
# 16.410 and 16.412: Principles of Autonomy and Decision Making


Prof Brian Williams, Prof Emilio Frazzoli and Sertac Karaman

September, 8th, 2010





## Assignments

- Homework:
  - Class signup, return at end of class;
  - Problem Set #1: Java warm up
    Out Today,
    Due next Wednesday, September 15th
- Reading:
  - Today: *[AIMA] Ch. 2, [JINS] Ch. 1-3,5*
  - Monday: search *[AIMA] Ch. 3*.1-4

# Outline

1. Trends in Computing
2. Examples of autonomous systems - Williams
3. Autonomous systems architectures
4. Principles = modeling + inference + search
5. More examples – Frazzoli
6. Course logistics and schedule
7. Projects and programming



# Human Brain

- 100 Billion neurons
- On average, connected to 1 K others
- Neurons are slow. Firing rates < 100 Hz.
- Can be classified into
  - Sensory
  - Motor
  - Central
    - (reasoning, problem solving, language..)

Images of brain activity removed due to copyright restrictions.

# Trends in Biological and Machine Evolution - Moravec

- 1 neuron = 1000 instructions/sec
- Human brain then processes 10^14 IPS
- 1 synapse = 1 byte of information
- Human brain then has 10^14 bytes of storage
- In 2000, we had10^9 IPS and 10^9 bytes on a desktop machine
- In 25 years, assuming Moore's law we obtain human level computing power



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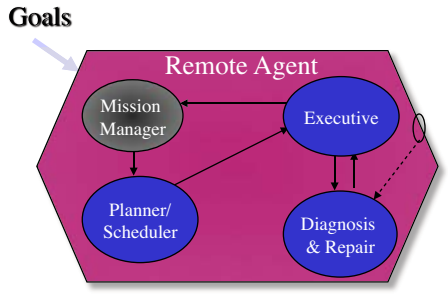
# Williams Research: Model-based Programming of Autonomous Systems

Robust, mission-directed agents:

1. Self-repairing agents
2. Agents that are agile
3. Science explorers



# Remote Agent on Deep Space One

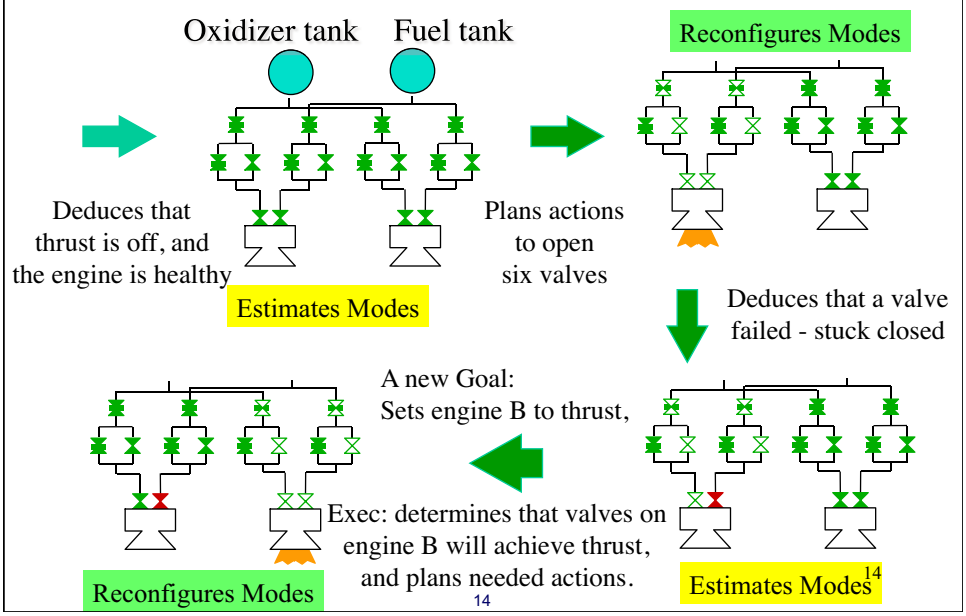



1. Commanded by giving goals
2. Reasoned from commonsense models
3. Closed loop on goals

[Williams & Nayak, AAAI 95; Muscettola et al, AIJ 00]



