# Modal Symbolic Learning: Appetizer

In [1]:

```
using Pkg
Pkg.activate(".")
Pkg.instantiate()
Pkg.update()
Pkg.status()
```

```
  Activating project at `~/Desktop/modal-symbolic-learning-course`
    Updating registry at `~/.julia/registries/General`
    Updating git-repo `https://github.com/JuliaRegistries/General.git`
  No Changes to `~/Desktop/modal-symbolic-learning-course/Project.toml`
  No Changes to `~/Desktop/modal-symbolic-learning-course/Manifest.toml`
Status `~/Desktop/modal-symbolic-learning-course/Project.toml`
  [a93c6f00] DataFrames v1.6.1
  [7806a523] DecisionTree v0.12.4
  [7073ff75] IJulia v1.24.2
⌅ [add582a8] MLJ v0.19.5
  [c6f25543] MLJDecisionTreeInterface v0.4.0
  [e54bda2e] ModalDecisionTrees v0.3.3
  [91a5bcdd] Plots v1.39.0
  [7b3b3b3f] Sole v0.3.1
  [b002da8f] SoleLogics v0.6.11
  [4249d9c7] SoleModels v0.5.3
  [2913bbd2] StatsBase v0.34.2
  [9a3f8284] Random
Info Packages marked with ⌅ have new versions available but compatibility co
nstraints restrict them from upgrading. To see why use `status --outdated`
```

In [2]:

```
# Import libraries for statistics & Machine Learning
using Random
using DataFrames
using MLJ
using Plots
```

In [3]:

```
# Import the Sole framework
using Sole

# Load an example time-series classification dataset as a tuple (DataFrame,
X, y = Sole.load_arff_dataset("NATOPS");
```

In [4]:

```
y
```

Loading [MathJax]/extensions/Safe.js

```
Out[4]: 360-element CategoricalArrays.CategoricalArray{String,1,UInt32}:
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
         "I have command"
          ⋮
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
         "Lock wings"
```

```
In [5]: X
```

Out[5]: 360×24 DataFrame *335 rows omitted*

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X[ |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | Ar |
| 1 | [-0.519771,<br>-0.52758,<br>-0.531415,<br>-0.517159,<br>-0.510312,<br>-0.518154,<br>-0.50362,<br>-0.485176,<br>-0.466677,<br>-0.444535<br>…<br>-0.45501,<br>-0.458937,<br>-0.465048,<br>-0.471251,<br>-0.470015,<br>-0.464627,<br>-0.462666,<br>-0.460253,<br>-0.459572,<br>-0.456737] | [-2.14011,<br>-2.18043,<br>-2.18425,<br>-2.16547,<br>-2.16635,<br>-2.18836,<br>-2.17162,<br>-2.15248,<br>-2.08072,<br>-2.00607<br>…<br>-2.17597,<br>-2.1638,<br>-2.17779,<br>-2.17766,<br>-2.17848,<br>-2.16689,<br>-2.15667,<br>-2.13474,<br>-2.13435,<br>-2.13855] | [-0.957224,<br>-0.970778,<br>-0.970232,<br>-0.960666,<br>-0.962437,<br>-0.970488,<br>-0.966847,<br>-0.96441,<br>-0.972943,<br>-0.979085<br>…<br>-1.04234,<br>-1.03616,<br>-1.03756,<br>-1.03275,<br>-1.02525,<br>-1.03115,<br>-1.02558,<br>-1.01884,<br>-1.01701,<br>-1.01059] | [0.675893,<br>0.699281,<br>0.673774,<br>0.700096,<br>0.765257,<br>0.980454,<br>1.43803,<br>1.78334,<br>2.08495,<br>2.32037 …<br>0.755717,<br>0.778103,<br>0.755128,<br>0.751274,<br>0.742517,<br>0.743311,<br>0.786792,<br>0.730863,<br>0.730482,<br>0.732217] | [-2.31794,<br>-2.36398,<br>-2.48698,<br>-2.3176,<br>-2.34228,<br>-2.34828,<br>-2.24596,<br>-1.8102,<br>-1.28214,<br>-0.703666<br>…<br>-2.45044,<br>-2.33026,<br>-2.44767,<br>-2.43509,<br>-2.44371,<br>-2.42475,<br>-2.25219,<br>-2.38539,<br>-2.38603,<br>-2.35704] | [-0.254602,<br>-0.246883,<br>-0.252635,<br>-0.235782,<br>-0.13363,<br>0.051243,<br>0.078424,<br>0.274688,<br>0.335957,<br>0.390646<br>…<br>-0.210761,<br>-0.181256,<br>-0.213764,<br>-0.206785,<br>-0.222643,<br>-0.214863,<br>-0.169845,<br>-0.20958,<br>-0.202703,<br>-0.201438] | [-(<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| 2 | [-0.489753,<br>-0.48607,<br>-0.484529,<br>-0.492771,<br>-0.492031,<br>-0.493076,<br>-0.491979,<br>-0.493256,<br>-0.493156,<br>-0.487527<br>…<br>-0.400825,<br>-0.414617,<br>-0.407231,<br>-0.397206,<br>-0.366296,<br>-0.354333,<br>-0.371938,<br>-0.386065,<br>-0.408146,<br>-0.415736] | [-1.55293,<br>-1.54966,<br>-1.55206,<br>-1.55821,<br>-1.556,<br>-1.56055,<br>-1.55812,<br>-1.5648,<br>-1.56414,<br>-1.56731<br>…<br>-1.6062,<br>-1.62319,<br>-1.61939,<br>-1.6173,<br>-1.58341,<br>-1.5697,<br>-1.55188,<br>-1.54089,<br>-1.52865,<br>-1.52388] | [-0.907814,<br>-0.911305,<br>-0.92587,<br>-0.921268,<br>-0.928352,<br>-0.928697,<br>-0.932141,<br>-0.930564,<br>-0.933592,<br>-0.932622<br>…<br>-0.989828,<br>-0.990365,<br>-0.998319,<br>-0.994962,<br>-0.994991,<br>-0.983351,<br>-0.976952,<br>-0.975923,<br>-0.963954,<br>-0.953944] | [0.632831,<br>0.633167,<br>0.637368,<br>0.640823,<br>0.635858,<br>0.63401,<br>0.634496,<br>0.637154,<br>0.640618,<br>0.643018<br>…<br>0.558287,<br>0.447356,<br>0.452128,<br>0.525122,<br>0.651756,<br>0.77637,<br>0.948441,<br>1.09432,<br>1.30458,<br>1.42438] | [-1.61526,<br>-1.61763,<br>-1.62374,<br>-1.61861,<br>-1.62068,<br>-1.62244,<br>-1.62164,<br>-1.6257,<br>-1.62654,<br>-1.62966<br>…<br>1.56275,<br>1.58349,<br>1.59581,<br>1.60302,<br>1.55387,<br>1.53016,<br>1.47453,<br>1.47069,<br>1.45205,<br>1.39396] | [-0.63772,<br>-0.637168,<br>-0.644338,<br>-0.651686,<br>-0.653233,<br>-0.654332,<br>-0.651011,<br>-0.6489,<br>-0.654768,<br>-0.653883<br>…<br>0.526364,<br>0.534895,<br>0.553634,<br>0.564454,<br>0.478762,<br>0.47897,<br>0.444671,<br>0.328608,<br>0.29968,<br>0.242647] | [-(<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| 3 | [-0.521346,<br>-0.518394,<br>-0.522321,<br>-0.519893,<br>-0.521016,<br>-0.521524,<br>-0.523362,<br>-0.511653,<br>-0.512519,<br>-0.511312<br>…<br>-0.514448,<br>-0.518708, | [-1.72326,<br>-1.72407,<br>-1.72326,<br>-1.72352,<br>-1.72479,<br>-1.72389,<br>-1.7244,<br>-1.76782,<br>-1.76903,<br>-1.76877<br>…<br>-1.79175,<br>-1.77926, | [-0.581362,<br>-0.578159,<br>-0.586091,<br>-0.582611,<br>-0.583196,<br>-0.582819,<br>-0.580284,<br>-0.57613,<br>-0.576047,<br>-0.575067<br>…<br>-0.64696,<br>-0.640021, | [0.480245,<br>0.413413,<br>0.425131,<br>0.420865,<br>0.481781,<br>0.483458,<br>0.415258,<br>0.429159,<br>0.449354,<br>0.476563<br>…<br>0.71045,<br>0.665733, | [-1.72509,<br>-1.79325,<br>-1.77693,<br>-1.78382,<br>-1.72083,<br>-1.72458,<br>-1.80616,<br>-1.77722,<br>-1.78057,<br>-1.79041<br>…<br>-1.57885,<br>-1.64564, | [-0.749465,<br>-0.814978,<br>-0.79228,<br>-0.801608,<br>-0.754548,<br>-0.74575,<br>-0.806902,<br>-0.788115,<br>-0.775095,<br>-0.768625<br>…<br>-1.16744,<br>-0.986366, | [-(<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0 |

