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## Knowledge Representation and Reasoning

**Project number 2:**  
**Deterministic Action With Cost**  
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# Contents

<b>1</b>	<b>Introduction</b>	<b>2</b>
<b>2</b>	<b>Syntax</b>	<b>2</b>
2.1	Signature : . . . . .	2
2.2	Literal : . . . . .	3
2.3	Statements : . . . . .	3
<b>3</b>	<b>Semantics</b>	<b>3</b>
<b>4</b>	<b>Examples</b>	<b>4</b>
4.1	Example 01 . . . . .	4
4.1.1	Description . . . . .	4
4.1.2	Representation . . . . .	5
4.1.3	Calculation . . . . .	5
4.1.4	Graph . . . . .	6
4.2	Example 02 . . . . .	6
4.2.1	Description . . . . .	6
4.2.2	Representation: . . . . .	7
4.2.3	Calculation: . . . . .	7
4.2.4	Graph . . . . .	8
4.3	Example 03 . . . . .	8
4.3.1	Description . . . . .	8
4.3.2	Representation in language . . . . .	9
4.3.3	Calculation . . . . .	9
4.3.4	Graph . . . . .	10
<b>5</b>	<b>Appendix</b>	<b>11</b>

# 1 Introduction

A dynamic system (DS) is viewed as

- a collection of objects, together with their properties, and
- a collection of actions which, while performed, change properties of objects (in consequence, the state of the world).

Let  $C2$  be a class of dynamic systems satisfying the following assumptions:

1. Inertia law
2. Complete information about all actions and fluent.
3. Only Determinism
4. Only sequential actions are allowed.
5. Characterizations of actions:
  - Precondition represented by set of literals(a fluent or its negation);if a precondition does not hold, the action is executed but with empty effect
  - Postcondition (effect of an action) represented by a set of literals.
  - Cost  $k \in N$  of an action, actions with empty effects cost 0. Each action has a fixed cost, if it leads to non-empty effects.
6. Effects of an action depends on the state where the action starts.
7. All actions are performed in all states.
8. Partial description of any state of the system are allowed.
9. No constraints are defined.

## 2 Syntax

### 2.1 Signature :

A signature is a triplet  $\Upsilon = (F, Ac, K)$  where  $F$  is a set of fluents;  $Ac$  is a set of actions as follows  $A1, A2, \dots, An$  where  $Ai \in Ac$  and  $i = 1$  to  $n$  and  $K$  is a set of positive integers representing Cost of each action  $Ai \in Ac$  as follows  $K1, K2, \dots, Kn$  where  $Ki \in K$  and  $i = 1$  to  $n$ .

## 2.2 Literal :

A literal is either a fluent  $f$  or its negation  $\neg f$ .

**Notation:** for a fluent  $f \in F$ , we write  $\bar{f}$  to denote the literal corresponding to  $f$ , i.e., either  $f$  or  $\neg f$ .

## 2.3 Statements :

The system and changes occurring within can be described through a sequence of statements defined in the table:

Statement	Format	Description
Effect Statement	$A_i$ causes $\bar{f}$ if $\bar{g1}, \dots, \bar{gk}$	If the action $A_i$ is performed in any state satisfying $\bar{g1}, \dots, \bar{gk}$ , then in the resulting state $\bar{f}$ holds.
Value Statement	$\bar{f}$ after $A_1 \dots A_n$ where $\bar{f} \in F$ and $A_i \in Ac$ , for $i = 1, \dots, n$	$\bar{f}$ holds after performing the sequence $A_1 \dots A_n$ of actions in the initial state.
Cost Statement	$A_i$ costs $k_i$ , $k_i \in K$ for $i = 1, \dots, n$	If the action $A_i$ is performed in any state satisfying $\bar{g1}, \dots, \bar{gk}$ , then change in state results in fixed cost $k_i$ .

