

AI Planning in Context

**AI Planning in the Context of Domain Modelling,
Task Assignment and Execution**

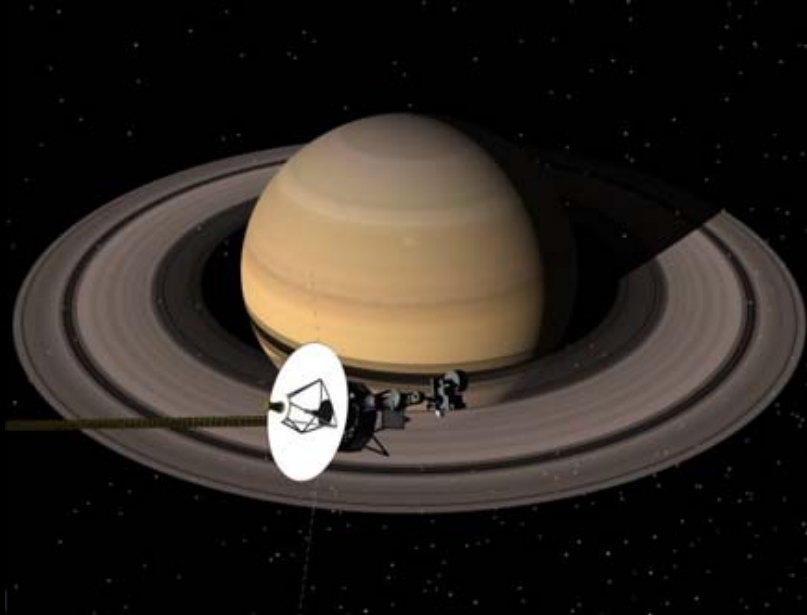
Overview

- Context of Practical Systems
- Context of Task Assignment & Execution
- Context of Multiple Agents
- Context of Plan Representation & Use
- Example Practical Planners
- Planning++

Overview

➡ Context of Practical Systems

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Practical AI Planners

<i>Planner</i>	<i>Reference</i>	<i>Applications</i>
STRIPS	Fikes & Nilsson 1971	Mobile Robot Control, etc.
HACKER	Sussman 1973	Simple Program Generation
NOAH	Sacerdoti 1977	Mechanical Engineers Apprentice Supervision
NONLIN	Tate 1977	Electricity Turbine Overhaul, etc.
NASL	McDermott 1978	Electronic Circuit Design
OPM	Hayes-Roth & Hayes-Roth 1979	Journey Planning
ISIS-II	Fox et. al. 1981	Job Shop Scheduling (Turbine Production)
MOLGEN	Stefik 1981	Experiment Planning in Molecular Genetics
DEVISER	Vere 1983	Spacecraft Mission Planning
FORBIN	Miller et al. 1985	Factory Control
SIPE-2	Wilkins 1988	Oil Spill Response, Military Planning, etc.
O-Plan	Currie & Tate 1991	Search and Rescue, Spacecraft Operations, etc.
SHOP/SHOP-2	Nau et al. 1999	Evacuation Planning, Forest Fires, Bridge Baron, etc.
I-X/I-Plan	Tate et al. 2000	Emergency Response, etc.

Course Reading

- **Review of AI Planners to 1990**

- Hendler, J.A., Tate, A. and Drummond, M. (1990) "AI Planning: Systems and Techniques", AI Magazine Vol. 11, No. 2, pp.61-77, Summer 1990, AAAI Press.
- <http://aaaipress.org/ojs/index.php/aimagazine/article/download/833/751>

- **Knowledge-Based Planners**

- Wilkins, D. E. and desJardins, M. (2001) "A Call for Knowledge-based Planning", AI Magazine, Vol. 22, No. 1, pp. 99-115, Spring 2001, AAAI Press.
- <http://www.aaai.org/ojs/index.php/aimagazine/article/view/1547/> or http://www.ai.sri.com/pub_list/808

- **O-Plan Paper**

- Tate, A. and Dalton, J. (2003) "O-Plan: a Common Lisp Planning Web Service", invited paper, in Proceedings of the International Lisp Conference 2003, October 12-25, 2003, New York, NY, USA, October 12-15, 2003.
- <http://www.aiai.ed.ac.uk/project/ix/documents/2003/2003-luc-tate-oplan-web.pdf>

- **Optimum-AIV Paper**

- Tate, A. (1996) "Responsive Planning and Scheduling Using AI Planning Techniques – Optimum-AIV", in "Trends & Controversies – AI Planning Systems in the Real World", IEEE Expert: Intelligent Systems & their Applications, Vol. 11 No. 6, pp. 4-12, December 1996.
- <http://www.aiai.ed.ac.uk/project/oplan/documents/1996/96-ieee-is-trends-and-controversies-orig.pdf>

