Module: Advanced Agent Competition - [PJ] Künstliche Intelligenz in Robocup

Human - Robot Collaboration and Teamwork "in Smart Urban Factory towards Industry 4.0"

Perspective taking (Theory of Mind) and adaptive decision-making in HRI

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MILESTONE 3 Presentation

Agenda

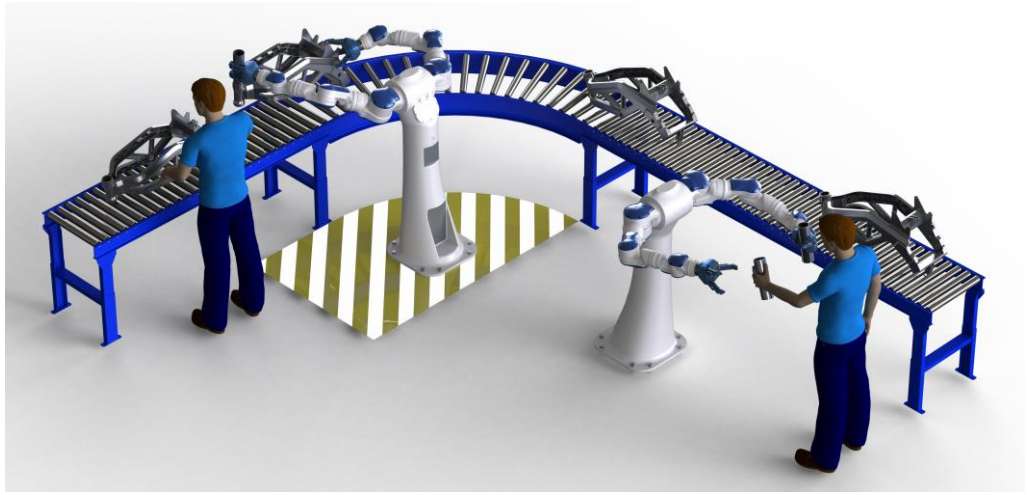
- Motivation
- Problem definition
- Architecture
- MDP/POMDP model
- Demo
- (if time left: Challenges)

