Fundamentos de Inteligência Artificial
Turma 010 - 2022/1
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Planejamento
Automático

Integrantes do Grupo

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Para a realização do trabalho escolhemos um domínio que simula o jogo Torre de Hanói no repositório AI-Planning (1), que consiste em uma quantidade n de pinos e uma quantidade m de discos que inicialmente são empilhados nos pinos em ordem de tamanho crescente e devem ser transpostos para outra posição respeitando as regras do jogo: apenas discos sem nenhum outro disco em cima conseguem ser movidos e nenhum disco pode ser colocado acima de um disco menor.

O código do domínio é o seguinte:
```
(define (domain hanoi)
(:requirements :strips)
(:predicates (clear ?x)
        (on ?x ?y)
        (smaller ?x ?y))

(:action move
:parameters (?disc ?from ?to)
:precondition (and (smaller ?to ?disc)
            (on ?disc ?from)
            (clear ?disc)
            (clear ?to))
:effect  (and (clear ?from)
        (on ?disc ?to)
        (not (on ?disc ?from))
        (not (clear ?to)))
 ))
```

Seus predicados são (clear ?x), que verifica se existe algo em cima de x, (on ?x ?y), que verifica se x está em cima de y e (smaller ?x ?y), que verifica se y é menor que x. A única ação presente no domínio é move(?disc ?from ?to), em que "disc" precisa ser um disco, porém "from" e "to" podem ser discos ou pinos. Suas pré-condições são que o disco seja menor que o disco ou pino para onde esteja sendo movido, que ele esteja em cima do disco ou pino apontado como "from" e que tanto o disco quanto o alvo usado como "to" não tenham nenhum disco acima.

Elaboramos a ação moveTwo, que permite que o planejador mova 2 discos de uma vez, respeitando as condições de que os discos estejam um em cima do outro, o de baixo seja maior e que o destino dos discos seja maior que o disco de baixo.

```
(:action moveTwo
:parameters (?topDisc ?bottomDisc ?from ?to)
:precondition (and (smaller ?to ?bottomDisc)
            (smaller ?bottomDisc ?topDisc)
            (on ?bottomDisc ?from)
            (on ?topDisc ?bottomDisc)
            (clear ?topDisc)
            (clear ?to))
:effect (and (clear ?from)
```

(on ?bottomDisc ?to)
                (on ?topDisc ?bottomDisc)
                (not (on ?bottomDisc ?from))
                (not (clear ?to))))

       O planejador utilizado para os testes foi o PDDL Editor (2). Essa ferramenta nos permitiu trabalhar em cima do nosso domínio e criar problemas que a máquina testava a viabilidade de respostas de planejamento. O planejador tinha um limite de iterações pois algumas de nossas tentativas foram interrompidas. Todos nossos resultados foram gerados em cima de problemas testados nesse programa. O PDDL Editor utiliza dois tipos de algoritmo de busca, Iterative Width (IW) e caso a árvore deste algoritmo fique muito grande, utiliza Breadth First Search (BFS).

       Desenvolvemos dez problemas para testar com o planejador, eles estão ordenados por quantidade crescente de ações que o planejador encontrou para solucionar o problema. Nenhum destes 10 testes utilizou a ação moveTwo.

Problema 1:

Output:

```
 --- OK.
 Match tree built with 18 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-1
        #Actions: 18
        #Fluents: 11
Landmarks found: 2
Starting search with IW (time budget is 60 secs)...
rel_plan size: 2
#RP_fluents 4
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{2/2/0}:IW(1) -> [2]rel_plan size: 1
#RP_fluents 2
{2/1/1}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 2
Total time: 0
Nodes generated during search: 6
Nodes expanded during search: 2
IW search completed
```

Encontrada solução com custo = 2 ações.

Problema 2:

Output:

```
 --- OK.
 Match tree built with 10 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-7
        #Actions: 10
        #Fluents: 10
Landmarks found: 2
Starting search with IW (time budget is 60 secs)...
rel_plan size: 2
#RP_fluents 4
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{2/2/0}:IW(1) -> [2]rel_plan size: 1
#RP_fluents 2
{2/1/1}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 2
Total time: 0
Nodes generated during search: 4
Nodes expanded during search: 2
IW search completed
```

Encontrada solução com custo = 2 ações.

