


COMP 141: Probabilistic Robotics for Human-Robot Interaction

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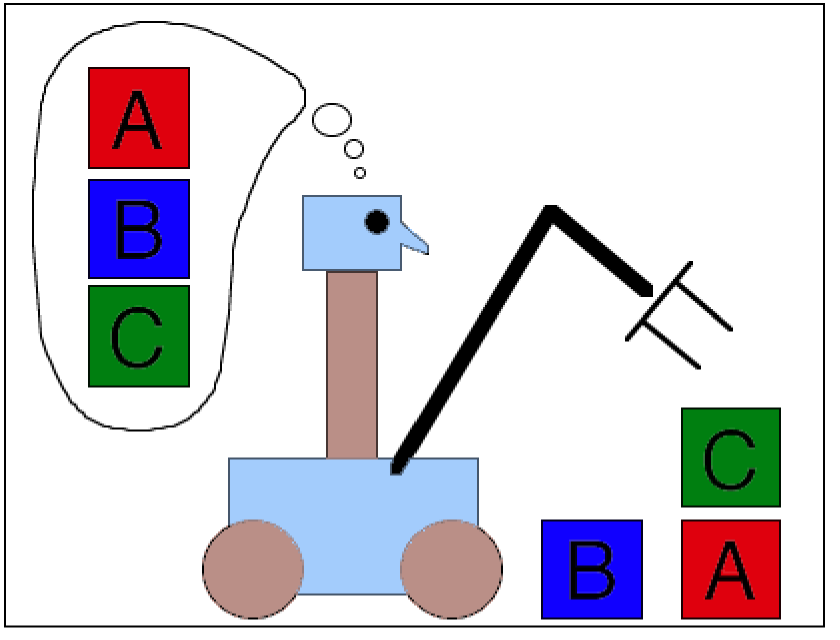
Next up: Planning



Announcements

Research Article Presentation

- Sign-up for research article presentation

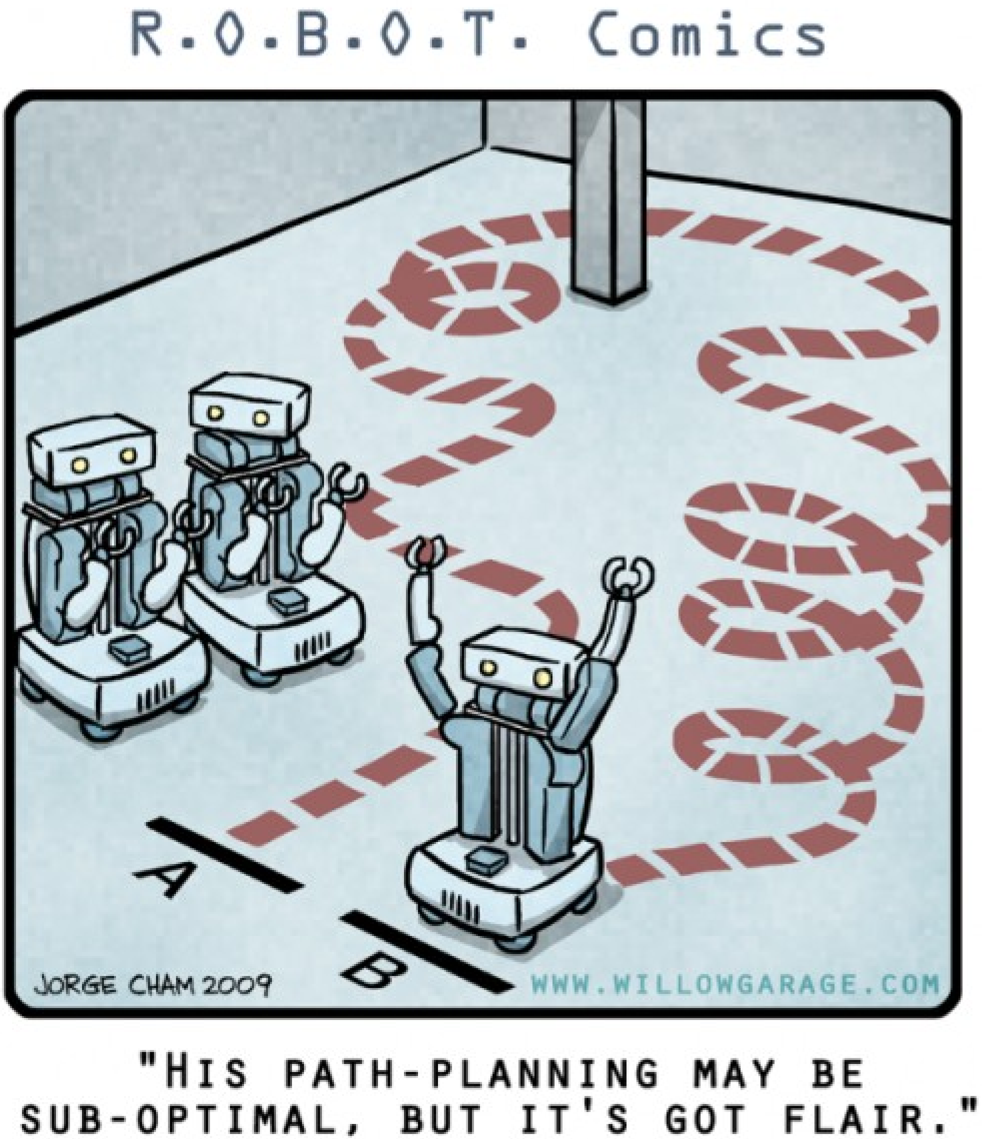
Reading Assignment

Khandelwal, P., Zhang, S., Sinapov, J., Leonetti, M., Thomason, J., Yang, F., Gori, I., Svetlik, M., Khante, P., Lifschitz, V., Aggarwal, J.K., Mooney, R., and Stone, P. (2017)

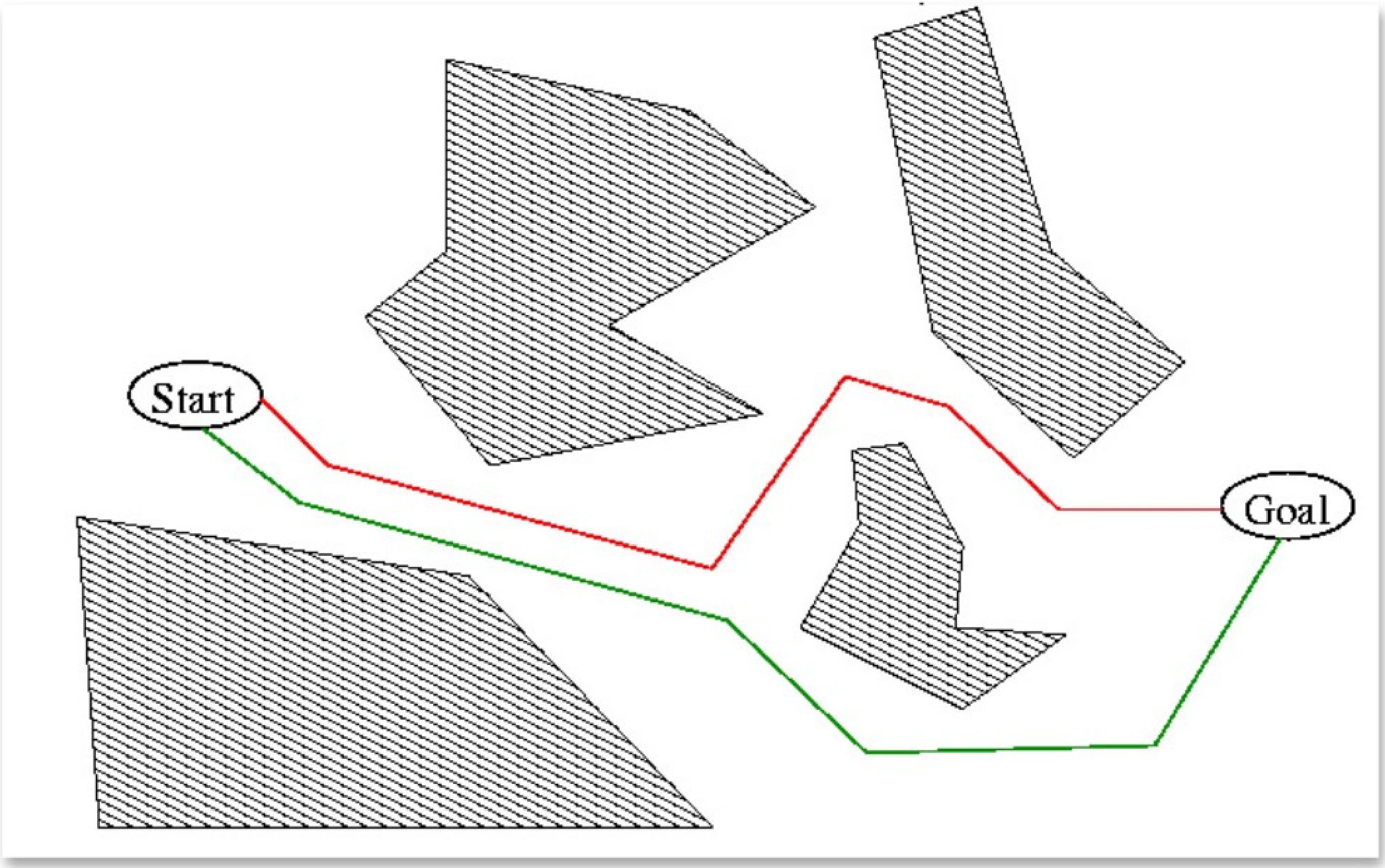
BWIBots: A platform for bridging the gap between AI and Human-Robot Interaction research

International Journal of Robotics Research, Vol. 36, No.5-7, pp. 635-659, 2017.