# A Goal sets engine A state to thrusting, and the agent . . .



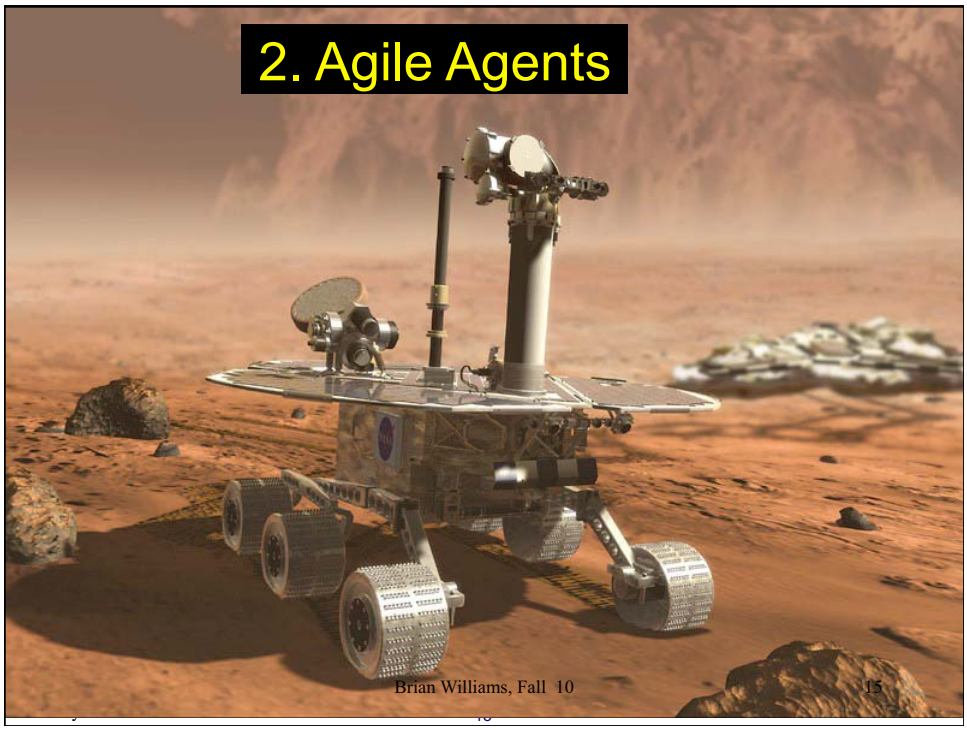



Image credit: NASA.

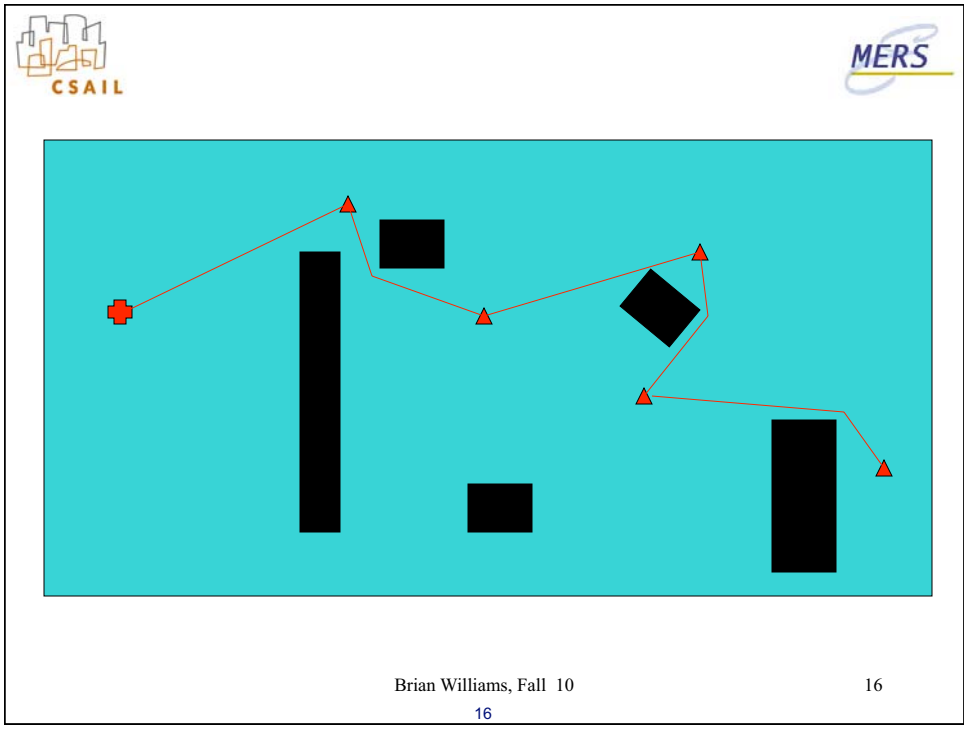
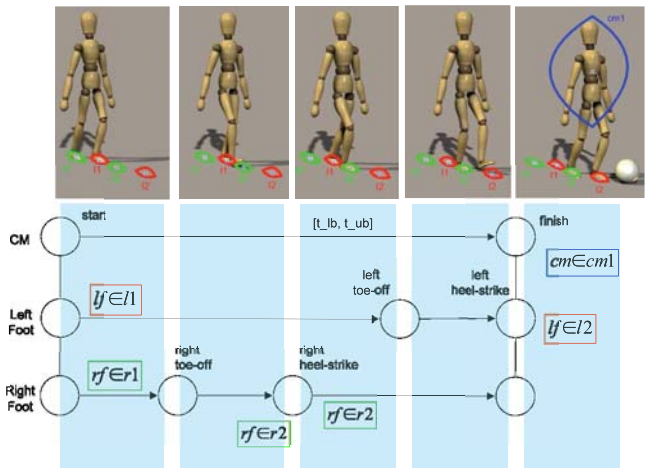


Image of hilly terrain removed due to copyright restrictions.