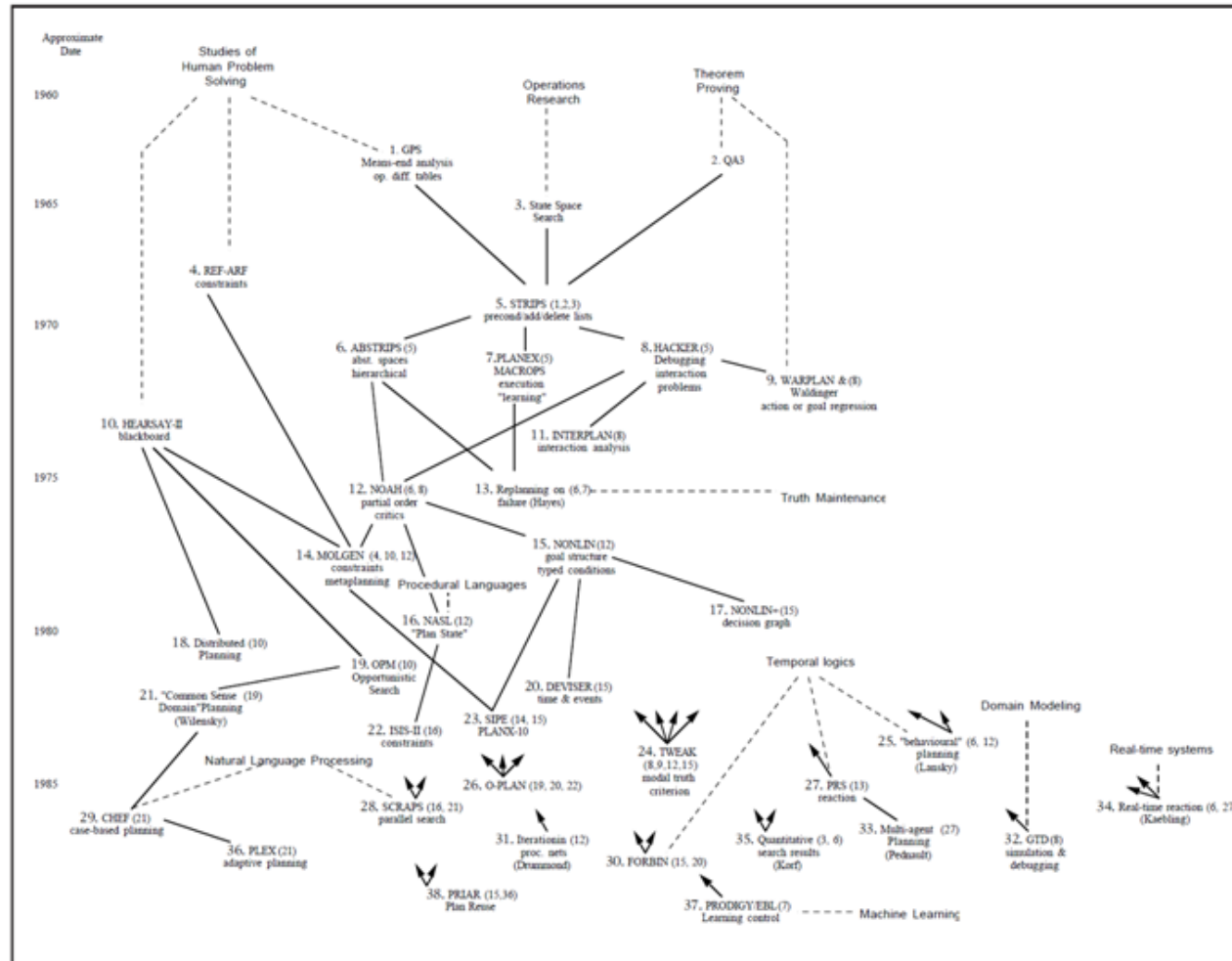
- **SHOP/SHOP2 Applications Paper**

- Nau, D., Au, T.-C., Ilghami, O., Kuter, U., Wu, D., Yaman, F., Muñoz-Avila, H., and Murdock, J.W. (2005) Applications of SHOP and SHOP2, IEEE Intelligent Systems, March-April 2005, Vol. 20, No. 2, pp.34-41, Computer Society.
- <http://www.cs.utexas.edu/~chiu/papers/Nau05shop2.pdf>

- **Other Practical Planners**


- Ghallab, M., Nau, D. and Traverso, P. (2004) "Automated Planning – Theory and Practice", Chapters 19, 22 and 23, Elsevier/Morgan Kaufmann.

Origins of some well known AI Planners

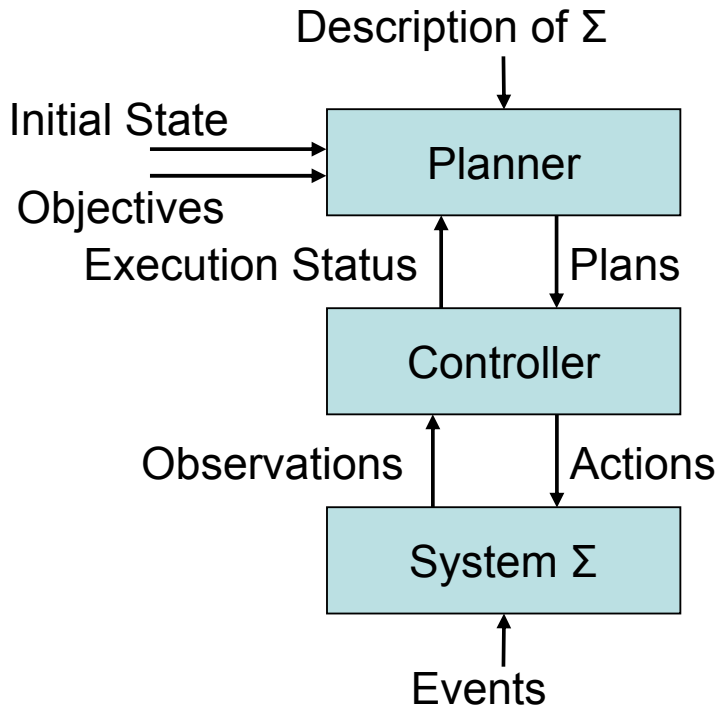


Hendler, Tate and Drummond,
AI Magazine, 1990

Overview

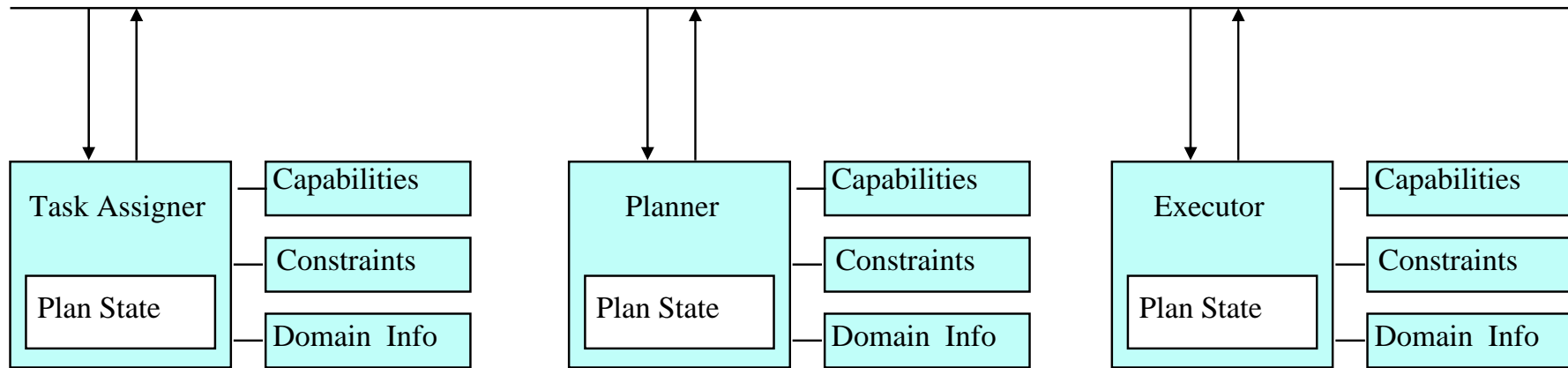
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Dynamic Planning