Loading [MathJax]/extensions/Safe.js

| Row | X[Hand tip l]<br>Array… | Y[Hand tip l]<br>Array… | Z[Hand tip l]<br>Array… | X[Hand tip r]<br>Array… | Y[Hand tip r]<br>Array… | Z[Hand tip r]<br>Array… | X[<br>Ar |
|---|---|---|---|---|---|---|---|
| | -0.521672,<br>-0.525064,<br>-0.514835,<br>-0.507935,<br>-0.521132,<br>-0.517193,<br>-0.517363,<br>-0.51327] | -1.77711,<br>-1.77828,<br>-1.77587,<br>-1.76419,<br>-1.77843,<br>-1.77882,<br>-1.77992,<br>-1.77987] | -0.630712,<br>-0.616814,<br>-0.62093,<br>-0.621969,<br>-0.621552,<br>-0.624645,<br>-0.621028,<br>-0.626299] | 0.621122,<br>0.557295,<br>0.519791,<br>0.48524,<br>0.481703,<br>0.488414,<br>0.485208,<br>0.479489] | -1.68675,<br>-1.81935,<br>-1.76374,<br>-1.76348,<br>-1.78189,<br>-1.7849,<br>-1.78435,<br>-1.78333] | -0.849024,<br>-0.767521,<br>-0.725116,<br>-0.723884,<br>-0.743611,<br>-0.736042,<br>-0.731239,<br>-0.733958] | -0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| **4** | [-0.57022,<br>-0.562064,<br>-0.565967,<br>-0.562913,<br>-0.567557,<br>-0.566175,<br>-0.566748,<br>-0.561748,<br>-0.55966,<br>-0.556271<br>…<br>-0.530846,<br>-0.535016,<br>-0.537207,<br>-0.533389,<br>-0.530497,<br>-0.532508,<br>-0.522586,<br>-0.53489,<br>-0.534332,<br>-0.54071] | [-1.91196,<br>-1.90369,<br>-1.90527,<br>-1.90405,<br>-1.90318,<br>-1.90619,<br>-1.90959,<br>-1.89934,<br>-1.8948,<br>-1.89346<br>…<br>-1.87427,<br>-1.87535,<br>-1.88059,<br>-1.8954,<br>-1.89976,<br>-1.89333,<br>-1.90898,<br>-1.91169,<br>-1.92236,<br>-1.92444] | [-0.753404,<br>-0.748702,<br>-0.747062,<br>-0.7541,<br>-0.751551,<br>-0.749891,<br>-0.75006,<br>-0.748899,<br>-0.745352,<br>-0.74102 …<br>-0.704626,<br>-0.713649,<br>-0.720423,<br>-0.721149,<br>-0.720037,<br>-0.727544,<br>-0.718666,<br>-0.731909,<br>-0.73111,<br>-0.727761] | [0.459493,<br>0.464525,<br>0.461903,<br>0.455969,<br>0.460419,<br>0.465137,<br>0.445696,<br>0.458416,<br>0.4603,<br>0.46256 …<br>2.09097,<br>1.91878,<br>1.58165,<br>1.21182,<br>0.941954,<br>0.708641,<br>0.537249,<br>0.464884,<br>0.459635,<br>0.46293] | [-1.90089,<br>-1.87507,<br>-1.89495,<br>-1.89809,<br>-1.87756,<br>-1.87972,<br>-1.9182,<br>-1.88876,<br>-1.8717,<br>-1.86988<br>…<br>-0.790038,<br>-1.22432,<br>-1.5668,<br>-1.69141,<br>-1.78663,<br>-1.85248,<br>-1.9406,<br>-1.96856,<br>-1.96701,<br>-1.9625] | [-0.764456,<br>-0.766048,<br>-0.757716,<br>-0.756718,<br>-0.767963,<br>-0.767328,<br>-0.754985,<br>-0.757794,<br>-0.759314,<br>-0.755372<br>…<br>-0.437201,<br>-0.560395,<br>-0.625109,<br>-0.675635,<br>-0.628565,<br>-0.654884,<br>-0.668321,<br>-0.737166,<br>-0.740219,<br>-0.737878] | [-<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| **5** | [-0.624417,<br>-0.626031,<br>-0.625388,<br>-0.62798,<br>-0.624838,<br>-0.623534,<br>-0.626624,<br>-0.626658,<br>-0.622853,<br>-0.622373<br>…<br>-0.606563,<br>-0.611505,<br>-0.614609,<br>-0.607108,<br>-0.598554,<br>-0.621197,<br>-0.625199,<br>-0.644386,<br>-0.657226,<br>-0.663721] | [-1.84287,<br>-1.84026,<br>-1.84688,<br>-1.84182,<br>-1.84628,<br>-1.84354,<br>-1.84273,<br>-1.83752,<br>-1.83289,<br>-1.83472<br>…<br>-1.68283,<br>-1.72178,<br>-1.77294,<br>-1.80126,<br>-1.81198,<br>-1.87223,<br>-1.89073,<br>-1.89526,<br>-1.9043,<br>-1.91686] | [-0.789348,<br>-0.786501,<br>-0.768675,<br>-0.779753,<br>-0.775049,<br>-0.77593,<br>-0.770693,<br>-0.771605,<br>-0.773377,<br>-0.76946 …<br>-0.831481,<br>-0.841451,<br>-0.848442,<br>-0.851784,<br>-0.846179,<br>-0.850705,<br>-0.837824,<br>-0.816053,<br>-0.801157,<br>-0.795484] | [0.58095,<br>0.57809,<br>0.579865,<br>0.577963,<br>0.576101,<br>0.576345,<br>0.575145,<br>0.579263,<br>0.579383,<br>0.579958<br>…<br>2.07734,<br>2.11504,<br>2.1128,<br>1.91689,<br>1.5704,<br>1.18571,<br>0.803449,<br>0.617248,<br>0.555628,<br>0.519571] | [-1.83512,<br>-1.83411,<br>-1.83304,<br>-1.83161,<br>-1.82641,<br>-1.82692,<br>-1.82371,<br>-1.81809,<br>-1.81299,<br>-1.81521<br>…<br>0.210206,<br>-0.240879,<br>-0.761203,<br>-1.25598,<br>-1.64153,<br>-1.92075,<br>-2.01471,<br>-1.99813,<br>-1.98928,<br>-2.0021] | [-0.748908,<br>-0.753321,<br>-0.749488,<br>-0.758251,<br>-0.764208,<br>-0.764563,<br>-0.768688,<br>-0.772309,<br>-0.774509,<br>-0.774836<br>…<br>0.212435,<br>0.104328,<br>-0.043032,<br>-0.286689,<br>-0.430668,<br>-0.572304,<br>-0.638792,<br>-0.682752,<br>-0.718812,<br>-0.761999] | [-<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| **6** | [-0.502501,<br>-0.502525,<br>-0.499415,<br>-0.501144,<br>-0.502677,<br>-0.501937, | [-2.17556,<br>-2.15613,<br>-2.18516,<br>-2.19291,<br>-2.15844,<br>-2.14539, | [-1.09413,<br>-1.07683,<br>-1.09008,<br>-1.09044,<br>-1.07624,<br>-1.06987, | [0.631689,<br>0.624567,<br>0.638725,<br>0.640064,<br>0.617619,<br>0.609287, | [-2.39645,<br>-2.35991,<br>-2.39196,<br>-2.35874,<br>-2.39011,<br>-2.38913, | [-0.174365,<br>-0.166227,<br>-0.164783,<br>-0.171156,<br>-0.171868,<br>-0.168856, | [-<br>-0<br>-0<br>-0<br>-0<br>-0 |

