Reinforcement Learning for Path Planning of Robotic Arms

Anton Mai

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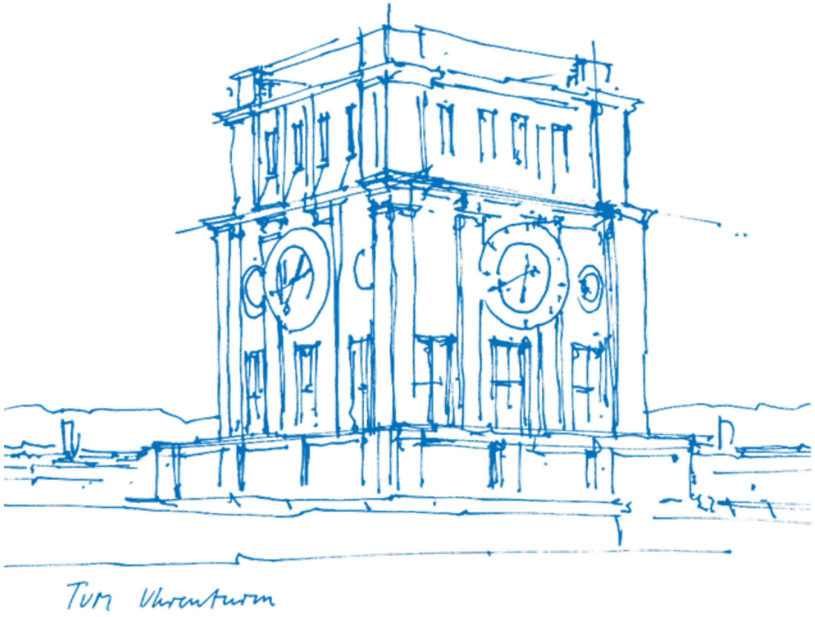
Department of Informatics

Chair of Robotics, Artificial Intelligence and Real-time Systems

München, 27. März 2015



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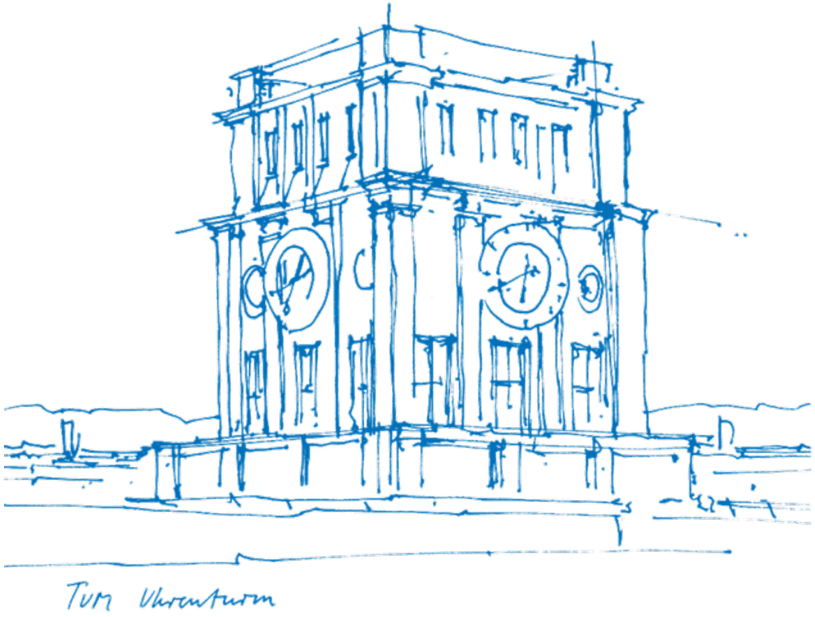
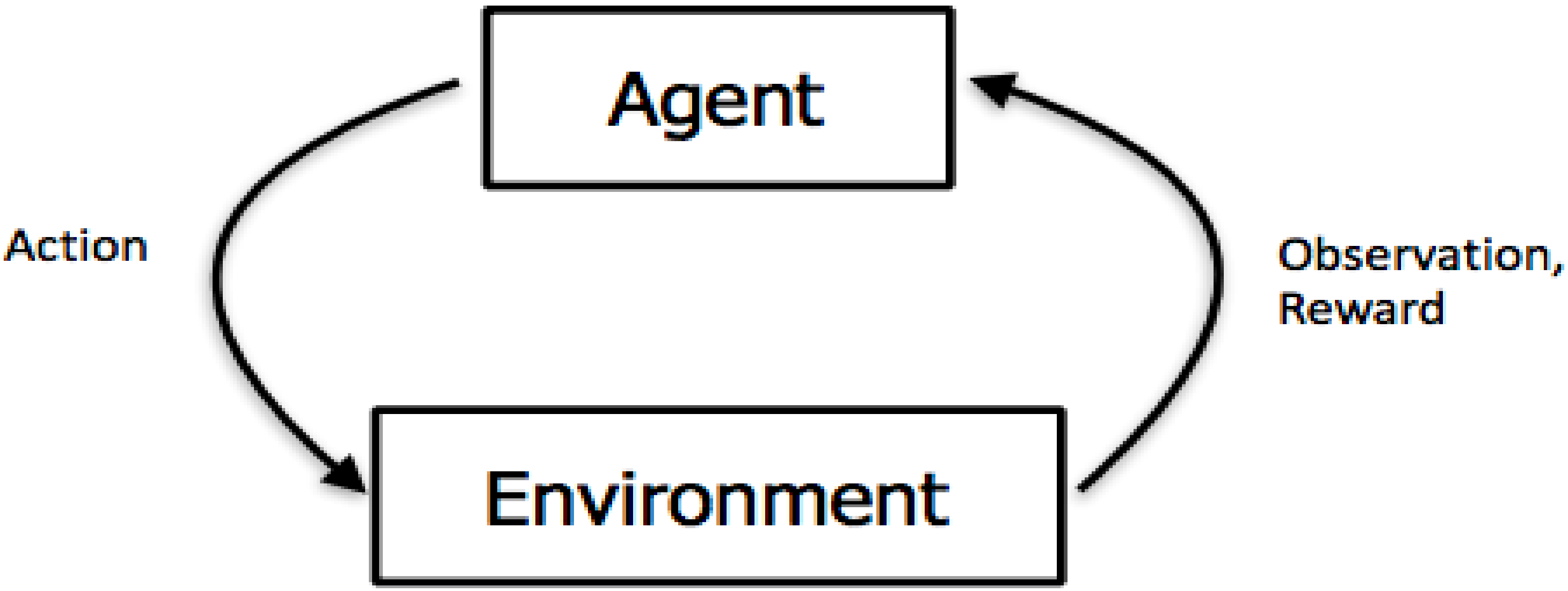


Outline

- Motivation
- Reinforcement Learning
- Hindsight Experience Replay
- Related Works
- Environment 1: FetchSlideball
- Environment 2: FetchToss

Titleist
3

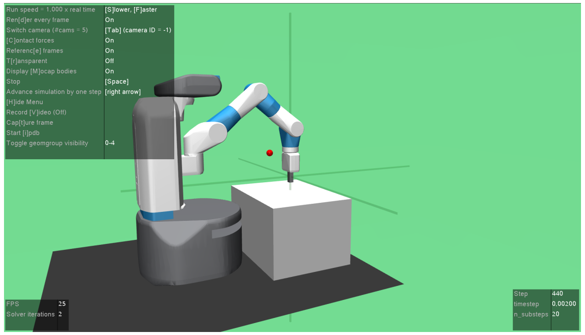
Reinforcement Learning

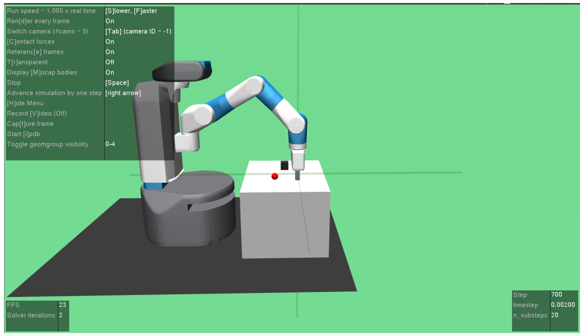


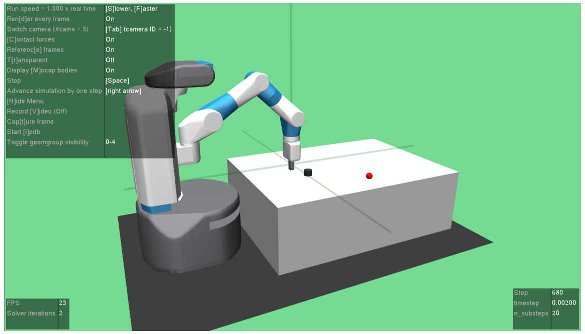
Hindsight Experience Replay

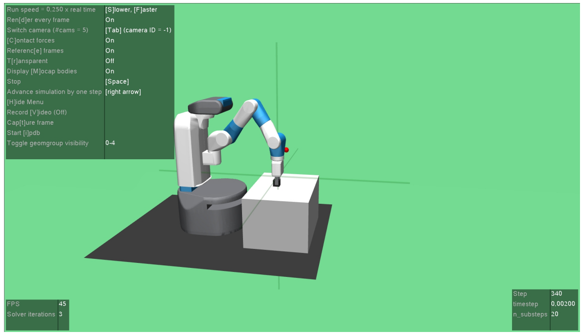
Some more HER ideas if I use them

Benchmarks


Run speed = 1.000 x real time
[S]lower, [F]aster
Ren[d]er every frame
On
Switch camera (#cams = 5)
[Tab] (camera ID = -1)
[C]ontact forces
On
Referenc[e] frames
On
T[r]ansparent
Off
Display [M]ocap bodies
On
Stop
[Space]
Advance simulation by one step
[right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility
0-4
FPS
25
Solver iterations
2
Step
440
timestep
0.00200
n_substeps
20


Run speed = 1.000 x real time
[S]lower, [F]aster
Ren[d]er every frame
On
Switch camera (#cams = 5)
[Tab] (camera ID = -1)
[C]ontact forces
On
Referenc[e] frames
On
T[r]ansparent
Off
Display [M]ocap bodies
On
Stop
[Space]
Advance simulation by one step
[right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility
0-4
FPS
23
Solver iterations
2
Step
700
timestep
0.00200
n_substeps
20


Run speed = 1.000 x real time
[S]lower, [F]aster
Ren[d]er every frame
On
Switch camera (#cams = 5)
[Tab] (camera ID = -1)
[C]ontact forces
On
Referenc[e] frames
On
T[r]ansparent
Off
Display [M]ocap bodies
On
Stop
[Space]
Advance simulation by one step
[right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility
0-4
FPS
23
Solver iterations
2
Step
680
timestep
0.00200
n_substeps
20