Motivation

- Human-Robot-Collaboration biggest part in Industry 4.0

- Human will be replaced more and more with robots in industrial production

- Advantages Robot:
  precise, fast, monotonous, repetitive work

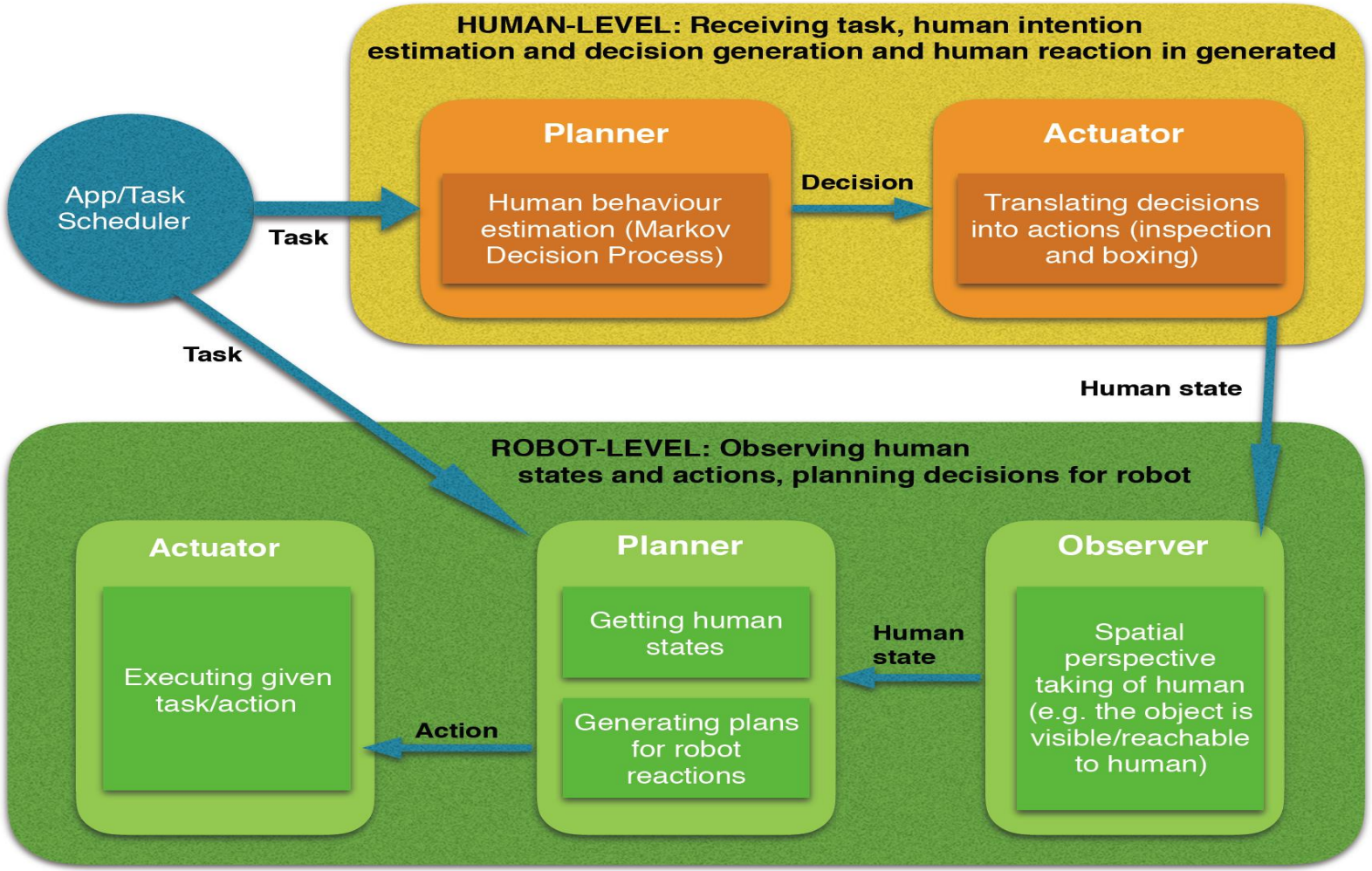


- Human-Robot-Collaboration is a future branch

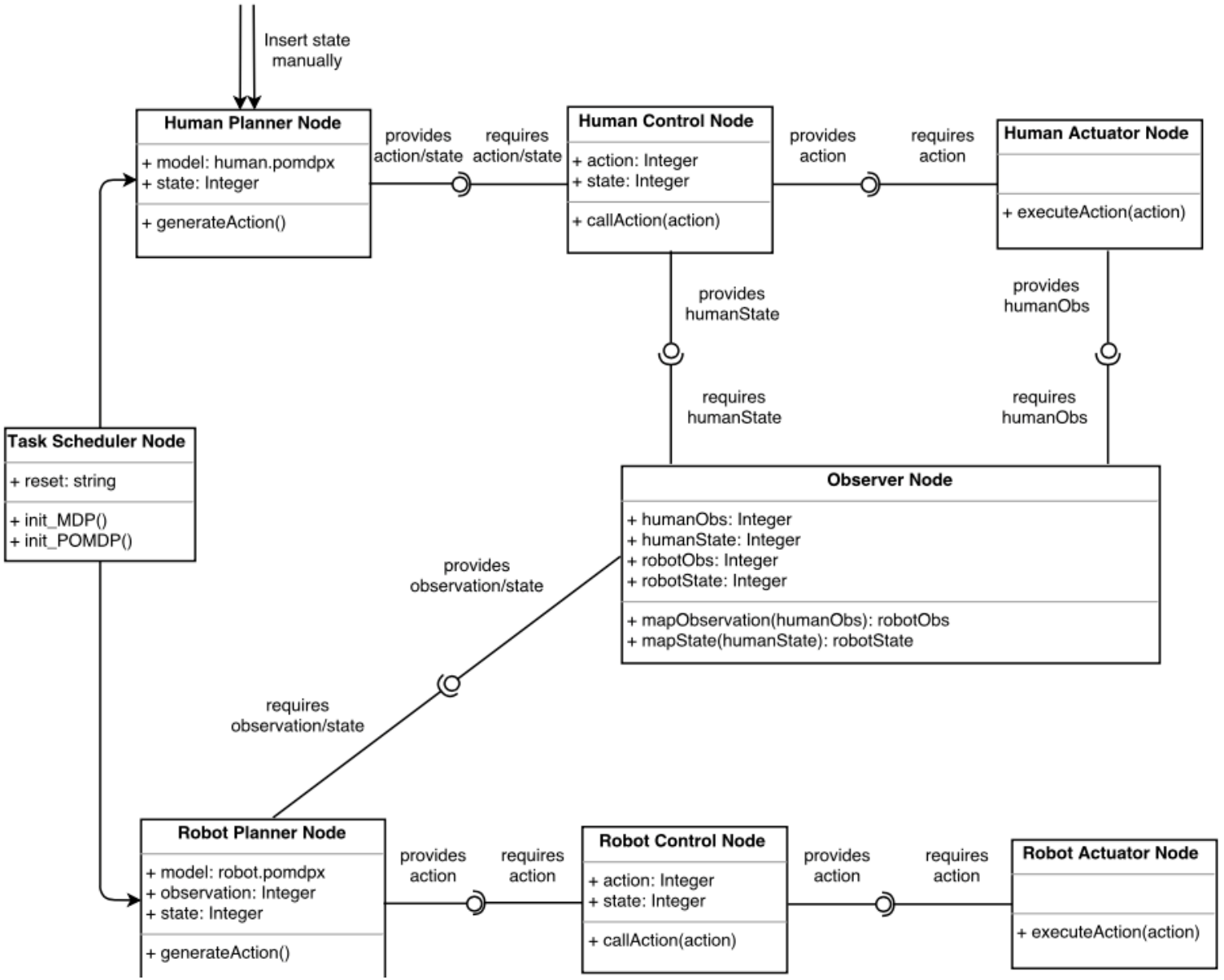
Problem definition

- Development of an interface to generate decisions according to the object parameters
- Animating and Modelling Human, Robot using MORSE
- Defining states and actions for Human using MDP (Markov Decision Process)
- Robot decision making and collaboration with Human using POMDP (Partially Observable Markov Decision Process)