Table 1: Syntax Table

## 3 Semantics

- A state is a mapping  $\sigma : F \rightarrow \{0, 1\}$ . For any  $f \in F$ , if  $\sigma(f) = 1$ , then we say that  $f$  holds in  $\sigma$  and write  $\sigma \models f$ . If  $\sigma(f) = 0$ , then we write  $\sigma \models \neg f$  and say that  $f$  does not hold in  $\sigma$ . Let  $\sum$  stand for the set of all states.
- A state transition function is a mapping  $\Psi : Ac \times \sum \rightarrow \sum$ . For any  $\sigma \in \sum$ , for any action  $A_i \in Ac$  where  $i = 1, \dots, n$ ,  $\Psi(A_i, \sigma)$  is the state resulting from performing the action  $A_i$  in the state  $\sigma$ . Also  $\Psi(A_i, \sigma)$  will results in same state if the effect of action is empty.
- A cost transition function is a mapping  $\Gamma : Ac \times \sum \rightarrow K$ . For any  $\sigma \in \sum$  and for any action  $A_i \in Ac$  where  $i = 1, \dots, n$ ,  $\Gamma(A_i, \sigma)$  is the fixed cost  $k_i$  corresponding to the action  $A_i$ , where  $k_i \in K$  and  $i=1, \dots, n$ , resulting from performing the action  $A_i$  in the state  $\sigma$ . Also  $\Gamma(A_i, \sigma)$  will results in 0 cost if there is no change in state.
- A transition function is generalized to the mapping  $\Psi^* : Ac^* \times \sum \rightarrow \sum$  as follows:

1.  $\Psi^* (\varepsilon, \sigma) = \sigma$ ,
  2.  $\Psi^* ((A1, \dots, An), \sigma) = \Psi(An, \Psi^* (A1, \dots, An-1))$ .
- Let L be an action language of the class A over the signature  $\Upsilon = (F, Ac, K)$ . A structure for L is a triplet  $S = (\Psi, \sigma_0, \Gamma)$  where  $\Psi$  is a state transition function,  $\Gamma$  is a cost transition function and  $\sigma_0 \in \Sigma$  is the initial state
  - Let  $S = (\Psi, \sigma_0, \Gamma)$  be a structure for L. A statement s is true in S, in symbols  $S \models s$ , iff
    1. s is of the form  $\bar{f}$  after  $A1, \dots, An$ , then  $\Psi((A1, \dots, An), \sigma_0) \models \bar{f}$ ;
    2. if s is of the form  $Ai$  causes  $\bar{f}$  if  $\bar{g1}, \dots, \bar{gk}$ , then for every  $\sigma \in \Sigma$  such that  $\sigma \models \bar{gj}$ ,  $j = 1, \dots, k$ ,  $\Psi(Ai, \sigma) \models \bar{f}$ .
    3. if s is of the form  $A1, \dots, An$  costs  $k1, \dots, kn$  respectively where  $ki \in K$ ,  $Ai \in Ac$  and  $i = 1, \dots, n$ , then every  $\sigma \in \Sigma$  such that  $\sigma \models \bar{gi}$ ,  $i = 1, \dots, k$ ,  $\Gamma(Ai, \sigma) \models ki$ .

Let D be an action domain in the language L over the signature  $\Upsilon = (F, Ac, K)$ .

A structure  $S = (\Psi, \sigma_0, \Gamma)$  is a model of D iff

(M1) for every statement  $s \in D$ ,  $S \models s$ ;

(M2) for every  $Ai \in Ac$  for every  $f, g1, \dots, gn \in F$ , for every  $ki \in K$  and for every  $\sigma \in \Sigma$ , if one of the following conditions holds:

(i) D contains an effect statement and a cost statement as follows:

- **Ai causes  $\bar{f}$  if  $\bar{g1}, \dots, \bar{gk}, \sigma \not\models \bar{gj}$  for some  $j = 1, \dots, k$**
- **Ai costs  $ki$** , if  $\Psi(Ai, \sigma) \not\models \sigma$ .

(ii) D does not contain an effect statement but contains a 0 cost statement, as follows:

- **Ai causes  $\bar{f}$  if  $\bar{g1}, \dots, \bar{gk}$  then  $\sigma \models f$  iff  $\Psi(Ai, \sigma) \models f$ .**
- **Ai costs 0**, if  $\Psi(Ai, \sigma) \models \sigma$ .