Planning

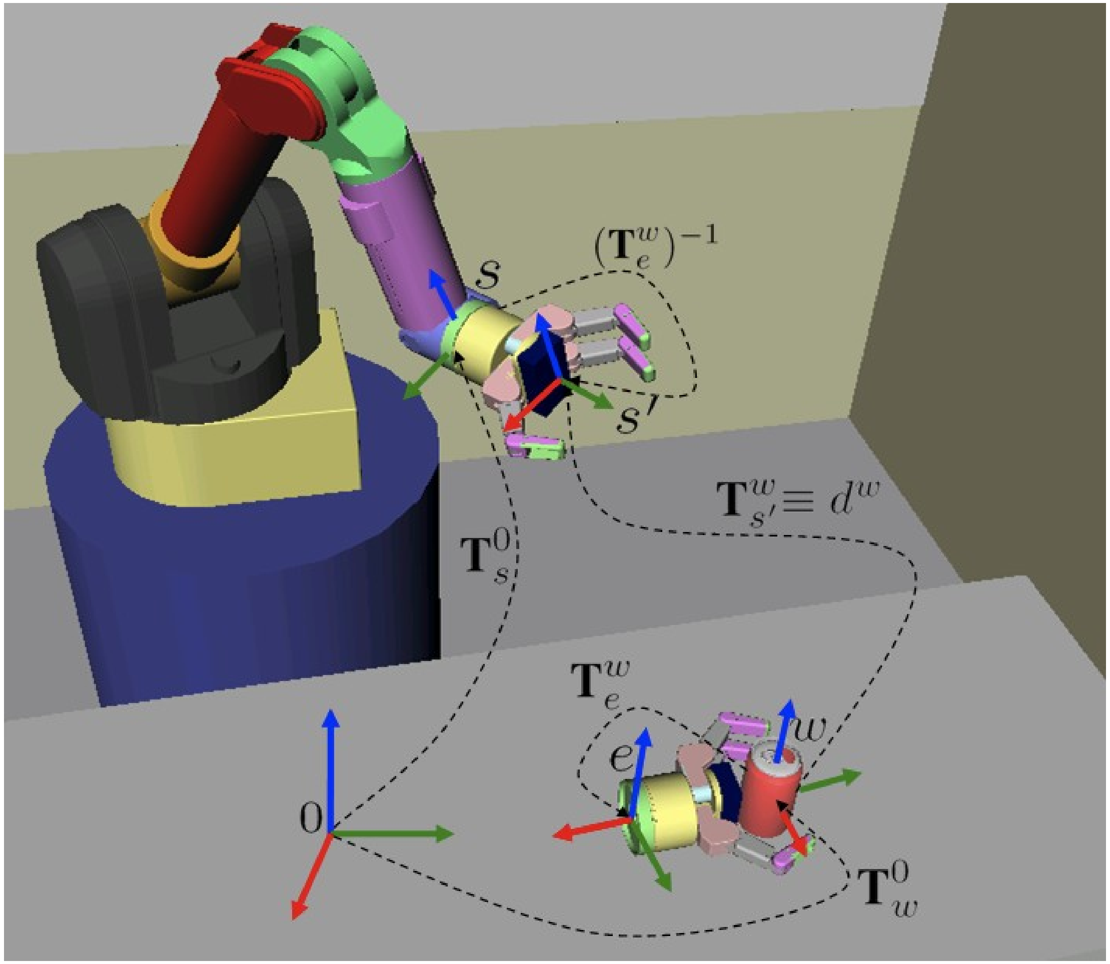

R.O.B.O.T. Comics
A
B
JORGE CHAM 2009
WWW.WILLOWGARAGE.COM
"HIS PATH-PLANNING MAY BE SUB-OPTIMAL, BUT IT'S GOT FLAIR."

Path Planning using A*



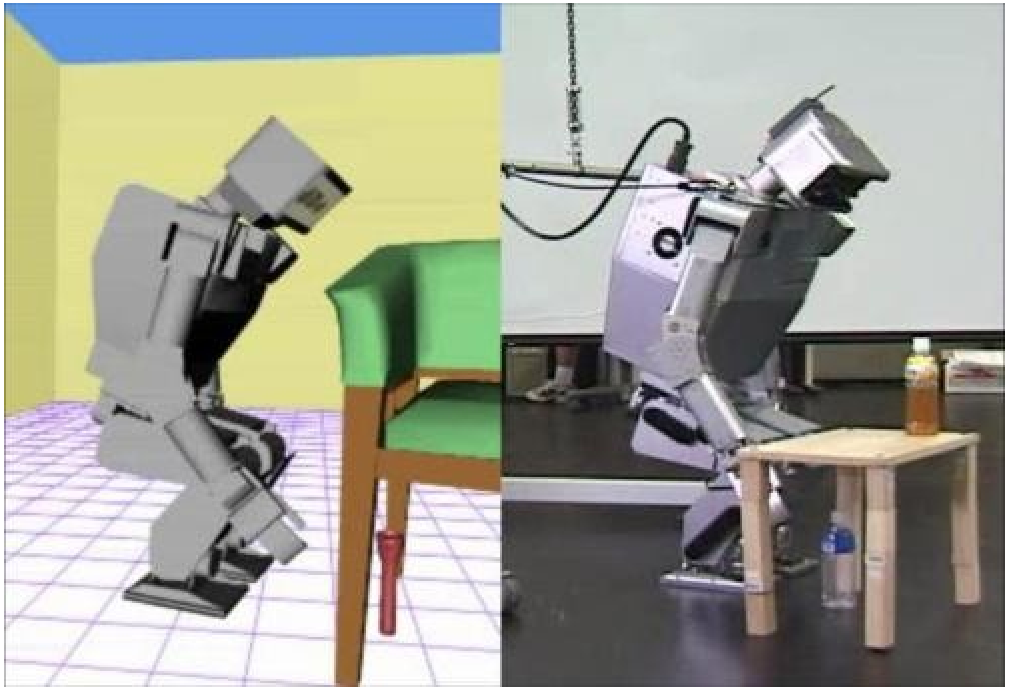
[from "Making Shakey 1966-1972"]

Planning for Manipulation

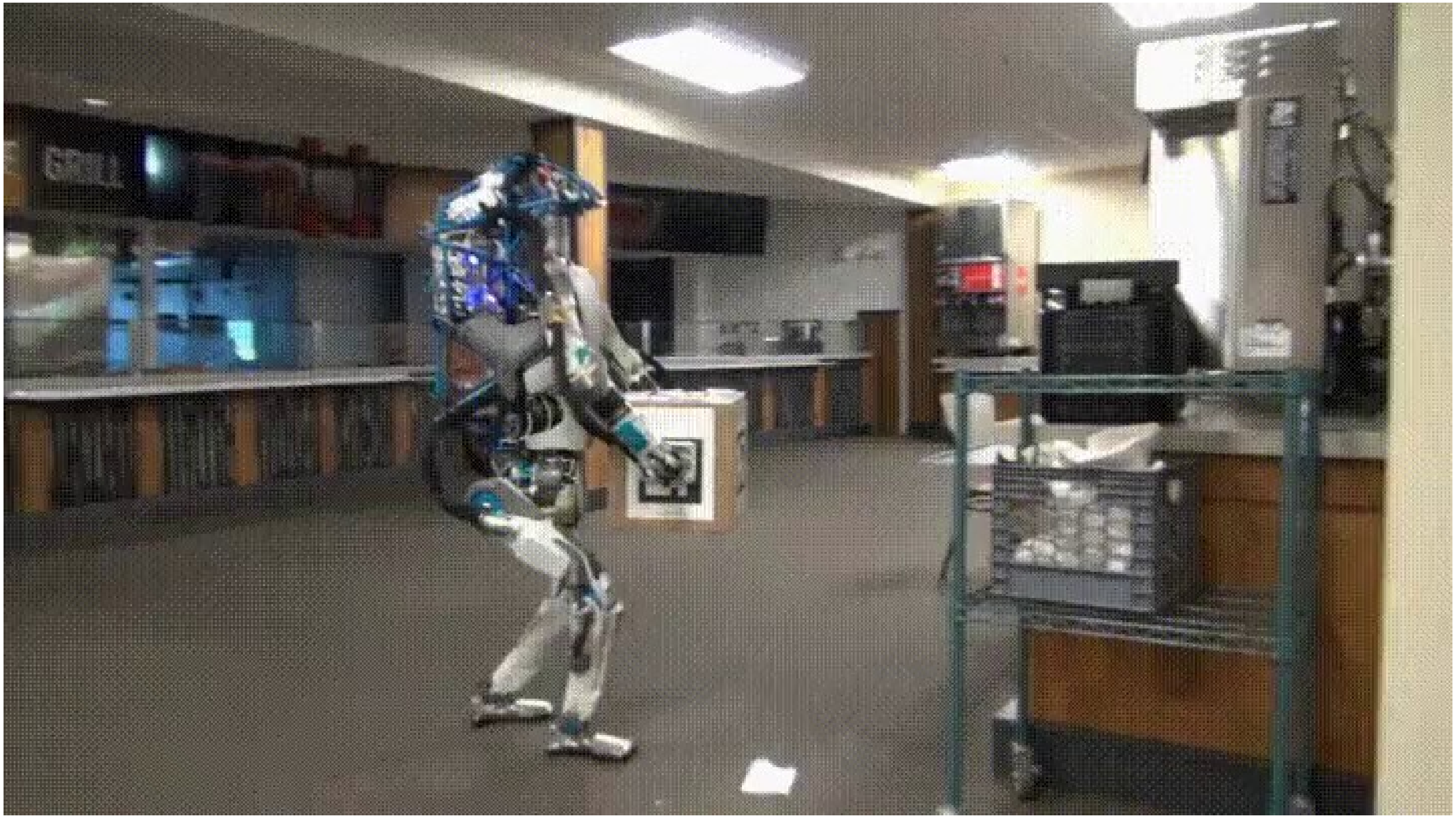


[http://arm.eecs.umich.edu/]