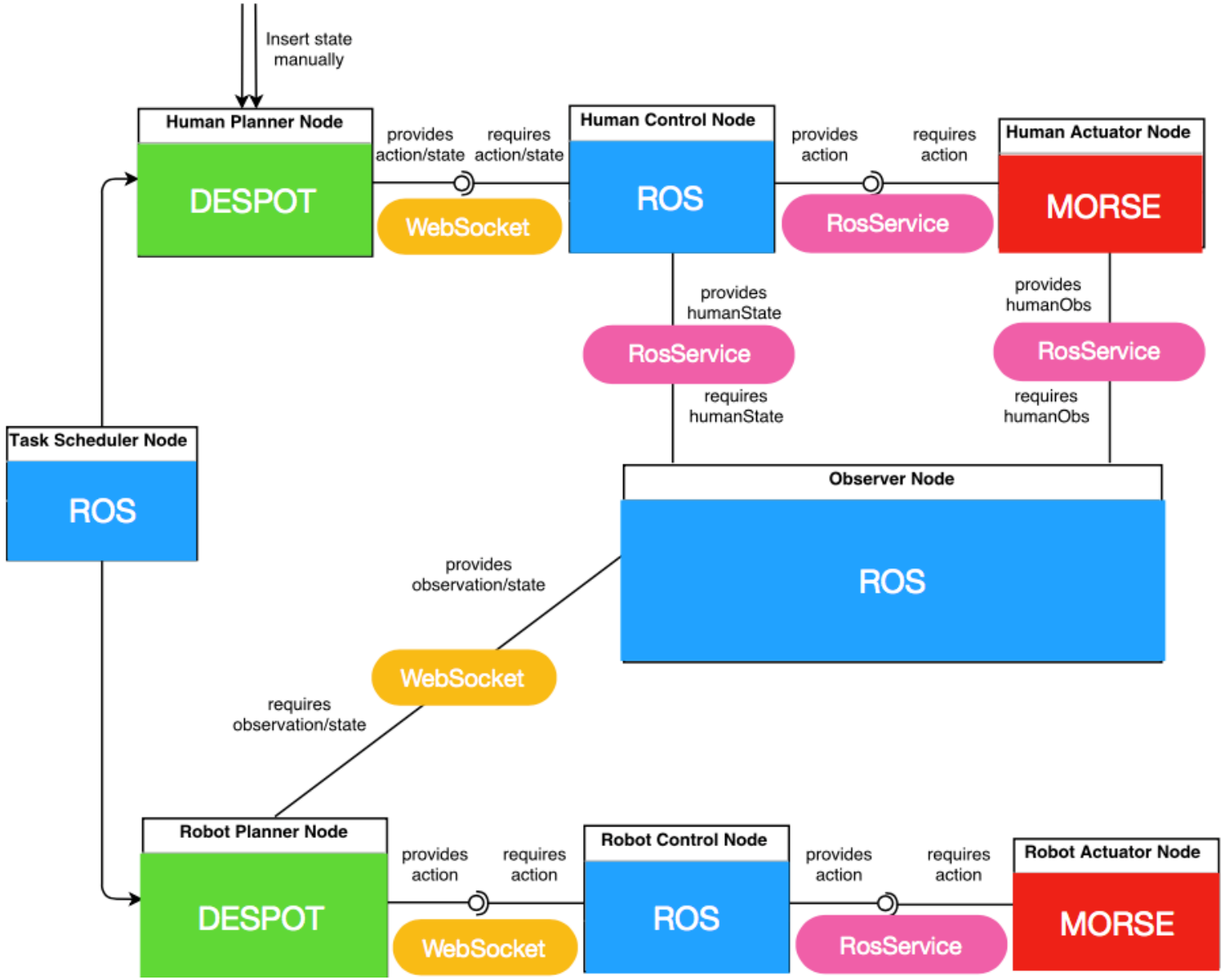
General architecture



Detailed Architecture

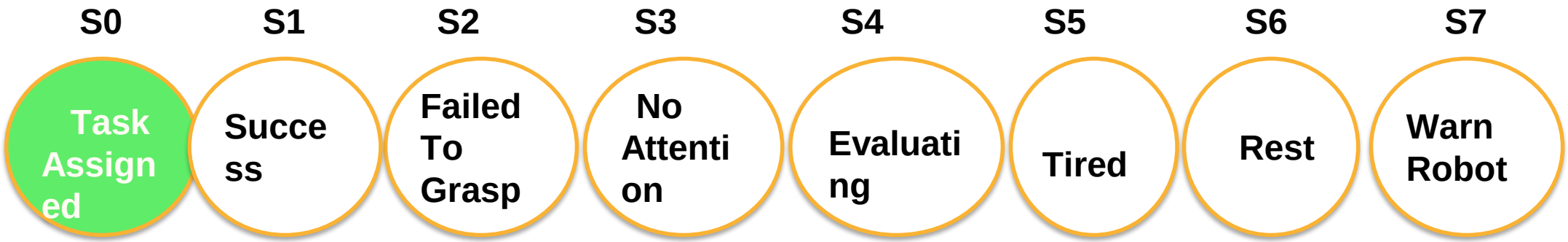


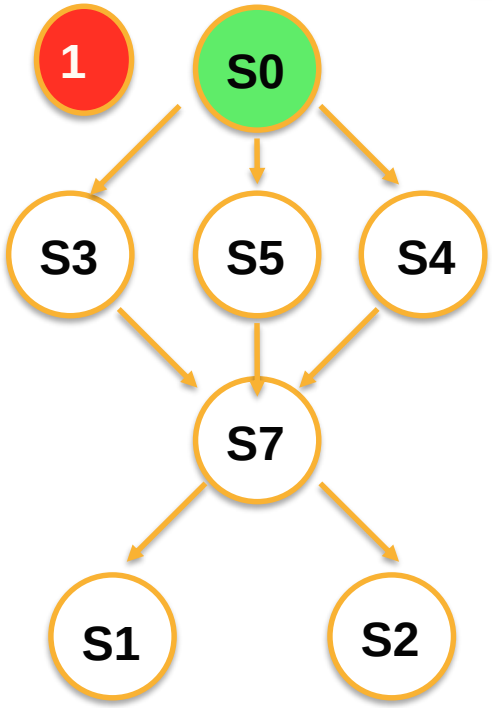
Solution Approach

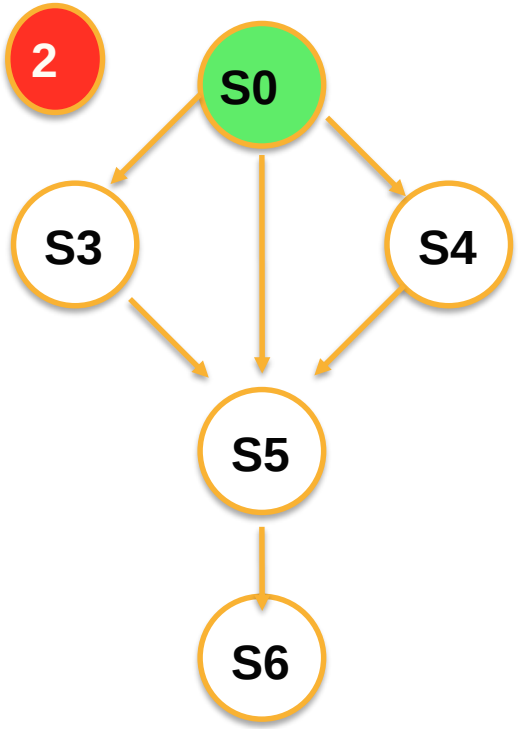


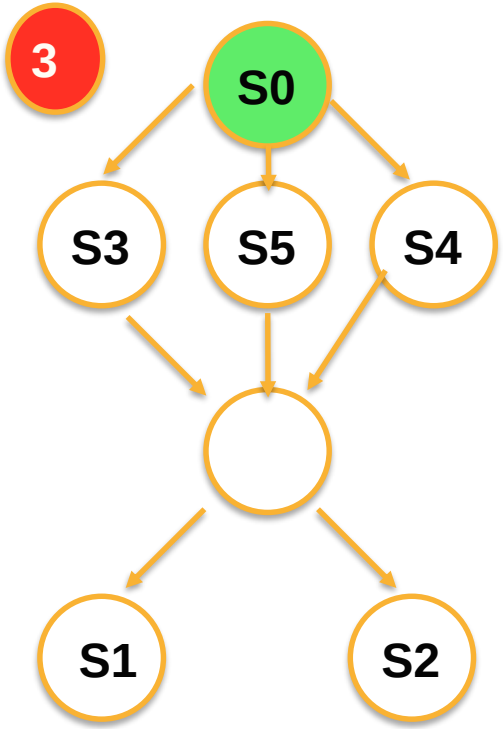
Human Modelling - Semi-Autonomous

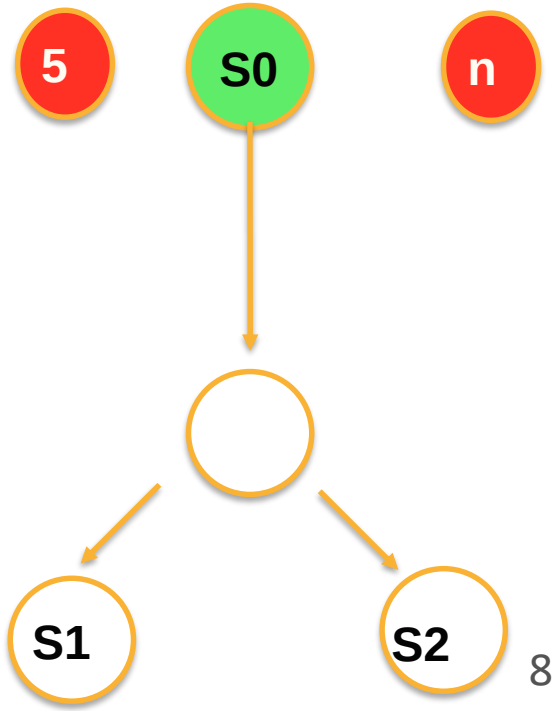
- States











Human Modelling - Fully Autonomous

```
curr state: 7 && prev state: 7
Model = N6despot6POMDPXE
Random root seed = 933698000
Search depth = 90
Discount = 0.98
Simulation steps = 90
Number of scenarios = 500
Search time per step = 1
Regularization constant = 0
Lower bound = DEFAULT
Upper bound = DEFAULT
Policy simulation depth = 90
Target gap ratio = 0.95
```

1

```
######################################## Round 0 ########
Initial state:
[state_1:task_assigned]

- Agent Acts = 2:idle
---------------------------------Round 0 Step 0----------
Agent Took: a2, in the State: [state_1:task_assigned]
```