- problem: real world differs from model described by Σ
- more realistic model: interleaved planning and execution
 - plan supervision
 - plan revision
 - re-planning
- dynamic planning: closed loop between planner and controller
 - execution status

O-Plan 3 Levels of Agents: Task Assignment, Planning & Execution



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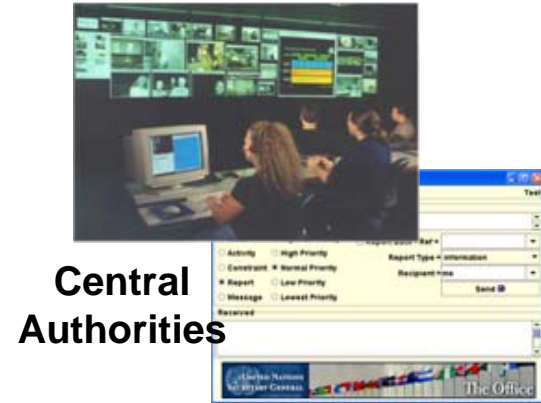
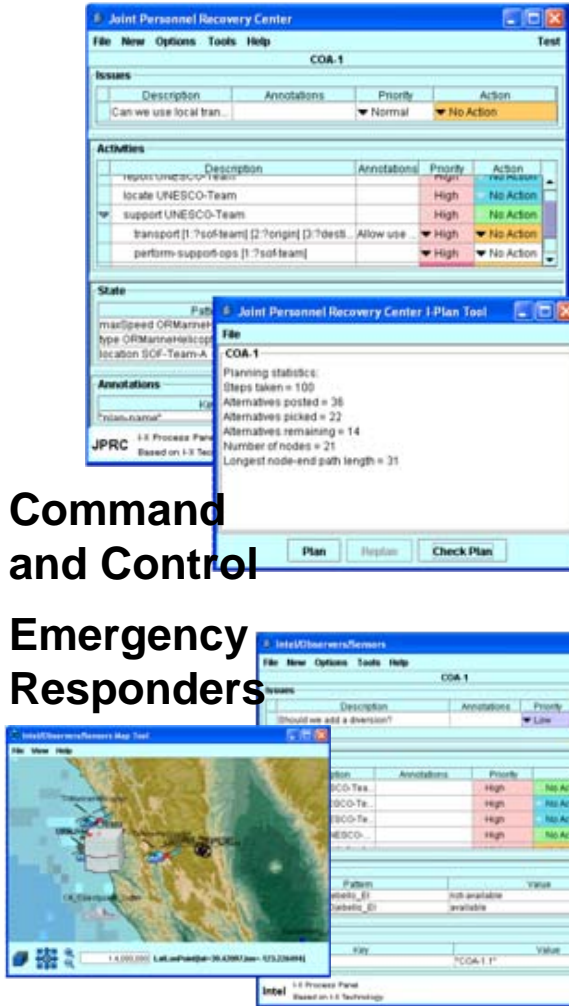
Multiple-Agent Platforms behind some Practical AI Planners

- Multiple Planning Agents (MPA) platform is the basis for the SRI International SIPE-2 Planner
- The Open Planning Architecture is the basis for O-Plan and is designed to handle multiple planner roles and levels, such as task assigner, planner, planning specialists, plan execution
- I-X is intended to support multiple types of command, sense-making, analysis, planning (I-Plan), decision making, execution and communications agents even in mixed agent frameworks.

Multiple Agents in the Context of Communications for Emergency Response

Collaboration and Communication

Command
and Control
Emergency
Responders



Example I-X Multiagent Applications

Commander Process Panel

File New Edit Tools Help

Issues

Description	Annotations	Priority	Action

Activities

Description	Annotations	Priority	Action
treat-injuries Town1	Executing	Normal	Execute task
treat-injuries Town2		Normal	
take-snapshot-and-return To...	Done	Normal	
take-snapshot-and-return To...	Done	Normal	
build-mobile-hospital Beacon1	Done	Normal	

Done
N/A
Refine using treat-injuries
Pass to SenseMaker
Delegate to UAVControl1
Delegate to UAVControl2
Delegate to Medic1
Delegate to Medic2
Delegate to Builder1
Delegate to TruckDriver1
Delegate to TruckDriver2
Delegate to TruckDriver3
Delegate to TruckDriver4
Execute Task



Coalition Search and Rescue Coordinator

File New Tools Help

Issues

Description	Annotations	Priority	Action
are country and sar-res...		Normal	No Action

Activities

Description	Annotations	Priority	Action
rescue F15-Pilot sea burns 18.0 40.0		High	Expand usin...
select-hospital burns [1.?hospital]		High	Expand usin...
establish [4.?med-capability:Bu...		High	Done
lookup-hospitals [4.?med-cap...		High	No Action
select [1.?hospital]		High	No Action
establish-country [1.?hospital] [2.?...		High	Done
select-sar-resource sea [2.?count...		High	N/A
notify [3.?sar-resource] F15-Pilot 1...		High	Invoke hospitals
notify [1.?hospital] F15-Pilot burns		High	Escalate to Binli-CFC


State

description	Value
PilotDownLand	Mirage
condition PilotDownLand	fractures
altitude PilotDownLand	500m
latitude PilotDownLand	14.00
longitude PilotDownLand	34.00