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X[ |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | A |
| | -0.500699, -0.501717, -0.501963, -0.504734 … -0.43365, -0.436541, -0.447761, -0.456823, -0.460775, -0.467277, -0.464943, -0.469757, -0.468361, -0.469486] | -2.17194, -2.14695, -2.13512, -2.12584 … -2.05511, -2.07088, -2.07849, -2.09125, -2.10468, -2.12407, -2.13097, -2.16563, -2.1762, -2.19243] | -1.07743, -1.07267, -1.0659, -1.0586 … -0.994042, -1.00038, -1.00443, -1.00719, -1.01067, -1.02072, -1.02934, -1.0372, -1.04505, -1.04952] | 0.623102, 0.614398, 0.60629, 0.591307 … 1.1434, 0.936468, 0.81356, 0.748232, 0.70633, 0.715475, 0.701832, 0.708491, 0.711467, 0.724143] | -2.4044, -2.3628, -2.33339, -2.39623 … -2.29177, -2.33778, -2.32335, -2.31428, -2.39301, -2.30433, -2.44085, -2.4951, -2.50935, -2.53032] | -0.167825, -0.166135, -0.168217, -0.164987 … 0.248703, 0.315796, 0.30116, 0.181476, 0.109893, 0.069707, 0.072417, 0.054247, 0.056288, 0.068829] | -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **7** | [-0.488461, -0.489463, -0.487539, -0.495673, -0.498767, -0.492156, -0.492845, -0.484968, -0.482085, -0.480355 … -0.493495, -0.492836, -0.49895, -0.503093, -0.509026, -0.513016, -0.515636, -0.523701, -0.519121, -0.512226] | [-2.17242, -2.18203, -2.18057, -2.18011, -2.16312, -2.16706, -2.1655, -2.16417, -2.16289, -2.16507 … -2.20638, -2.24703, -2.26315, -2.27173, -2.2962, -2.3206, -2.28483, -2.26507, -2.30022, -2.30896] | [-0.968068, -0.970886, -0.972168, -0.964309, -0.968031, -0.964959, -0.965357, -0.96689, -0.961591, -0.971308 … -0.946976, -0.954752, -0.957002, -0.954402, -0.956824, -0.959061, -0.951237, -0.939096, -0.95456, -0.970996] | [0.56396, 0.595508, 0.563289, 0.562872, 0.569912, 0.59887, 0.597455, 0.59935, 0.588259, 0.616466 … 1.90101, 1.68372, 1.45597, 1.22308, 1.03946, 0.896663, 0.789375, 0.750815, 0.748015, 0.753018] | [-2.39541, -2.32961, -2.40599, -2.4037, -2.38496, -2.30025, -2.29899, -2.29647, -2.34951, -2.34849 … -1.68622, -2.01573, -2.27071, -2.44548, -2.54653, -2.61704, -2.58102, -2.42942, -2.45797, -2.3098] | [-0.189166, -0.156892, -0.183036, -0.188968, -0.182562, -0.155315, -0.159691, -0.162753, -0.167263, -0.126656 … 0.428323, 0.353664, 0.283833, 0.227649, 0.192813, 0.144374, 0.100455, 0.056708, 0.020836, -0.010608] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **8** | [-0.468105, -0.410602, -0.473909, -0.475146, -0.465564, -0.459415, -0.408703, -0.407192, -0.406746, -0.471503 … -0.403425, -0.38908, -0.388014, -0.376936, -0.386189, -0.383457, -0.379303, -0.379167, -0.35105, -0.37192] | [-1.86535, -1.89011, -1.87105, -1.87014, -1.86305, -1.86513, -1.88585, -1.88192, -1.88197, -1.86255 … -1.70318, -1.71049, -1.71516, -1.72376, -1.72854, -1.75506, -1.78602, -1.83142, -1.82577, -1.85042] | [-0.697004, -0.708269, -0.681783, -0.685562, -0.700491, -0.698824, -0.712602, -0.714313, -0.709702, -0.683408 … -0.694703, -0.696871, -0.685235, -0.698665, -0.689877, -0.695257, -0.711887, -0.716584, -0.716449, -0.711233] | [0.51303, 0.535447, 0.526609, 0.529012, 0.516169, 0.514988, 0.515586, 0.504798, 0.504606, 0.531836 … 1.64002, 1.79941, 1.99117, 2.07635, 2.11726, 2.06097, 1.95247, 1.74608, 1.46703, 1.22156] | [-1.89671, -1.86846, -1.87776, -1.86998, -1.90863, -1.90658, -1.89158, -1.91002, -1.9078, -1.88441 … 0.980896, 0.775941, 0.411292, 0.105297, -0.240116, -0.606455, -0.99533, -1.35875, -1.59084, -1.78522] | [-0.72422, -0.706672, -0.716476, -0.716994, -0.720904, -0.726877, -0.722421, -0.730964, -0.734788, -0.696653 … -0.583728, -0.670627, -0.697702, -0.731501, -0.745341, -0.771108, -0.766031, -0.755091, -0.675288, -0.632553] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X[ |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | Ar |
| **9** | [-0.568195, -0.572936, -0.571337, -0.577742, -0.562071, -0.563401, -0.56426, -0.56251, -0.567891, -0.568983 … -0.572375, -0.573012, -0.570897, -0.571727, -0.572124, -0.56665, -0.568694, -0.576087, -0.577822, -0.576184] | [-1.79059, -1.78162, -1.78303, -1.77291, -1.79029, -1.79301, -1.7906, -1.79415, -1.78852, -1.78192 … -1.71373, -1.712, -1.71488, -1.71719, -1.724, -1.73081, -1.73278, -1.74117, -1.74922, -1.7542] | [-0.629271, -0.631997, -0.629313, -0.636701, -0.635508, -0.634023, -0.639724, -0.637628, -0.638034, -0.642679 … -0.59198, -0.595464, -0.590844, -0.597421, -0.599602, -0.605654, -0.595905, -0.590594, -0.592675, -0.593041] | [0.574572, 0.572953, 0.58065, 0.576566, 0.576827, 0.576204, 0.578404, 0.575839, 0.571202, 0.578351 … 1.11163, 1.28867, 1.47037, 1.62137, 1.73751, 1.76605, 1.68489, 1.51916, 1.30435, 1.10295] | [-1.82092, -1.82256, -1.8185, -1.81975, -1.81878, -1.81891, -1.81806, -1.82086, -1.82313, -1.8185 … 1.05829, 0.920416, 0.710814, 0.407749, 0.04714, -0.35929, -0.776797, -1.13484, -1.41145, -1.55159] | [-0.617017, -0.615382, -0.612141, -0.614752, -0.611139, -0.616751, -0.615291, -0.615829, -0.618155, -0.617481 … -0.349956, -0.491946, -0.653769, -0.814871, -0.892301, -0.952159, -0.969561, -0.944127, -0.865372, -0.795585] | [-0 -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **10** | [-0.517579, -0.515374, -0.517325, -0.516505, -0.514786, -0.513077, -0.518725, -0.520816, -0.519732, -0.521663 … -0.470503, -0.478416, -0.476322, -0.483407, -0.494542, -0.497023, -0.503007, -0.511892, -0.516592, -0.506665] | [-1.73887, -1.74072, -1.7397, -1.73405, -1.73453, -1.73561, -1.7393, -1.71604, -1.72597, -1.73219 … -1.72644, -1.73147, -1.73613, -1.75607, -1.76061, -1.78371, -1.80105, -1.82082, -1.83392, -1.84493] | [-0.693497, -0.691899, -0.687666, -0.692099, -0.686091, -0.6872, -0.693279, -0.690005, -0.68333, -0.693432 … -0.746989, -0.737197, -0.732215, -0.722234, -0.737401, -0.737225, -0.742772, -0.742642, -0.749105, -0.749828] | [0.514507, 0.526694, 0.549404, 0.506781, 0.550714, 0.548035, 0.542946, 0.536573, 0.54797, 0.515168 … 2.05311, 2.01937, 2.0615, 2.14439, 2.14045, 2.15822, 2.0852, 1.93771, 1.70293, 1.46727] | [-1.83433, -1.81353, -1.76559, -1.82393, -1.76616, -1.76641, -1.7819, -1.79043, -1.76682, -1.8396 … 0.671155, 0.405484, 0.170111, -0.095538, -0.391807, -0.683817, -0.992354, -1.32681, -1.56162, -1.79568] | [-0.711129, -0.706901, -0.695049, -0.725259, -0.690311, -0.68963, -0.702482, -0.705599, -0.698506, -0.715266 … -0.295706, -0.343539, -0.356921, -0.385912, -0.405628, -0.440152, -0.444337, -0.468822, -0.478764, -0.456275] | [-0 -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **11** | [-0.631494, -0.629032, -0.630474, -0.628314, -0.625873, -0.620084, -0.622708, -0.615488, -0.604842, -0.609029 … -0.614349, -0.623253, -0.624818, -0.61368, | [-1.98071, -1.98581, -1.98407, -1.98487, -1.98305, -1.98431, -1.98929, -1.98398, -2.00128, -1.99469 … -1.96031, -1.97189, -1.97785, -1.98624, | [-0.747038, -0.74841, -0.747703, -0.75014, -0.754128, -0.759453, -0.75647, -0.766852, -0.762574, -0.767539 … -0.729413, -0.732674, -0.739823, -0.731681, | [0.856043, 0.857518, 0.851185, 0.859634, 0.858619, 0.854354, 0.905673, 1.16508, 1.42501, 1.71238 … 1.209, 1.07754, 0.957434, 0.851525, 0.757334, | [-2.03258, -2.0345, -2.03402, -2.03329, -2.03401, -2.034, -2.02314, -1.8548, -1.60643, -0.912175 … -1.78783, -1.91655, -2.02219, -2.06767, | [-0.865939, -0.864099, -0.862266, -0.86024, -0.852186, -0.85945, -0.842965, -0.9574, -1.05019, -1.05552 … -0.972505, -0.913282, -0.893715, -0.822636, -0.784828, | [-0 -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 |