Courtesy JPL

# Describe Tasks as Temporal Plans over Qualitative Poses

Input:
Qualitative
State Plan




Hofmann PhD - Chekov Brian Williams, Fall 10 18

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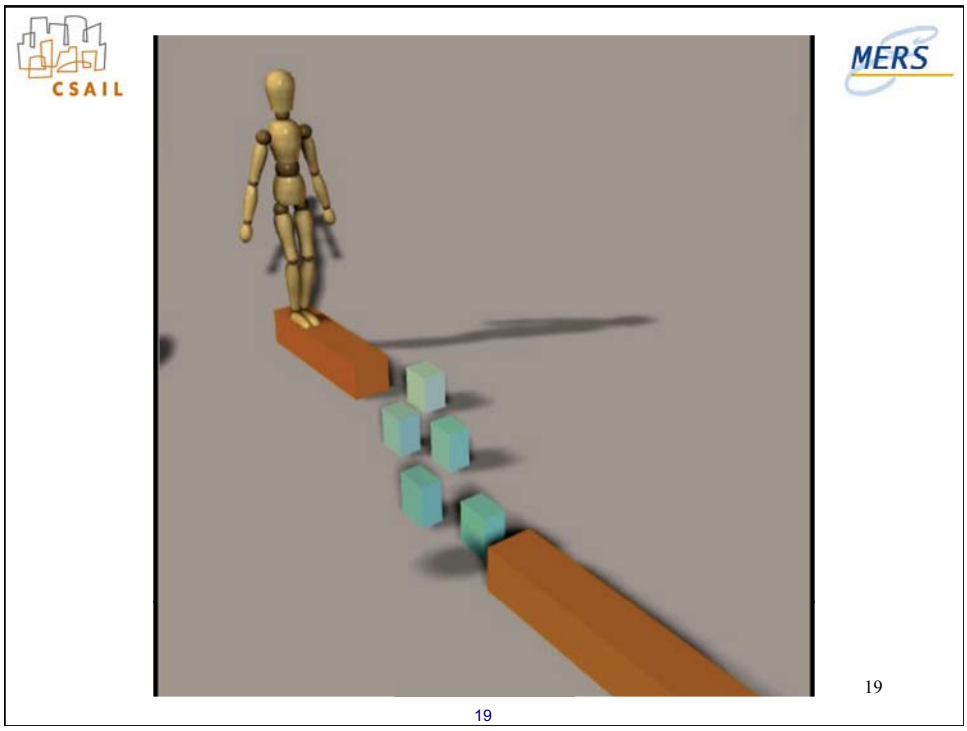


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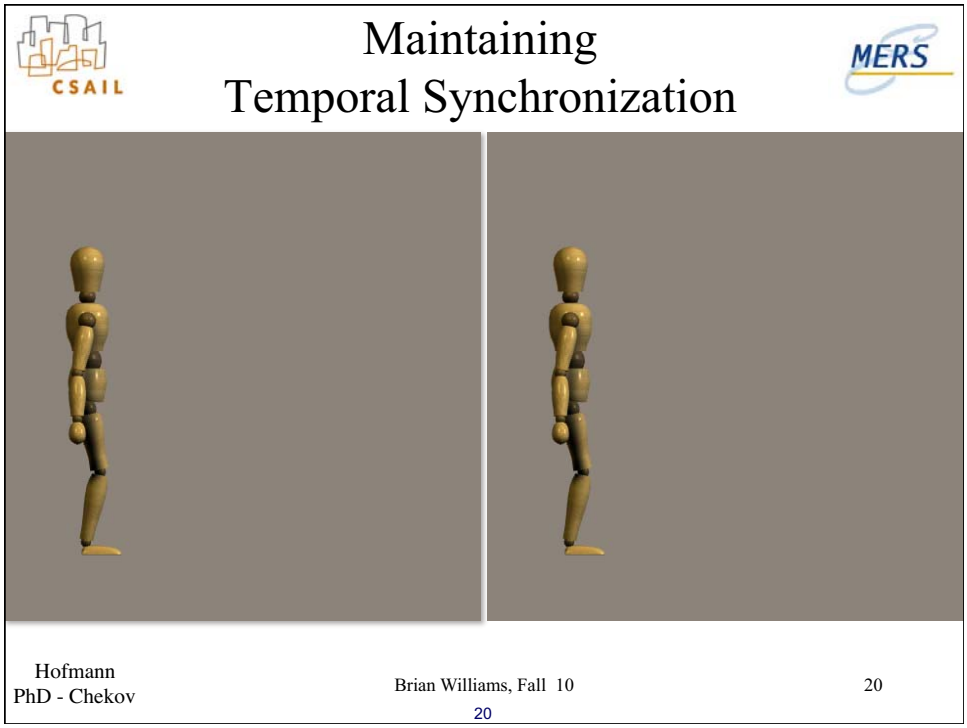