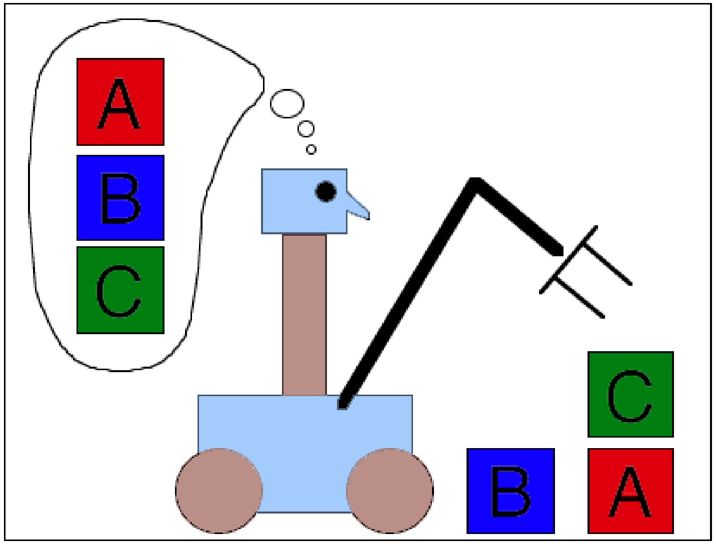
Whole-Body Motion Planning

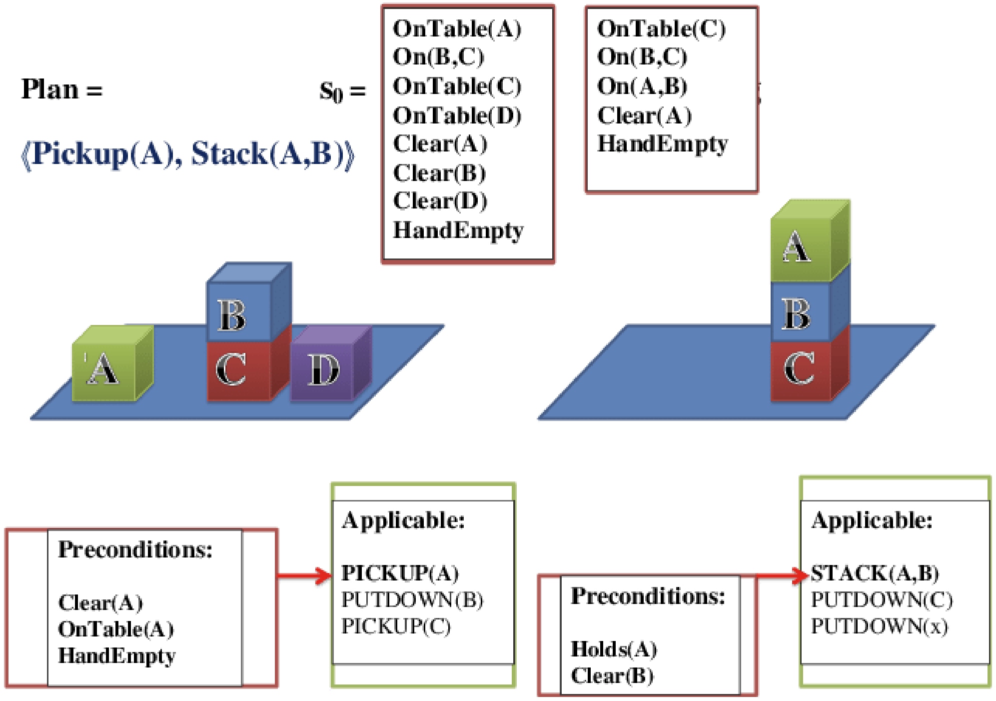


Whole-Body Motion Planning



Planning with Symbols

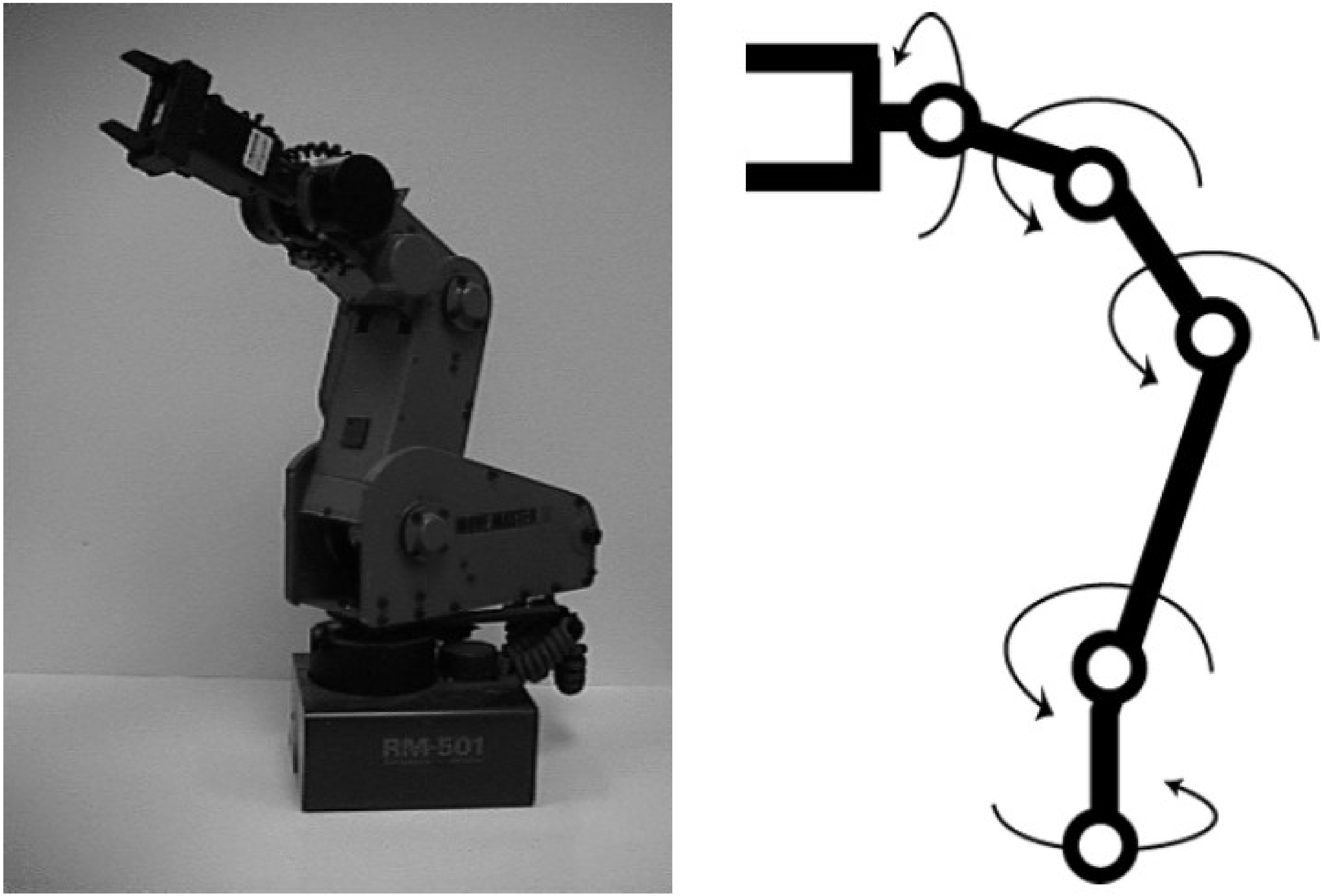




Teleoperation

Figure 1.2 A Model 8 Telemanipulator. The upper portion of the device is placed in the ceiling, and the portion on the right extends into the hot cell. (Photograph courtesy Central Research Laboratories.)

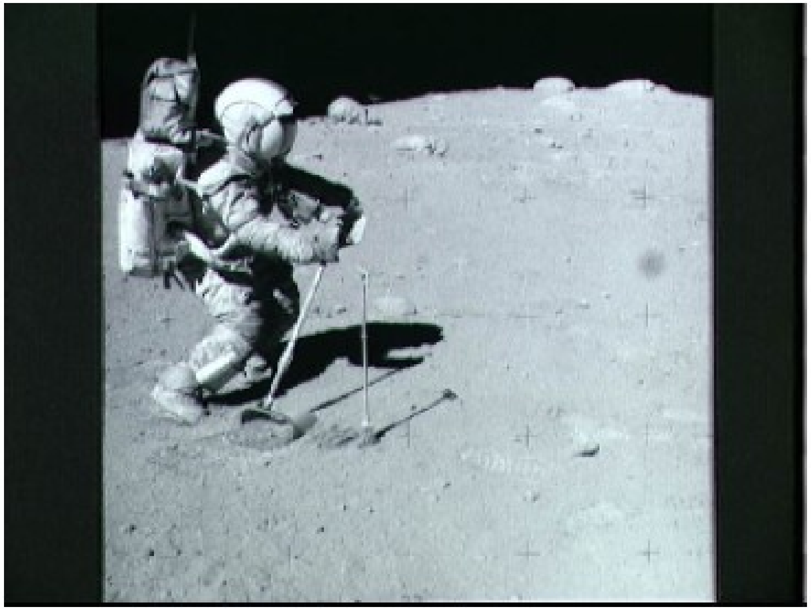
Teleoperation



a. b.