| Row | X[Hand tip l]<br>Array… | Y[Hand tip l]<br>Array… | Z[Hand tip l]<br>Array… | X[Hand tip r]<br>Array… | Y[Hand tip r]<br>Array… | Z[Hand tip r]<br>Array… | X[<br>A |
|---|---|---|---|---|---|---|---|
|  | -0.615468,<br>-0.620129,<br>-0.619546,<br>-0.617533,<br>-0.623453,<br>-0.620921] | -1.98397,<br>-1.97893,<br>-1.97566,<br>-1.97111,<br>-1.96347,<br>-1.97802] | -0.733116,<br>-0.739864,<br>-0.741084,<br>-0.742643,<br>-0.748294,<br>-0.737384] | 0.744572,<br>0.701962,<br>0.779988,<br>0.778182,<br>0.778619] | -2.06231,<br>-2.04269,<br>-2.01127,<br>-1.73125,<br>-1.7347,<br>-1.73614] | -0.733635,<br>-0.782048,<br>-0.759991,<br>-0.75973,<br>-0.756357] | -0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| **12** | [-0.628575,<br>-0.621757,<br>-0.631781,<br>-0.634901,<br>-0.628957,<br>-0.637745,<br>-0.635805,<br>-0.629445,<br>-0.632091,<br>-0.635745<br>…<br>-0.591855,<br>-0.582347,<br>-0.588977,<br>-0.598174,<br>-0.599671,<br>-0.619432,<br>-0.621313,<br>-0.628482,<br>-0.633884,<br>-0.627249] | [-1.64959,<br>-1.65482,<br>-1.6445,<br>-1.65008,<br>-1.65215,<br>-1.64652,<br>-1.64085,<br>-1.65269,<br>-1.64934,<br>-1.64933<br>…<br>-1.65049,<br>-1.66718,<br>-1.6695,<br>-1.67345,<br>-1.67695,<br>-1.6821,<br>-1.68837,<br>-1.69011,<br>-1.68936,<br>-1.69211] | [-0.826129,<br>-0.820825,<br>-0.825739,<br>-0.822362,<br>-0.825972,<br>-0.82397,<br>-0.82843,<br>-0.827873,<br>-0.833039,<br>-0.834004<br>…<br>-0.850629,<br>-0.836348,<br>-0.83736,<br>-0.830908,<br>-0.825183,<br>-0.81275,<br>-0.804439,<br>-0.805276,<br>-0.816357,<br>-0.813985] | [0.63093,<br>0.630534,<br>0.619773,<br>0.626157,<br>0.621542,<br>0.621468,<br>0.613933,<br>0.637572,<br>0.767764,<br>1.01477 …<br>1.33375,<br>1.03323,<br>0.808823,<br>0.693519,<br>0.658938,<br>0.589302,<br>0.627916,<br>0.67699,<br>0.70274,<br>0.72096] | [-1.73747,<br>-1.73717,<br>-1.7373,<br>-1.73898,<br>-1.7427,<br>-1.74377,<br>-1.73731,<br>-1.74702,<br>-1.75181,<br>-1.73828<br>…<br>-1.70125,<br>-1.79771,<br>-1.87956,<br>-1.89704,<br>-1.86995,<br>-1.96147,<br>-1.91128,<br>-1.85101,<br>-1.8577,<br>-1.83568] | [-0.701359,<br>-0.702162,<br>-0.706464,<br>-0.704693,<br>-0.705164,<br>-0.697885,<br>-0.693803,<br>-0.691132,<br>-0.704814,<br>-0.670501<br>…<br>-0.380183,<br>-0.407226,<br>-0.445143,<br>-0.422019,<br>-0.475656,<br>-0.479682,<br>-0.47908,<br>-0.507252,<br>-0.51364,<br>-0.539279] | [-(<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| **13** | [-0.635968,<br>-0.613303,<br>-0.636138,<br>-0.635273,<br>-0.636906,<br>-0.633466,<br>-0.633318,<br>-0.628543,<br>-0.627045,<br>-0.624422<br>…<br>-0.61882,<br>-0.614184,<br>-0.626042,<br>-0.633471,<br>-0.634397,<br>-0.639003,<br>-0.645128,<br>-0.654244,<br>-0.651518,<br>-0.649729] | [-1.96703,<br>-1.98867,<br>-1.96746,<br>-1.9631,<br>-1.96258,<br>-1.96333,<br>-1.96385,<br>-1.9627,<br>-1.96265,<br>-1.96134<br>…<br>-1.84131,<br>-1.85966,<br>-1.85407,<br>-1.83433,<br>-1.84256,<br>-1.83536,<br>-1.82502,<br>-1.82088,<br>-1.82251,<br>-1.80934] | [-0.661007,<br>-0.672837,<br>-0.656478,<br>-0.658991,<br>-0.65884,<br>-0.659275,<br>-0.655378,<br>-0.658712,<br>-0.654345,<br>-0.651957<br>…<br>-0.577366,<br>-0.578097,<br>-0.565833,<br>-0.580407,<br>-0.577185,<br>-0.581951,<br>-0.598315,<br>-0.612136,<br>-0.617067,<br>-0.631079] | [0.630916,<br>0.629885,<br>0.629919,<br>0.630639,<br>0.629542,<br>0.63015,<br>0.630143,<br>0.630747,<br>0.630963,<br>0.629108<br>…<br>2.06203,<br>2.03448,<br>1.9007,<br>1.64908,<br>1.37607,<br>1.14622,<br>0.918773,<br>0.727559,<br>0.594801,<br>0.538287] | [-2.01777,<br>-2.01644,<br>-2.01636,<br>-2.01498,<br>-2.01403,<br>-2.01435,<br>-2.01093,<br>-2.01459,<br>-2.01451,<br>-2.01158<br>…<br>-0.037665,<br>-0.489951,<br>-0.950234,<br>-1.36542,<br>-1.63791,<br>-1.74946,<br>-1.86018,<br>-1.92242,<br>-1.96731,<br>-1.97118] | [-0.713973,<br>-0.720726,<br>-0.720042,<br>-0.715272,<br>-0.72197,<br>-0.720044,<br>-0.719547,<br>-0.715168,<br>-0.712008,<br>-0.717159<br>…<br>-0.679075,<br>-0.752105,<br>-0.784518,<br>-0.804115,<br>-0.727146,<br>-0.627818,<br>-0.604224,<br>-0.602402,<br>-0.59308,<br>-0.614281] | [-(<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>…<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0<br>-0 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **349** | [-0.616689,<br>-0.614287,<br>-0.616339,<br>-0.611394,<br>-0.615198,<br>-0.652625, | [-1.94958,<br>-1.94994,<br>-1.94992,<br>-1.95348,<br>-1.93972,<br>-2.09082, | [-0.755485,<br>-0.760594,<br>-0.755267,<br>-0.755398,<br>-0.751462,<br>-0.75515, | [0.664354,<br>0.657678,<br>0.663926,<br>0.653829,<br>0.672965,<br>0.729495, | [-2.00496,<br>-2.03505,<br>-2.01516,<br>-2.05454,<br>-2.06293,<br>-2.0968, | [-0.547348,<br>-0.552963,<br>-0.548251,<br>-0.563437,<br>-0.571891,<br>-0.557266, | [-(<br>-0<br>-0<br>-0<br>-0<br>-0 |

Loading [MathJax]/extensions/Safe.js

| Row | X[Hand tip l]<br>Array… | Y[Hand tip l]<br>Array… | Z[Hand tip l]<br>Array… | X[Hand tip r]<br>Array… | Y[Hand tip r]<br>Array… | Z[Hand tip r]<br>Array… | X[<br>Ar |
|---|---|---|---|---|---|---|---|
|  | -0.758759, -0.926013, -1.16653, -1.45786 … -0.634068, -0.638292, -0.638414, -0.633326, -0.629956, -0.624907, -0.628131, -0.623601, -0.621252, -0.619131] | -2.07774, -2.07786, -2.03293, -1.95337 … -2.01936, -2.01745, -2.01658, -2.01221, -2.01132, -2.00823, -1.99968, -1.99785, -1.99715, -1.99688] | -0.740546, -0.726338, -0.712166, -0.657644 … -0.700128, -0.702082, -0.69888, -0.70226, -0.701131, -0.708299, -0.705904, -0.705396, -0.706151, -0.706053] | 0.949406, 1.34799, 1.67983, 1.83766 … 0.595432, 0.637802, 0.679586, 0.636176, 0.597256, 0.593704, 0.595663, 0.594957, 0.59227, 0.590825] | -1.96131, -1.51774, -0.880203, -0.12666 … -2.20064, -1.99626, -1.91715, -1.99687, -2.19972, -2.19755, -2.19723, -2.19504, -2.19353, -2.19285] | -0.713681, -0.837412, -0.903952, -0.789053 … -0.568336, -0.569397, -0.532565, -0.553386, -0.551853, -0.553435, -0.551775, -0.55471, -0.553742, -0.553014] | -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **350** | [-0.596139, -0.596019, -0.594476, -0.591199, -0.59016, -0.587625, -0.589226, -0.59427, -0.614432, -0.712729 … -0.575696, -0.57971, -0.582036, -0.585876, -0.576416, -0.57689, -0.578217, -0.57949, -0.578794, -0.575571] | [-1.67946, -1.68074, -1.67967, -1.68043, -1.68028, -1.67404, -1.68079, -1.67452, -1.66515, -1.63637 … -1.6783, -1.66726, -1.66698, -1.66767, -1.6741, -1.67276, -1.67021, -1.66882, -1.66735, -1.66801] | [-0.41818, -0.410148, -0.404465, -0.404289, -0.397016, -0.404511, -0.393309, -0.403948, -0.41825, -0.471417 … -0.358823, -0.375101, -0.372223, -0.371538, -0.370928, -0.37131, -0.378007, -0.373494, -0.373474, -0.379876] | [0.496632, 0.49866, 0.496747, 0.50127, 0.493619, 0.49165, 0.497987, 0.49167, 0.516722, 0.582021 … 0.430446, 0.429438, 0.434283, 0.434753, 0.433317, 0.432706, 0.429335, 0.431152, 0.432418, 0.429916] | [-1.6367, -1.63157, -1.63873, -1.63019, -1.63165, -1.63523, -1.62979, -1.63167, -1.59549, -1.48439 … -1.70408, -1.7138, -1.70738, -1.70491, -1.69697, -1.70152, -1.71372, -1.70201, -1.70447, -1.70052] | [-0.739211, -0.742347, -0.733166, -0.738768, -0.734405, -0.734872, -0.736452, -0.734485, -0.784128, -0.965686 … -0.707477, -0.698281, -0.703048, -0.703093, -0.706035, -0.702741, -0.694049, -0.696337, -0.688899, -0.695393] | [- -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **351** | [-0.937442, -1.02995, -0.985338, -0.828794, -0.719483, -0.764852, -0.790658, -0.906044, -1.06143, -1.24269 … -1.11567, -0.915111, -0.690979, -0.683455, -0.758403, -0.722961, -0.661048, -0.674346, -0.687475, -0.68439] | [-2.10495, -1.96835, -1.95082, -2.09426, -2.13928, -2.08863, -2.23229, -2.28766, -2.27454, -2.06905 … -1.9192, -1.99392, -1.94095, -2.02532, -2.04187, -2.00124, -1.94335, -1.91709, -1.91269, -1.90738] | [-0.445069, -0.419463, -0.494451, -0.546546, -0.592364, -0.584375, -0.554674, -0.464802, -0.479882, -0.533597 … -0.758341, -0.621436, -0.620878, -0.632757, -0.6223, -0.690714, -0.73709, -0.740402, -0.738781, -0.740575] | [0.593855, 0.611397, 0.602737, 0.584278, 0.563043, 0.581611, 0.588664, 0.595967, 0.858367, 1.31364 … 0.827272, 0.658031, 0.608874, 0.625905, 0.608621, 0.608801, 0.613776, 0.596233, 0.588538, 0.590146] | [-2.01059, -2.01198, -2.019, -2.02334, -2.07292, -2.11766, -2.14359, -2.12517, -2.2062, -2.03789 … -2.15671, -1.94299, -1.94304, -1.95421, -1.96479, -1.95365, -1.95082, -1.93788, -1.94164, -1.88977] | [-0.460162, -0.438999, -0.433038, -0.449091, -0.514482, -0.526686, -0.511987, -0.479525, -0.090289, 0.001343 … -0.13886, -0.521114, -0.532044, -0.553127, -0.572179, -0.632077, -0.637166, -0.669985, -0.66622, -0.659614] | [- -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X[ |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | A |
| 352 | [-0.595625, -0.593605, -0.588495, -0.584801, -0.59971, -0.595148, -0.59403, -0.591524, -0.591834, -0.591661 … -0.631753, -0.613123, -0.604525, -0.578524, -0.539126, -0.486437, -0.4675, -0.453359, -0.445844, -0.454189] | [-1.93897, -1.93641, -1.93761, -1.91826, -1.97002, -1.97009, -1.966, -1.94677, -1.94209, -1.93865 … -2.05116, -2.02755, -1.97911, -1.93749, -1.94224, -1.95526, -1.95181, -1.94552, -1.94973, -1.96401] | [-0.683665, -0.694508, -0.682787, -0.701766, -0.747765, -0.744019, -0.744061, -0.72129, -0.711405, -0.707665 … -0.40507, -0.479012, -0.569021, -0.649807, -0.70869, -0.75495, -0.780949, -0.791049, -0.774547, -0.751589] | [0.676463, 0.682937, 0.682541, 0.685074, 0.686095, 0.681547, 0.680452, 0.681045, 0.684939, 0.676113 … 0.660947, 0.637387, 0.590117, 0.57134, 0.574835, 0.595796, 0.619714, 0.625665, 0.638661, 0.6339] | [-1.8211, -1.82324, -1.82337, -1.82025, -1.87301, -1.86164, -1.8572, -1.83805, -1.83235, -1.82618 … -1.90219, -1.88858, -1.87824, -1.87888, -1.88442, -1.89448, -1.90057, -1.90804, -1.90383, -1.91231] | [-0.693638, -0.693881, -0.685873, -0.687236, -0.726534, -0.726996, -0.728512, -0.706081, -0.696437, -0.698008 … -0.650799, -0.709445, -0.729737, -0.740974, -0.743894, -0.735067, -0.731009, -0.713037, -0.708452, -0.695166] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| 353 | [-0.466582, -0.469372, -0.43454, -0.432809, -0.480658, -0.500828, -0.532364, -0.552448, -0.453876, -0.439888 … -0.715931, -0.734048, -0.696927, -0.643663, -0.575416, -0.492768, -0.422277, -0.389059, -0.394768, -0.411497] | [-1.71874, -1.72861, -1.58691, -1.58583, -1.70418, -1.64664, -1.61578, -1.6056, -1.52025, -1.30873 … -1.81162, -1.98329, -1.972, -1.93991, -1.8876, -1.85807, -1.83981, -1.81063, -1.75395, -1.65299] | [-1.03662, -1.03794, -0.949864, -0.954459, -1.04864, -1.078, -1.1047, -1.15505, -1.40861, -1.56395 … -0.820564, -0.976599, -1.03893, -1.08675, -1.09675, -1.09772, -1.07486, -1.03899, -1.04458, -1.0622] | [0.59468, 0.594129, 0.593619, 0.602656, 0.641599, 0.735446, 0.882214, 1.15693, 1.48269, 1.78098 … 0.40946, 0.618935, 0.637069, 0.640586, 0.635214, 0.636883, 0.636803, 0.632184, 0.609569, 0.601727] | [-1.84908, -1.84819, -1.85054, -1.85237, -1.85198, -1.90322, -1.86753, -1.73999, -1.51691, -1.05561 … -1.63182, -1.88926, -1.90622, -1.89375, -1.86071, -1.83122, -1.80992, -1.7971, -1.7638, -1.75888] | [-0.365797, -0.368545, -0.357051, -0.344981, -0.34665, -0.378178, -0.396243, -0.545071, -0.604943, -0.635584 … -0.569574, -0.114756, -0.139989, -0.165661, -0.214669, -0.267517, -0.306533, -0.329637, -0.362193, -0.385993] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| 354 | [-0.500404, -0.502824, -0.504771, -0.505733, -0.505021, -0.510656, -0.477738, -0.455724, -0.450382, -0.43636 … -0.62565, -0.617651, -0.588326, -0.552376, [illegible]29874, | [-1.89209, -1.88986, -1.89188, -1.88755, -1.88602, -1.92025, -1.89595, -1.88366, -1.85715, -1.8259 … -1.95207, -1.95965, -1.95948, -1.98069, -1.98885, | [-0.667846, -0.671957, -0.666312, -0.67298, -0.671848, -0.673591, -0.705428, -0.734485, -0.761981, -0.783711 … -0.707524, -0.715147, -0.718432, -0.710816, | [0.604001, 0.608896, 0.619072, 0.620853, 0.622834, 0.630271, 0.618775, 0.598823, 0.585954, 0.59969 … 0.562149, 0.525271, 0.513633, 0.528847, 0.554589, | [-1.73447, -1.74005, -1.74104, -1.73596, -1.73738, -1.7684, -1.76486, -1.75967, -1.71397, -1.62112 … -1.75231, -1.76314, -1.76987, -1.79338, | [-0.852622, -0.847307, -0.850225, -0.849992, -0.843751, -0.848163, -0.854097, -0.872344, -0.9205, -0.982214 … -0.955112, -0.961629, -0.94402, -0.937481, | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 |