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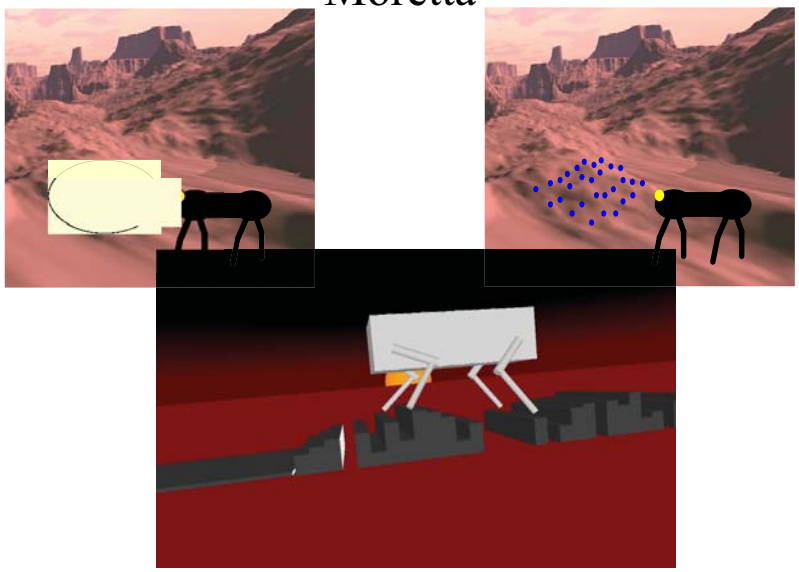
# CDIO Capstone: Moretta



Hofmann
PhD - Chekov



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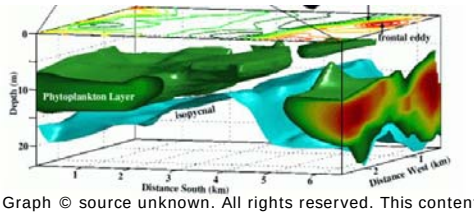
# 3. Science Explorers

MBARI Dorado-class AUV:
- 6000m rated
- 20 hour operation
- Multibeam Sonars
- 3+ knots speed






Challenges:
- Long mission duration
- Limited communication
- GPS unavailable
- Uncertainty
  - tides and currents
  - estimation error

# Robust, Goal-directed Deep Sea Exploration

00:00 Go to $x_1,y_1$
00:20 Go to $x_2,y_2$
00:40 Go to $x_3,y_3$
…
04:10 Go to $x_n,y_n$

**Command script**

**Commands**

**Plant**

Brian Williams, Fall 10

Leaute & Williams, AAAI 05



# Robust, Goal-directed Deep Sea Exploration

*"Remain in mapping region for at least 100s, then remain in bloom region for at least 50s, then return to pickup region. Avoid obstacles at all times"*

**Qualitative State Plan**

**Model-based Executive**

**Observations**

**Commands**

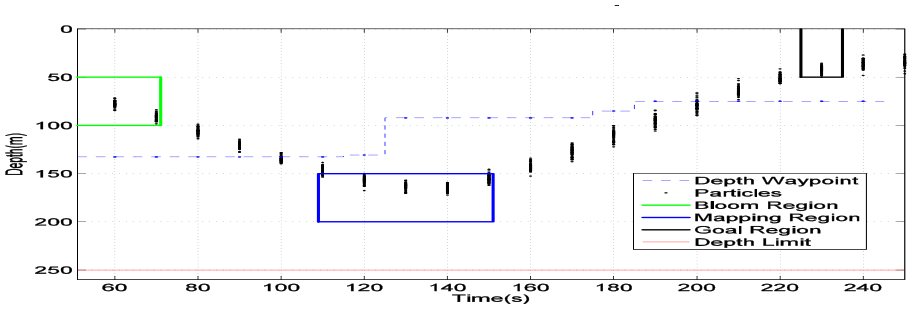
**Plant**

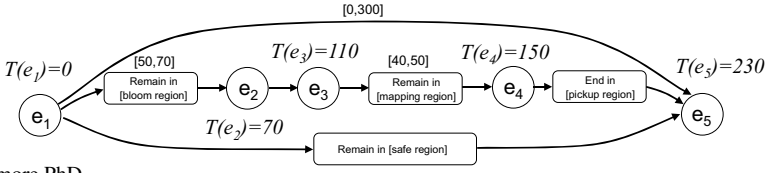
**Optimal**

Brian Williams, Fall 10

Leaute & Williams, AAAI 05

# Example Execution




Blackmore PhD

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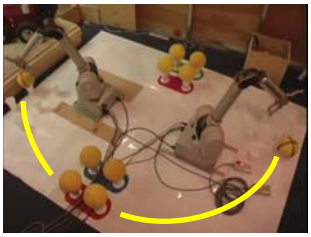
# Multi-Robot Teamwork