Run speed = 0.250 x real time
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Switch camera (#cams = 5)
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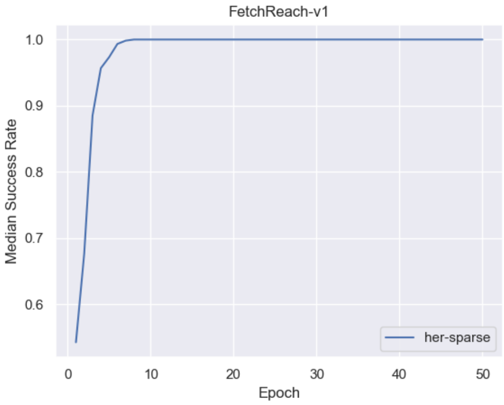
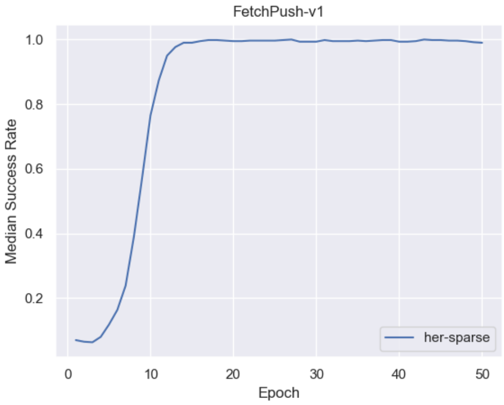
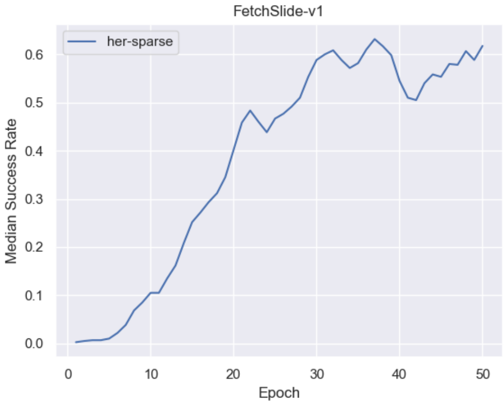
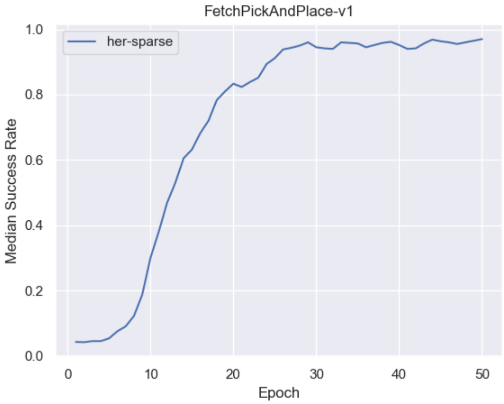
[C]ontact forces
On
Referenc[e] frames
On
T[r]ansparent
Off
Display [M]ocap bodies
On
Stop
[Space]
Advance simulation by one step
[right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility
0-4
FPS
45
Solver iterations
3
Step
340
timestep
0.00200
n_substeps
20

Benchmarks


FetchReach-v1
Median Success Rate
1.0
0.9
0.8
0.7
0.6
her-sparse
0
10
20
30
40
50
Epoch

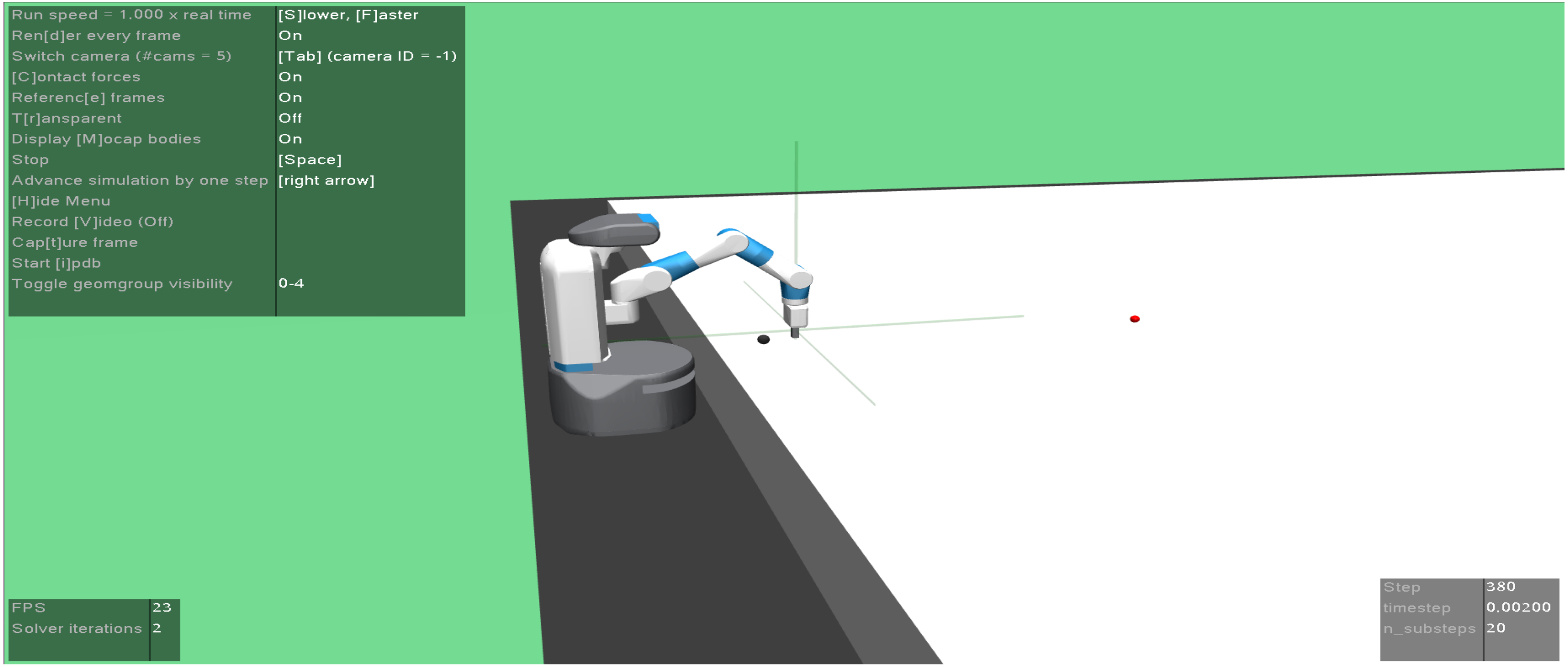

FetchPush-v1
Median Success Rate
1.0
0.8
0.6
0.4
0.2
her-sparse
0
10
20
30
40
50
Epoch


FetchSlide-v1
her-sparse
Median Success Rate
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
Epoch


FetchPickAndPlace-v1
her-sparse
Median Success Rate
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
Epoch

FetchSlideball

Environment Picture Extending FetchSlide



```
Run speed = 1.000 x real time       [S]lower, [F]aster
Ren[d]er every frame                On
Switch camera (#cams = 5)           [Tab] (camera ID = -1)
[C]ontact forces                    On
Referenc[e] frames                  On
T[r]ansparent                       Off
Display [M]ocap bodies              On
Stop                                [Space]
Advance simulation by one step      [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility         0-4
```

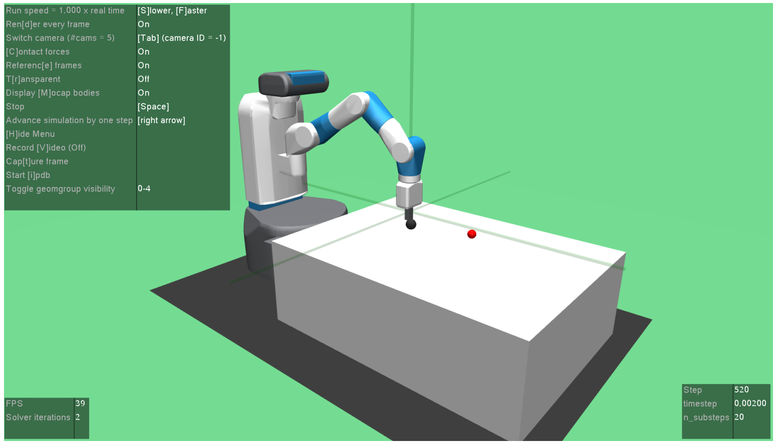
```
FPS                 23
Solver iterations   2
```

```
Step         380
timestep     0.00200
n_substeps   20
```

Goal: bigger distance

FetchSlideball Version 1

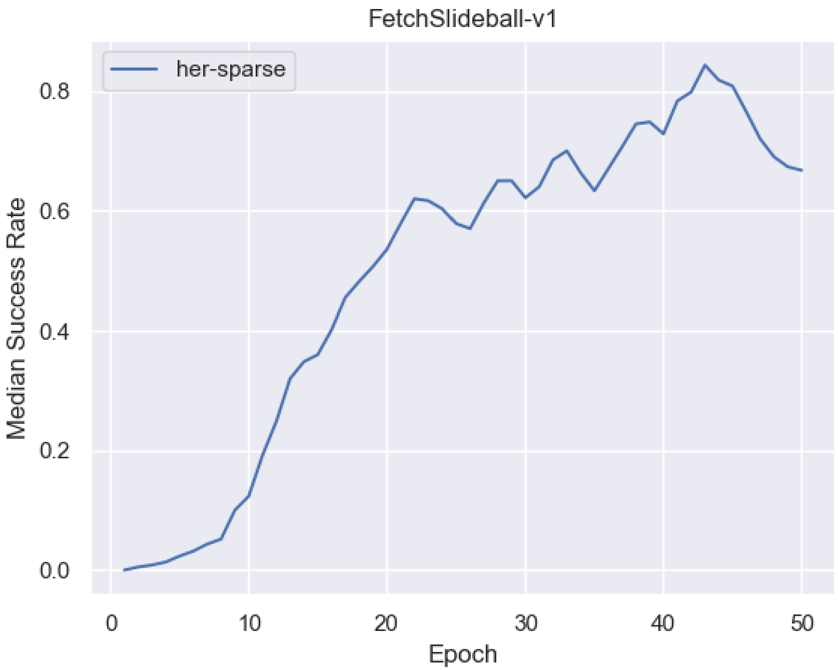
Same Distance as FetchSlide-v1, but with a ball



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	39
Solver iterations	2

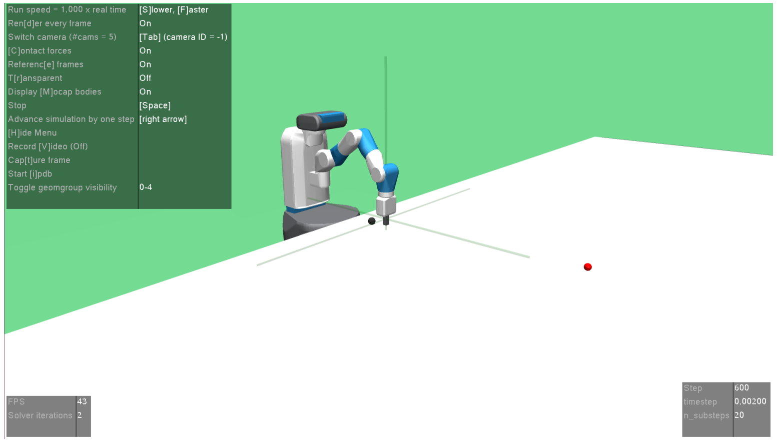
Step	520
timestep	0.00200
n_substeps	20



FetchSlideball Version 2

Doubled the distance

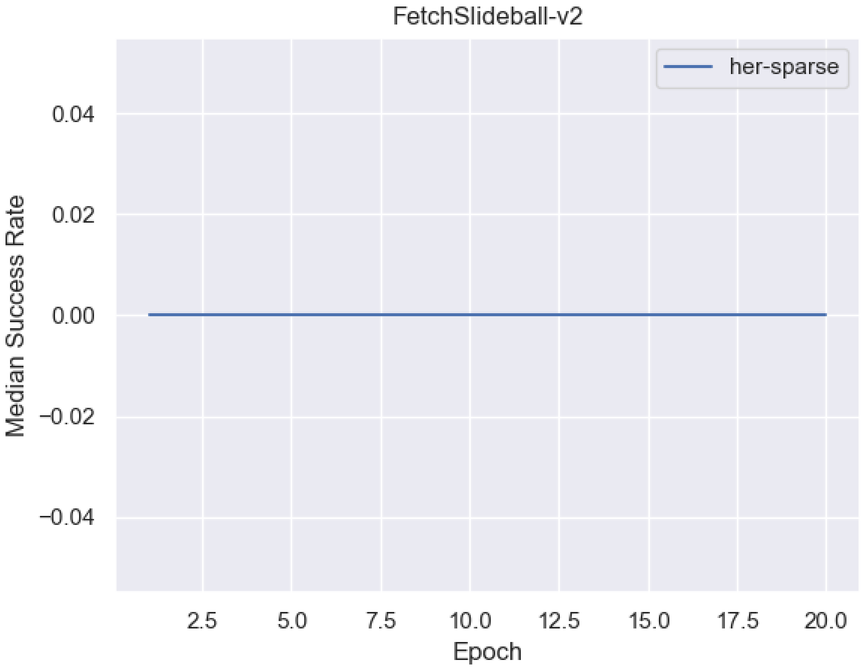
Problem: Arm not strong enough too push it far enc



```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4
```