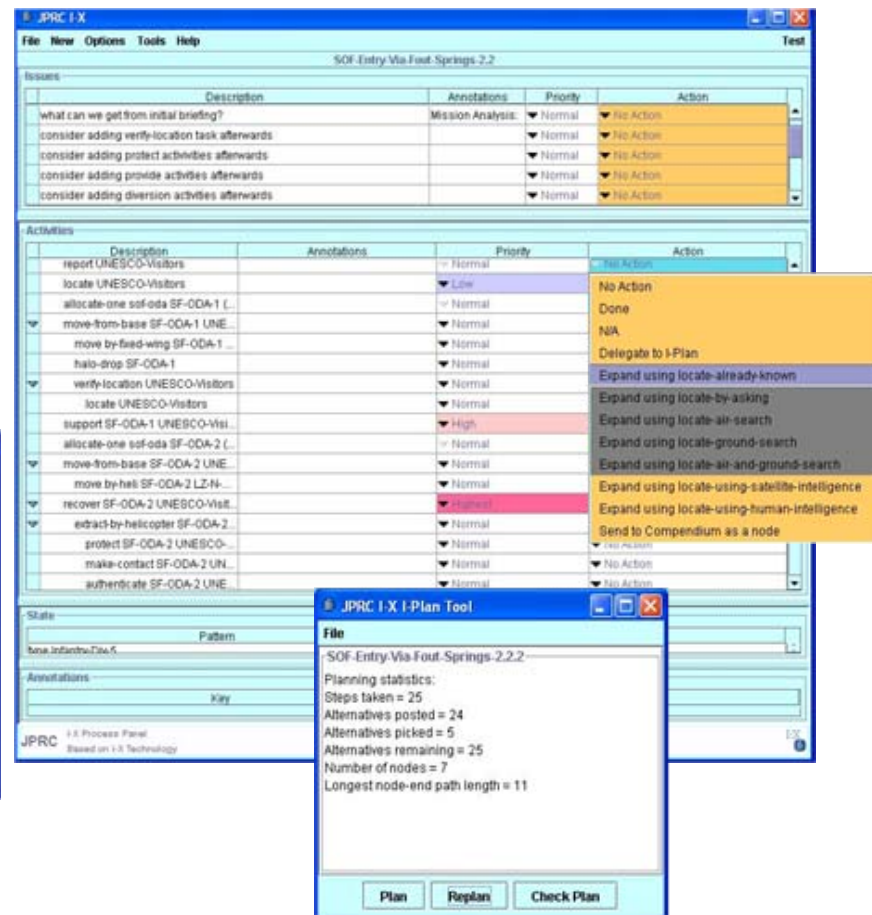
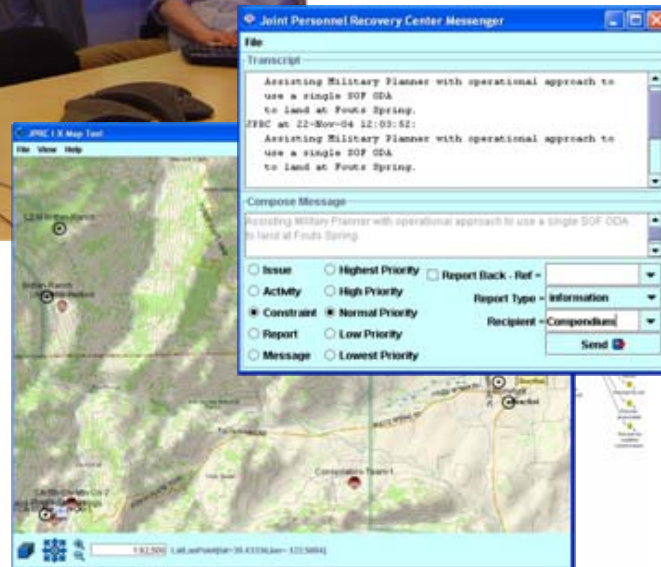
Map Visualisation Close Map