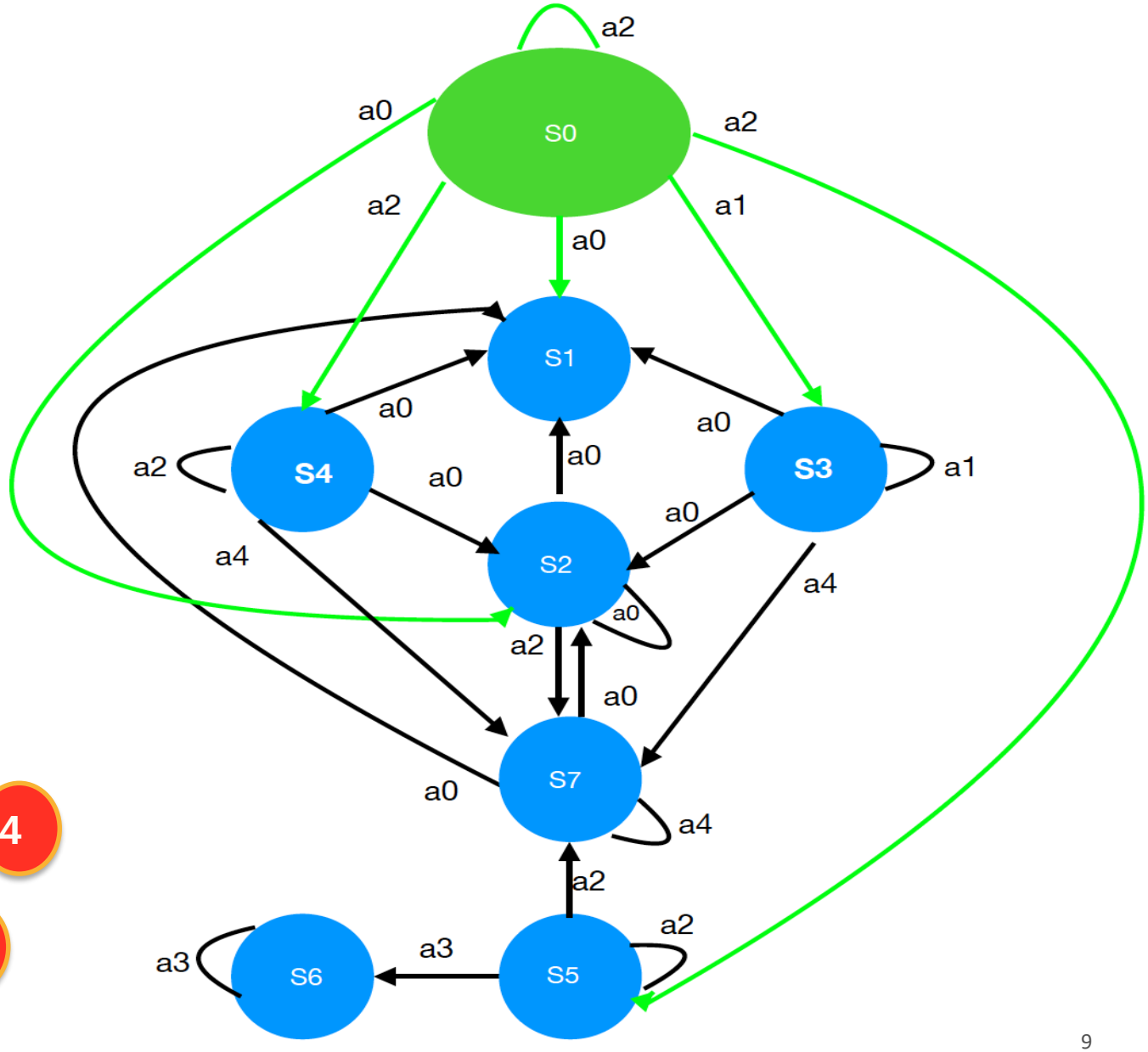
2

```
Please enter the next state [integer from 0 to 6, press any
State is manually entered: 6
curr state: 6 && prev state: 0
prev_state before cast: (state_id = -1, weight = 0, text =
prev_state after cast: (state_id = -1, weight = 0, text = |
=== RESULTS ===
- Resulting State:[state_1:recovery]
- Reward = 0
- Accumulated rewards:
  discounted / undiscounted = 0 / 0

- Agent's belief for the obs:0:  [state_1:evaluating] = 0.:
 [state_1:evaluating] = 0.354785
 [state_1:task_assigned] = 0.0452148
- Agent Acts = 2:idle
---------------------------------Round 0 Step 1----------
Agent Took: a2, in the State: [state_1:recovery]
```

3

4

5



```
gazelle@ubuntu:~/appl-0.96/src$ ./pom

Loading the model ...
  input file   : ../examples/POMDP/hu
  loading time : 0.00s
Generate MDP Policy
gazelle@ubuntu:~/appl-0.96/src$ ./pom

Loading the model ...
  input file   : ../examples/POMDP/hu

Loading the policy ...
  input file   : out.policy

Simulating ...
  action selection :  one-step look ahead

---------------------------------
 #Simulations   | Exp Total Reward
---------------------------------
 100            212.403
 200            212.375
 300            212.305
 400            212.309
 500            212.35
 600            212.371
 700            212.371
 800            212.356
 900            212.345
 1000           212.34
---------------------------------

Finishing ...
```

Simulations

```
---------------------------------------------------------
 #Simulations   | Exp Total Reward | 95% Confidence Interval
---------------------------------------------------------
 1000           212.34             (212.202, 212.478)
---------------------------------------------------------
```

