Artificial Intelligence -- 15-381
Real-Time AI Systems

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OUTLINE:

- What exactly is "Real-Time"?
- Real-Time Planning
- Agenda-Control Methods
- A Case Study of RT Rule-Based AI

Real-Time AI: What is it?

Possible Operational Definitions

- AI system that runs very efficiently
- AVE Decision-cycle(AI)
  < AVE Action-cycle(World)
- MAX Decision-cycle(AI)
  < MIN Action-cycle(World)
- Forall(xεEvents)[time(d(x),AI) + time(a(x),AI)
  < time(a(x),W)]
- Forall(xεE Exists(y)εDC & Exists(z)εAC
  [time(y(x)) + time(z(y(x))) < time(a(x),W]
  Note: Above is 2nd-order logic expression

Need for Real-Time AI

- Robotic applications (most kinds)
- Autonomous driving (no-hands across America)
- Sensor-based warning/action systems (Smokey)
- Self-repairing telephone or electric networks
- ATM or Credit-card fraud detection

The SMOKEY System

Task Definition

- Sensor-based location, prediction, control of onboard fires in Aircraft carriers.
- **Sensors:** smoke, heat, chemical analysis
- **Knowledge:** sensor topology, ship map, loc of flammables, ...
- **Actions:** evacuate and/or seal-off section, equip and send firefighters, all-clear, ...

Objectives

- Real-time reaction
- Better performance than humans
- Robust behavior

Knowledge Sources for SMOKEY

Static

- Ship topology (graph data structure)
- Ventilation System topology
- Sensor system topology
- Sensor system types (smoke, heat, chemical)
- Flammable materials (paint, paper, fuel, electrical insulation, munitions, ...)
- Fire suppressants (water, O_2-denial gas/foam, ...)

Dynamic

- Location of crew members
- Location of fire-control team(s)
- Settings of hatches
- Settings of ventilation system

Agenda-Based Control

Agenda Data Structure

```
Level-1:  T1,1, T1,2, ..., T1,j
Level-2:  T2,1, T2,2, ..., T2,k
    .
    .
    .
Level-n:  Tn,1, Tn,2, ..., Tn,m
```

Fields in each $T_{i,j}$

```
 Name       Domain                     Range
----------------------------------------------
TRIGGER:   pat X WM X A   ->  {F, T(bindings)}
DYNAMIC:   pat X WM X sen ->  {F, T(bindings)}
----------------------------------------------
WM-UPDATE: WM X bindings  ->  WM
A-UPDATE+: A X bindings   ->  A
A-UPDATE-: A X bindings   ->  A
A-FLUSH:   Bindings       ->  A
----------------------------------------------
ACT:       Bindings       ->  World
          (X sen X WM)
----------------------------------------------
```

Agenda-Based Control
Individual Task-Execution Method

If Active($T_{i.j}$, A)
& Match($T_{i,j}$.TRIGGER, WM)
& Match($T_{i,j}$.DYNAMIC, WM, f(sensors))

THEN Execute($T_{i.j}$.ACT, bindings)
& Update($T_{i,j}$.WM, WM, binding)
& Add($T_{i.j}$.A-UPDATE+, A)
& Delete($T_{i,j}$.A-UPDATE-, A)

ELSE-IF Match($T_{i,j}$.A-FLUSH, A)
THEN Delete($T_{i,j}$.ID, A)

Note: $T_{i,j}$.A-UPDATE+ :=
(<bindings.level, bindings.task> ...)

Agenda-Based Control
Task Selection Methods

N-Level Priority-Queue

$Fail(T_{i,j}) \Rightarrow T_{i,j+1}$
$Succ(T_{i,j}) \Rightarrow T_{i,1}$
$j+1 > j_{max} \Rightarrow T_{i+1,1}$
$i+1 > i_{max} \Rightarrow T_{1,1}$

Global Priority-Queue

$Fail(T_{i,j}) \Rightarrow T_{i,j+1}$
$Succ(T_{i,j})\ \&\ \Delta t < \Delta t_{threshold} \Rightarrow T_{i,1}$
$Succ(T_{i,j})\ \&\ \Delta t >= \Delta t_{threshold} \Rightarrow T_{1,1}$
$j+1 > j_{max} \Rightarrow T_{i+1,1}$
$i+1 > i_{max} \Rightarrow T_{1,1}$

Other Agenda Disciplines

- Linear order with interrupts
- Declining time guarantees per level
  (e.g. min of 50% for L1, 25% L2, 12% L3, ...)
- And more...

Anytime Planning

Definitions:

***Deliberative Planning* --** Think first (full plan of action), act later.

***Reactive "Planning"* --** No thinking, reflex-action only.

***Anytime Planning* --** Think exactly as long as external world permits, or you reach final conclusion, but have always tentative answer ready. Deliberative planner with interrupts that always has a best-so-far.

***Probabilistic Planner* --** Accounts for uncertain consequences of actions and uncertain states of the world.

Properties

- Deliberation => potential for subgoaling, backtracking, weighing alternatives.
- Reactivity => potential for real-time behavior.
- Any-time => [At least some of] both advantages.
- Anytime probabilistic planning => Optimal, but difficult. Best robotic agents are anytime planners.