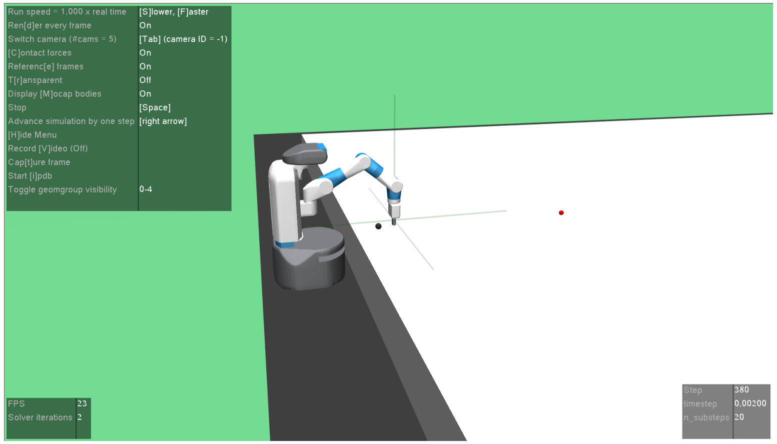
```
FPS                43
Solver iterations  2
```

```
Step        600
timestep    0.00200
n_substeps  20
```



FetchSlideball Version 3

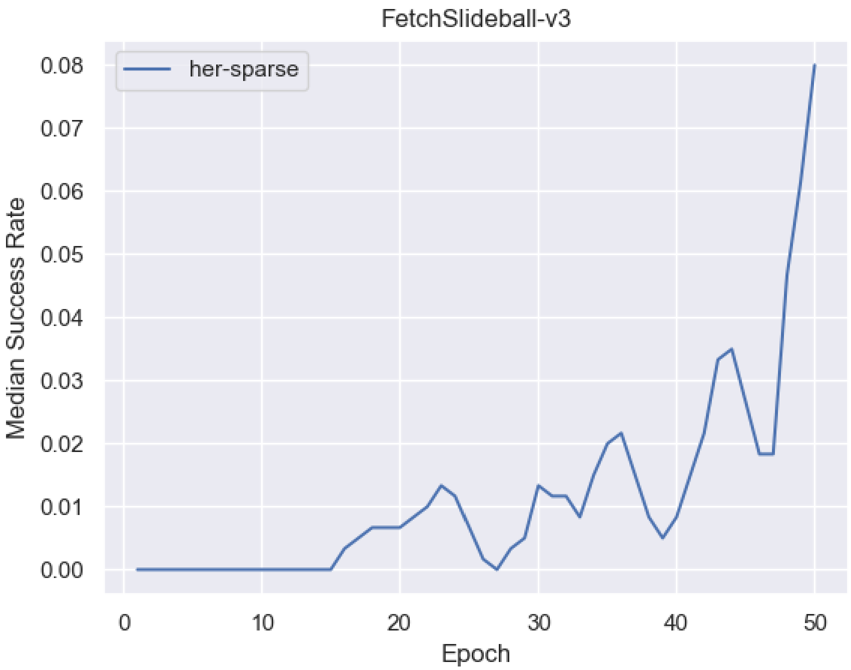
10% friction



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

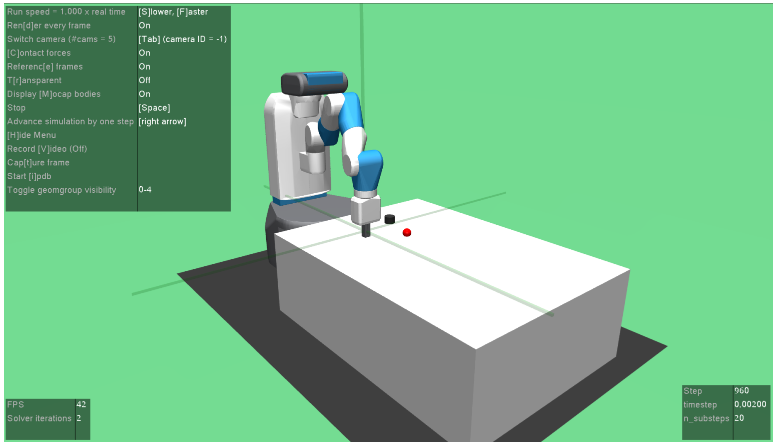
FPS	23
Solver iterations	2

Step	380
timestep	0.00200
n_substeps	20



FetchSlideball Version 4

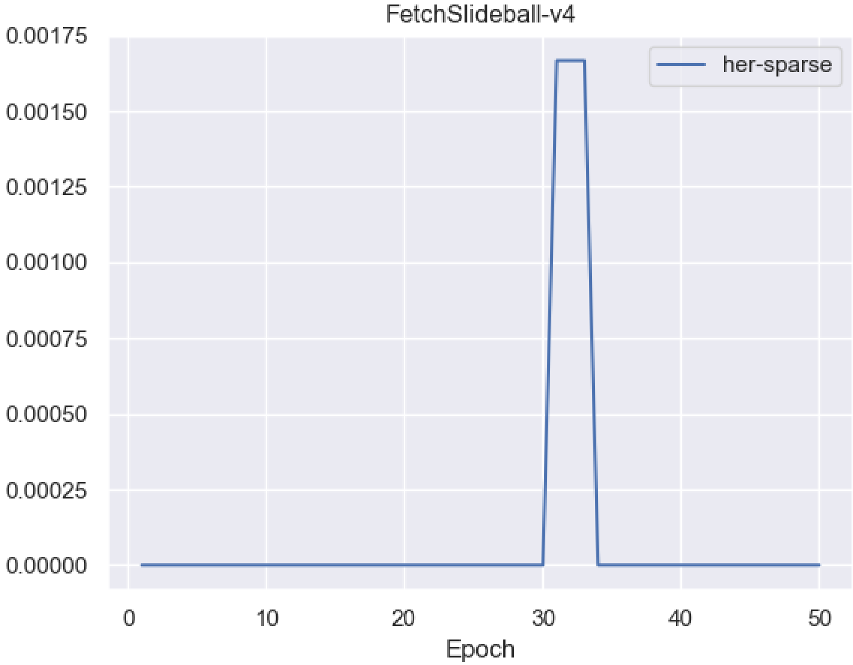
50% friction



```
Run speed = 1.000 x real time     [S]lower, [F]aster
Ren[d]er every frame              On
Switch camera (#cams = 5)         [Tab] (camera ID = -1)
[C]ontact forces                  On
Referenc[e] frames                On
T[r]ansparent                     Off
Display [M]ocap bodies            On
Stop                              [Space]
Advance simulation by one step    [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility       0-4
```

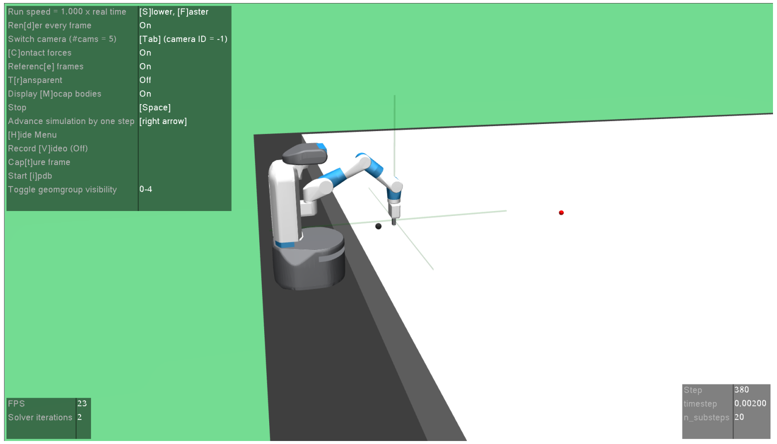
```
FPS                42
Solver iterations  2
```

```
Step         960
timestep     0.00200
n_substeps   20
```

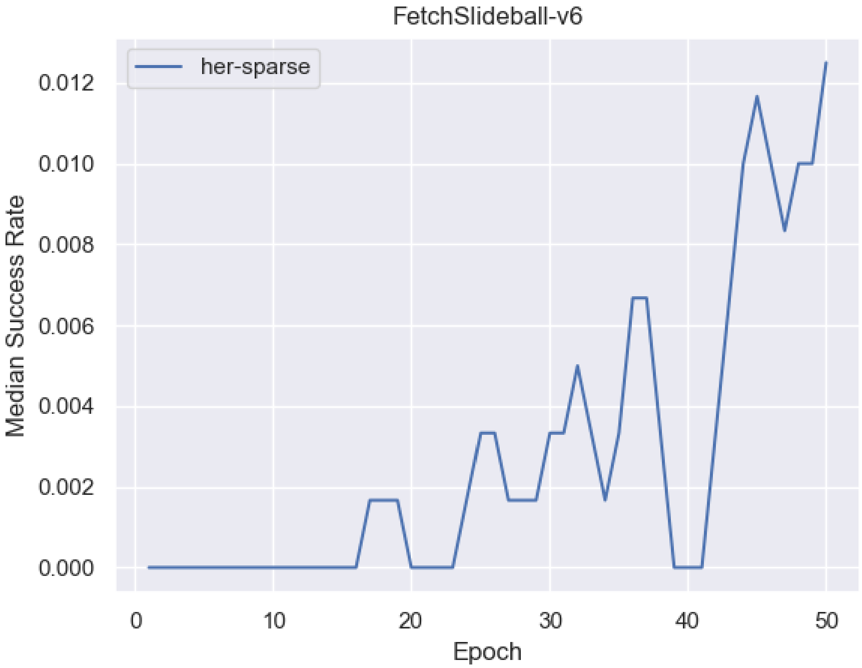


FetchSlideball Version 6

25% friction



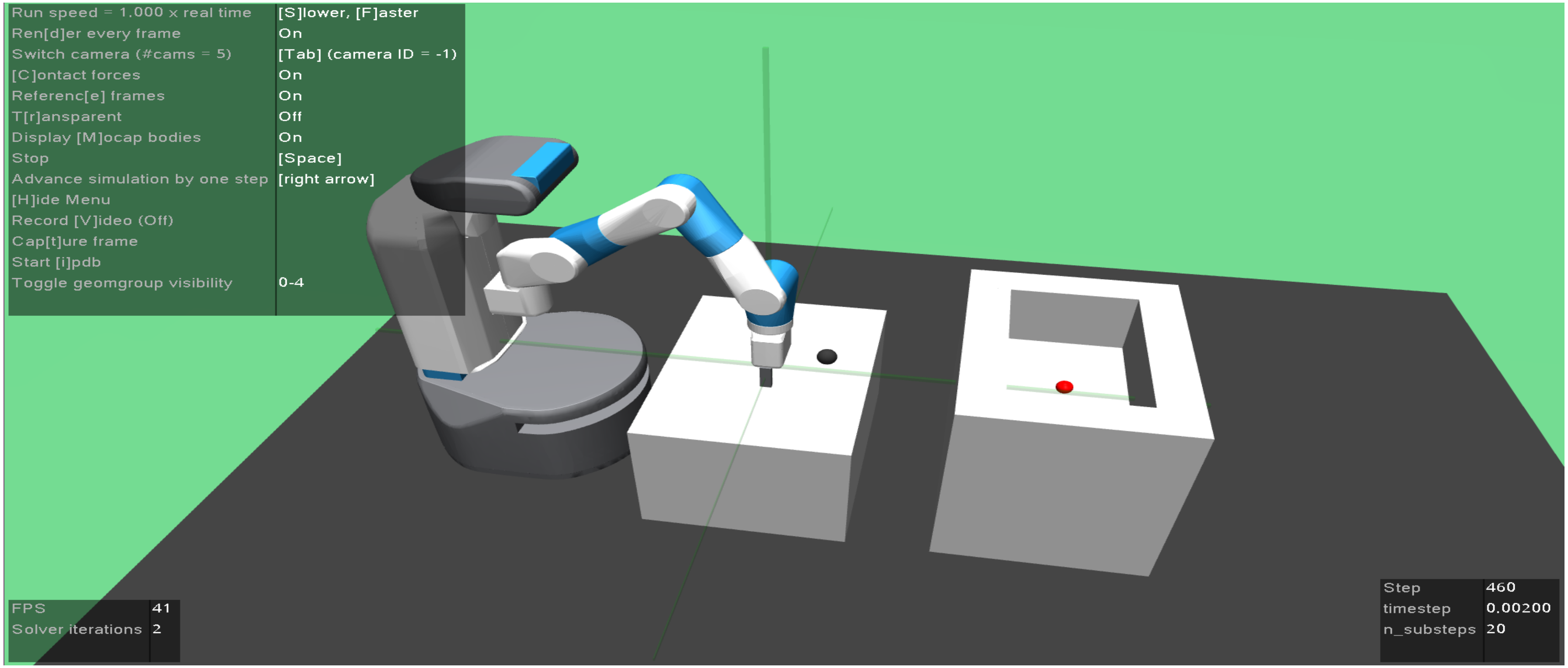
```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4

FPS                 23
Solver iterations   2

Step         380
timestep     0.00200
n_substeps   20
```