Problema 3:

Output:

```
 --- OK.
 Match tree built with 21 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-2
        #Actions: 21
        #Fluents: 13
Landmarks found: 2
Starting search with IW (time budget is 60 secs)...
rel_plan size: 3
#RP_fluents 5
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{2/2/0}:IW(1) -> [2][3]rel_plan size: 1
#RP_fluents 2
{2/1/1}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 3
Total time: 0
Nodes generated during search: 10
Nodes expanded during search: 4
IW search completed
```

Encontrada solução com custo = 3 ações.

Problema 4:

Output:

```
    --- OK.
 Match tree built with 124 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-6
        #Actions: 124
        #Fluents: 36
Landmarks found: 5
Starting search with IW (time budget is 60 secs)...
rel_plan size: 7
#RP_fluents 12
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{5/5/0}:IW(1) -> [2]rel_plan size: 5
#RP_fluents 9
{5/4/1}:IW(1) -> [2]rel_plan size: 3
#RP_fluents 6
{5/3/2}:IW(1) -> [2]rel_plan size: 2
#RP_fluents 4
{5/2/3}:IW(1) -> [2]rel_plan size: 1
#RP_fluents 2
{5/1/4}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 4.99503
Total time: -1.8999e-10
Nodes generated during search: 16
Nodes expanded during search: 5
IW search completed
```

Encontrada solução com custo = 5 ações.

Problema 5:

Output:

```
    --- OK.
 Match tree built with 56 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-3
        #Actions: 56
        #Fluents: 20
Landmarks found: 3
Starting search with IW (time budget is 60 secs)...
rel_plan size: 3
#RP_fluents 6
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{3/3/0}:IW(1) -> [2][3][4][5][6][7];; NOT I-REACHABLE ;;
Total time: 0.004
Nodes generated during search: 46
Nodes expanded during search: 46
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 3]--
--[1 / 3]--
--[1 / 2]--
--[1 / 1]--
--[1 / 0]--
--[0 / 0]--
Total time: -1.8999e-10
Nodes generated during search: 37
```

```
Nodes expanded during search: 10
Plan found with cost: 7
BFS search completed
```

Encontrada solução com custo = 7 ações.

Problema 6:

Output:

```
--- OK.
 Match tree built with 212 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-5
        #Actions: 212
        #Fluents: 43
Landmarks found: 5
Starting search with IW (time budget is 60 secs)...
rel_plan size: 6
#RP_fluents 11
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{5/5/0}:IW(1) -> [2][3]rel_plan size: 4
#RP_fluents 8
{5/4/1}:IW(1) -> [2][3][4][5][6]rel_plan size: 3
#RP_fluents 6
{5/3/2}:IW(1) -> [2][3][4][5][6][7][8][9];; NOT I-REACHABLE ;;
Total time: 0.004
Nodes generated during search: 266
Nodes expanded during search: 219
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 6]--
--[2 / 6]--
--[2 / 5]--
--[2 / 4]--
```

```
--[1 / 4]--
--[1 / 3]--
--[1 / 2]--
--[1 / 1]--
--[1 / 0]--
--[0 / 0]--
Total time: -3.7998e-10
Nodes generated during search: 78
Nodes expanded during search: 11
Plan found with cost: 8
BFS search completed
```

Encontrada solução com custo = 8 ações.

Problema 7:

Output:

```
--- OK.
 Match tree built with 98 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-4
        #Actions: 98
        #Fluents: 28
Landmarks found: 4
Starting search with IW (time budget is 60 secs)...
rel_plan size: 5
#RP_fluents 9
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{4/4/0}:IW(1) -> [2][3]rel_plan size: 4
#RP_fluents 7
{4/3/1}:IW(1) -> [2]rel_plan size: 2
#RP_fluents 4
{4/2/2}:IW(1) -> [2][3][4][5][6];; NOT I-REACHABLE ;;
Total time: -1.8999e-10
Nodes generated during search: 62
Nodes expanded during search: 52
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 6]--
--[1 / 6]--
--[1 / 4]--
--[1 / 2]--
```

```
--[1 / 1]--
--[1 / 0]--
--[0 / 0]--
Total time: -1.8999e-10
Nodes generated during search: 145
Nodes expanded during search: 43
Plan found with cost: 17
BFS search completed
```

Encontrada solução com custo = 17 ações.