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X[ |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | Ar |
| | -0.553498, -0.572458, -0.588936, -0.604985, -0.611643] | -1.97063, -1.99709, -2.00647, -2.00631, -2.00625] | -0.693616, -0.713655, -0.704543, -0.704291, -0.710759, -0.712378] | 0.577905, 0.581103, 0.576899, 0.575532, 0.577343] | -1.80963, -1.81876, -1.82579, -1.82698, -1.80892, -1.808] | -0.934921, -0.935206, -0.925465, -0.917304, -0.927874, -0.930375] | -0 -0 -0 -0 -0 -0 |
| **355** | [-0.686893, -0.690966, -0.710514, -0.771405, -0.865657, -1.10153, -1.28476, -1.3701, -1.17664, -0.759236 … -0.590119, -0.586947, -0.58872, -0.586027, -0.586456, -0.587513, -0.590223, -0.588903, -0.591829, -0.591138] | [-2.04375, -2.05011, -2.07035, -2.08768, -2.11075, -2.08723, -2.01236, -1.89968, -1.62723, -1.3901 … -2.01395, -2.0175, -2.01779, -2.00809, -2.00814, -2.00896, -2.01059, -2.01857, -2.0202, -2.01936] | [-0.763731, -0.739648, -0.709582, -0.698519, -0.695876, -0.734551, -0.780351, -0.911202, -1.30088, -1.56614 … -0.750251, -0.749495, -0.755412, -0.75954, -0.761369, -0.763274, -0.76296, -0.76822, -0.767053, -0.773619] | [0.619419, 0.641105, 0.677359, 0.750174, 0.969919, 1.55344, 1.8599, 2.083, 1.98471, 1.68652 … 0.736513, 0.739569, 0.743421, 0.743809, 0.735055, 0.766925, 0.749379, 0.748856, 0.740557, 0.744968] | [-2.08314, -2.08161, -2.08674, -2.08547, -2.02839, -1.70898, -1.29341, -0.711759, 0.182653, 0.622182 … -1.97317, -1.97663, -1.97623, -1.97845, -2.14337, -2.07043, -1.98182, -1.9928, -2.13751, -2.12822] | [-0.63965, -0.621357, -0.591876, -0.534126, -0.468331, -0.174424, -0.017619, 0.10863, 0.149411, 0.097924 … -0.510329, -0.509272, -0.517616, -0.512647, -0.534151, -0.5225, -0.516237, -0.519779, -0.529337, -0.530785] | [-( -0 -0 -0 -0 -0 -0 -0 -1 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **356** | [-0.525938, -0.516073, -0.5177, -0.516002, -0.517101, -0.531324, -0.598619, -0.632816, -0.641388, -0.624213 … -0.506511, -0.53477, -0.536864, -0.537779, -0.545924, -0.540783, -0.544388, -0.550136, -0.546228, -0.545995] | [-1.69259, -1.70519, -1.70824, -1.72114, -1.72487, -1.74597, -1.73602, -1.70956, -1.66064, -1.55737 … -1.7578, -1.67215, -1.66308, -1.6627, -1.64937, -1.66342, -1.66382, -1.66711, -1.67062, -1.66981] | [-0.514372, -0.521267, -0.51823, -0.507091, -0.489786, -0.500235, -0.559973, -0.659927, -0.761855, -0.891289 … -0.536724, -0.524299, -0.517065, -0.522152, -0.517777, -0.526417, -0.521008, -0.531884, -0.52938, -0.531231] | [0.385693, 0.391897, 0.387426, 0.391813, 0.416009, 0.49509, 0.833951, 1.08184, 1.34254, 1.6102 … 0.473226, 0.439757, 0.435853, 0.444632, 0.418755, 0.410171, 0.416042, 0.413618, 0.409138, 0.410571] | [-1.71975, -1.72145, -1.72375, -1.72402, -1.73314, -1.73277, -1.60902, -1.50969, -1.29886, -0.787043 … -1.7279, -1.71693, -1.71674, -1.7201, -1.72104, -1.72351, -1.74602, -1.75108, -1.74972, -1.74926] | [-0.715464, -0.711937, -0.712161, -0.714993, -0.70302, -0.716358, -0.748026, -0.79191, -0.858587, -0.998692 … -0.702175, -0.710662, -0.711929, -0.700321, -0.716329, -0.719247, -0.716009, -0.72007, -0.723947, -0.720406] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **357** | [-0.440887, -0.452221, -0.447185, -0.451468, -0.451852, -0.460196, -0.454885, -0.456595, | [-1.90444, -1.91917, -1.91652, -1.92718, -1.92486, -1.93992, -1.93326, -1.931, | [-1.07556, -1.08468, -1.08069, -1.08455, -1.08098, -1.08955, -1.08634, -1.08236, | [0.601969, 0.607711, 0.600509, 0.620354, 0.619002, 0.601562, 0.59883, 0.585152, | [-2.15266, -2.17978, -2.19577, -2.043, -2.03998, -2.21929, -2.21141, -2.21772, | [-0.432073, -0.435872, -0.42879, -0.406766, -0.410107, -0.432601, -0.431501, -0.438689, | [-( -0 -0 -0 -0 -0 -0 -0 |