## 4 Examples

### 4.1 Example 01

#### 4.1.1 Description

Andrew wants to travel by his car to a place. Travelling costs him 50\$ if he uses fuel from the fuel tank of the car. If in case of emergency, Andrew is

carrying a bottle of fuel as reserve, which can cost him 50\$ for travelling.  
 buying Fuel costs him 100\$ if both fuel and reserve are empty. and buying  
 causes both his Fuel and Reserve are filled.

#### 4.1.2 Representation

Fluents:  $F = \{\text{fuel}, \text{reserve}\}$

Actions:  $Ac = \{\text{buy}, \text{travel}\}$

Costs:  $K = \{100, 50\}$

Initially: fuel, reserve

travel causes  $\neg\text{fuel}$  if fuel

travel costs 50

travel causes  $\neg\text{reserve}$  if  $\neg\text{fuel}, \text{reserve}$

travel costs 50

buy causes fuel if  $\neg\text{fuel}, \neg\text{reserve}$

buy causes reserve if  $\neg\text{fuel}, \neg\text{reserve}$

buy costs 100

#### 4.1.3 Calculation

$\Sigma = \{ \sigma_0, \sigma_1, \sigma_2, \sigma_3 \}$

$\sigma_0 = \{ \text{fuel}, \text{reserve} \}$        $\sigma_1 = \{ \neg\text{fuel}, \text{reserve} \}$

$\sigma_2 = \{ \neg\text{fuel}, \neg\text{reserve} \}$        $\sigma_3 = \{ \text{fuel}, \neg\text{reserve} \}$

$\Psi(\text{buy}, \sigma_0) = \sigma_0$

$\Psi(\text{travel}, \sigma_0) = \sigma_1$

$\Gamma(\text{buy}, \sigma_0) = 0$

$\Gamma(\text{travel}, \sigma_0) = 50$

$\Psi(\text{buy}, \sigma_1) = \sigma_1$

$\Psi(\text{travel}, \sigma_1) = \sigma_2$

$\Gamma(\text{buy}, \sigma_1) = 0$

$\Gamma(\text{travel}, \sigma_1) = 50$

$\Psi(\text{buy}, \sigma_2) = \sigma_0$

$\Psi(\text{travel}, \sigma_2) = \sigma_2$

$\Gamma(\text{buy}, \sigma_2) = 100$

$\Gamma(\text{travel}, \sigma_2) = 0$

$$\begin{aligned}
\Psi(\text{buy}, \sigma_3) &= \sigma_3 \\
\Psi(\text{travel}, \sigma_3) &= \sigma_2 \\
\Gamma(\text{buy}, \sigma_3) &= 0 \\
\Gamma(\text{travel}, \sigma_3) &= 50
\end{aligned}$$

#### 4.1.4 Graph

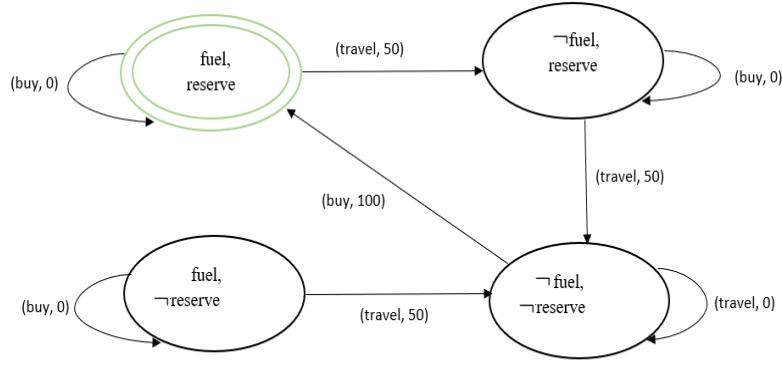


Figure 1: Example 01

## 4.2 Example 02

### 4.2.1 Description

John visits a painter to buy a specific painting. The cost of painting is 200\$ if its available in the shop. But if painting is not available then John needs to order a new one to be painted and will buy once its available. Order costs 50\$ At any time only one copy of painting is available and another one to be ordered once sold.