Figure 1.4 A MOVEMASTER robot: a.) the robot arm and b.) the associated joints.

Teleoperation

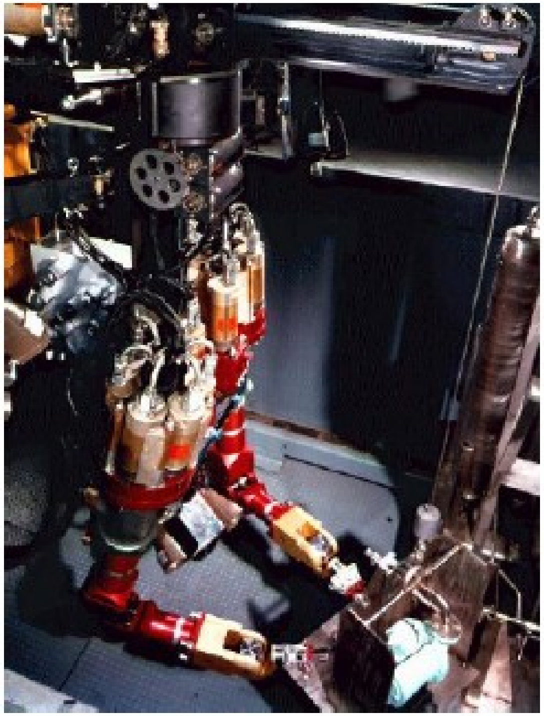


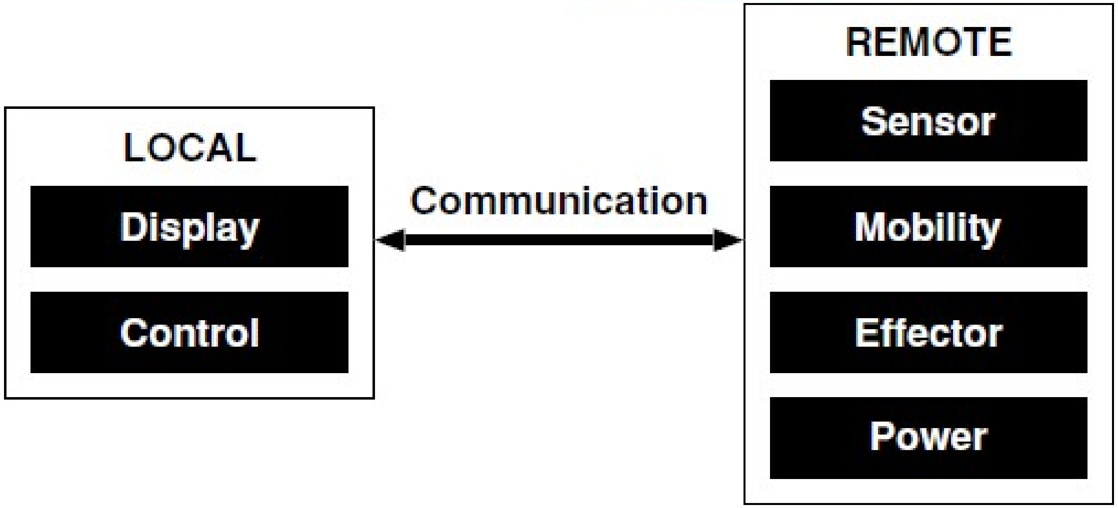
a.

b.

Figure 1.5 Motivation for intelligent planetary rovers: a.) Astronaut John Young awkwardly collecting lunar samples on Apollo 16, and b.) Astronaut Jim Irwin stopping the lunar rover as it slides down a hill on Apollo 15. (Photographs courtesy of the National Aeronautics and Space Administration.)

Teleoperation





Teleoperation

Figure 1.7 Sojourner Mars rover. (Photograph courtesy of the National Aeronautics and Space Administration.)

Teleoperation

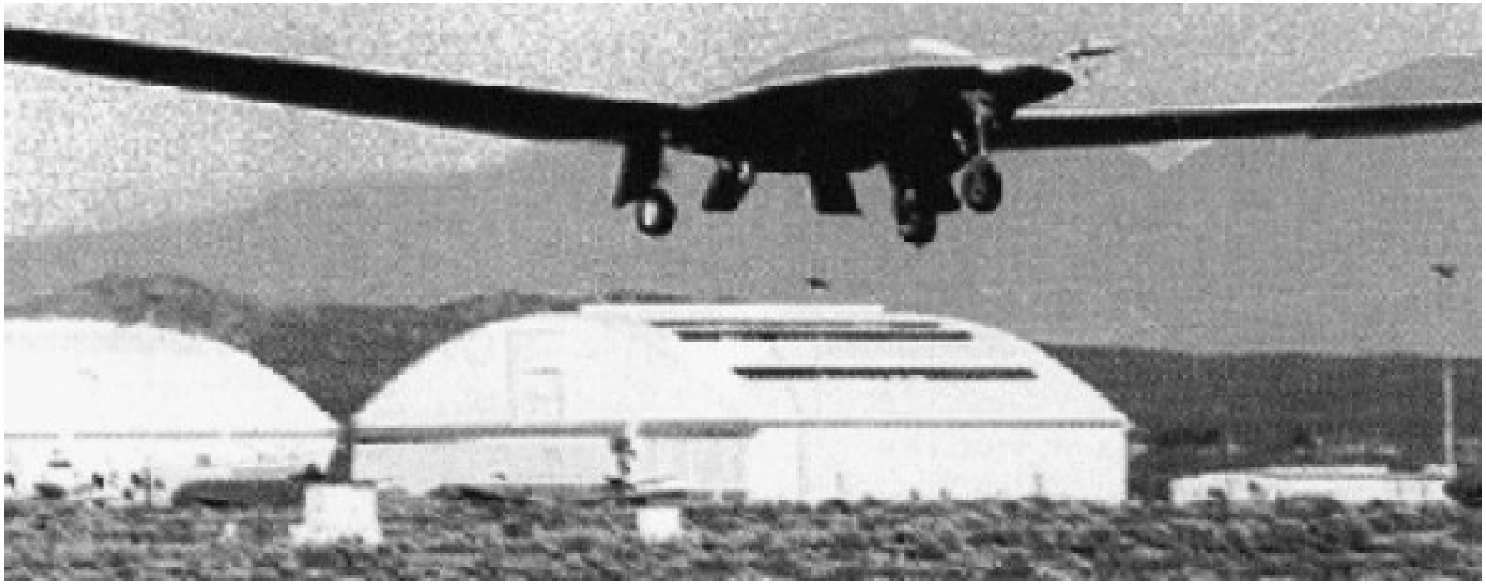


Figure 1.8 Dark Star unmanned aerial vehicle. (Photograph courtesy of DefenseLink, Office of the Assistant Secretary of Defense-Public Affairs.)

Robotics Timeline

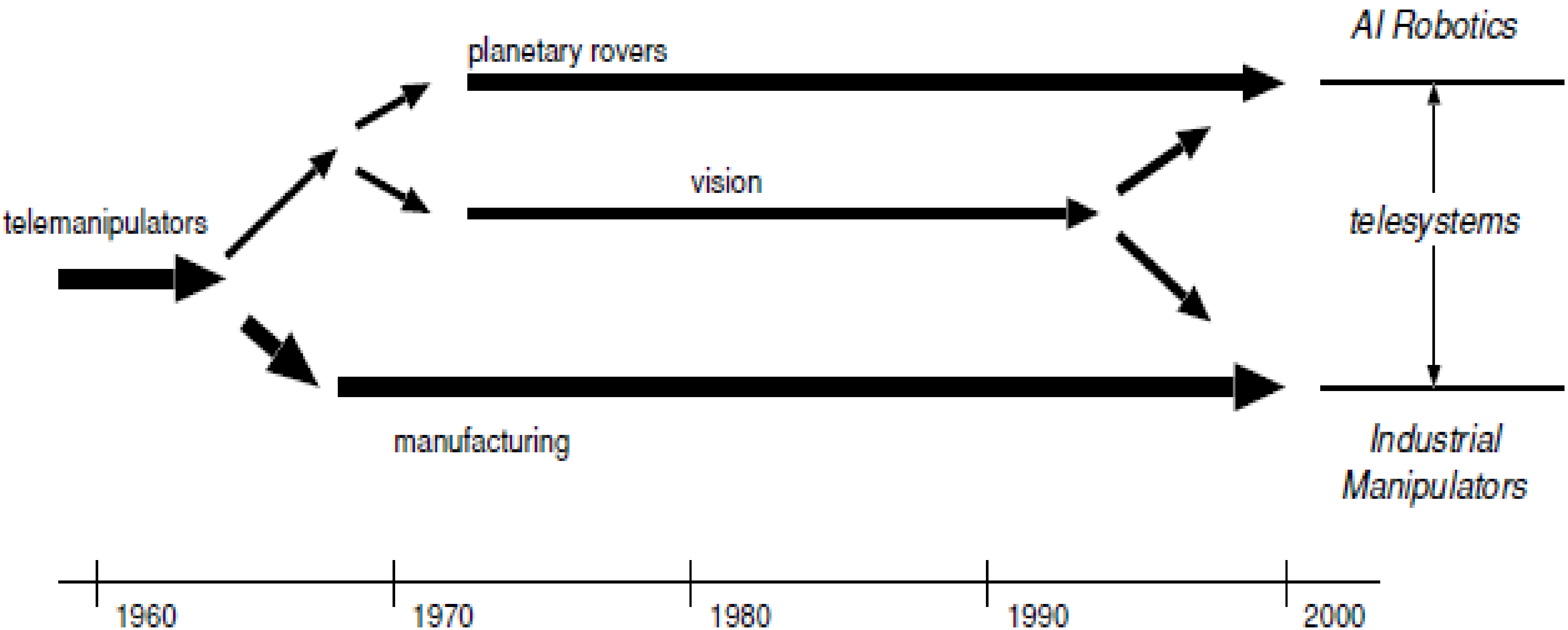


Figure 1.1 A timeline showing forks in development of robots.