FetchSlideball

Show results, all in one page. Explain how I did these things

FetchToss



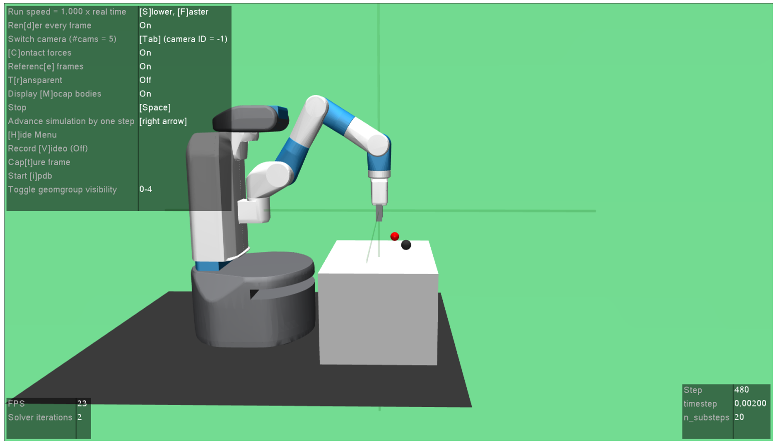
```
Run speed = 1.000 x real time     [S]lower, [F]aster
Ren[d]er every frame              On
Switch camera (#cams = 5)         [Tab] (camera ID = -1)
[C]ontact forces                  On
Referenc[e] frames                On
T[r]ansparent                     Off
Display [M]ocap bodies            On
Stop                              [Space]
Advance simulation by one step    [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility       0-4
```

```
FPS                 41
Solver iterations   2
```

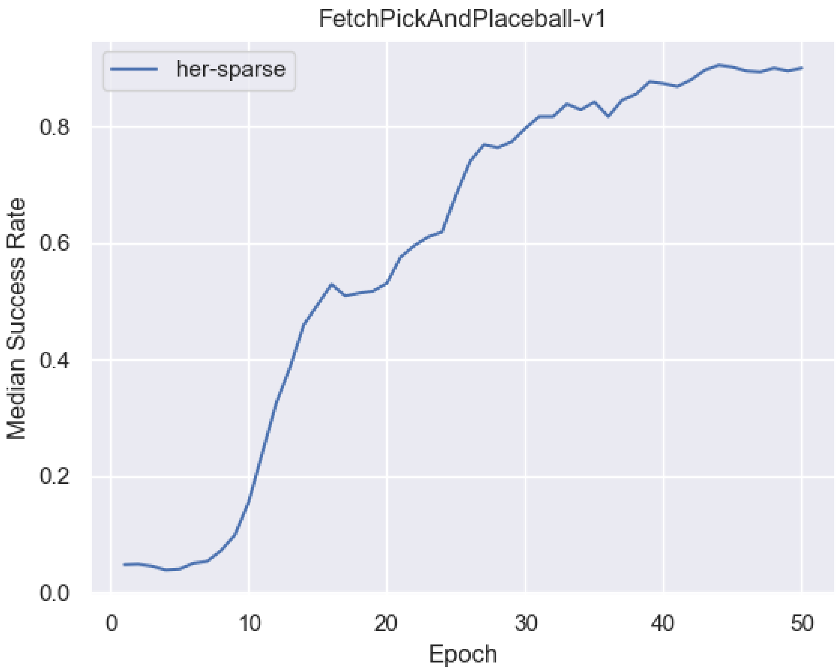
```
Step         460
timestep     0.00200
n_substeps   20
```

FetchPickAndPlaceball

Testing PickAndPlace with a ball for comparison

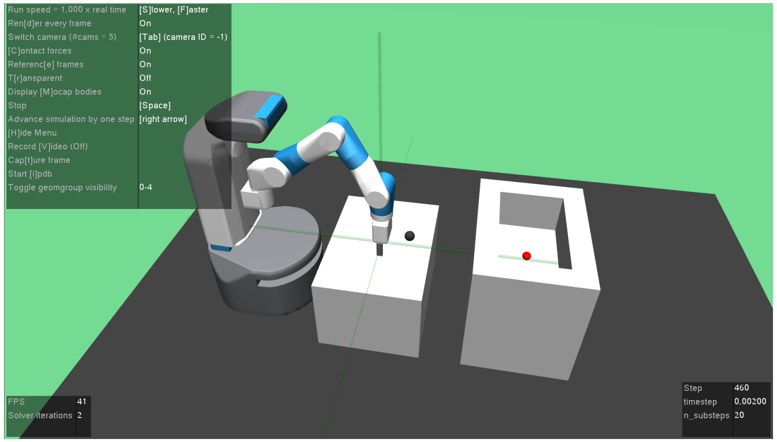


```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4

FPS                23
Solver iterations  2

Step        480
timestep    0.00200
n_substeps  20
```



FetchToss Version 1

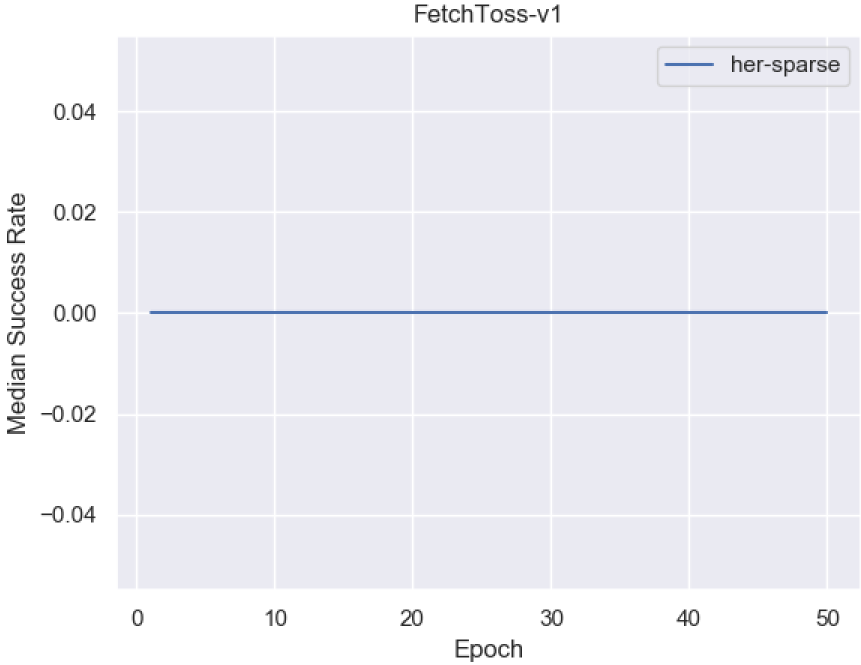
Goal is only in the box



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

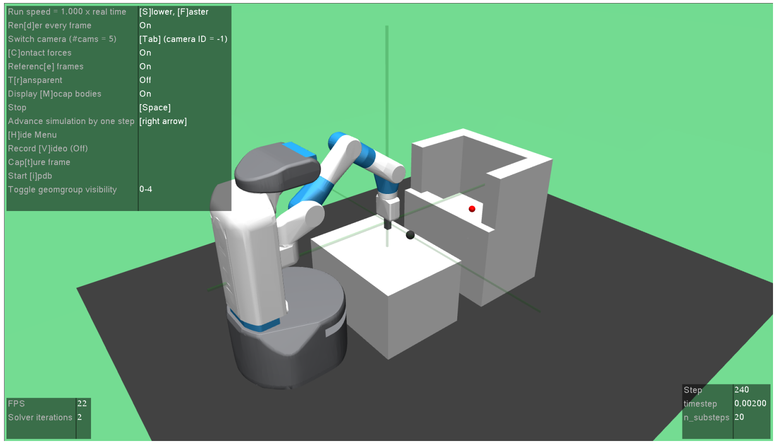
FPS	41
Solver iterations	2

Step	460
timestep	0.00200
n_substeps	20



FetchToss Version 2

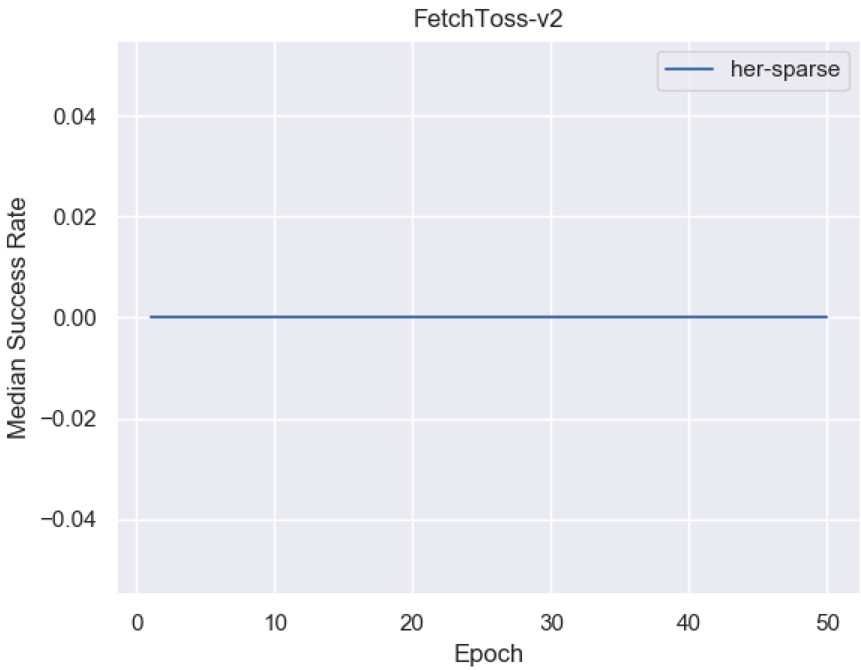
Better box, some friction added, double training ste