CoSAR I-X Process Panels Based on I-X Technology

US-SAR I-X Process Panel Based on I-X Technology



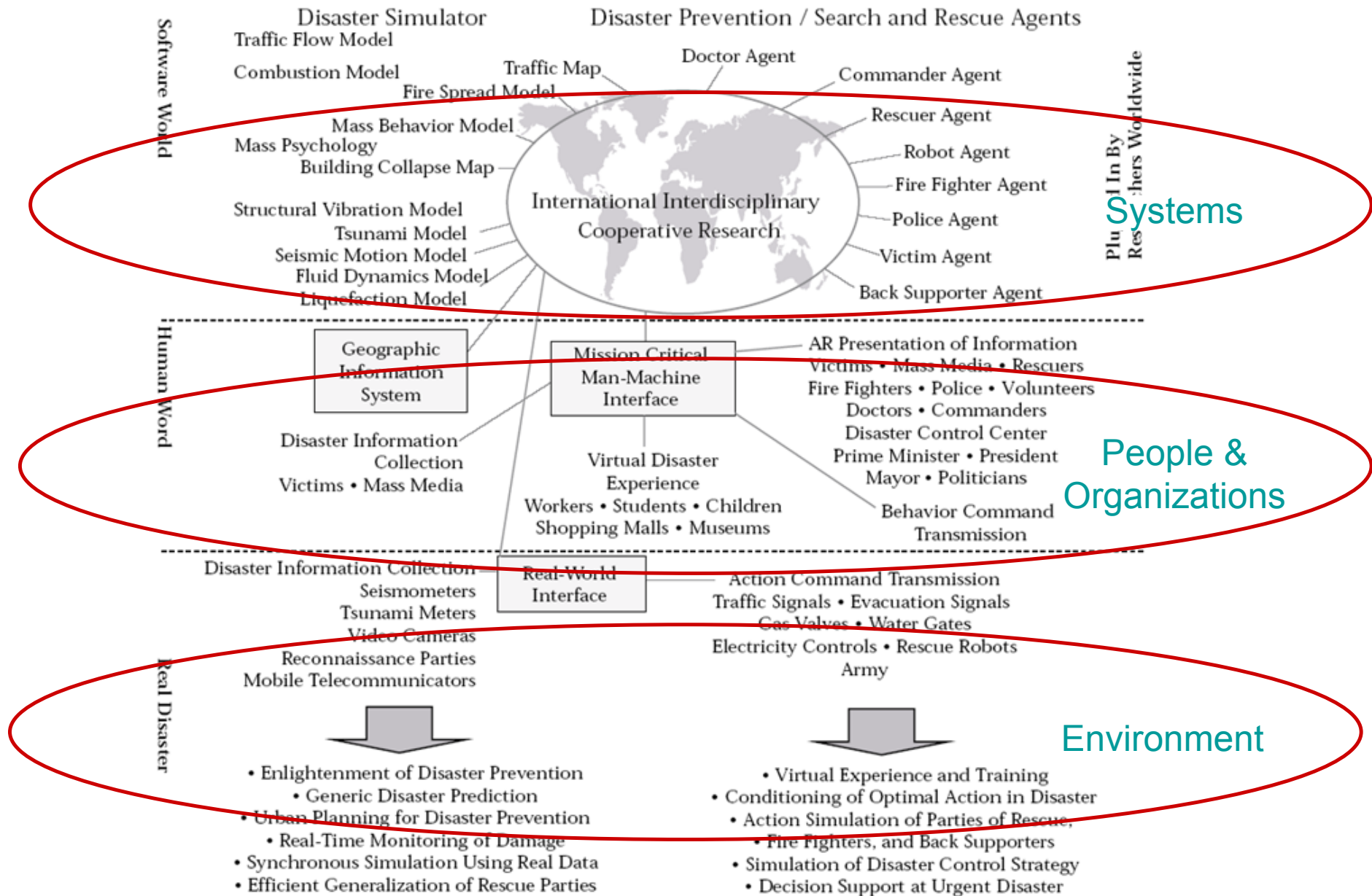
Example I-X Multiagent Applications



Example I-X Multiagent Applications

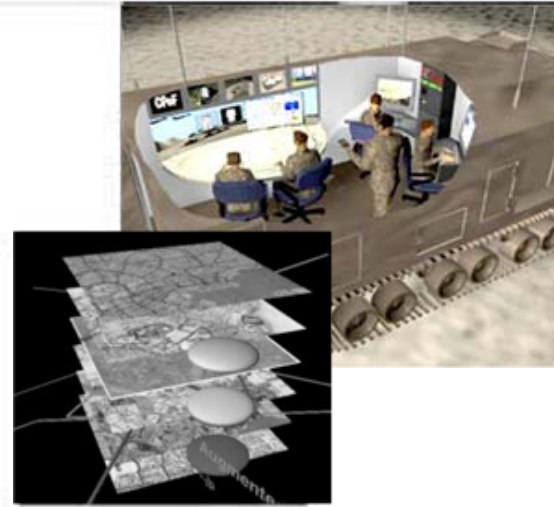
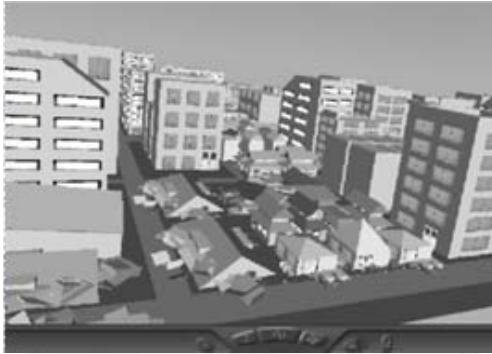
You can view video demonstrations of a couple of sample applications of I-X in the context of multiagent systems

- CoSAR-TS: Coalition Search & Rescue Task Support
- I-Globe: Planning and Execution in a Dynamic multiagent environment



Command, Control, and Communication

Simulation and Decision Support System



Data Collection



Rescue Robots



PDA



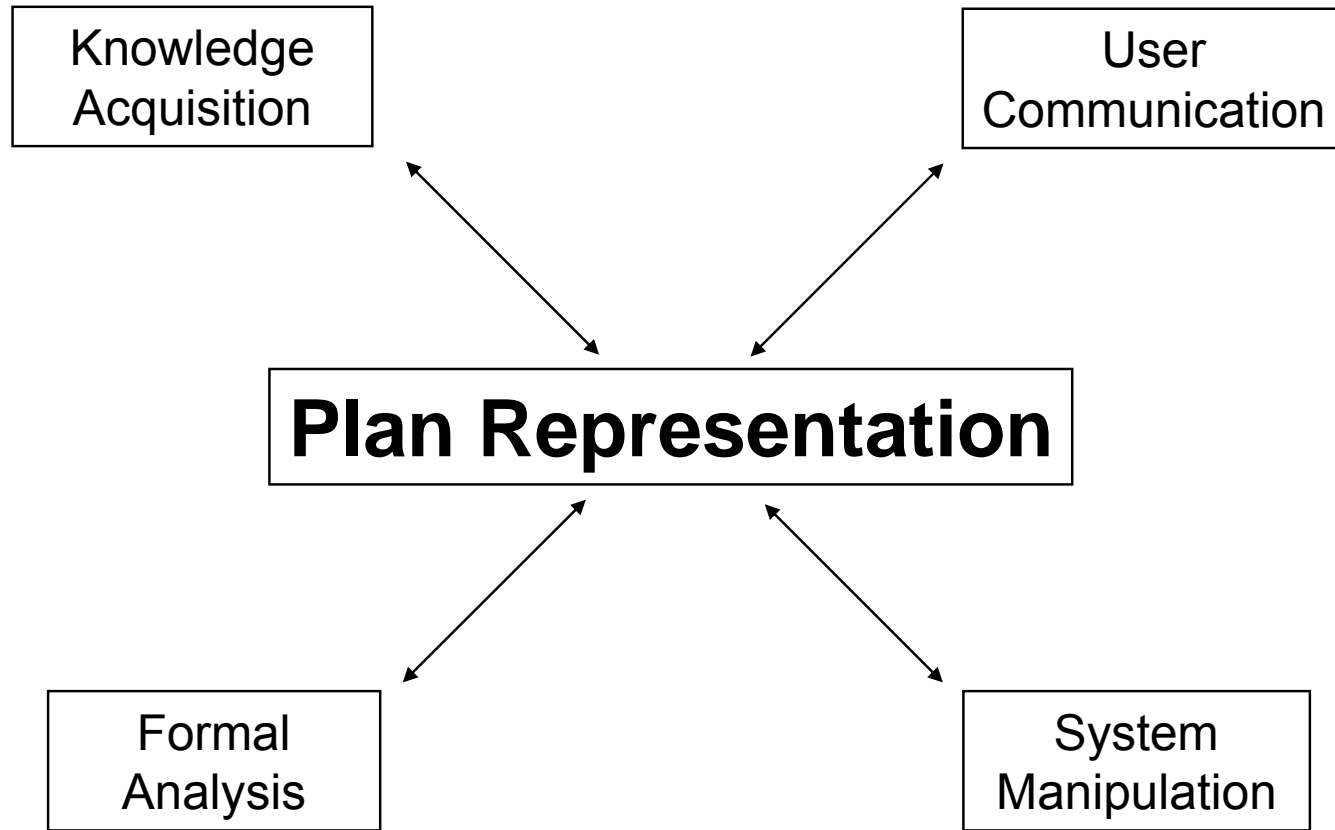
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Plan Representation & Use

- Plan representation itself an important area.
- Plans are used in many areas beyond activity planning ... such as situation understanding and summarisation, natural language interpretation and generation, etc.
- Plans provide an ontological and formal representation core for a wide range of practical applications and uses.