| Row | X[Hand tip l]<br>Array… | Y[Hand tip l]<br>Array… | Z[Hand tip l]<br>Array… | X[Hand tip r]<br>Array… | Y[Hand tip r]<br>Array… | Z[Hand tip r]<br>Array… | X[<br>Ar |
|---|---|---|---|---|---|---|---|
|  | -0.453205, -0.469354 … 0.181187, -0.131194, -0.541423, -0.777776, -0.953652, -1.04438, -0.984894, -0.891926, -0.788926, -0.698249] | -1.89117, -1.90504 … -1.18755, -1.39716, -1.36595, -1.59362, -1.67972, -1.74415, -1.83087, -1.86974, -1.92518, -1.86742] | -1.07372, -1.08595 … -1.38186, -1.4358, -1.35391, -1.36938, -1.34895, -1.24551, -1.14865, -1.07423, -1.03839, -1.01313] | 0.58419, 0.583967 … 1.82576, 2.01202, 1.99811, 2.14004, 1.9395, 1.61937, 1.20757, 0.874289, 0.691181, 0.562766] | -2.21474, -2.23002 … 0.350891, 0.023507, -0.423043, -0.812878, -1.24957, -1.70558, -2.05941, -2.229, -2.24742, -2.19937] | -0.431665, -0.434617 … -0.097338, -0.017904, 0.118915, 0.111467, 0.145836, 0.084069, 0.021073, -0.070298, -0.066992, -0.291861] | -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **358** | [-0.647672, -0.653511, -0.642305, -0.6383, -0.637352, -0.641916, -0.641393, -0.641784, -0.644001, -0.646141 … -0.224099, -0.500692, -0.682501, -0.758069, -0.765982, -0.72369, -0.645501, -0.624031, -0.62637, -0.628032] | [-1.6173, -1.61051, -1.60491, -1.59955, -1.60063, -1.60052, -1.60037, -1.60233, -1.61603, -1.62083 … -1.3884, -1.479, -1.63708, -1.65932, -1.664, -1.6762, -1.69198, -1.6986, -1.69814, -1.69324] | [-0.505743, -0.499972, -0.497074, -0.500385, -0.494025, -0.496815, -0.49508, -0.503109, -0.513043, -0.515419 … -0.97989, -0.827817, -0.673086, -0.504513, -0.400298, -0.340097, -0.315575, -0.317331, -0.321467, -0.327659] | [0.500621, 0.496023, 0.498986, 0.498838, 0.504341, 0.500749, 0.503862, 0.504645, 0.505147, 0.504536 … 0.293131, 0.443811, 0.581705, 0.631393, 0.575838, 0.527186, 0.534738, 0.529456, 0.518023, 0.517005] | [-1.61356, -1.61504, -1.61717, -1.61682, -1.61745, -1.61724, -1.6164, -1.6166, -1.61653, -1.61602 … -0.727617, -1.1854, -1.55158, -1.64122, -1.65639, -1.67336, -1.67886, -1.68227, -1.6856, -1.68569] | [-0.682743, -0.680679, -0.674725, -0.676847, -0.673253, -0.674156, -0.676122, -0.674299, -0.673238, -0.675257 … -1.2196, -1.11147, -0.889893, -0.700757, -0.638817, -0.619261, -0.614219, -0.615918, -0.62318, -0.623297] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |
| **359** | [-0.476117, -0.4705, -0.474443, -0.475678, -0.475745, -0.476801, -0.466286, -0.470162, -0.466426, -0.456026 … -0.310213, -0.498413, -0.660566, -0.792202, -0.859166, -0.837351, -0.769369, -0.684986, -0.545003, -0.53447] | [-1.70846, -1.7099, -1.70912, -1.70614, -1.70891, -1.70891, -1.70919, -1.70437, -1.71174, -1.71172 … -1.01014, -1.24986, -1.4634, -1.57394, -1.71292, -1.80086, -1.85209, -1.84221, -1.8798, -1.78985] | [-0.5028, -0.509458, -0.508224, -0.509525, -0.508446, -0.505009, -0.504267, -0.49798, -0.500755, -0.489398 … -1.27009, -1.1431, -1.00582, -0.793894, -0.569638, -0.399036, -0.319151, -0.279739, -0.295245, -0.332945] | [0.379579, 0.380022, 0.381541, 0.37959, 0.387175, 0.383584, 0.39284, 0.397443, 0.395351, 0.395874 … 0.733999, 0.871185, 0.973005, 0.972278, 0.867967, 0.770433, 0.654358, 0.552439, 0.431852, 0.378889] | [-1.62798, -1.63086, -1.63214, -1.63089, -1.62406, -1.63349, -1.62449, -1.60594, -1.59181, -1.58358 … 0.25072, -0.203643, -0.645084, -1.02025, -1.43843, -1.60047, -1.74759, -1.79286, -1.89259, -1.82064] | [-0.840636, -0.834709, -0.83162, -0.833223, -0.83019, -0.823642, -0.817607, -0.812333, -0.80052, -0.792545 … -1.65719, -1.75717, -1.73933, -1.55679, -1.24865, -1.06737, -0.932671, -0.84789, -0.79027, -0.771634] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |

| Row | X[Hand tip l] | Y[Hand tip l] | Z[Hand tip l] | X[Hand tip r] | Y[Hand tip r] | Z[Hand tip r] | X\| |
|---|---|---|---|---|---|---|---|
| | Array… | Array… | Array… | Array… | Array… | Array… | A\| |
| **360** | [-0.553245, -0.551704, -0.548044, -0.544929, -0.546446, -0.546651, -0.554797, -0.580788, -0.634431, -0.679319 … -0.605506, -0.606554, -0.662612, -0.709257, -0.727722, -0.721847, -0.687693, -0.655425, -0.627145, -0.613324] | [-1.69493, -1.69349, -1.69951, -1.7085, -1.71117, -1.71164, -1.70638, -1.68895, -1.66512, -1.63018 … -1.76228, -1.75493, -1.74816, -1.73299, -1.72764, -1.72671, -1.725, -1.72086, -1.71081, -1.70149] | [-0.756008, -0.762863, -0.760376, -0.756736, -0.756973, -0.758584, -0.766189, -0.790081, -0.83163, -0.879984 … -0.568478, -0.590416, -0.601258, -0.618041, -0.641417, -0.648827, -0.660898, -0.674366, -0.687214, -0.689185] | [0.569726, 0.570003, 0.573506, 0.572164, 0.621714, 0.696098, 0.876118, 1.12203, 1.47091, 1.64837 … 0.503982, 0.51867, 0.550847, 0.56638, 0.586101, 0.585824, 0.581762, 0.575169, 0.572896, 0.568447] | [-1.8093, -1.80937, -1.80944, -1.80935, -1.8126, -1.85915, -1.8061, -1.67266, -1.36509, -1.061 … -1.84879, -1.81557, -1.82067, -1.82043, -1.8186, -1.8199, -1.81979, -1.8188, -1.81805, -1.81838] | [-0.448892, -0.45103, -0.445198, -0.449493, -0.440023, -0.397585, -0.392426, -0.419542, -0.481797, -0.566341 … -0.39616, -0.374028, -0.372259, -0.369527, -0.37349, -0.374199, -0.375562, -0.382328, -0.383967, -0.382463] | [-( -0 -0 -0 -0 -0 -0 -0 -0 -0 … -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 |

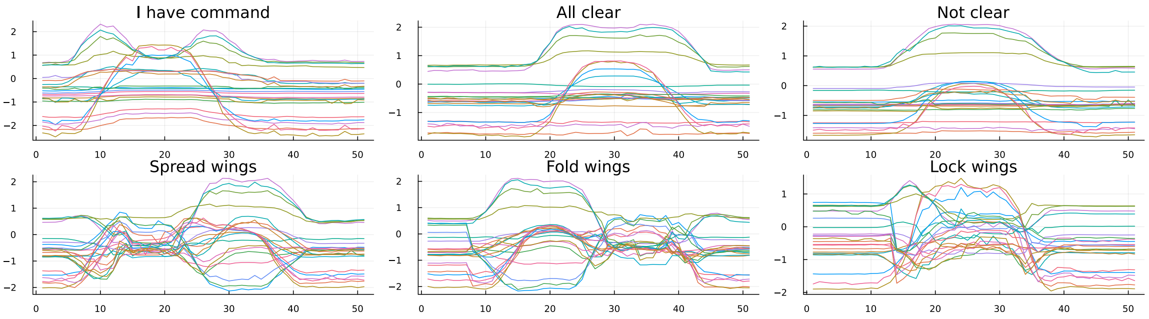
In [6]:
```
names(X)
```

Out[6]:
```
24-element Vector{String}:
 "X[Hand tip l]"
 "Y[Hand tip l]"
 "Z[Hand tip l]"
 "X[Hand tip r]"
 "Y[Hand tip r]"
 "Z[Hand tip r]"
 "X[Elbow l]"
 "Y[Elbow l]"
 "Z[Elbow l]"
 "X[Elbow r]"
 "Y[Elbow r]"
 "Z[Elbow r]"
 "X[Wrist l]"
 "Y[Wrist l]"
 "Z[Wrist l]"
 "X[Wrist r]"
 "Y[Wrist r]"
 "Z[Wrist r]"
 "X[Thumb l]"
 "Y[Thumb l]"
 "Z[Thumb l]"
 "X[Thumb r]"
 "Y[Thumb r]"
 "Z[Thumb r]"
```

In [7]:
```
# Let's inspect an instance for each class.
plot(map(i->plot(collect(X[i,:]), labels=nothing,title=y[i]), 1:30:180)...,
```

Loading [MathJax]/extensions/Safe.js

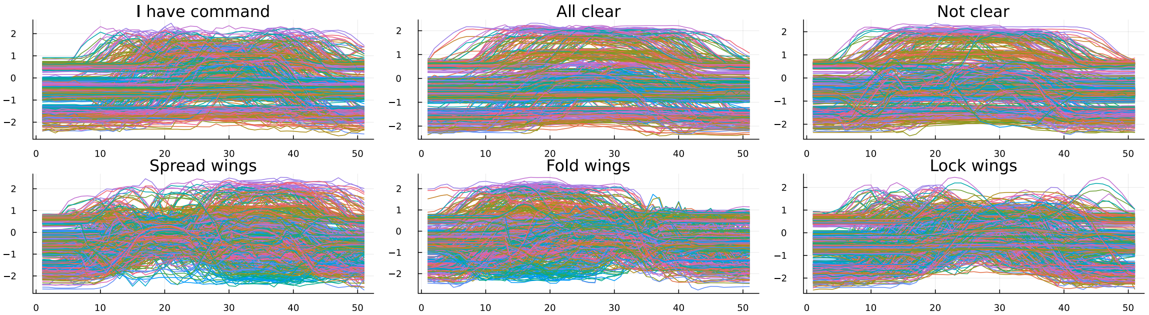
Out[7]:



In [8]:

```
# All instances, grouped by class
plot(map(i->plot(collect.(eachrow(X[i:(i+30),:])), labels=nothing,title=y[i]
```

Out[8]:



In [9]:

```
# Randomly split the data: 20% training, 80% testing
N = nrow(X)
perm = randperm(Random.MersenneTwister(1), N)
train_idxs, test_idxs = perm[1:round(Int, N*.2)], perm[round(Int, N*.2)+1:en
println("Using $(length(train_idxs)) instances for training")
println("Using $(length(test_idxs)) instances for testing")
```

```
Using 72 instances for training
Using 288 instances for testing
```

In [10]:

```
DecisionTreeClassifier = @load DecisionTreeClassifier pkg=DecisionTree verbo

# Instantiate the tree learning algorithm
model = DecisionTreeClassifier(;)
```

Out[10]:

```
DecisionTreeClassifier(
  max_depth = -1,
  min_samples_leaf = 1,
  min_samples_split = 2,
  min_purity_increase = 0.0,
  n_subfeatures = 0,
  post_prune = false,
  merge_purity_threshold = 1.0,
  display_depth = 5,
  feature_importance = :impurity,
  rng = Random._GLOBAL_RNG())
```

In [11]:

```
# Bind data to learning algorithm
dt_mach = machine(model, X, y)

# Train!
@time fit!(dt_mach; rows=train_idxs)
```

Loading [MathJax]/extensions/Safe.js

```
┌ Warning: The number and/or types of data arguments do not match what the s
pecified model
│ supports. Suppress this type check by specifying `scitype_check_level=0`.
│ 
│ Run `@doc DecisionTree.DecisionTreeClassifier` to learn more about your mo
del's requirements.
│ 
│ Commonly, but non exclusively, supervised models are constructed using the
syntax
│ `machine(model, X, y)` or `machine(model, X, y, w)` while most other model
s are
│ constructed with `machine(model, X)`.  Here `X` are features, `y` a targe
t, and `w`
│ sample or class weights.
│ 
│ In general, data in `machine(model, data...)` is expected to satisfy
│ 
│     scitype(data) <: MLJ.fit_data_scitype(model)
│ 
│ In the present case:
│ 
│ scitype(data) = Tuple{Table{AbstractVector{AbstractVector{Continuous}}}, A
bstractVector{Multiclass{6}}}
│ 
│ fit_data_scitype(model) = Tuple{Table{<:Union{AbstractVector{<:Continuou
s}, AbstractVector{<:Count}, AbstractVector{<:OrderedFactor}}}, AbstractVect
or{<:Finite}}
└ @ MLJBase ~/.julia/packages/MLJBase/ByFwA/src/machines.jl:230
[ Info: Training machine(DecisionTreeClassifier(max_depth = -1, …), …).
  4.591025 seconds (7.37 M allocations: 459.327 MiB, 4.78% gc time, 99.61% c
ompilation time)
```

Out[11]:

```
trained Machine; caches model-specific representations of data
  model: DecisionTreeClassifier(max_depth = -1, …)
  args:
    1:  Source @571 ⏎ Table{AbstractVector{AbstractVector{Continuous}}}
    2:  Source @244 ⏎ AbstractVector{Multiclass{6}}
```

In [12]:

```julia
X_static = Matrix(X)
cols = []
for i_var in 1:size(X_static, 2)
    var_unroll = hcat(X_static[:,i_var]...)
    append!(cols, eachrow(var_unroll))
end
X_static = DataFrame(cols, ["$n[$i]" for n in names(X) for i in 1:51])
```

Loading [MathJax]/extensions/Safe.js

Out[12]: 360×1224 DataFrame *1124 columns and 335 rows omitted*

| Row | X[Hand tip l][1] | X[Hand tip l][2] | X[Hand tip l][3] | X[Hand tip l][4] | X[Hand tip l][5] | X[Hand tip l][6] | X[Hanc tip l][7 |
|---|---|---|---|---|---|---|---|
| | Float64 | Float64 | Float64 | Float64 | Float64 | Float64 | Float6 |
| 1 | -0.519771 | -0.52758 | -0.531415 | -0.517159 | -0.510312 | -0.518154 | -0.503 |
| 2 | -0.489753 | -0.48607 | -0.484529 | -0.492771 | -0.492031 | -0.493076 | -0.4919 |
| 3 | -0.521346 | -0.518394 | -0.522321 | -0.519893 | -0.521016 | -0.521524 | -0.5233 |
| 4 | -0.57022 | -0.562064 | -0.565967 | -0.562913 | -0.567557 | -0.566175 | -0.5667 |
| 5 | -0.624417 | -0.626031 | -0.625388 | -0.62798 | -0.624838 | -0.623534 | -0.6266 |
| 6 | -0.502501 | -0.502525 | -0.499415 | -0.501144 | -0.502677 | -0.501937 | -0.5006 |
| 7 | -0.488461 | -0.489463 | -0.487539 | -0.495673 | -0.498767 | -0.492156 | -0.4928 |
| 8 | -0.468105 | -0.410602 | -0.473909 | -0.475146 | -0.465564 | -0.459415 | -0.4087 |
| 9 | -0.568195 | -0.572936 | -0.571337 | -0.577742 | -0.562071 | -0.563401 | -0.564 |
| 10 | -0.517579 | -0.515374 | -0.517325 | -0.516505 | -0.514786 | -0.513077 | -0.5187 |
| 11 | -0.631494 | -0.629032 | -0.630474 | -0.628314 | -0.625873 | -0.620084 | -0.6227 |
| 12 | -0.628575 | -0.621757 | -0.631781 | -0.634901 | -0.628957 | -0.637745 | -0.6358 |
| 13 | -0.635968 | -0.613303 | -0.636138 | -0.635273 | -0.636906 | -0.633466 | -0.6333 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | |
| 349 | -0.616689 | -0.614287 | -0.616339 | -0.611394 | -0.615198 | -0.652625 | -0.7587 |
| 350 | -0.596139 | -0.596019 | -0.594476 | -0.591199 | -0.59016 | -0.587625 | -0.5892 |
| 351 | -0.937442 | -1.02995 | -0.985338 | -0.828794 | -0.719483 | -0.764852 | -0.7906 |
| 352 | -0.595625 | -0.593605 | -0.588495 | -0.584801 | -0.59971 | -0.595148 | -0.594 |
| 353 | -0.466582 | -0.469372 | -0.43454 | -0.432809 | -0.480658 | -0.500828 | -0.5323 |
| 354 | -0.500404 | -0.502824 | -0.504771 | -0.505733 | -0.505021 | -0.510656 | -0.4777 |
| 355 | -0.686893 | -0.690966 | -0.710514 | -0.771405 | -0.865657 | -1.10153 | -1.284 |
| 356 | -0.525938 | -0.516073 | -0.5177 | -0.516002 | -0.517101 | -0.531324 | -0.5986 |
| 357 | -0.440887 | -0.452221 | -0.447185 | -0.451468 | -0.451852 | -0.460196 | -0.4548 |
| 358 | -0.647672 | -0.653511 | -0.642305 | -0.6383 | -0.637352 | -0.641916 | -0.6413 |
| 359 | -0.476117 | -0.4705 | -0.474443 | -0.475678 | -0.475745 | -0.476801 | -0.4662 |
| 360 | -0.553245 | -0.551704 | -0.548044 | -0.544929 | -0.546446 | -0.546651 | -0.5547 |

In [13]:

```
# Bind data to learning algorithm
dt_mach_static = machine(model, X_static, y)

# Train!
@time fit!(dt_mach_static; rows=train_idxs);
```

Loading [MathJax]/extensions/Safe.js

```
report(dt_mach_static).print_tree()

# Compute accuracy
yhat = predict_mode(dt_mach_static; rows=test_idxs)
acc = MLJ.accuracy(yhat, y[test_idxs])
println("Accuracy: $(acc)")
```

```
[ Info: Training machine(DecisionTreeClassifier(max_depth = -1, …), …).
  1.099162 seconds (1.21 M allocations: 93.505 MiB, 7.58% gc time, 95.68% co
mpilation time)
Feature 994 < -1.235 ?
├─ Feature 790 < 1.396 ?
    ├─ 3 : 12/12
    └─ Feature 499 < 1.055 ?
        ├─ Feature 1005 < -1.419 ?
            ├─ 1 : 16/16
            └─ 5 : 4/4
        └─ Feature 23 < -0.399 ?
            ├─ 5 : 5/5
            └─ 3 : 1/1
└─ Feature 380 < -0.02374 ?
    ├─ Feature 296 < -0.4259 ?
        ├─ 4 : 13/13
        └─ Feature 522 < -0.4685 ?
            ├─ 6 : 7/7
            └─ 4 : 1/1
    └─ Feature 526 < -0.0592 ?
        ├─ 2 : 12/12
        └─ 6 : 1/1
Accuracy: 0.5590277777777778
```

In [14]:
```
println(names(X_static)[686])
println(names(X_static)[790])
```

```
Y[Wrist l][23]
X[Wrist r][25]
```