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

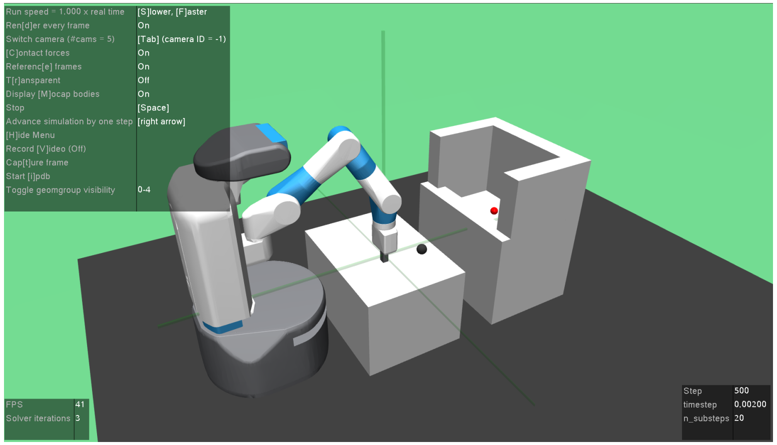
FPS	22
Solver iterations	2

Step	240
timestep	0.00200
n_substeps	20

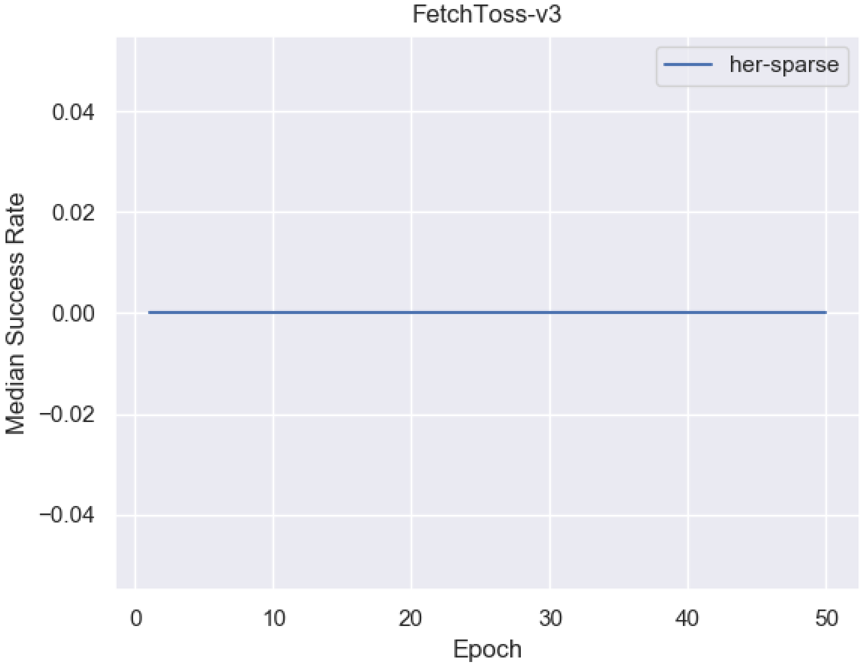


FetchToss Version 3

1% weight on the ball



```
Run speed = 1.000 x real time    [S]lower, [F]aster
Ren[d]er every frame             On
Switch camera (#cams = 5)        [Tab] (camera ID = -1)
[C]ontact forces                 On
Referenc[e] frames               On
T[r]ansparent                    Off
Display [M]ocap bodies           On
Stop                             [Space]
Advance simulation by one step   [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility      0-4

FPS                41
Solver iterations  3

Step        500
timestep    0.00200
n_substeps  20
```

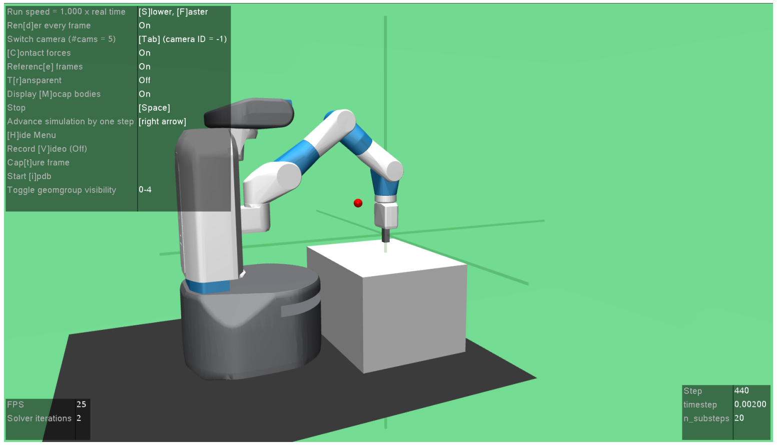


Presentation Sources

https://blog.goodaudience.com/what-is-inverse-reinforcement-learning-e333228af146

Backup Slides

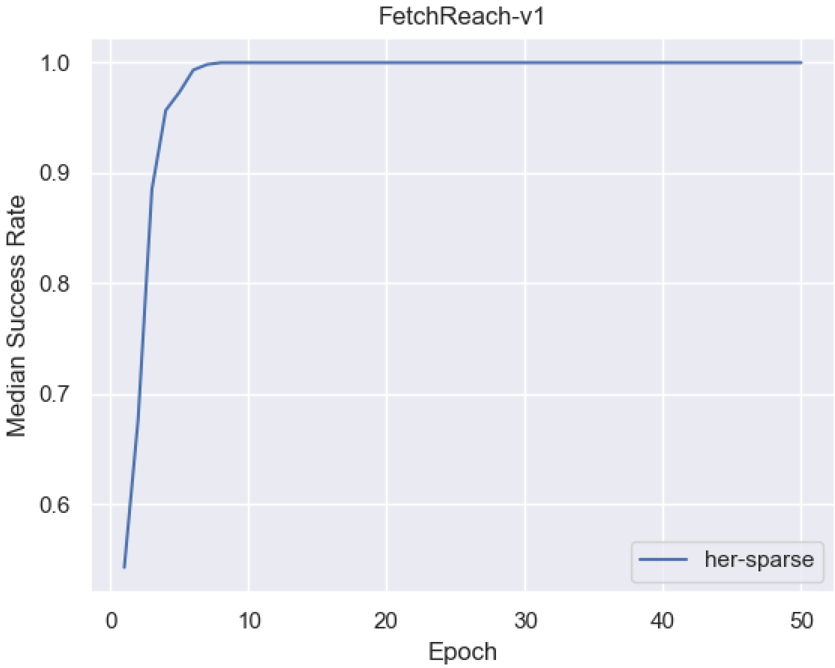
FetchReach-v1



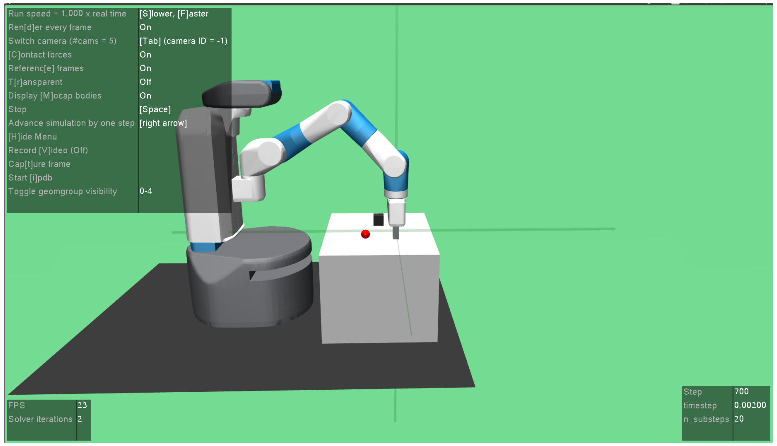
```
Run speed = 1.000 x real time     [S]lower, [F]aster
Ren[d]er every frame              On
Switch camera (#cams = 5)         [Tab] (camera ID = -1)
[C]ontact forces                  On
Referenc[e] frames                On
T[r]ansparent                     Off
Display [M]ocap bodies            On
Stop                              [Space]
Advance simulation by one step    [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility       0-4
```

```
FPS                25
Solver iterations  2
```

```
Step         440
timestep     0.00200
n_substeps   20
```



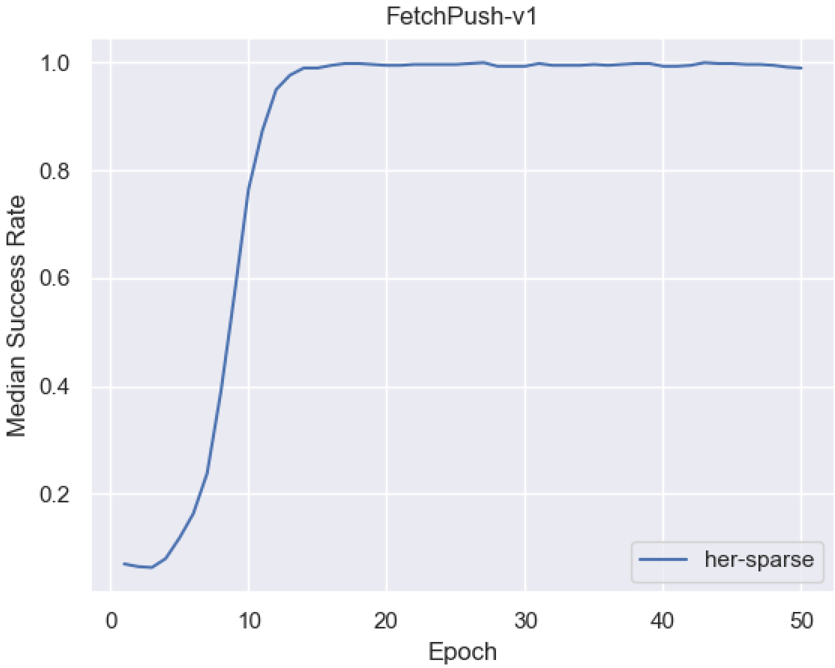
FetchPush-v1



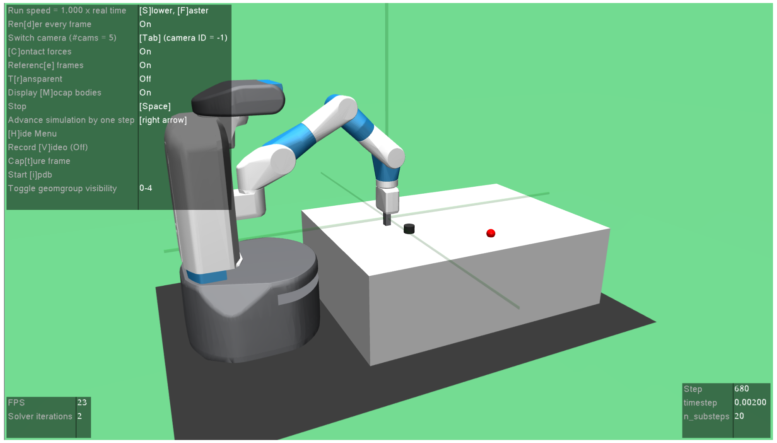
Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	23
Solver iterations	2

Step	700
timestep	0.00200
n_substeps	20



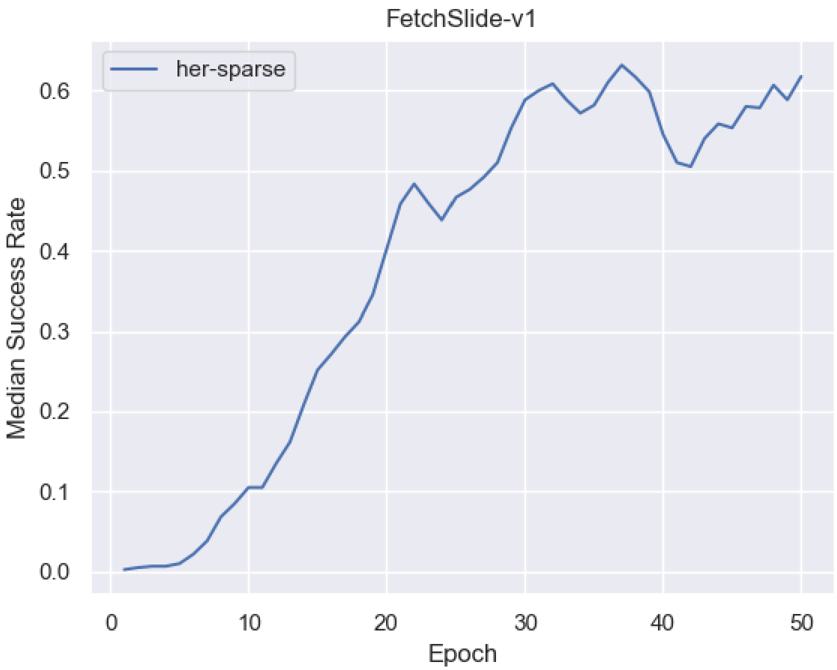
FetchSlide-v1



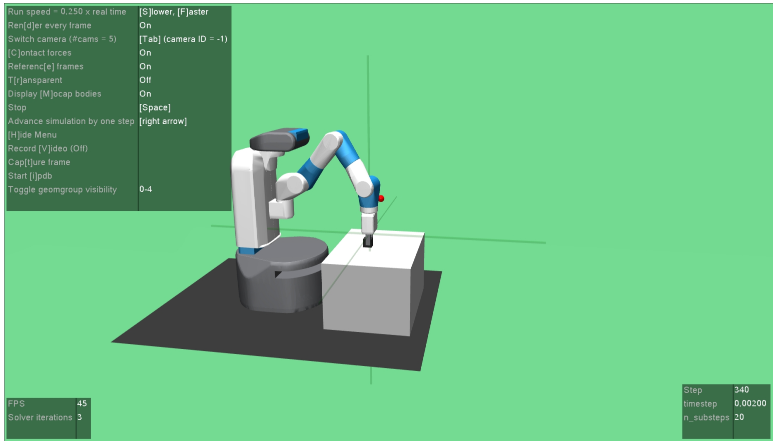
```
Run speed = 1.000 x real time     [S]lower, [F]aster
Ren[d]er every frame              On
Switch camera (#cams = 5)         [Tab] (camera ID = -1)
[C]ontact forces                  On
Referenc[e] frames                On
T[r]ansparent                     Off
Display [M]ocap bodies            On
Stop                              [Space]
Advance simulation by one step    [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility       0-4
```

```
FPS                23
Solver iterations  2
```

```
Step        680
timestep    0.00200
n_substeps  20
```