Uses of a Plan Representation



Plan Representation & Use

- AI planning work has influenced standards related to process and plan representations used by many industries and fields. E.g.,
 - MIT Process Handbook Process Interchange Format (PIF)
 - NIST Process Specification Language (PSL)
 - DARPA Shared Planning & Activity Representation (SPAR)
 - ISO 18629 Industrial Automation Systems and Integration - Process Specification Language

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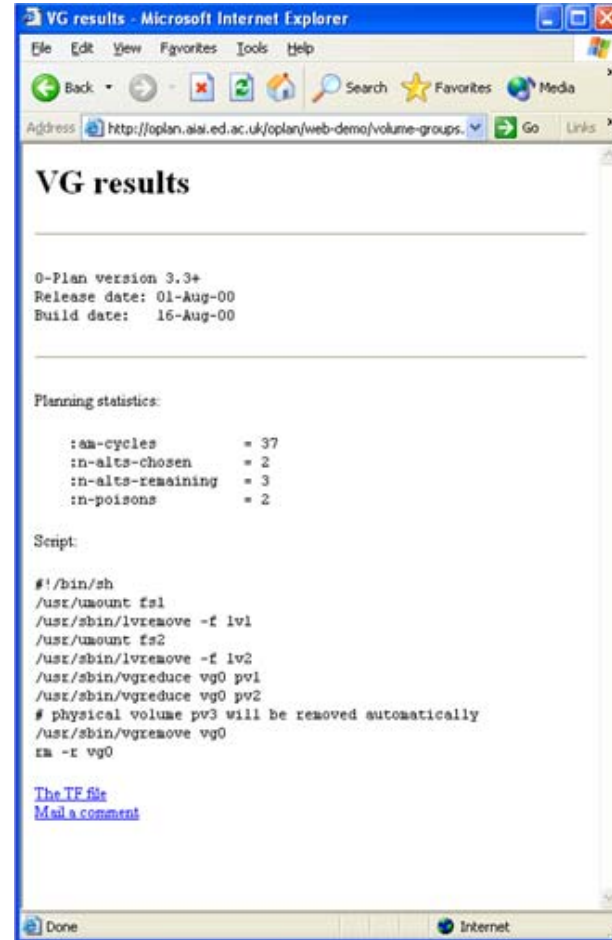
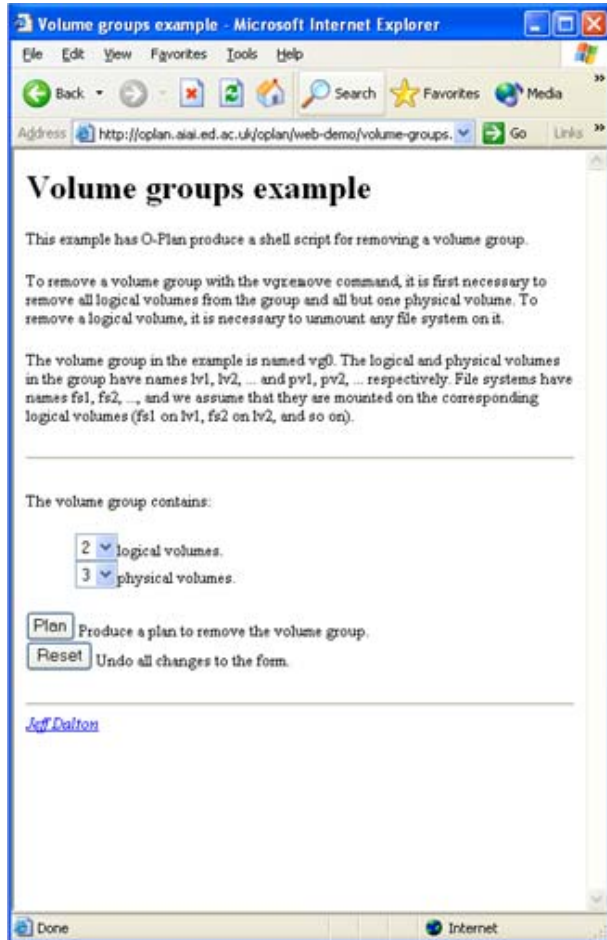
Nonlin (1974-1977)

- Hierarchical Task Network Planning
- Partial Order Planner
- Plan Space Planner
- Goal structure-based plan development – only considers alternative “approaches” based on plan rationale
- QA/“Modal Truth Criterion” condition achievement
- Condition “types” to limit search
- Allows for multiple “contributors” to achieve facts for plan robustness
- “Compute Conditions” for links to external data bases and systems (attached procedures)
- Operations Research algorithms for time and resource constraints
- Nonlin core is a basis for text book descriptions of HTN Planning

O-Plan (1983-1999) Features

- Domain knowledge elicitation and modelling tools
- Rich plan representation and use
- Hierarchical Task Network Planning
- Detailed constraint management
- Goal structure-based plan monitoring
- Dynamic issue handling
- Plan repair in low and high tempo situations
- Interfaces for users with different roles
- Management of planning and execution workflow

O-Plan Unix Sys Admin Aid



O-Plan MOUT Task Description, Planning and Workflow Aids

O-Plan Task Assigner - COA-2 Definition - Microsoft Internet ...

File Edit View Favorites Tools Help

Back Forward Stop Reload Search Favorites Media

Address http://oplan.aii.ed.ac.uk:40017/gpdt3/ta/coa-def/2 Go Links

[Simple process editor](#) | [<N-OYA> process editor screen](#)

Objectives

1	evacuate injured	Abyss
2	evacuate injured	Barnacle
3	evacuate injured	Calypso
4	repair gas leak	Barnacle
5		

Situation

Weather	Time Limit	Road Delta Abyss	Road Abyss Barnacle	Road Barnacle Calypso	Road Calypso Delta
clear	24	open	open	open	open

[Define COA 2](#) [Undo changes to form](#) [Back to matrix without change](#)

COA objectives

COA	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5
1	Evacuate injured Abyss	Evacuate injured Barnacle	Evacuate injured Calypso	Repair gas leak Barnacle	

Done Internet

O-Plan Task Assigner - COA Evaluation Matrix - Microsoft Inte...