#### 4.2.2 Representation:

Fluents:  $F = \{\text{available}, \text{sold}\}$   
Actions:  $Ac = \{\text{buy}, \text{order}\}$   
Costs:  $K = \{200, 50\}$   
Initially:  $\neg\text{available}, \neg\text{sold}$   
buy causes sold if available  
buy causes  $\neg\text{available}$   
buy costs 200\$  
order causes available if  $\neg\text{available}$   
order costs 50\$

#### 4.2.3 Calculation:

$\Sigma = \{\sigma_0, \sigma_1, \sigma_2, \sigma_3\}$   
 $\sigma_0 = \{\neg\text{available}, \neg\text{sold}\}$   
 $\sigma_1 = \{\text{available}, \neg\text{sold}\}$   
 $\sigma_2 = \{\neg\text{available}, \text{sold}\}$   
 $\sigma_3 = \{\text{available}, \text{sold}\}$

$\Psi(\text{buy}, \sigma_0) = \sigma_0$   
 $\Psi(\text{order}, \sigma_0) = \sigma_1$   
 $\Gamma(\text{buy}, \sigma_0) = 0$   
 $\Gamma(\text{order}, \sigma_0) = 50$

$\Psi(\text{buy}, \sigma_1) = \sigma_2$   
 $\Psi(\text{order}, \sigma_1) = \sigma_1$   
 $\Gamma(\text{buy}, \sigma_1) = 200$   
 $\Gamma(\text{order}, \sigma_1) = 0$

$\Psi(\text{buy}, \sigma_2) = \sigma_2$   
 $\Psi(\text{order}, \sigma_2) = \sigma_1$   
 $\Gamma(\text{buy}, \sigma_2) = 0$   
 $\Gamma(\text{order}, \sigma_2) = 50$

$\Psi(\text{buy}, \sigma_3) = \sigma_2$   
 $\Psi(\text{order}, \sigma_3) = \sigma_3$   
 $\Gamma(\text{buy}, \sigma_3) = 200$



$$\Gamma(\text{order}, \sigma_3) = 0$$

#### 4.2.4 Graph

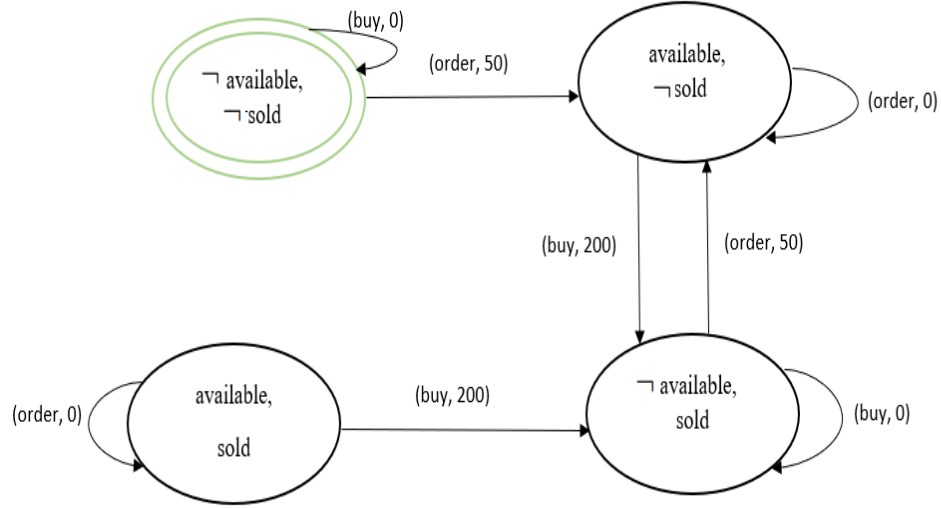


Figure 2: Example 02

### 4.3 Example 03

#### 4.3.1 Description

There is a man. He can cook, eat, and play. Cooking makes food cooked. he can eat food if it is cooked. After eating he feels not hungry, and food is not cooked again. He can play. Playing makes him hungry. He just can play if he is not hungry. He just cooks when there is no food is cooked. Initially, he is hungry, and no food is cooked. In terms of energy, eating costs 5, cooking costs 15, playing costs 20.