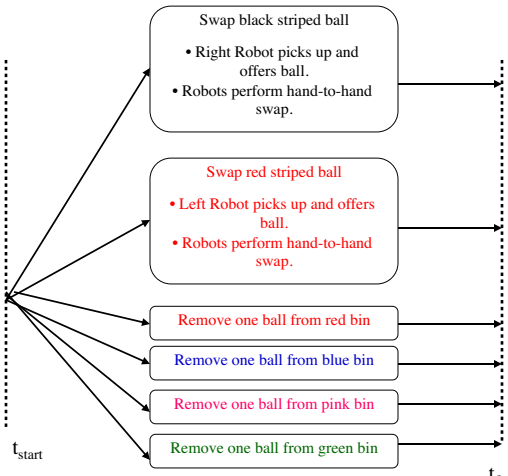


Agents choose and schedule activities

(Someone) Remove one ball from red bin

Remove one ball from red bin


L[32,39] V R[42,55]



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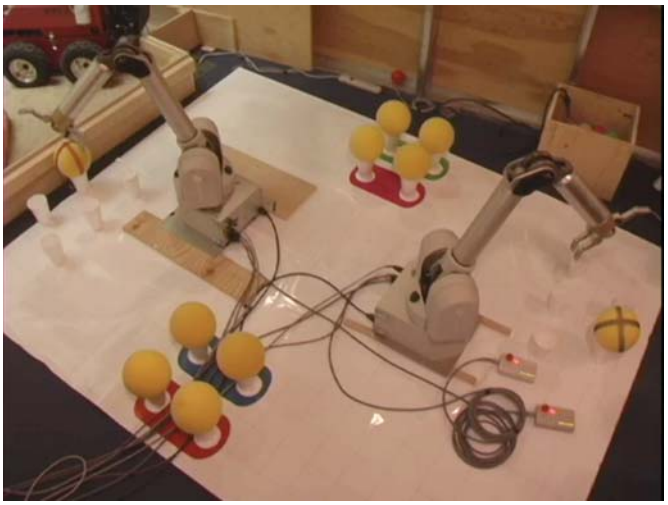

- Mu-tiomdial
- Marttier at aTta di reaTotiae to teammate'a Mdoureb



Image of Vecna's Bear Robot removed due to copyright restrictions.





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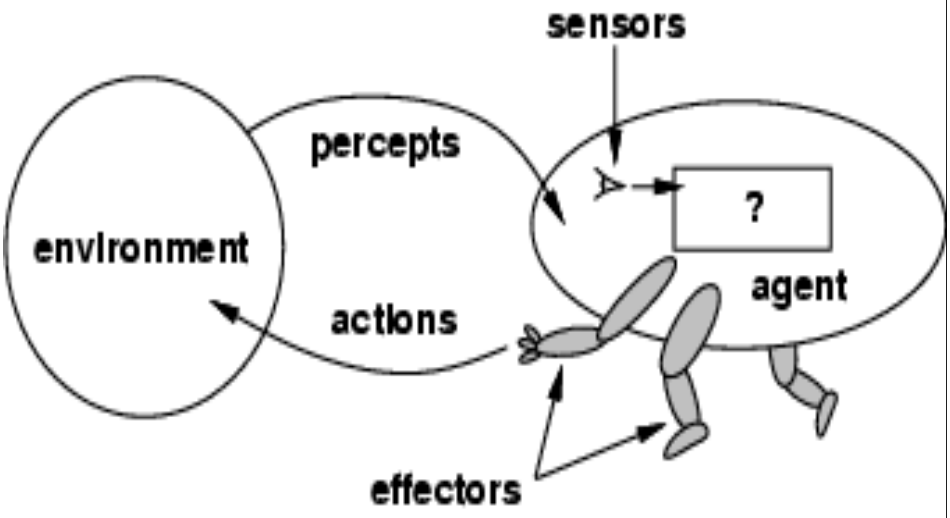
# Agent Paradigms