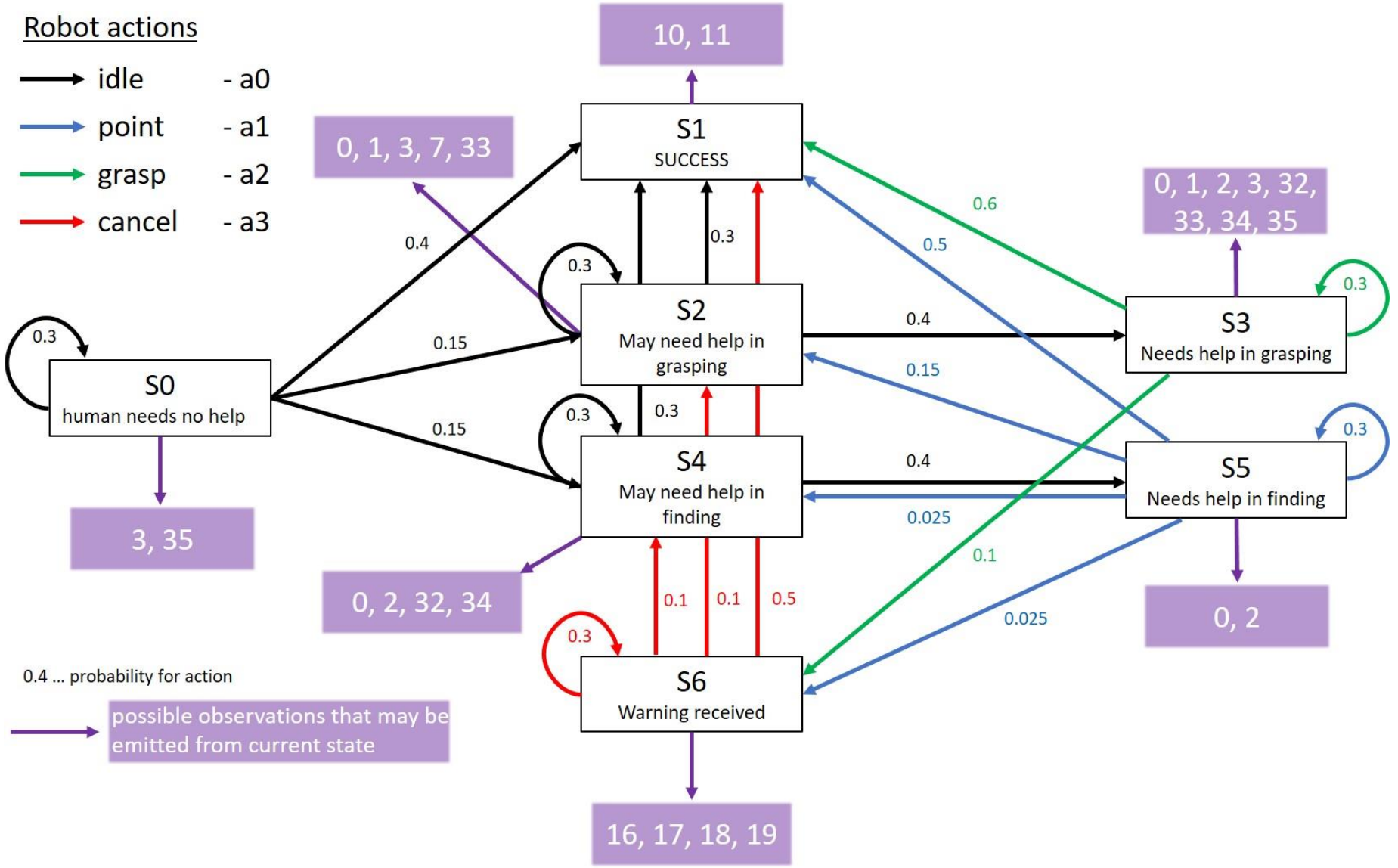
```
<Vector action="2" obsValue="0">110.571 0 118.318 87.1199 221.613 48.4387 48.4387 253.329 </Vector>
<Vector action="2" obsValue="0">115.256 0 122.793 85.3775 221.681 51.97 51.97 248.263 </Vector>
<Vector action="2" obsValue="0">125.555 0 124.217 97.6401 237.281 55.4306 55.4306 238.431 </Vector>
<Vector action="2" obsValue="0">129.582 0 127.554 95.6872 237.035 58.822 58.822 233.663 </Vector>
<Vector action="3" obsValue="0">0 0 0 111.021 220.684 0 0 322.829 </Vector>
<Vector action="2" obsValue="0">16.3235 0 15.7272 126.966 240.97 4.5 4.5 310.045 </Vector>
<Vector action="2" obsValue="0">30.9253 0 30.0593 124.427 240.65 8.91 8.91 303.844 </Vector>
<Vector action="2" obsValue="0">44.0046 0 43.0985 121.939 240.337 13.2318 13.2318 297.767 </Vector>
<Vector action="2" obsValue="0">68.7885 0 64.3793 [illegible] 251.994 21.6178 21.6178 280.256 </Vector>
<Vector action="2" obsValue="0">78.5785 0 73.8[illegible] 25.6855 25.6855 274.651 </Vector>
<Vector action="2" obsValue="0">87.3861 0 82.4[illegible]5 29.6718 29.6718 269.158 </Vector>
<Vector action="2" obsValue="0">95.3238 0 90.2016 [illegible] 250.407 33.5783 33.5783 263.775 </Vector>
<Vector action="2" obsValue="0">102.491 0 97.1276 121.122 249.899 37.4068 37.4068 258.499 </Vector>
<Vector action="2" obsValue="0">136.031 0 122.588 117.075 253.277 58.822 58.822 224.41 </Vector>
<Vector action="2" obsValue="0">150.664 0 128.726 115.529 254.264 71.7227 71.7227 202.849 </Vector>
<Vector action="4" obsValue="0">0 0 0 0 0 0 0 350 </Vector>
```

Policy

```
2115.52 1098    74255    126.421    186.181    59.7608    180    27940
2117.54 1099    74327    126.421    186.178    59.757     180    27968
2118.36 1099    74350    126.421    186.178    59.757     180    27983
2119.1  1100    74403    126.421    186.176    59.7552    180    27997
2121.14 1101    74489    126.421    186.175    59.7543    179    28035
2121.35 1101    74500    126.421    186.175    59.7543    180    28036
2123.36 1102    74569    126.421    186.167    59.7465    180    28064
^C*** Received SIGINT. User pressed control-C. ***

Terminating

-------------------------------------------------------------------------------
 Time    |#Trial |#Backup |LBound    |UBound    |Precision  |#Alphas |#Beliefs
-------------------------------------------------------------------------------
 2124.04 1102    74583    126.421    186.167    59.7465     180      28074
-------------------------------------------------------------------------------

Writing out policy ...
```