Teleoperation vs Telepresence

- An early attempt to improve teleoperation was to add more cameras / displays
- Telepresence aims for placing the operator in a *virtual reality* that mimics the robot's surroundings

Telepresence Robots

Making Your Presence Robotic

A new generation of robots is making it possible to be, in effect, in two places at once. From anywhere with a computer and a Wi-Fi connection, the operator can use the robot to hear, talk, see and be seen and move around a workplace far away. Early adopters include doctors, technology workers and supervisors. The robots range in size, features and price. Here is a sampling.

	Vgo (made by Vgo Communications)	**Tilr** (RoboDynamics)	**Texai** (Willow Garage)	**RP-7i** (InTouch Health)	**QB** (Anybots)
HEIGHT	4'0"	3'8" or 4'2"	5'2"	5'5"	2'6" to 6'0"
TOP SPEED	3.75 m.p.h.	2.4 m.p.h.	1.5 m.p.h.	2 m.p.h.	3.5 m.p.h.
DISPLAY SIZE	7"	8" (touchscreen)	15"	15"	3.5"
FIELD OF VIEW	60 degrees	55 degrees	140 degrees	360 degrees	130 degrees
CONNECTION	400 kbps	500 kbps	500 kbps	600 kbps	500 kbps
PRICE	$4,995	$10,000	Not available	Not available	$15,000
UNIQUE FEATURES	Text-to-speech; camera auto-tilts based on drive speed; remote monitoring headlights and auto-docking to the charger.	Web-based controls; can use own video like Skype, Google Vid Chat, MSN, etc.	Technology agnostic (can pilot on Windows, Mac or Linux), secure connection between pilot and Texai (SSL and VPN tunnel).	FDA-cleared, connects directly to Class II medical devices including electronic stethoscopes, otoscopes and ultrasound.	Untippable, two-wheel drive design; stabilized video; Web-based controls.

Sources: the companies

THE NEW YORK TIMES

http://www.pilotpresence.com/wp-content/uploads/2011/01/remote-presence-systemsv2.jpg

The need for (semi-) autonomy

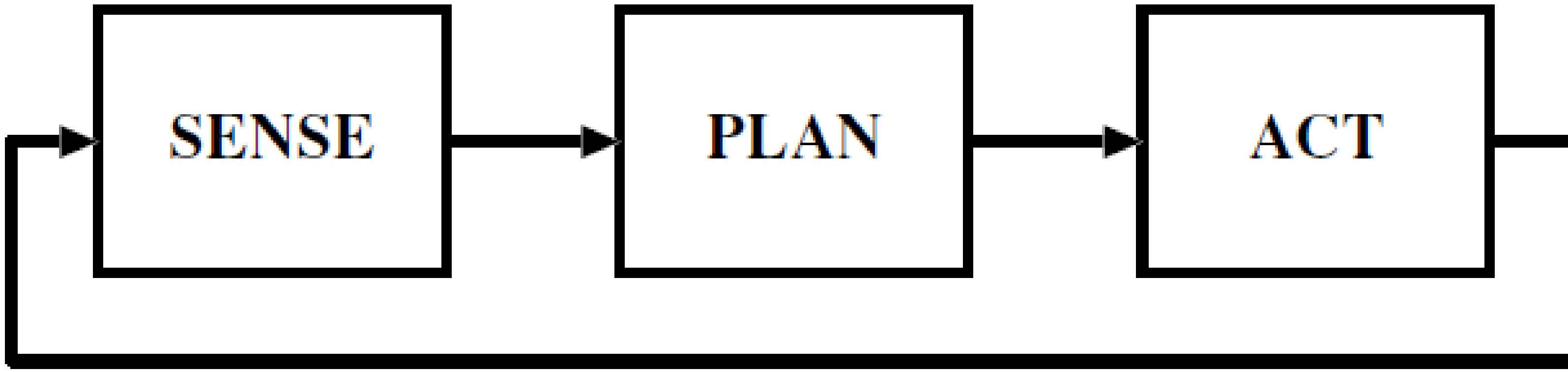
How should autonomy be achieved and organized?

Robot Primitives

ROBOT PRIMITIVES	**INPUT**	**OUTPUT**
SENSE	Sensor data	Sensed information
PLAN	Information (sensed and/or cognitive)	Directives
ACT	Sensed information or directives	Actuator commands

Figure I.2 Robot primitives defined in terms of inputs and outputs.

The Early Answer (1967): Sense-Plan-Act



The Early Answer (1967): Sense-Plan-Act

ROBOT PRIMITIVES	INPUT	OUTPUT
SENSE	Sensor data	Sensed information
PLAN	Information (sensed and/or cognitive)	Directives
ACT	[redacted] directives	Actuator commands

Figure I.4 Another view of the Hierarchical Paradigm.

Early Example of S-P-A

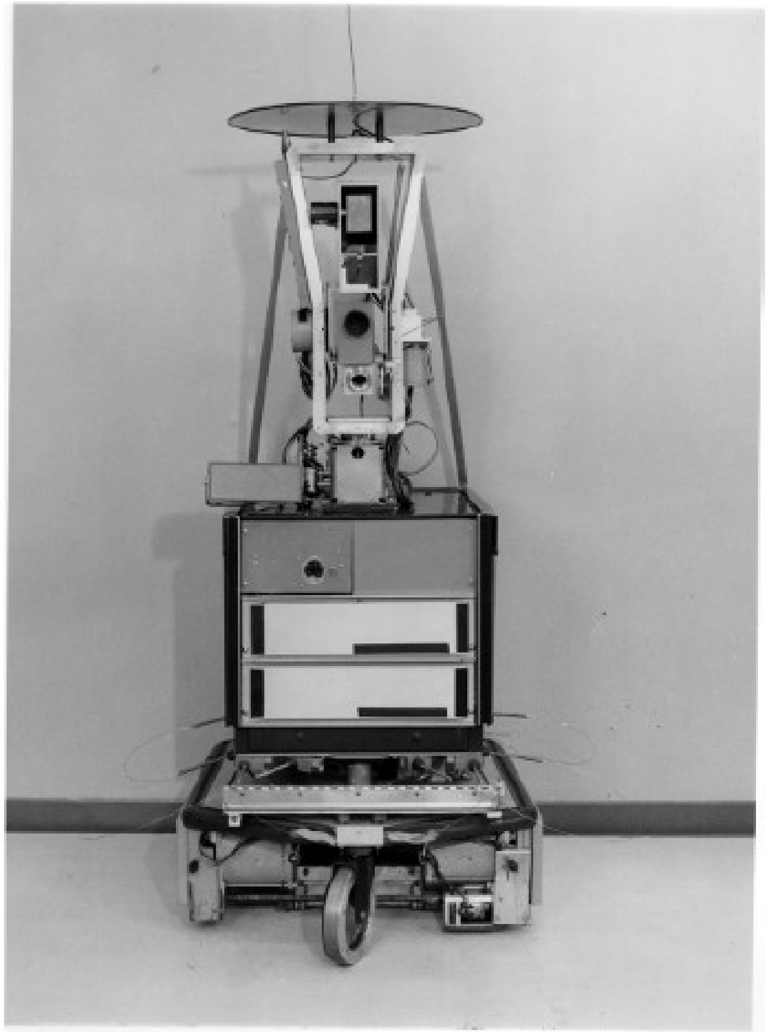


Figure 2.1 Shakey, the first AI robot. It was built by SRI for DARPA 1967–70. (Photograph courtesy of SRI.)