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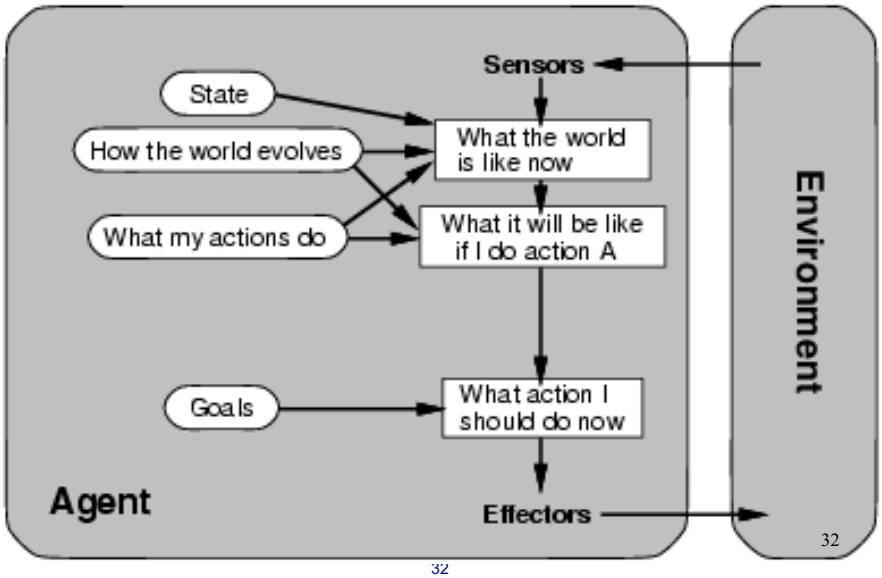
# Goal-Oriented Agents

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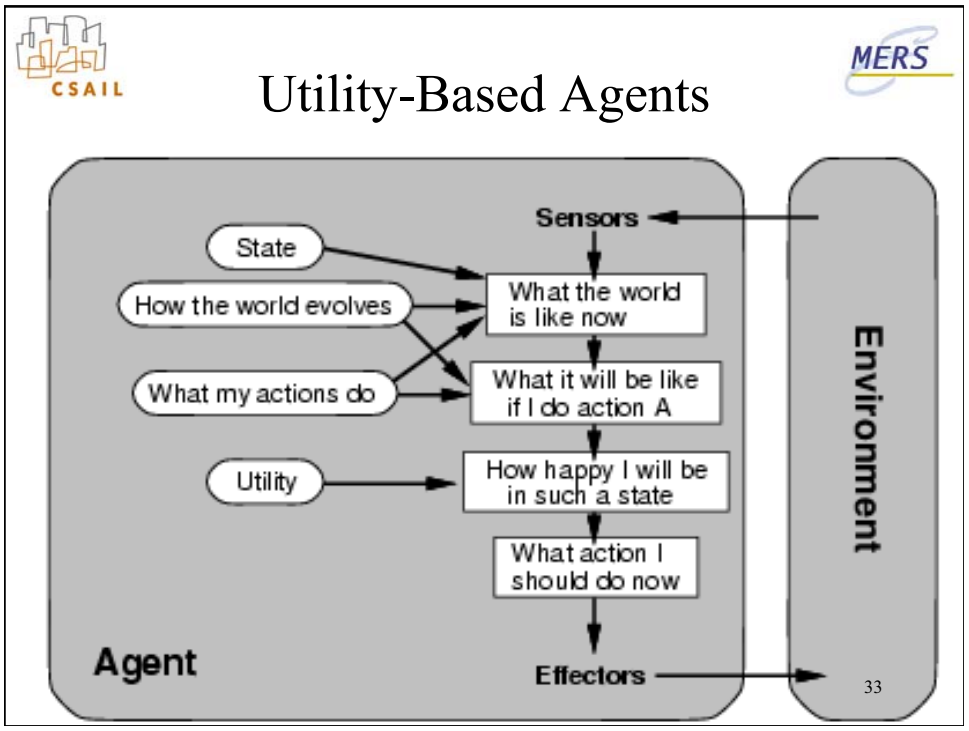