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Address http://oplan.aii.ed.ac.uk:40017/gpdt3/ta/matrix Reload

[Restart](#) | [Help](#) | [Map](#) | [Scenario](#) | [TF file](#) | [Server status](#) | [Select COA](#) | [Select evaluations](#) | [Exit](#)

[Add COA](#)

Define task: COA-1
Split COA: [Split](#)
Add to task: [Add](#)
Set authority: Auth
Generate plan: Plan
actions in plan: 132
levels in plan: 3
longest path length: 113
minimum duration: 17 hrs
effectiveness: 77%
Address issues: 3
View plan: [View](#)

COA objectives

COA	Objective 1	Objective 2	Objective 3	Objective 4
1	Evacuate injured Abyss	Evacuate injured Barnacle	Evacuate injured Calypso	Repair gas leak Barnacle

COA initial situations

COA	Weather	Time Limit	Road Delta Abyss	Road Abyss Barnacle	Road Barnacle Calypso	Road Calypso Delta
1	clear	24	open	open	open	open

The default is used as a base

Internet

O-Plan Planner - COA Evaluation Matrix - Microsoft Internet ...

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Address http://oplan.aii.ed.ac.uk:40017/gpdt3/p/matrix Reload

[Help](#) | [Map](#) | [Scenario](#) | [TF file](#) | [Server status](#) | [Select evaluations](#) | [Logout](#) | [Reload](#)

	COA-2.1	COA-2.2	COA-2.3	COA-2.4
Advise planner:	Advise	Advise	Advise	Advise
Add constraints:	Add	Add	Add	Add
Set authority:	Auth	Auth	Auth	Auth
Generate plan:	Replan	Replan	Replan	Replan
actions in plan	33	33	33	33
levels in plan	3	3	3	3
longest path length	69	57	57	41
minimum duration	10 hrs	9 hrs	9 hrs	7 hrs
object types	6	7	7	8
object values	2	2	2	10
effectiveness	89%	91%	91%	94%
Address issues:	1	1	1	1
View plan:	View	View	View	View
Select for return:	Yes	Yes	Yes	Yes

[Return plans](#)

COA objectives

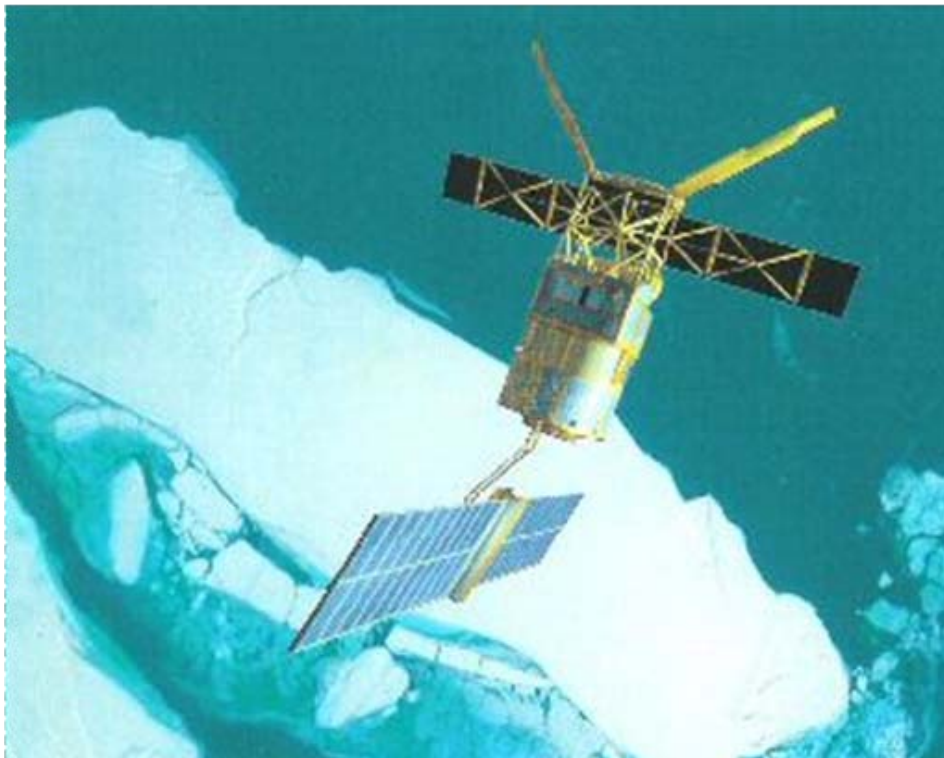
COA	Objective 1	Objective 2	Objective 3	Objective 4	Objective 5
2.1	Send medical supplies Abyss	Evacuate injured Barnacle	Send medical supplies Calypso	Repair gas leak Barnacle	
2.2	Send medical supplies Abyss	Evacuate injured Barnacle	Send medical supplies Calypso	Repair gas leak Barnacle	
2.3	Send medical supplies Abyss	Evacuate injured Barnacle	Send medical supplies Calypso	Repair gas leak Barnacle	
2.4	Send medical supplies Abyss	Evacuate injured Barnacle	Send medical supplies Calypso	Repair gas leak Barnacle	

Internet

Try out O-Plan as an Example Planner

- Web accessible HTN AI Planner: See <http://www.aiai.ed.ac.uk/project/oplan/web-demo/>
- Try the Unix Systems administration script generator. Consider other applications for which this generation technique may be suitable.
- Try a few block stacking examples, and ponder why the “Sussman Anomaly” task was not able to be solved by early AI planners.
- Try the “three pigs” resource constrained house building examples. Look at the domain and task description file. Can you explain why some tasks need little or no search and others more? Why does one task have no solution in the given domain?
- :am-cycles = Agenda management cycles (problem solving cycles)
- :n-alts-chosen = Number of alternatives chosen. 0 means the planner had no search at all
- :n-alts-remaining = Number of alternatives remaining. Indicating choices possible.
- :n-poisons = Number of dead ends reached (diagnostic - should be same as :n-alts-chosen)

Optimum-AIV



Optimum-AIV (1992-4) Features

- Based on O-Plan design
- Rich plan representation and use
- Hierarchical Task Network (HTN) Planning
- Detailed constraint management
- Plan and User rationale recorded
- Dynamic issue handling
- Plan repair using test failure recovery plans
- Integration with ESA's Artemis Project Management System

Typical Features of Practical AI Planners

- Hierarchical Task Network (HTN) Planning
- Partial Order Planning (POP)
- Rich domain model
- Detailed constraint management, simulations and analyses
- Integration with other systems (user interfaces, databases, spreadsheets, project management systems, etc).