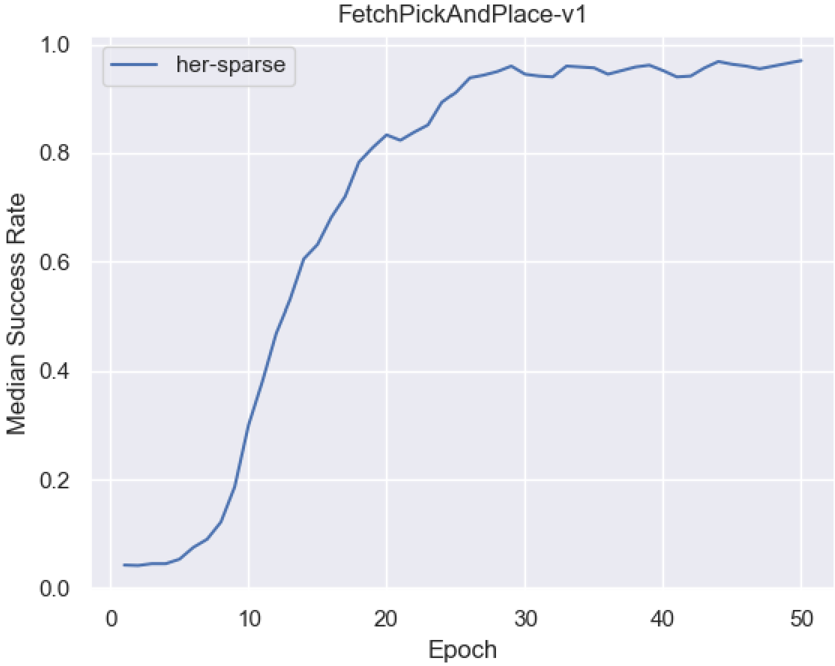
FetchPickAndPlace-v1



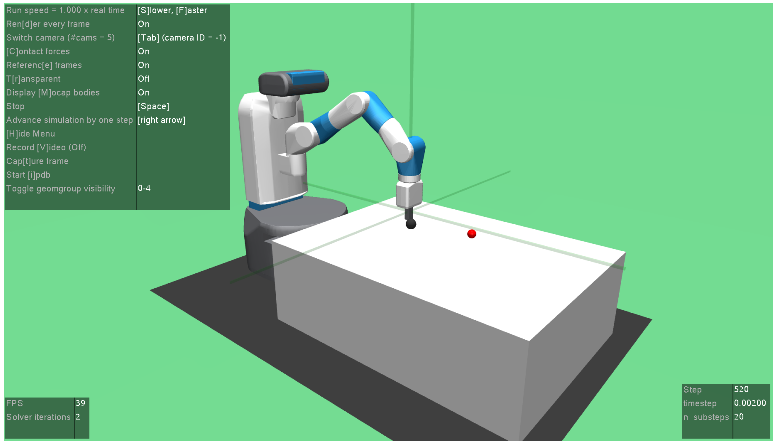
Run speed = 0.250 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	45
Solver iterations	3

Step	340
timestep	0.00200
n_substeps	20



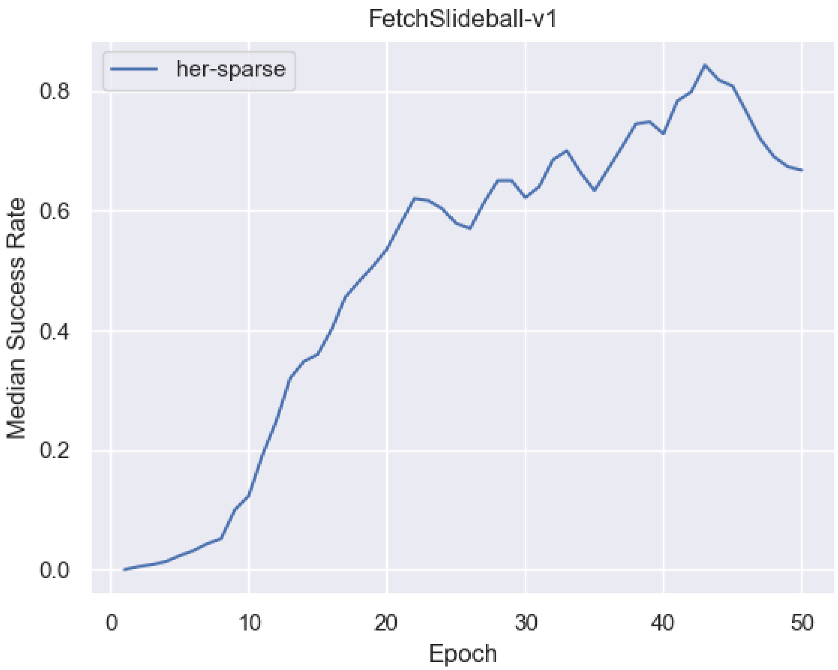
FetchSlideball-v1



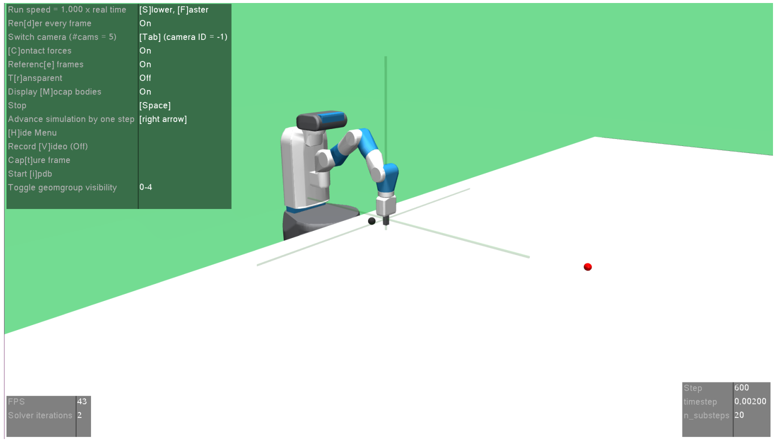
```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4
```

```
FPS                 39
Solver iterations   2
```

```
Step         520
timestep     0.00200
n_substeps   20
```



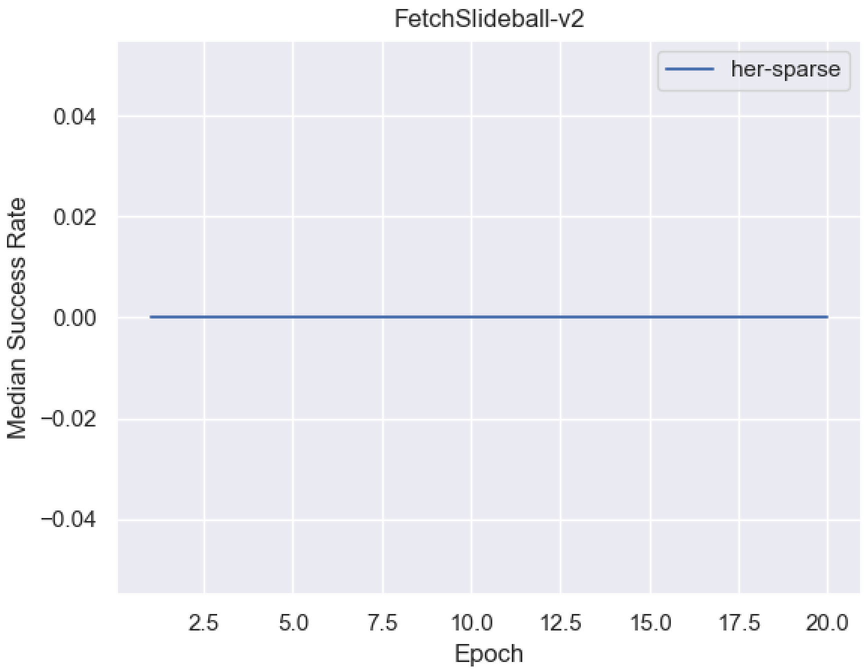
FetchSlideball-v2



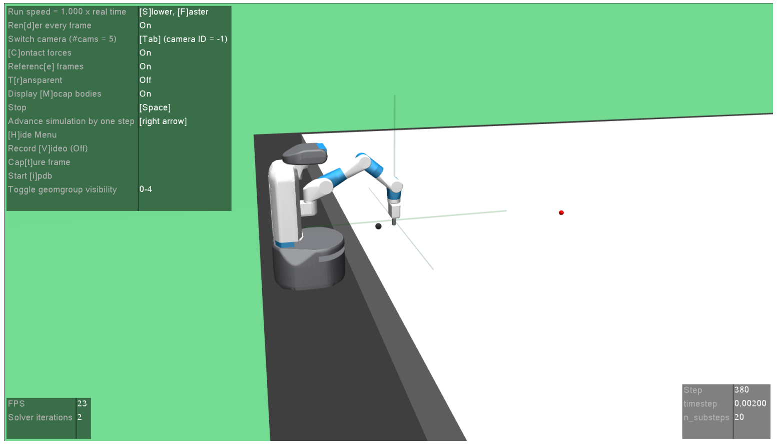
Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	43
Solver iterations	2

Step	600
timestep	0.00200
n_substeps	20



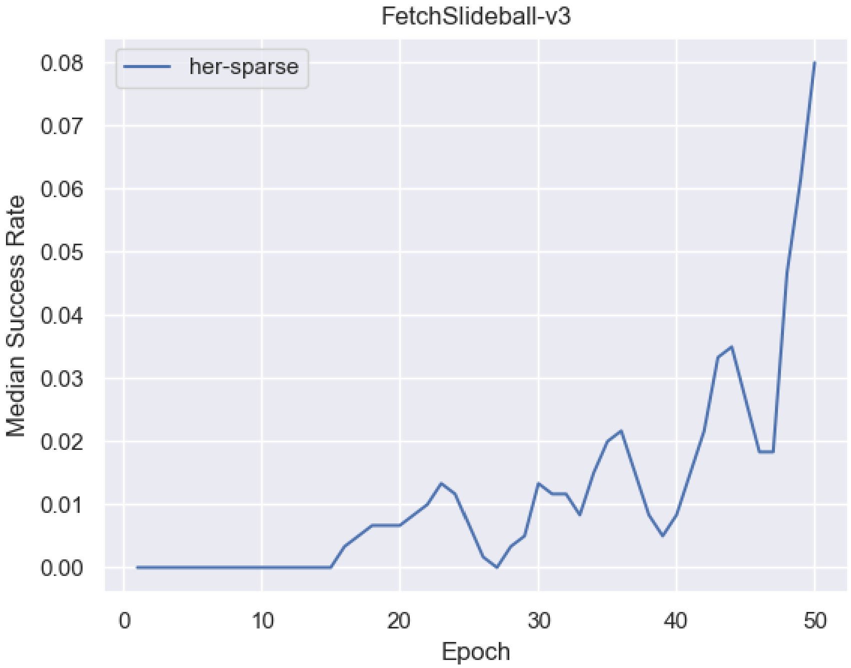
FetchSlideball-v3



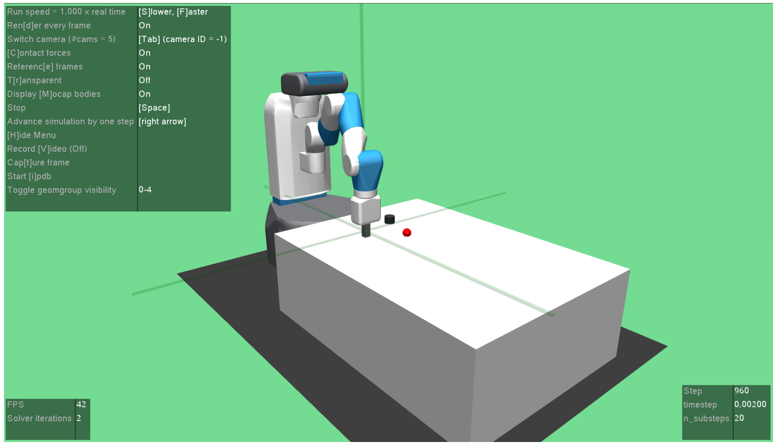
```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4
```

```
FPS                23
Solver iterations  2
```

```
Step         380
timestep     0.00200
n_substeps   20
```