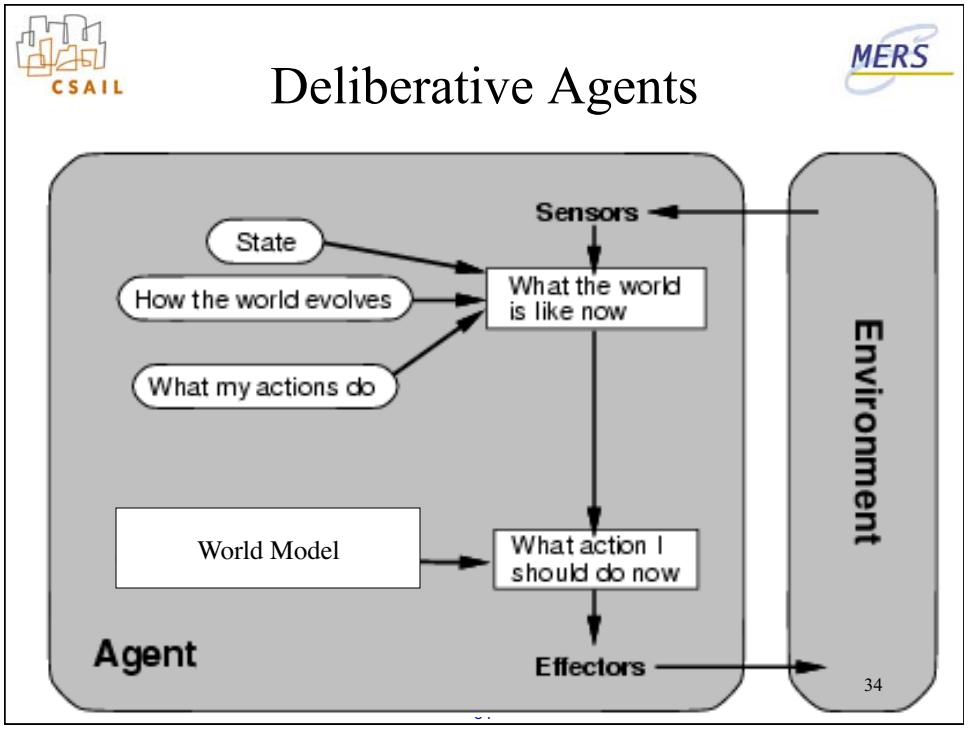


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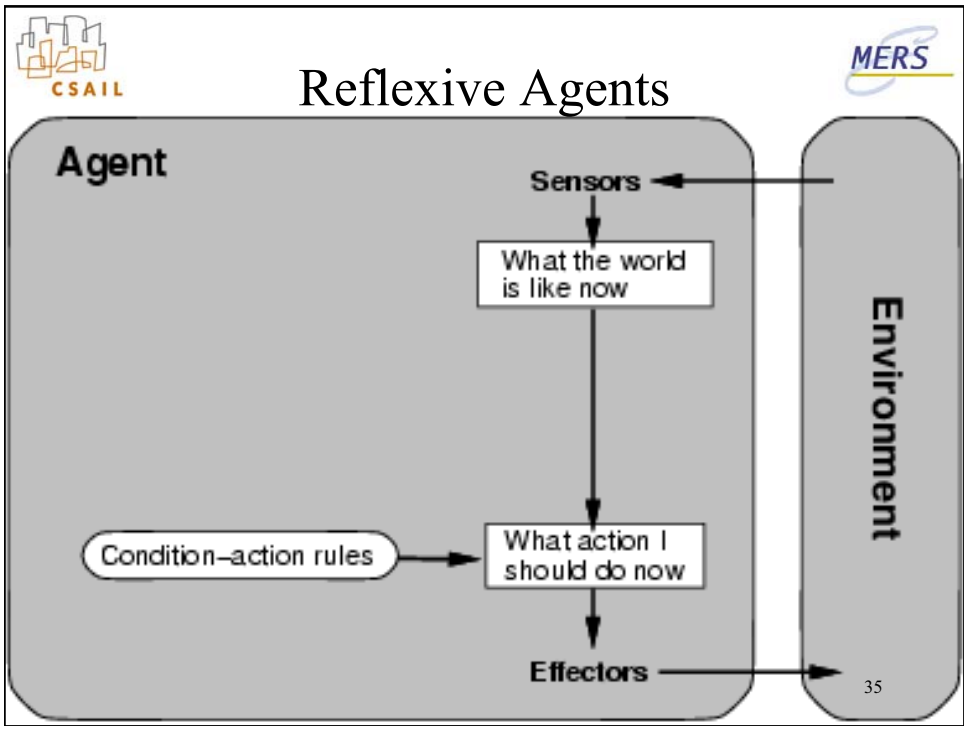