Shakey Video

Early Work on Planning

initial state:	Tampa, Florida (0,0)
goal state:	Stanford, California (1000,2828)
difference:	3,000

Early Work on Planning

initial state:	Tampa, Florida (0,0)
goal state:	Stanford, California (1000,2828)
difference:	3,000

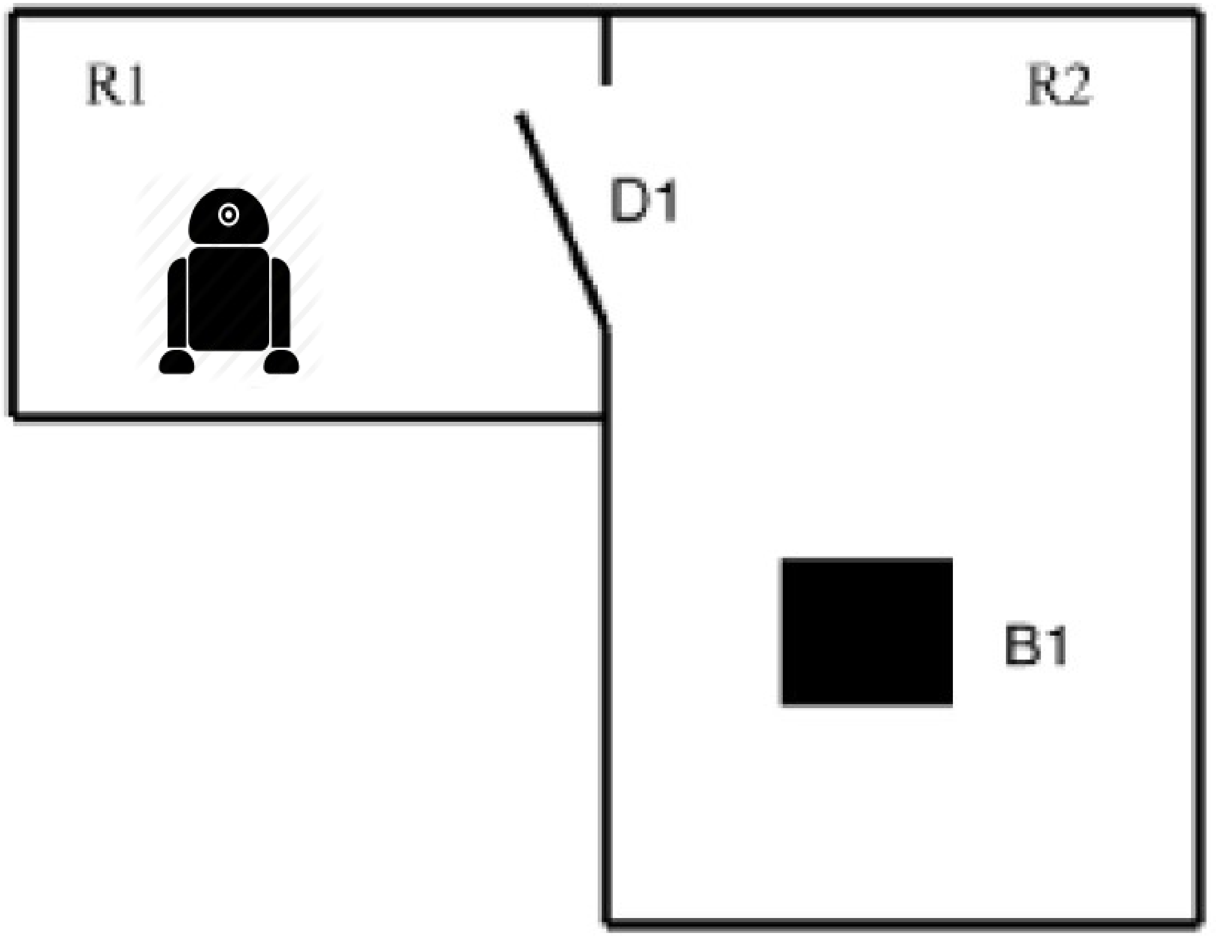
difference	operator
d≥200	fly
100<d < 200	ride_train
d ≤ 100	drive
d< 1	walk

Early Work on Planning

initial state:	Tampa, Florida (0,0)
goal state:	Stanford, California (1000,2828)
difference:	3,000

difference	operator	preconditions
d≤200	fly	
100<d<200	ride_train	
d≤100	drive_rental	at airport
	drive_personal	at home
d<1	walk	

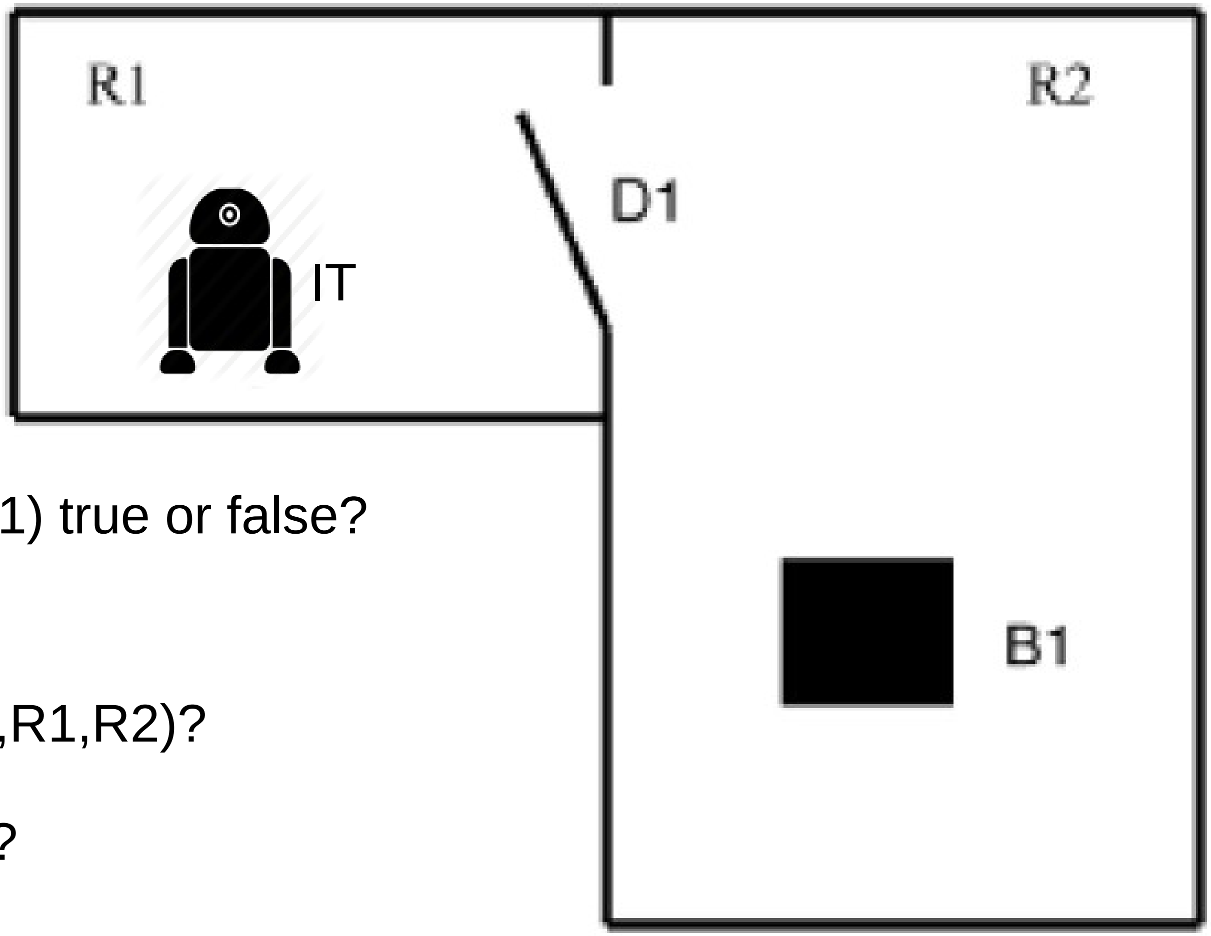
A More Realistic Example



A More Realistic Example

`INROOM(x, r)`	where `x` is an object of type `movable_object`, `r` is type `room`
`NEXTTO(x, t)`	where `x` is a `movable_object`, `t` is type `door` or `movable_object`
`STATUS(d, s)`	where `d` is type `door`, `s` is an enumerated type: `OPEN` or `CLOSED`
`CONNECTS(d, rx, ry)`	where `d` is type `door`, `rx, ry` are the `room`