### 4.3.2 Representation in language

Fluents:  $F = \{\text{cooked}, \text{hungry}\}$

Actions:  $Ac = \{\text{cook}, \text{eat}, \text{play}\}$

Costs:  $K = \{15, 5, 20\}$

initially  $\neg\text{cooked}, \text{hungry}$

cook causes cooked if  $\neg\text{cooked}$

cook costs 15

eat causes  $\neg\text{cooked}, \neg\text{hungry}$  if cooked

eat costs 5

play causes hungry if  $\neg\text{hungry}$

play costs 20

### 4.3.3 Calculation

$$\Sigma = \{\sigma_0, \sigma_1, \sigma_2, \sigma_3\}$$

$$\sigma_0 = \{\neg\text{cooked}, \text{hungry}\}$$

$$\sigma_1 = \{\text{cooked}, \text{hungry}\}$$

$$\sigma_2 = \{\neg\text{cooked}, \neg\text{hungry}\}$$

$$\sigma_3 = \{\text{cooked}, \neg\text{hungry}\}$$

$$\Psi(\text{eat}, \sigma_0) = \sigma_0$$

$$\Psi(\text{cook}, \sigma_0) = \sigma_1$$

$$\Psi(\text{play}, \sigma_0) = \sigma_0$$

$$\Gamma(\text{eat}, \sigma_0) = 0$$

$$\Gamma(\text{cook}, \sigma_0) = 15$$

$$\Gamma(\text{play}, \sigma_0) = 0$$

$$\Psi(\text{eat}, \sigma_1) = \sigma_2$$

$$\Psi(\text{cook}, \sigma_1) = \sigma_1$$

$$\Psi(\text{play}, \sigma_1) = \sigma_1$$

$$\Gamma(\text{eat}, \sigma_1) = 5$$

$$\Gamma(\text{cook}, \sigma_1) = 0$$

$$\Gamma(\text{play}, \sigma_1) = 0$$

$$\Psi(\text{eat}, \sigma_2) = \sigma_2$$

$$\begin{aligned}
\Psi(\text{cook}, \sigma_2) &= \sigma_3 \\
\Psi(\text{play}, \sigma_2) &= \sigma_1 \\
\Gamma(\text{eat}, \sigma_2) &= 0 \\
\Gamma(\text{cook}, \sigma_2) &= 15 \\
\Gamma(\text{play}, \sigma_2) &= 20
\end{aligned}$$

$$\begin{aligned}
\Psi(\text{eat}, \sigma_3) &= \sigma_2 \\
\Psi(\text{cook}, \sigma_3) &= \sigma_3 \\
\Psi(\text{play}, \sigma_3) &= \sigma_1 \\
\Gamma(\text{eat}, \sigma_3) &= 5 \\
\Gamma(\text{cook}, \sigma_3) &= 0 \\
\Gamma(\text{play}, \sigma_3) &= 20
\end{aligned}$$

#### 4.3.4 Graph

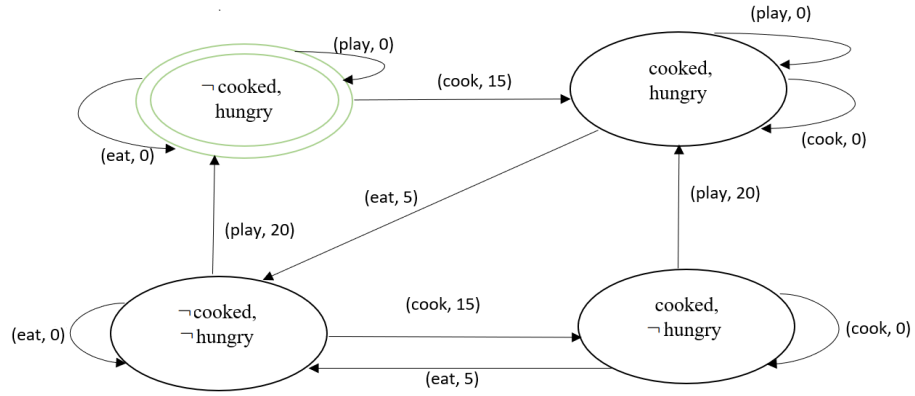


Figure 3: Example 03

## 5 Appendix

### List of Figures

1	Example 01 . . . . .	6
2	Example 02 . . . . .	8
3	Example 03 . . . . .	10

### List of Tables

1	Syntax Table . . . . .	3
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