Solving Time

Robot Modeling - POMDP



Binary Overview of Observations

Binary overview all possible observations =2^m

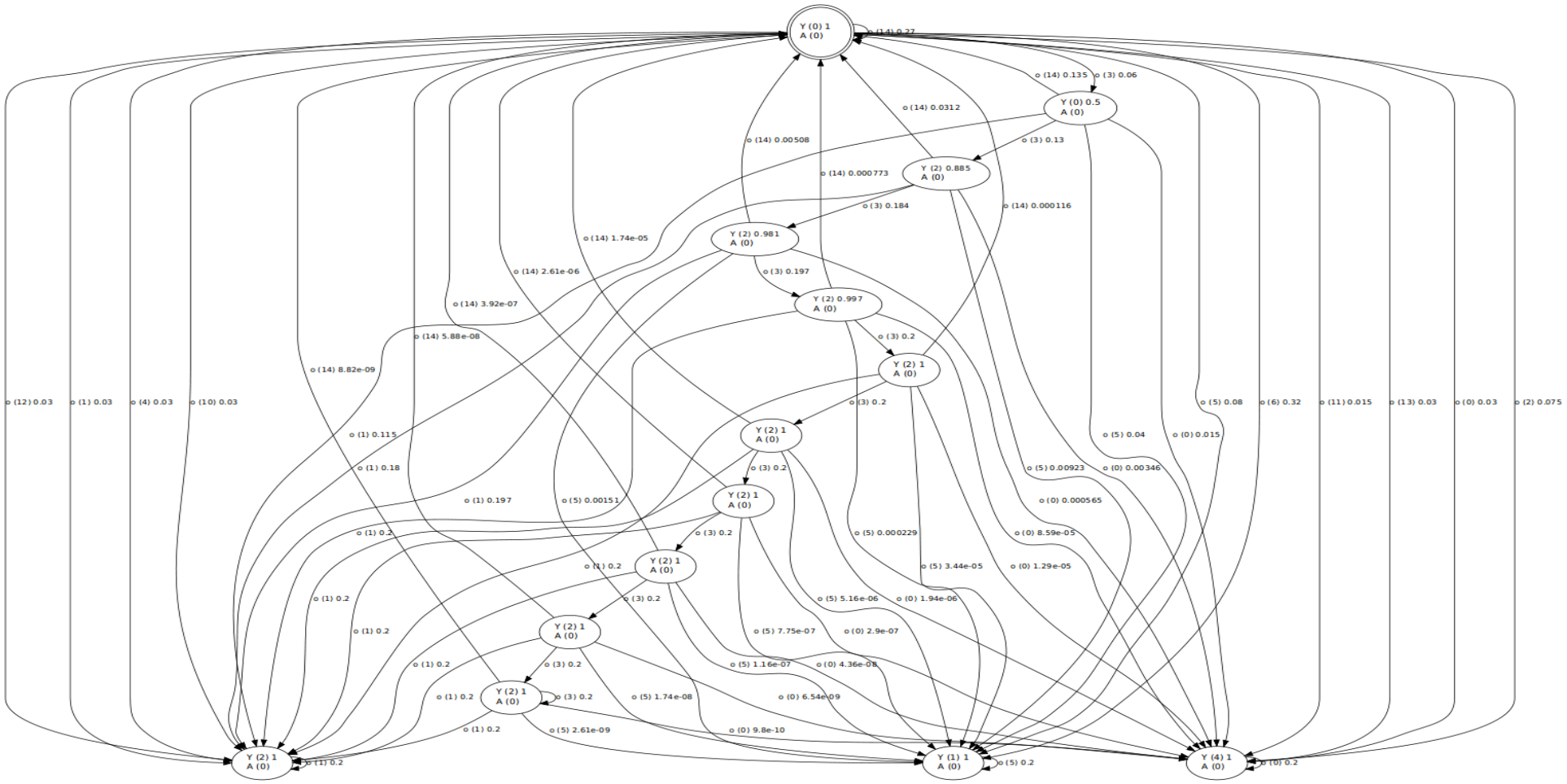
# of observations	object visible	object in range	grasping attempt a0	has object	warning received a4	idle a2	omit reason
0	0	0	0	0	0	0	
1	1	0	0	0	0	0	
2	0	1	0	0	0	0	
3	1	1	0	0	0	0	
~~4~~	~~0~~	~~0~~	~~1~~	~~0~~	~~0~~	~~0~~	Logic
~~5~~	~~1~~	~~0~~	~~1~~	~~0~~	~~0~~	~~0~~	Logic
~~6~~	~~0~~	~~1~~	~~1~~	~~0~~	~~0~~	~~0~~	Logic
7	1	1	1	0	0	0	
~~8~~	~~0~~	~~0~~	~~0~~	~~1~~	~~0~~	~~0~~	
~~9~~	~~1~~	~~0~~	~~0~~	~~1~~	~~0~~	~~0~~	Logic
10	0	1	0	1	0	0	
11	1	1	0	1	0	0	
~~12~~	~~0~~	~~0~~	~~1~~	~~1~~	~~0~~	~~0~~	Logic

POMDP Example: Different state transitions and their visualization

```
##########################################
# State Transitions
#
#

T : rIdle
0.3     0.4     0.15    0       0.15    0       0
0       1       0       0       0       0       0
0       0       1       0       0       0       0
0       0       0       1       0       0       0
0       0       0       0       1       0       0
0       0       0       0       0       1       0
0       0       0       0       0       0       1

#T : rIdle
#0.3    0.4     0.15    0       0.15    0       0
#0      1       0       0       0       0       0
#0      0.3     0.3     0.4     0       0       0
#0      0       0       1       0       0       0
#0      0.3     0       0       0.3     0.4     0
#0      0       0       0       0       1       0
#0      0       0       0       0       0       1


T : rPoint_obj
1       0       0       0       0       0       0
0       1       0       0       0       0       0
0       0       1       0       0       0       0
0       0       0       1       0       0       0
```