A More Realistic Example

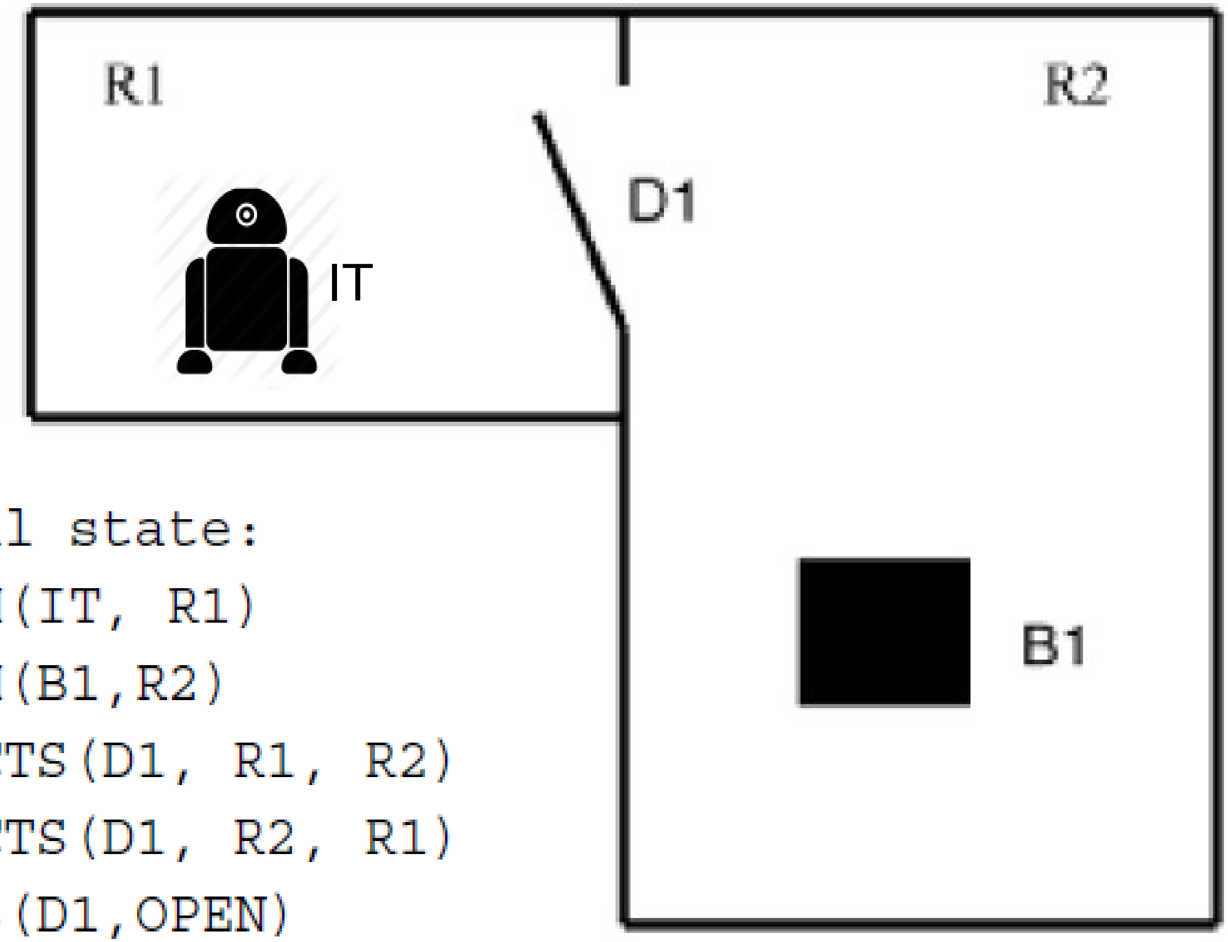


Is INROOM(IT,R1) true or false?

CONNECTS(D1,R1,R2)?

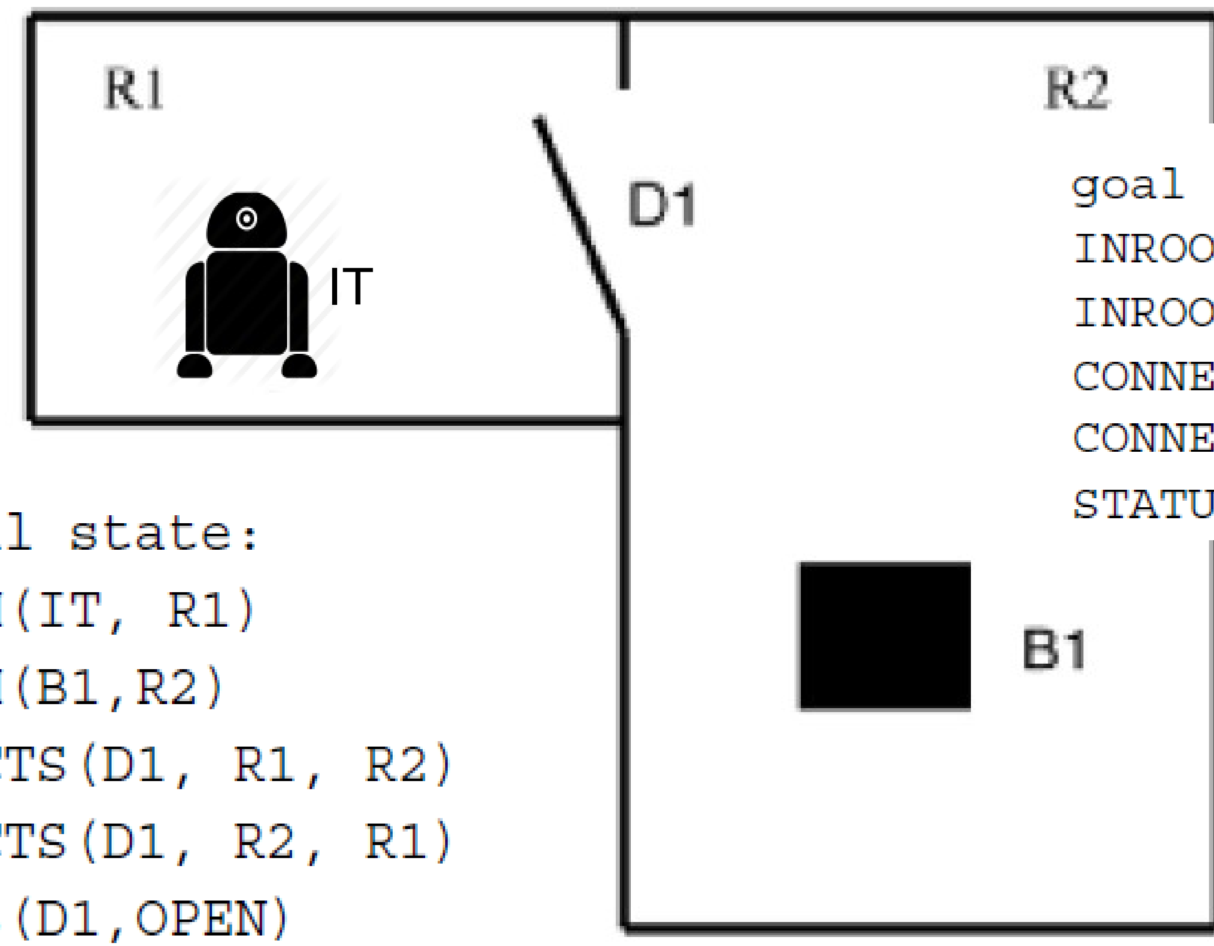
INROOM(IT,R2)?

Representing Initial State




```
initial state:
INROOM(IT, R1)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)
```

Representing Goal State



goal state:
INROOM(IT,R2)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

initial state:
INROOM(IT, R1)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

The “difference” table

operator	preconditions	add-list	delete-list
OP1: GOTODOOR(IT,dx)	INROOM(IT,rk) CONNECT(dx,rk,rm)	NEXTTO(IT,dx)	
OP2: GOTHRUDOOR(IT,dx)	CONNECT(dx,rk,rm) NEXTTO(IT,dx) STATUS(dx, OPEN) INROOM(IT,rk)	INROOM(IT,rm)	INROOM(IT,rk)

Logical Difference

goal state:
INROOM(IT,R2)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

—

initial state:
INROOM(IT, R1)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

=

¬INROOM(IT, R2)

or

INROOM(IT, R2)=FALSE

Finding the Plan

operator	preconditions	add-list	delete-list
OP1: GOTODOOR(IT,dx)	INROOM(IT,rk) CONNECT(dx,rk,rm)	NEXTTO(IT,dx)	
OP2: GOTHRUDOOR(IT,dx)	CONNECT(dx,rk,rm) NEXTTO(IT,dx) STATUS(dx, OPEN) INROOM(IT,rk)	INROOM(IT,rm)	INROOM(IT,rk)

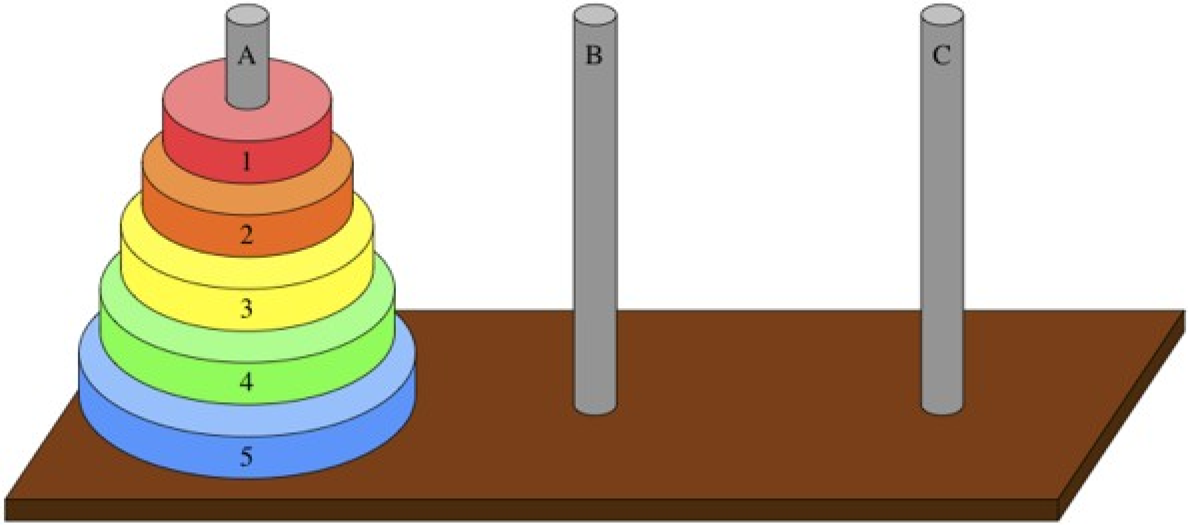
goal state:
INROOM(IT,R2)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

initial state:
INROOM(IT, R1)
INROOM(B1,R2)
CONNECTS(D1, R1, R2)
CONNECTS(D1, R2, R1)
STATUS(D1,OPEN)