Problema 8:

Output:

```
 --- OK.
 Match tree built with 678 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-8
        #Actions: 678
        #Fluents: 88
Landmarks found: 8
Starting search with IW (time budget is 60 secs)...
rel_plan size: 14
#RP_fluents 22
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{8/8/0}:IW(1) -> [2][3][4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22];; NOT I-REACHABLE ;;
Total time: 0.052
Nodes generated during search: 938
Nodes expanded during search: 938
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 23]--
--[8 / 23]--
--[8 / 21]--
--[7 / 21]--
--[6 / 21]--
--[6 / 20]--
--[6 / 19]--
--[6 / 18]--
```

```
--[6 / 18]--
--[6 / 17]--
--[5 / 17]--
--[5 / 15]--
--[4 / 15]--
--[4 / 14]--
--[4 / 12]--
--[3 / 12]--
--[3 / 11]--
--[3 / 10]--
--[3 / 8]--
--[3 / 6]--
--[2 / 6]--
--[2 / 4]--
--[2 / 3]--
--[1 / 3]--
--[1 / 2]--
--[1 / 1]--
--[1 / 0]--
--[0 / 0]--
Total time: 0.04
Nodes generated during search: 673
Nodes expanded during search: 63
Plan found with cost: 28
BFS search completed
```

Encontrada solução com custo = 28 ações.

Problema 9:

Output:

```
  --- OK.
  Match tree built with 544 nodes.

  PDDL problem description loaded:
          Domain: HANOI
          Problem: HANOI-9
          #Actions: 544
          #Fluents: 79
  Landmarks found: 8
  Starting search with IW (time budget is 60 secs)...
  rel_plan size: 13
  #RP_fluents 21
  Caption
  {#goals, #UNnachieved,  #Achieved} -> IW(max_w)

  {8/8/0}:IW(1) -> [2][3][4][5][6][7][8][9][10][11][12][13][14][15][16][17];; NOT I-REACHABLE ;;
  Total time: 0.024
  Nodes generated during search: 597
  Nodes expanded during search: 597
  IW search completed
  Starting search with BFS(novel,land,h_add)...
  --[4294967295 / 31]--
  --[8 / 31]--
  --[8 / 27]--
  --[8 / 26]--
  --[8 / 24]--
  --[8 / 22]--
  --[8 / 21]--
  --[7 / 21]--
```

```
  --[7 / 20]--
  --[7 / 19]--
  --[6 / 19]--
  --[6 / 18]--
  --[5 / 18]--
  --[5 / 17]--
  --[4 / 17]--
  --[4 / 16]--
  --[3 / 16]--
  --[3 / 15]--
  --[3 / 14]--
  --[3 / 12]--
  --[3 / 11]--
  --[3 / 10]--
  --[2 / 10]--
  --[2 / 9]--
  --[2 / 8]--
  --[2 / 7]--
  --[2 / 6]--
  --[2 / 5]--
  --[2 / 4]--
  --[1 / 4]--
  --[1 / 3]--
  --[1 / 2]--
  --[1 / 1]--
  --[1 / 0]--
  --[0 / 0]--
  Total time: 0.496
  Nodes generated during search: 7398
  Nodes expanded during search: 1161
```

```
  Nodes expanded during search: 1161
  Plan found with cost: 66
  BFS search completed
```

Encontrada solução com custo = 66 ações.

