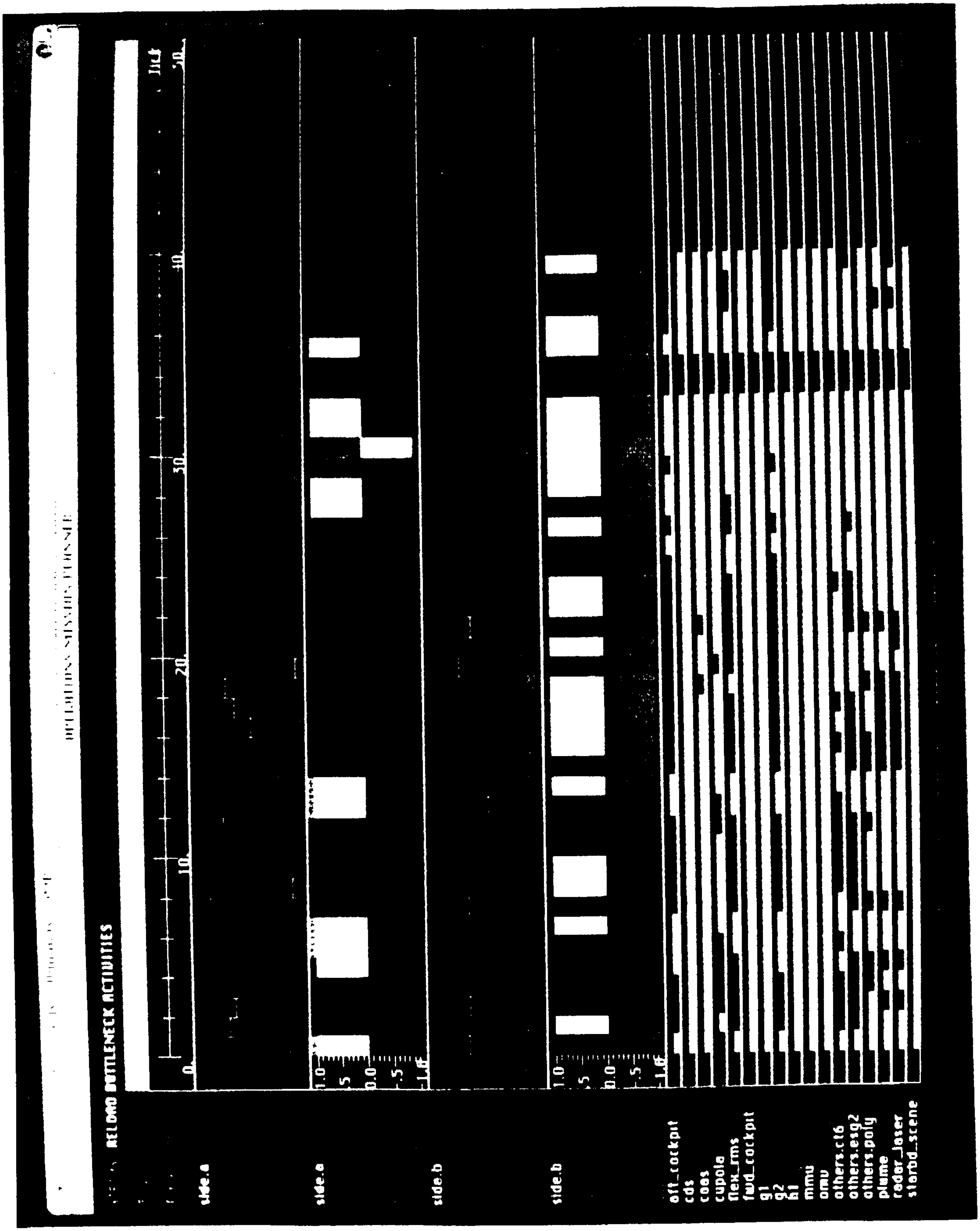
## Initial OMP - COMPASS

We have already sent a file continuing COMPASS output to OMP. OMP reads in this data and produces a modified schedule. The output will then be sent in a file back to COMPASS for redisplay.


RELOAD BOTTLENECK ACTIVITIES
side.a
side.a
side.b
side.b
aft_cockpit
cds
coas
cupola
flex_rms
fwd_cockpit
g1
g2
h1
mmu
omu
others.c16
others.exg2
others.poly
plume
radar_laser
starbd_scene

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# ACCOMPLISHMENTS (FY91)

- **Demonstrated New AI-based Scheduling Techniques**
  - Interleaved Interative Refinement
  - Bottleneck Identification using Process Chronologies
- **Developed MacOMP**
  - Received and parsed data from COMPASS
  - Ported OMP to Macintosh
- **Integrated OR Strategies into OMP**
  - Enhanced Chronology System
  - Strategies Produce Better Results then OMP I or II

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## Accomplishments (FY91)

In FY91 we have finished demonstrating the concepts of interleaved interative refinement and bottleneck identification using process chronologies. These concepts form the core of OMP architecture.

The newest concept demonstrated is the integration of Operation Research techniques with the chronology system. This will become the basis for out future work.

The new hardware platforms (SUN SPARC and Macintosh) have been procured and installed. The basic schedule representations are being ported to Common LISP and are being revised to support the newly designed scheduling engine. A set of graphical scheduling animation primitives have been implemented on the SUN SPARC and on the Macintosh workstations.

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# PLANS (FY92)

- Implement Generic Scheduling Interface Architecture
  - X-Windows/Sum MacToolBox/Macintosh
- Integrate Optimize Phase with OMP Chronology System
  - Next Generation OMP
- Demonstrate OMP III with COMPASS

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## Plans (FY92)

During FY91 we will complete the implementation of OMP on a SUN SPARC and Macintosh workstations. The new implementation of OMP will prototype the Load and Optimize phases of the general OMP scheduling theory. The basic representation of OMP will be expanded to include several new constraints (Renewable-Consumables, States) and will feature an extended version of its current goal planning capability

This new version of OMP will be transferred to Code MT by way of JSC's COMPASS scheduling system. A COMPASS generated schedule and a new unscheduled activity will be sent electronically to OMP where the schedule is modified to include the new activity. The resulting schedule is then sent to COMPASS to be displayed.

Other goals for this year include implementing the generic scheduling graphics substrate in both X-Windows.and the MacToolBox.

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# SUMMARY

- Extended State of the Art in AI-based Scheduling
  - Advanced Control of Search Process
  - Minimally Disruptive Replanning Demonstrated
- Established Interface with COMPASS
- Demonstrated OMP Techniques on SSF-relevant Domains

## Summary

The demonstration of multiple classes of scheduling knowledge, the use of chronologies to identify scheduling bottlenecks, the classification of these bottlenecks in determining which type of scheduling heuristic to use, and the interleaving of finding and solving bottlenecks, were all major research objectives demonstrated in the OMP prototype. This prototype was tested using COMPASS supplied data from a real world scheduling problem. The purpose of developing these techniques is to show the feasibility of an automatic scheduler which can use the knowledge gained in trying to construct a schedule and which operates by continually modifying an existing schedule. These techniques allow the construction of automatic schedulers which will be able to quickly and optimally construct large and complex schedules. The same systems will also be able to maintain the schedule in a minimally disruptive manner.