Discussion

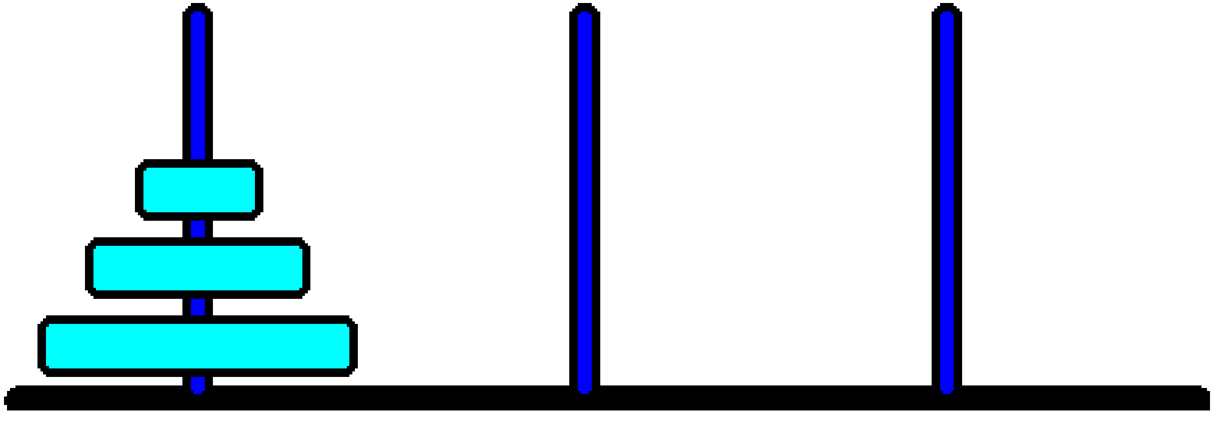
- How did you solve the problem?
- What are some limitations of planning with STRIPS?
- Where do the predicates, operators, etc. come from?

Towers of Hanoi with PDDL



[https://s3.amazonaws.com/ka-cs-algorithms/hanoi-5-init.png]

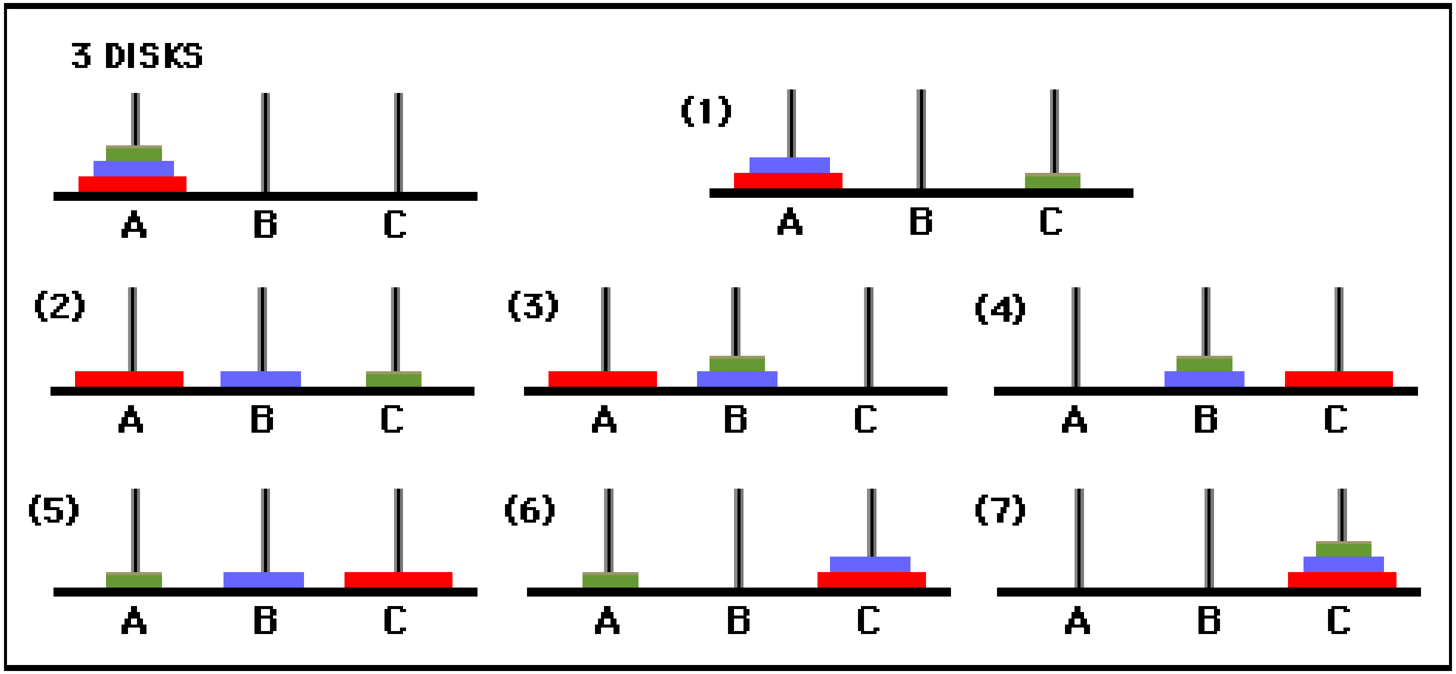
3-Disk Hanoi



Breakout Exercise

- Specify the **domain** for the Towers of Hanoi Problem
  - The domain should include all predicates needed to represent the world and all actions (hint: all you need is 3 predicates, 1 action, no type hierarchy)
- Specify the **problem** for 3-disk Towers of Hanoi
  - The problem should specify the current objects in the world, the initial state (in terms of which predicates are true), and the goal (which predicates must become true)

Final Plan



PDDL

- Editor: http://editor.planning.domains/
- Tutorial: https://www.cs.toronto.edu/~sheila/2542/s14/A1/introtopddl2.pdf
- Example PDDL files: http://www.ida.liu.se/%7ETDDC17/info/labs/planning/strips/

Actions

- Action name and parameters:
- Preconditions:
- Effects:

Planning Exercise

- Consider a service robot operating in a human environment such as an office or our department
- Specify three high-level actions, with preconditions and end-effects
  - You will need to specify the relevant predicates as well
  - Specify a planning problem within the domain

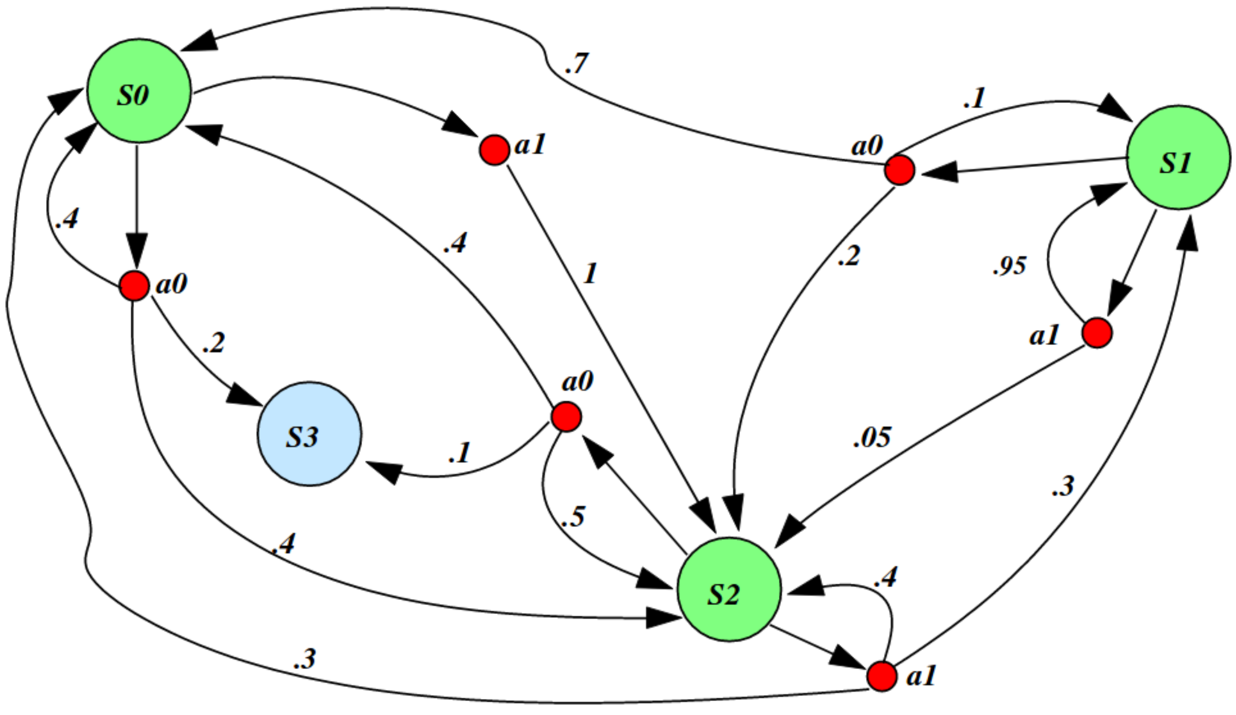
Further Reading

- Planning with STRIPS: A gentle introduction

  http://www.primaryobjects.com/2015/11/06/artificial-intelligence-planning-with-strips-a-gentle-introduction/

- Cashmore, Michael, et al. "**ROSplan: Planning in the robot operating system.**" Twenty-Fifth International Conference on Automated Planning and Scheduling. 2015.

Next time...planning in stochastic domains



- 4 states; $S = \{s_0, \ldots, s_3\}$
- 2 actions; $A = \{a_0, a_1\}$
- 1 goal; $G = \{s_3\}$
- $p(s_2|s_0, a_1) = 1.0$
- $p(s_0|s_1, a_0) = 0.7$
- $p(s_2|s_2, a_1) = 0.4$

THE END