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Planning Research Areas & Techniques

– Domain Modelling	HTN, SIPE-2	– Plan Repair	O-Plan
– Domain Description	PDDL, NIST PSL	– Re-planning	O-Plan
– Domain Analysis	TIMS	– Plan Monitoring	O-Plan, IPEM
– Search Methods	Heuristics, A*	– Plan Generalisation	Macrops, EBL
– Graph Planning Algtms	GraphPlan	– Case-Based Planning	CHEF, PRODIGY
– Partial-Order Planning	Nonlin, UCPOP	– Plan Learning	SOAR, PRODIGY
– Hierarchical Planning	NOAH, Nonlin, O-Plan	– User Interfaces	SIPE-2, O-Plan
– Refinement Planning	Kambhampati	– Plan Advice	SRI/Myers
– Opportunistic Search	OPM	– Mixed-Initiative Plans	TRIPS/TRAINS
– Constraint Satisfaction	CSP, OR, TMMS	– Planning Web Services	O-Plan, SHOP2
– Optimisation Method	NN, GA, Ant Colony Opt	– Plan Sharing & Comms	I-X, <I-N-C-A>
– Issue/Flaw Handling	O-Plan	– NL Generation	...
– Plan Analysis	NOAH, Critics	– Dialogue Management	...
– Plan Simulation	QinetiQ		
– Plan Qualitative Modelling	Excalibur		

**Deals with whole
life cycle of plans**

Planning Research Areas & Techniques

– Domain Modelling	HTN, SIPE-2	– Plan Repair	O-Plan
– Domain Description	PDDL, NIST PSL	– Re-planning	O-Plan
– Domain Analysis	TIMS	– Plan Monitoring	O-Plan, IPEM
– Search Methods	Heuristics, A*	– Plan Generalisation	Macrops, EBL
– Graph Planning Algtms	GraphPlan	– Case Based Planning	CHEF, PRODIGY
– Partial-Order Planning	Nonlin, USPOP	– Plan Learning	SOAR, PRODIGY
– Hierarchical Planning	NOAH, Nonlin, O-Plan	– User Interfaces	SIPE-2, O-Plan
– Refinement Planning	Kambhampati	– Plan Advice	SRI/Myers
– Opportunistic Search	QIM	– Mixed-Initiative Plans	TRIPS/TRAINS
– Constraint Satisfaction	OSP, OR, TIMS	– Planning Web Services	O-Plan, SHOP2
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– Issue/Flaw Handling	O-Plan	– NL Generation	...
– Plan Analysis	NOAH, Critics	– Dialogue Management	...
– Plan Simulation	QinetiQ		
– Plan Qualitative Modelling	Excalibur		

Problem is to make sense of all these techniques

**Deals with whole
life cycle of plans**

A More Collaborative Planning Framework

- Human relatable and presentable objectives, issues, sense-making, advice, multiple options, argumentation, discussions and outline plans for higher levels
- Detailed planners, search engines, constraint solvers, analyzers and simulators act in this framework in an understandable way to provide feasibility checks, detailed constraints and guidance
- Sharing of processes and information about process products between humans and systems
- Current status, context and environment sensitivity
- Links between informal/unstructured planning, more structured planning and methods for optimisation

I-X/I-Plan (2000-)

- Shared, intelligible, easily communicated and extendible conceptual model for objectives, processes, standard operating procedures and plans:
 - I Issues
 - N Nodes/Activities
 - C Constraints
 - A Annotations
- Communication of dynamic status and presence for agents, and their collaborative processes and process products
- Context sensitive presentation of options for action
- Intelligent activity planning, execution, monitoring, re-planning and plan repair via I-Plan and I-P² (I-X Process Panels)

I-X aim is a Planning, Workflow and Task Messaging “Catch All”

- Can take ANY requirement to:
 - Handle an issue
 - Perform an activity
 - Respect a constraint
 - Note an annotation
- Deals with these via:
 - Manual activity
 - Internal capabilities
 - External capabilities
 - Reroute or delegate to other panels or agents
 - Plan and execute a composite of these capabilities (I-Plan)
- Receives reports and interprets them to:
 - Understand current status of issues, activities and constraints
 - Understand current world state, especially status of process products
 - Help user control the situation
- Copes with partial knowledge of processes and organisations

I-X for Emergency Response

Process Panel

Domain Editor

Map Tool

The screenshot displays the JPRC I-X software interface, which is used for emergency response planning. The interface is divided into several main windows:

- Domain Editor:** This window on the left shows a list of tasks and a central workspace for creating a process flow. The task list includes various recovery actions like "provide communication", "provide medical advice", "provide medical supplies", "provide medical team", "provide other support", "provide technical advice", "recover by civilian means", "recover by gray force", "recover by negotiation", "recover by self", "recover covertly", and "rescue". The central workspace shows a flowchart with nodes and connecting lines.
- Process Panel:** This window in the top center shows a mission analysis table with columns for "Annotations" and "Priority". It lists various mission tasks and their associated priorities.
- Map Tool:** This window on the right shows a topographic map of a mountainous region. It includes a scale bar and a legend. A yellow box highlights the "Expand using locate-using-satellite-intelligence" and "Expand using locate-using-human-intelligence" options.
- Messenger:** This window at the bottom left shows a transcript of messages and a "Compose Message" section. The transcript includes a message from "JPRC at 22-Nov-04 12:03:52" regarding a military planner's approach to land at Fouts Spring. The "Compose Message" section allows users to select the message type (Issue, Activity, Constraint, Report, Message) and priority (Highest, High, Normal, Low, Lowest), and to specify the report type and recipient.
- I-Plan:** This window at the bottom right shows planning statistics for the "SOF-Entry-Via-Fouts-Springs-2.2.2" mission. The statistics include: Steps taken = 25, Alternatives posted = 24, Alternatives picked = 5, Alternatives remaining = 25, Number of nodes = 7, and Longest node-end path length = 11. It also includes buttons for "Plan", "Replan", and "Check Plan".

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