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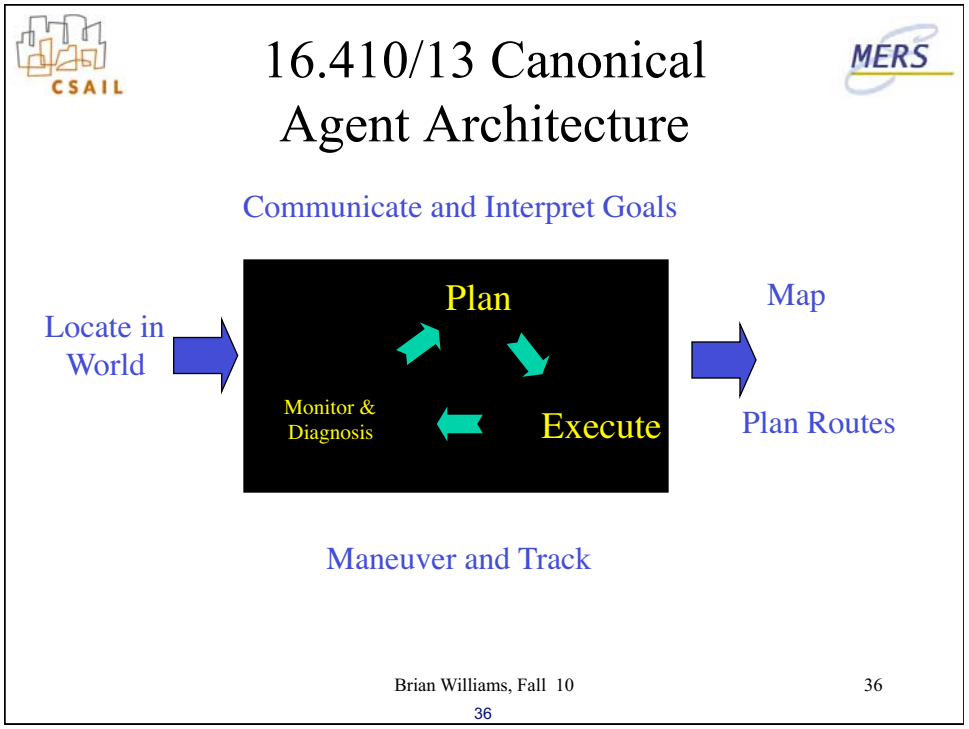

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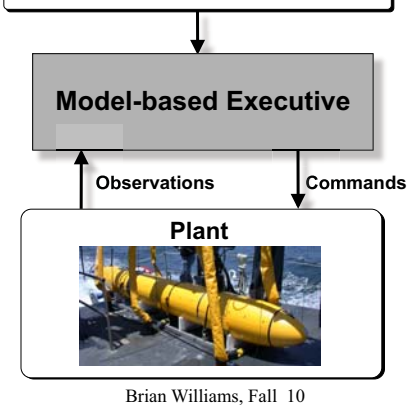
# Modeling Example: Robust, Goal-directed Deep Sea Exploration

*"Remain in mapping region for at least 100s, then remain in bloom region for at least 50s, then return to pickup region. Avoid obstacles at all times"*

**Qualitative State Plan**

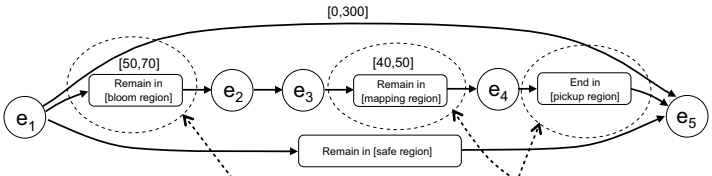



**Optimal**

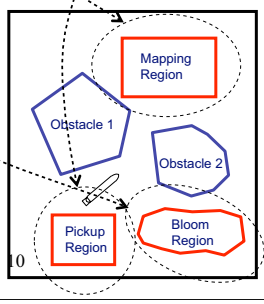
Leaute & Williams, AAAI 05

# Modeling Goal Behavior using Qualitative State Plans

A qualitative state plan is a model-based program that is unconditional, timed, and hybrid and provides flexibility in state and time.




*"Remain in bloom region for between 50 and 70 seconds. Afterwards, remain in mapping region for between 40s and 50s. End in the pickup region. Avoid obstacles at all times. Complete the mission within 300s"*




Approach: Frame as Model-Predictive Control using Mixed Logic or Integer / Linear Programming.



# Modeling Goal-directed Planning as a Mathematical Program

$$\min_{\mathbf{U}} J(\mathbf{X},\mathbf{U}) + H(x_T)$$

Cost function (e.g. fuel consumption)

$$s.t.$$

**Dynamics** (Discrete time)

$$\forall_{0 \le t \le T-1} \; x_{t+1} = Ax_t + Bu_t$$

**Constraints**

$$\bigwedge_{t=0}^{T} \bigwedge_{i=0}^{N} \bigvee_{j=0}^{M} h_t^{iT} x_t \le g_t^{ij}$$

**Mixed Logic or Integer**

$\mathbf{X} = [x_0 \cdots x_t]^T$ State vector (e.g. position of vehicle)

$\mathbf{U} = [u_0 \cdots u_{t-1}]^T$ Control inputs

# Specify Building Blocks using Declarative Programming

- Mathematical Programming
- Constraint Programming
- Logic Programming
- Agent Programming
  - Model-based programming
  - Timed concurrent constraint programming
  - Golog
  - Temporal logic programming



# Solve Declarative Programs using:

Search + Inference

Search: try taking the subway, or
try taking the bus.

Inference: It takes 35 minutes to get to MIT,
20 min subway + 15 min walking.



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16.410 / 16.413 Principles of Autonomy and Decision Making

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