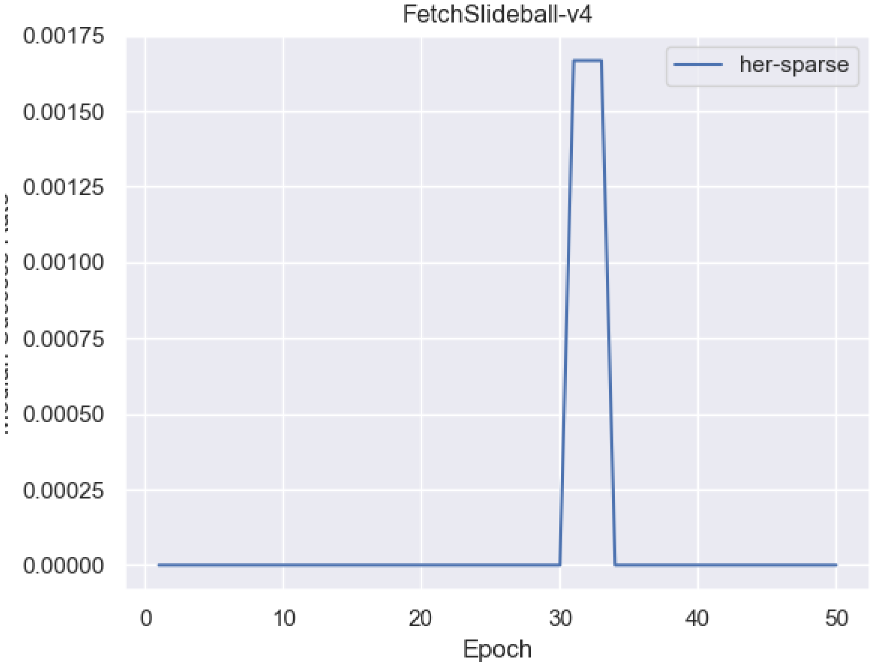
FetchSlideball-v4



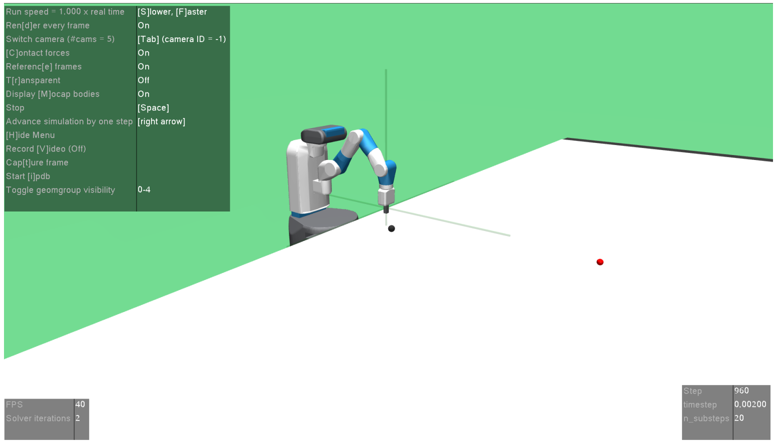
Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	42
Solver iterations	2

Step	960
timestep	0.00200
n_substeps	20



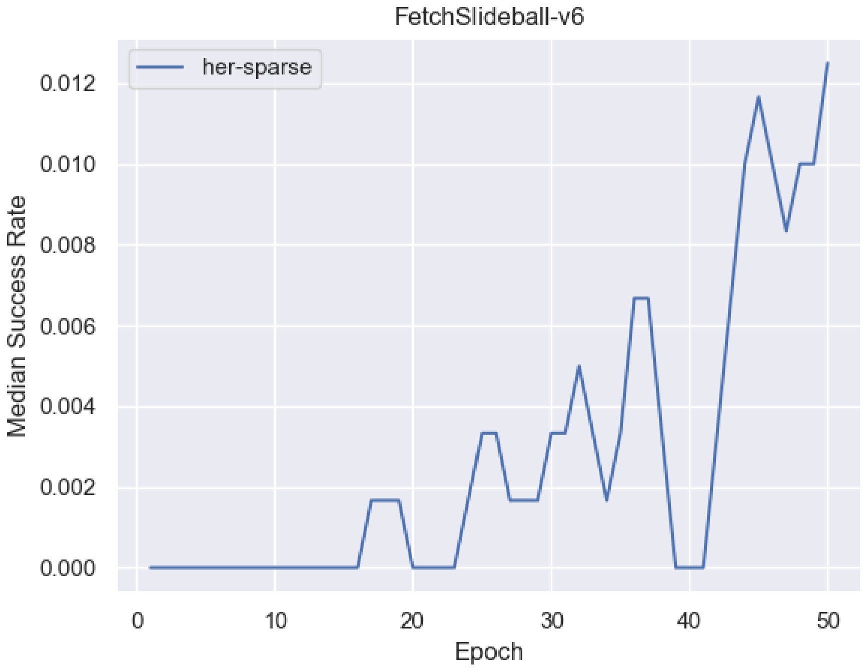
FetchSlideball-v6



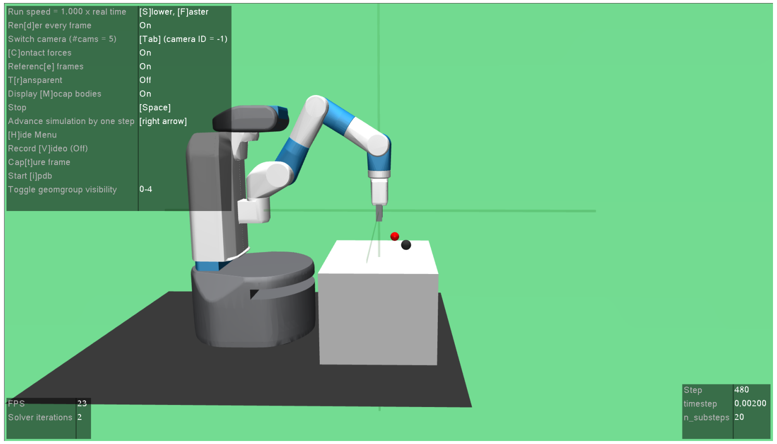
```
Run speed = 1.000 x real time      [S]lower, [F]aster
Ren[d]er every frame               On
Switch camera (#cams = 5)          [Tab] (camera ID = -1)
[C]ontact forces                   On
Referenc[e] frames                 On
T[r]ansparent                      Off
Display [M]ocap bodies             On
Stop                               [Space]
Advance simulation by one step     [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility        0-4
```

```
FPS                 40
Solver iterations   2
```

```
Step         960
timestep     0.00200
n_substeps   20
```



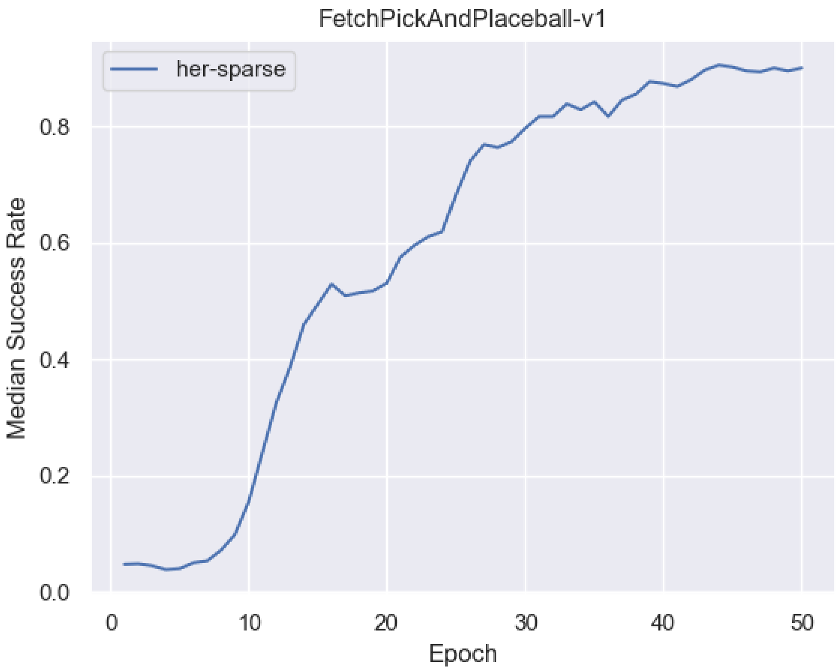
FetchPickAndPlaceball-v1



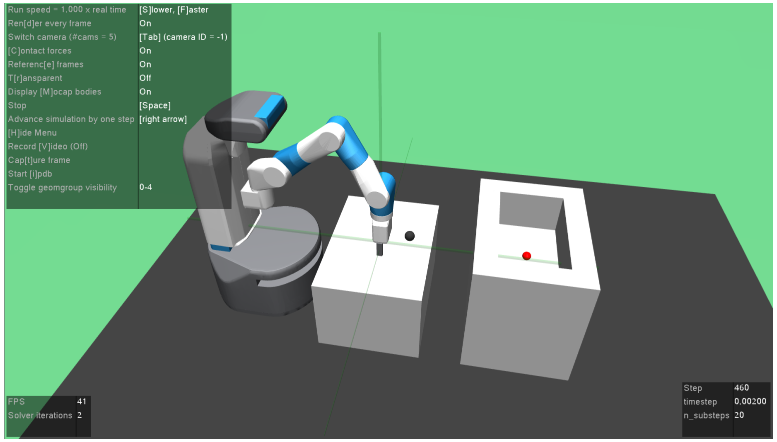
```
Run speed = 1.000 x real time    [S]lower, [F]aster
Ren[d]er every frame             On
Switch camera (#cams = 5)        [Tab] (camera ID = -1)
[C]ontact forces                 On
Referenc[e] frames               On
T[r]ansparent                    Off
Display [M]ocap bodies           On
Stop                             [Space]
Advance simulation by one step   [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility      0-4
```

```
FPS                23
Solver iterations  2
```

```
Step        480
timestep    0.00200
n_substeps  20
```