Problema 10:

Output:

```
--- OK.
 Match tree built with 426 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-10
        #Actions: 426
        #Fluents: 70
Landmarks found: 8
Starting search with IW (time budget is 60 secs)...
rel_plan size: 8
#RP_fluents 16
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{8/8/0}:IW(1) -> [2][3][4][5][6][7][8][9][10][11][12][13];; NOT I-REACHABLE ;;
Total time: 0.004
Nodes generated during search: 243
Nodes expanded during search: 243
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 8]--
--[1 / 8]--
--[1 / 7]--
--[1 / 6]--
--[1 / 5]--
--[1 / 4]--
--[1 / 3]--
--[1 / 2]--
```

```
--[1 / 1]--
--[1 / 0]--
--[0 / 0]--
Total time: 1.596
Nodes generated during search: 23213
Nodes expanded during search: 7005
Plan found with cost: 346
BFS search completed
```

Encontrada solução com custo = 346 ações

Também realizamos testes com um problema bônus e com os problemas 1, 5 e 10 para testar a ação moveTwo.

Problema Extra:

Output:

```
  --- OK.
 Match tree built with 78 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOIEXTRA
        #Actions: 78
        #Fluents: 21
Landmarks found: 4
Starting search with IW (time budget is 60 secs)...
rel_plan size: 2
#RP_fluents 4
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{4/4/0}:IW(1) -> rel_plan size: 2
#RP_fluents 4
{4/2/2}:IW(1) -> [2]rel_plan size: 1
#RP_fluents 2
{4/1/3}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 2
Total time: -1.8999e-10
Nodes generated during search: 7
Nodes expanded during search: 2
 IW search completed
```

Encontrada solução com custo = 2 ações.

Problema 1:
Para o problema 1 não houveram alterações em relação à primeira solução.

Output:

```
  --- OK.
 Match tree built with 24 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-1
        #Actions: 24
        #Fluents: 11
Landmarks found: 2
Starting search with IW (time budget is 60 secs)...
rel_plan size: 2
#RP_fluents 4
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{2/2/0}:IW(1) -> [2]rel_plan size: 1
#RP_fluents 2
{2/1/1}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 2
Total time: -1.8999e-10
Nodes generated during search: 6
Nodes expanded during search: 2
 IW search completed
```

Problema 5:
Para o problema 5 foi encontrada uma solução com 3 ações, 4 a menos que na versão sem a ação moveTwo.

Output:

```
--- OK.
 Match tree built with 138 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-5
        #Actions: 138
        #Fluents: 20
Landmarks found: 3
Starting search with IW (time budget is 60 secs)...
rel_plan size: 2
#RP_fluents 4
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{3/3/0}:IW(1) -> rel_plan size: 2
#RP_fluents 4
{3/2/1}:IW(1) -> [2][3]rel_plan size: 1
#RP_fluents 2
{3/1/2}:IW(1) -> [2]rel_plan size: 0
#RP_fluents 0Plan found with cost: 3
Total time: -1.8999e-10
Nodes generated during search: 28
Nodes expanded during search: 7
IW search completed
```

Problema 10:

Nesta versão foi encontrada uma solução com 19 movimentos, uma melhoria significativa em comparação com a versão anterior, de 346 movimentos.

Output:

```
--- OK.
 Match tree built with 1728 nodes.

PDDL problem description loaded:
        Domain: HANOI
        Problem: HANOI-3
        #Actions: 1728
        #Fluents: 70
Landmarks found: 8
Starting search with IW (time budget is 60 secs)...
rel_plan size: 4
#RP_fluents 8
Caption
{#goals, #UNnachieved,  #Achieved} -> IW(max_w)

{8/8/0}:IW(1) -> rel_plan size: 4
#RP_fluents 8
{8/4/4}:IW(1) -> [2][3][4][5][6][7][8][9][10][11][12];; NOT I-REACHABLE ;;
Total time: 0.004
Nodes generated during search: 310
Nodes expanded during search: 309
IW search completed
Starting search with BFS(novel,land,h_add)...
--[4294967295 / 4]--
--[1 / 4]--
--[1 / 3]--
--[1 / 2]--
--[1 / 1]--
--[1 / 0]--
```

```
Total time: 0.024
Nodes generated during search: 296
Nodes expanded during search: 36
Plan found with cost: 19
BFS search completed
```

Bibliografia:

(1) Repositório AI-Planning -
https://github.com/AI-Planning/classical-domains/tree/master/classical
(2) PDDL Editor - http://editor.planning.domains/