Graph

Human Modeling - MDP



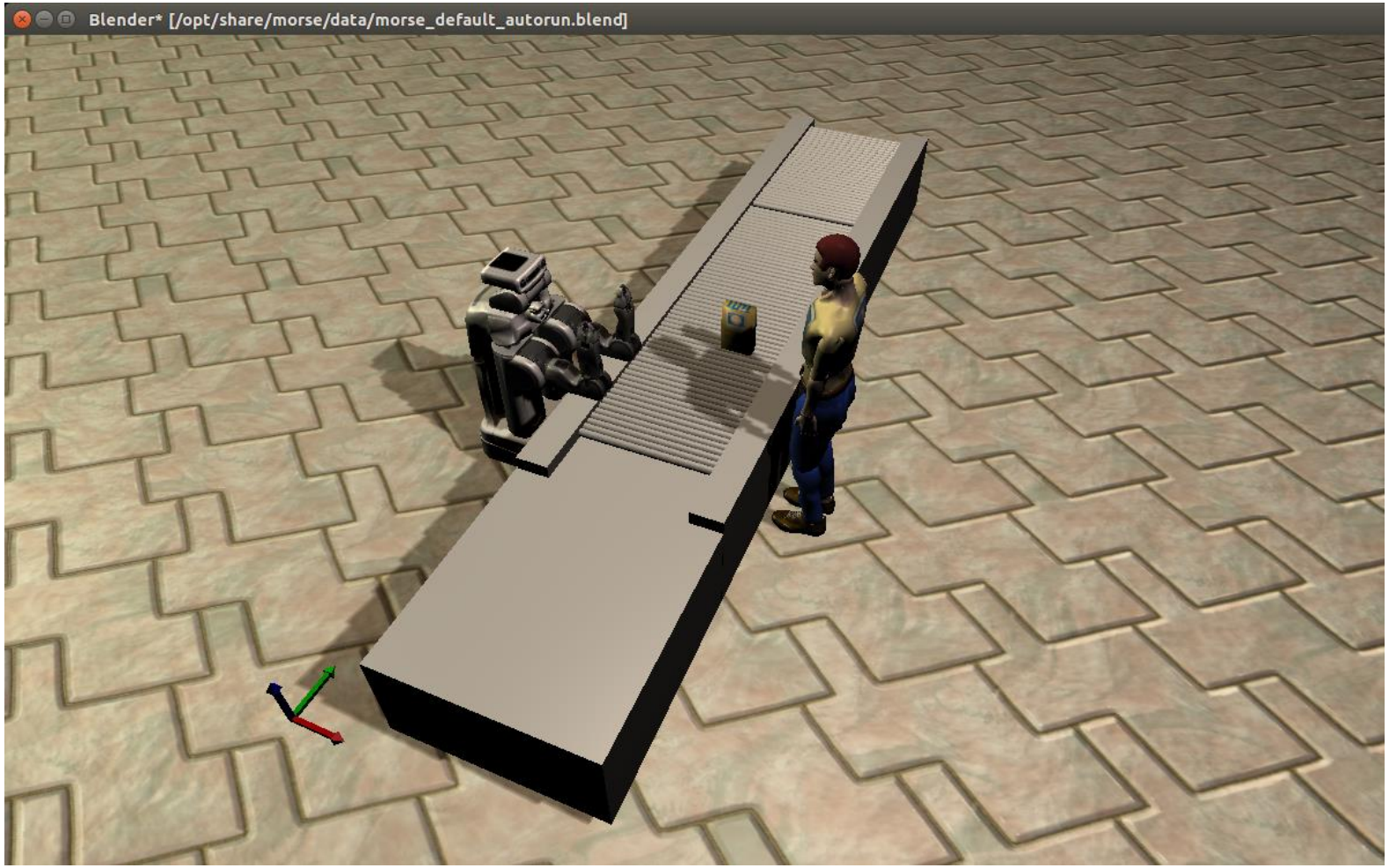
Human Modeling - MDP

```
-------------------------------------------------------------------------------
Time   |#Trial |#Backup |LBound     |UBound     |Precision  |#Alphas |#Beliefs
-------------------------------------------------------------------------------
0      0       0        -8.33525e-05 7.16734     7.16742     4        1
0      3       50       6.70426     7.02582     0.321562    36       21
0      6       100      6.86548     6.95732     0.0918391   67       39
0.01   8       150      6.88694     6.94384     0.0569017   100      59
0.02   11      209      6.89289     6.93114     0.038247    151      80
0.02   12      250      6.89305     6.92961     0.0365587   180      97
0.03   15      300      6.89312     6.91561     0.0224853   225      104
0.04   17      357      6.89702     6.90697     0.0099472   238      122
0.06   18      400      6.89773     6.90526     0.00753515  280      144
0.07   20      461      6.898       6.905       0.00699308  314      159
0.08   22      507      6.89801     6.90463     0.00661937  339      176
0.1    24      555      6.89802     6.9027      0.0046799   381      188
0.11   26      607      6.89804     6.90195     0.00390427  412      203
0.13   27      650      6.89805     6.90181     0.00376455  442      223
0.15   29      700      6.89805     6.9015      0.0034538   458      238
0.18   31      755      6.89806     6.90099     0.00292904  477      260
0.2    33      807      6.89825     6.90074     0.00249829  520      273
0.22   34      850      6.89826     6.90071     0.00244848  563      292
0.26   36      915      6.89828     6.90038     0.00210772  606      315
0.28   37      950      6.89828     6.90036     0.00208363  625      328
0.32   39      1003     6.89835     6.89965     0.00130364  657      345
0.36   40      1050     6.89838     6.89951     0.00112529  682      362
0.4    41      1100     6.89839     6.8995      0.00111304  732      376
0.45   43      1159     6.89839     6.8995      0.00110839  758      396
0.48   44      1200     6.89839     6.89949     0.00110541  780      405
0.52   45      1250     6.89839     6.89946     0.00106739  830      431
0.58   47      1303     6.89839     6.89941     0.00101755  823      448
0.62   48      1351     6.89839     6.89941     0.00101689  871      467
0.68   50      1409     6.89839     6.89941     0.00101605  900      484
0.73   51      1450     6.89839     6.8994      0.00100579  904      496
0.8    53      1517     6.89839     6.8994      0.00100565  971      513
0.83   54      1543     6.89839     6.89922     0.000831687 962      517
-------------------------------------------------------------------------------

SARSOP finishing ...
  target precision reached
  target precision  : 0.001000
  precision reached : 0.000832

-------------------------------------------------------------------------------
Time   |#Trial |#Backup |LBound     |UBound     |Precision  |#Alphas |#Beliefs
-------------------------------------------------------------------------------
0.84   54      1543     6.89839     6.89922     0.000831687 962      517
-------------------------------------------------------------------------------

Writing out policy ...
  output file : out.policy
```

DEMO

1. Evaluating Human

2. Tired Human



Thank you for your interest!

A|O|T

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Challenges

- Poor documentation of MORSE for simulating our Human and Robot
    - Overwriting MORSE functions and overlaying ROS services for MORSE
- Not enough resource for writing model for MDP and running it with no Belief interfere
- SPARK for observation
    - Problems in installation (no support for MORSE)
    - Workaround with binary overview for observations
- Integration
    - Adding web sockets
    - No available ROS package for our models (POMDP/MDP)
- Synchronisation problem
    - Two independent models and difficulties in adding interruptions in between actions