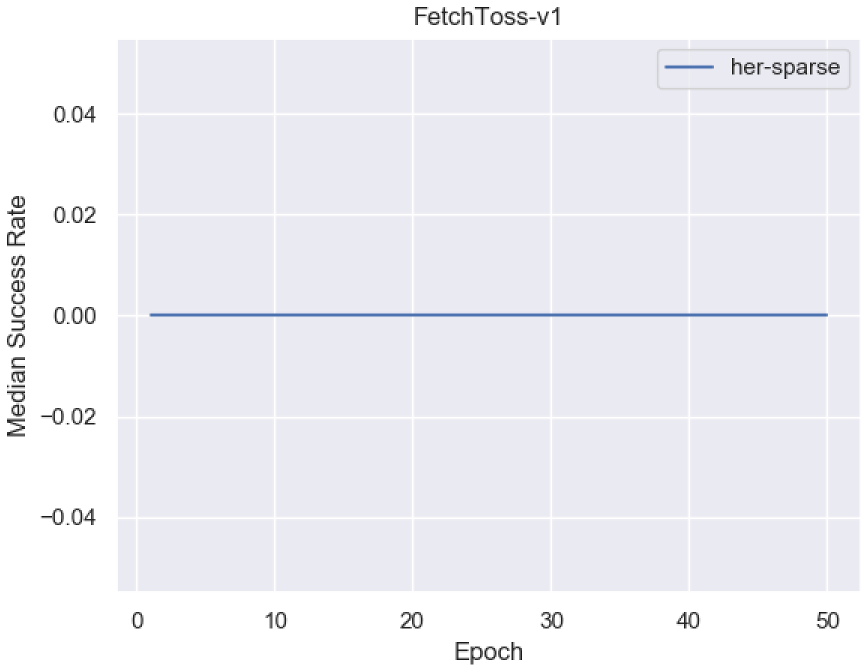
FetchToss-v1



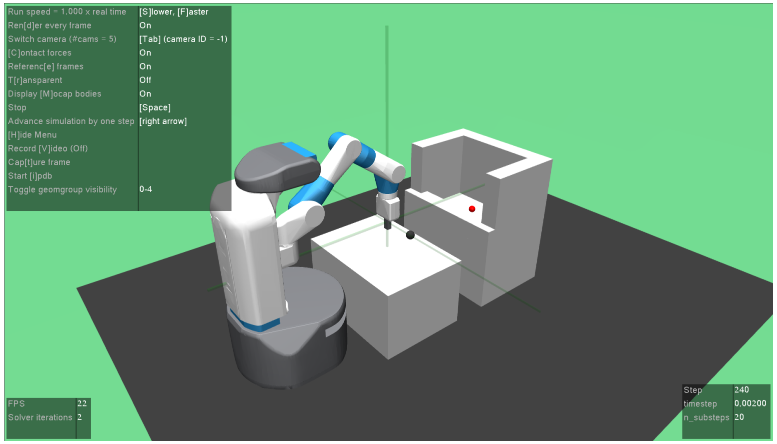
```
Run speed = 1.000 x real time     [S]lower, [F]aster
Ren[d]er every frame              On
Switch camera (#cams = 5)         [Tab] (camera ID = -1)
[C]ontact forces                  On
Referenc[e] frames                On
T[r]ansparent                     Off
Display [M]ocap bodies            On
Stop                              [Space]
Advance simulation by one step    [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility       0-4
```

```
FPS                41
Solver iterations  2
```

```
Step        460
timestep    0.00200
n_substeps  20
```



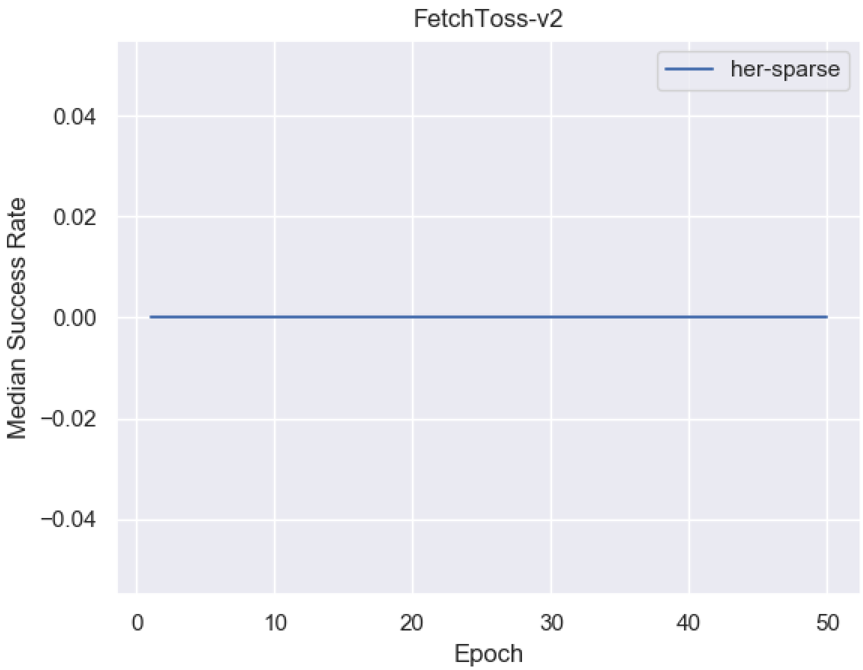
FetchToss-v2



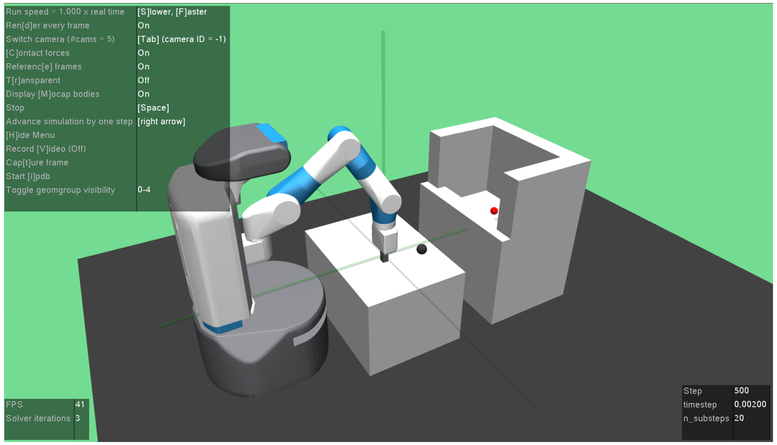
```
Run speed = 1.000 x real time    [S]lower, [F]aster
Ren[d]er every frame             On
Switch camera (#cams = 5)        [Tab] (camera ID = -1)
[C]ontact forces                 On
Referenc[e] frames               On
T[r]ansparent                    Off
Display [M]ocap bodies           On
Stop                             [Space]
Advance simulation by one step   [right arrow]
[H]ide Menu
Record [V]ideo (Off)
Cap[t]ure frame
Start [i]pdb
Toggle geomgroup visibility      0-4
```

```
FPS                22
Solver iterations  2
```

```
Step        240
timestep    0.00200
n_substeps  20
```



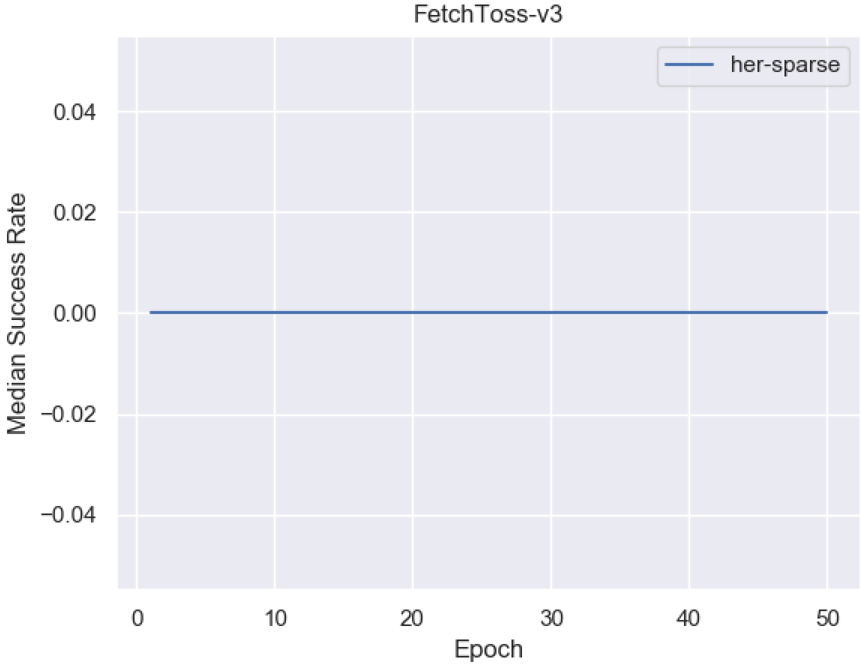
FetchToss-v3



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	41
Solver iterations	3

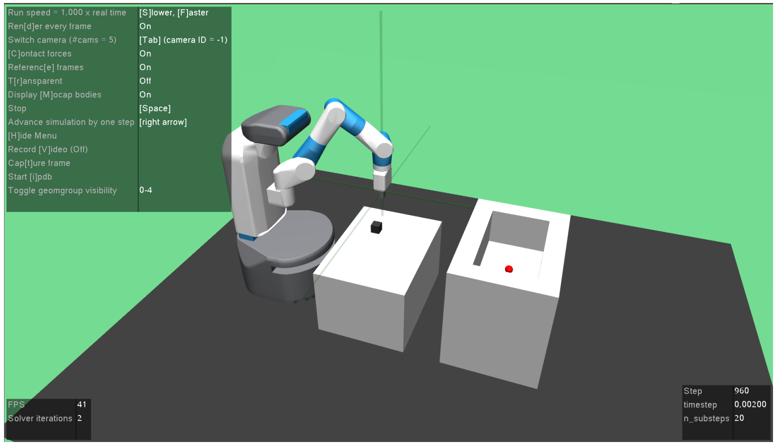
Step	500
timestep	0.00200
n_substeps	20



FetchToss-v0 (Tossing is possible)

FetchTosscube-v1

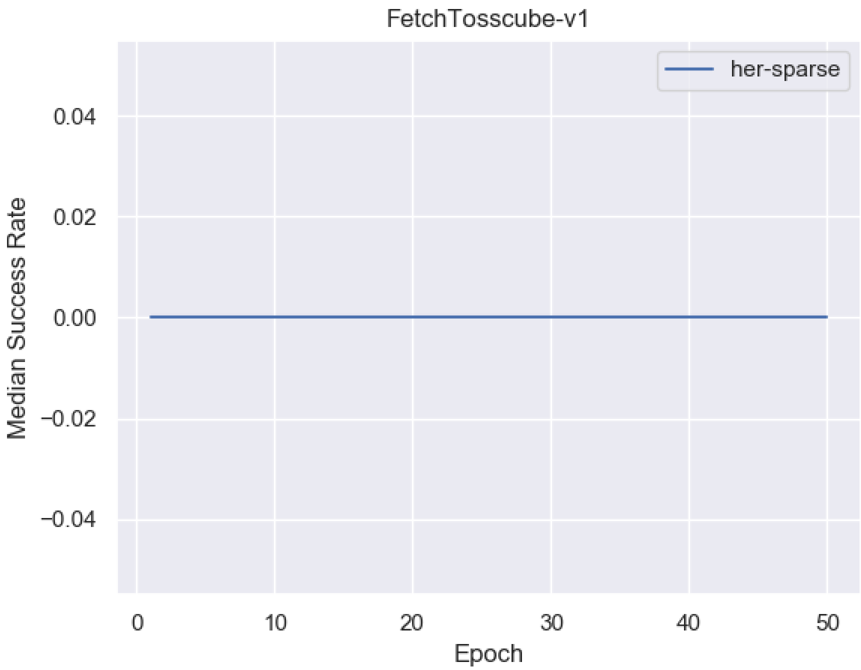
Tossing a cube (with v3 parameters



Run speed = 1.000 x real time	[S]lower, [F]aster
Ren[d]er every frame	On
Switch camera (#cams = 5)	[Tab] (camera ID = -1)
[C]ontact forces	On
Referenc[e] frames	On
T[r]ansparent	Off
Display [M]ocap bodies	On
Stop	[Space]
Advance simulation by one step	[right arrow]
[H]ide Menu	
Record [V]ideo (Off)	
Cap[t]ure frame	
Start [i]pdb	
Toggle geomgroup visibility	0-4

FPS	41
Solver iterations	2

Step	960
timestep	0.00200
n_substeps	20



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Chair of Robotics, Artificial Intelligence and Real-time Systems

München, 27. März 2015

Präsentationsmuster

kann auch als Kapiteltrenner verwendet werden