In [15]:
```
feature_importances(dt_mach_static)
```

```
Out[15]: 1224-element Vector{Pair{Symbol, Float64}}:
             Symbol("Y[Thumb l][25]") => 0.39197281914934023
             Symbol("X[Wrist r][25]") => 0.1587983771952398
             Symbol("Y[Elbow l][23]") => 0.15430650160975126
          Symbol("Z[Hand tip r][41]") => 0.08149246071839794
             Symbol("Y[Thumb l][36]") => 0.0787799819908887
             Symbol("X[Elbow r][40]") => 0.061892156492178774
             Symbol("Y[Elbow r][16]") => 0.027751246591978567
             Symbol("Y[Elbow r][12]") => 0.02372646104198667
          Symbol("X[Hand tip l][23]") => 0.021279995210238066
           Symbol("X[Hand tip l][1]") => 0.0
           Symbol("X[Hand tip l][2]") => 0.0
           Symbol("X[Hand tip l][3]") => 0.0
           Symbol("X[Hand tip l][4]") => 0.0
                                       ⋮
             Symbol("Z[Thumb r][40]") => 0.0
             Symbol("Z[Thumb r][41]") => 0.0
             Symbol("Z[Thumb r][42]") => 0.0
             Symbol("Z[Thumb r][43]") => 0.0
             Symbol("Z[Thumb r][44]") => 0.0
             Symbol("Z[Thumb r][45]") => 0.0
             Symbol("Z[Thumb r][46]") => 0.0
             Symbol("Z[Thumb r][47]") => 0.0
             Symbol("Z[Thumb r][48]") => 0.0
             Symbol("Z[Thumb r][49]") => 0.0
             Symbol("Z[Thumb r][50]") => 0.0
             Symbol("Z[Thumb r][51]") => 0.0
```

```
In [16]: X_mean = DataFrame(mean.(Matrix(X)), ["mean($n)" for n in names(X)])
```

Loading [MathJax]/extensions/Safe.js

Out[16]: 360×24 DataFrame *335 rows omitted*

| Row | mean(X[Hand tip l])<br>Float64 | mean(Y[Hand tip l])<br>Float64 | mean(Z[Hand tip l])<br>Float64 | mean(X[Hand tip r])<br>Float64 | mean(Y[Ha tip r])<br>Float64 |
|---|---|---|---|---|---|
| **1** | -0.441529 | -1.99325 | -0.974478 | 1.17753 | -1.13 |
| **2** | -0.433127 | -1.55045 | -0.954742 | 0.927408 | -0.379 |
| **3** | -0.514139 | -1.76206 | -0.624403 | 0.702343 | -0.627 |
| **4** | -0.54604 | -1.86853 | -0.725127 | 1.08656 | -0.584 |
| **5** | -0.608619 | -1.7987 | -0.827025 | 1.00417 | -0.43 |
| **6** | -0.452965 | -1.9987 | -1.01116 | 1.07126 | -1.06 |
| **7** | -0.475165 | -2.09609 | -0.941348 | 1.23749 | -0.965 |
| **8** | -0.402244 | -1.79774 | -0.706467 | 1.21315 | -0.449 |
| **9** | -0.581116 | -1.75254 | -0.618155 | 1.03402 | -0.639 |
| **10** | -0.483915 | -1.74924 | -0.720024 | 1.33397 | -0.624 |
| **11** | -0.611767 | -1.9223 | -0.736676 | 0.991164 | -0.24 |
| **12** | -0.595399 | -1.63924 | -0.862169 | 1.19874 | -0.368 |
| **13** | -0.647034 | -1.87037 | -0.628469 | 1.18445 | -0.731 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | |
| **349** | -0.528628 | -1.47935 | -0.871592 | 0.871904 | -0.614 |
| **350** | -0.391091 | -1.24245 | -0.649191 | 0.429929 | -0.759 |
| **351** | -0.294253 | -1.21454 | -0.883526 | 0.727772 | -0.610 |
| **352** | -0.149389 | -1.0713 | -0.864521 | 0.560025 | -0.542 |
| **353** | -0.423029 | -1.19482 | -1.04728 | 0.938631 | -0.554 |
| **354** | -0.26923 | -1.38106 | -0.871616 | 0.453254 | -0.792 |
| **355** | -0.342298 | -1.4574 | -0.950301 | 1.01039 | -0.930 |
| **356** | -0.134113 | -1.10602 | -0.824465 | 0.750383 | -0.467 |
| **357** | 0.097314 | -1.13352 | -1.00926 | 0.985647 | -0.620 |
| **358** | -0.191882 | -1.13238 | -0.680037 | 0.579504 | -0.473 |
| **359** | -0.323847 | -1.13138 | -0.822845 | 0.649077 | -0.54 |
| **360** | -0.196397 | -1.13002 | -0.815892 | 0.803101 | -0.52 |

In [17]:

```
# Bind data to learning algorithm
dt_mach_mean = machine(model, X_mean, y)

# Train!
@time fit!(dt_mach_mean; rows=train_idxs);
```

Loading [MathJax]/extensions/Safe.js

```
report(dt_mach_mean).print_tree()

# Compute accuracy
yhat = predict_mode(dt_mach_mean; rows=test_idxs)
acc = MLJ.accuracy(yhat, y[test_idxs])
println("Accuracy: $(acc)")
```

```
  0.014304 seconds (11.21 k allocations: 831.303 KiB, 89.37% compilation tim
e)
Feature 20 < -1.249 ?
├─ Feature 23 < -0.7454 ?
    ├─ Feature 14 < -1.301 ?
        ├─ Feature 16 < 1.062 ?
            ├─ Feature 15 < -0.7726 ?
                ├─ 3 : 2/2
                └─
            └─ Feature 3 < -0.6793 ?
                ├─ 1 : 10/10
                └─
        └─ 5 : 4/4
    └─ Feature 1 < -0.3344 ?
        ├─ Feature 19 < -0.753 ?
            ├─ 5 : 1/1
            └─ 3 : 10/10
        └─ 4 : 2/2
└─ Feature 19 < -0.4694 ?
    ├─ Feature 11 < -0.4122 ?
        ├─ Feature 8 < -0.4618 ?
            ├─ Feature 19 < -0.6424 ?
                ├─ 6 : 4/4
                └─ 2 : 1/1
            └─ 2 : 11/11
        └─ Feature 18 < -0.4754 ?
            ├─ 4 : 1/1
            └─ 6 : 4/4
    └─ 4 : 11/11
Accuracy: 0.5729166666666667
```

```
[ Info: Training machine(DecisionTreeClassifier(max_depth = -1, …), …).
```

In [18]:

```
feature_importances(dt_mach_mean)
```

Loading [MathJax]/extensions/Safe.js

```
Out[18]: 24-element Vector{Pair{Symbol, Float64}}:
             Symbol("mean(Y[Thumb l])") => 0.34414598502954147
             Symbol("mean(X[Thumb l])") => 0.18106955171786127
             Symbol("mean(Y[Thumb r])") => 0.11855588688427983
          Symbol("mean(Z[Hand tip l])") => 0.0750540336604416
             Symbol("mean(Y[Elbow l])") => 0.051129205956262525
             Symbol("mean(X[Wrist r])") => 0.047341464077600454
             Symbol("mean(Y[Elbow r])") => 0.047081868037396314
             Symbol("mean(Y[Wrist l])") => 0.04550508659728294
          Symbol("mean(X[Hand tip l])") => 0.043933318313957734
             Symbol("mean(Z[Wrist r])") => 0.019694995497722176
          Symbol("mean(Y[Hand tip r])") => 0.015031274537197794
             Symbol("mean(Z[Wrist l])") => 0.011457329690455903
          Symbol("mean(Y[Hand tip l])") => 0.0
          Symbol("mean(X[Hand tip r])") => 0.0
          Symbol("mean(Z[Hand tip r])") => 0.0
             Symbol("mean(X[Elbow l])") => 0.0
             Symbol("mean(Z[Elbow l])") => 0.0
             Symbol("mean(X[Elbow r])") => 0.0
             Symbol("mean(Z[Elbow r])") => 0.0
             Symbol("mean(X[Wrist l])") => 0.0
             Symbol("mean(Y[Wrist r])") => 0.0
             Symbol("mean(Z[Thumb l])") => 0.0
             Symbol("mean(X[Thumb r])") => 0.0
             Symbol("mean(Z[Thumb r])") => 0.0
```

```
In [19]: X_features = DataFrame([
             eachcol(mean.(Matrix(X)))...,
             eachcol(maximum.(Matrix(X)))...,
             eachcol(minimum.(Matrix(X)))...,
         ], ["$f($n)" for n in names(X) for f in ["mean", "max", "min"]])
```

Out[19]: 360×72 DataFrame *335 rows omitted*

| Row | mean(X[Hand tip l])<br>Float64 | max(X[Hand tip l])<br>Float64 | min(X[Hand tip l])<br>Float64 | mean(Y[Hand tip l])<br>Float64 | max(Y[Hand tip l])<br>Float64 |
|---|---|---|---|---|---|
| **1** | -0.441529 | -1.99325 | -0.974478 | 1.17753 | -1.13545 |
| **2** | -0.433127 | -1.55045 | -0.954742 | 0.927408 | -0.379828 |
| **3** | -0.514139 | -1.76206 | -0.624403 | 0.702343 | -0.627035 |
| **4** | -0.54604 | -1.86853 | -0.725127 | 1.08656 | -0.584427 |
| **5** | -0.608619 | -1.7987 | -0.827025 | 1.00417 | -0.43575 |
| **6** | -0.452965 | -1.9987 | -1.01116 | 1.07126 | -1.06485 |
| **7** | -0.475165 | -2.09609 | -0.941348 | 1.23749 | -0.965224 |
| **8** | -0.402244 | -1.79774 | -0.706467 | 1.21315 | -0.449356 |
| **9** | -0.581116 | -1.75254 | -0.618155 | 1.03402 | -0.639092 |
| **10** | -0.483915 | -1.74924 | -0.720024 | 1.33397 | -0.624704 |
| **11** | -0.611767 | -1.9223 | -0.736676 | 0.991164 | -0.24062 |
| **12** | -0.595399 | -1.63924 | -0.862169 | 1.19874 | -0.368009 |
| **13** | -0.647034 | -1.87037 | -0.628469 | 1.18445 | -0.731339 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **349** | -0.528628 | -1.47935 | -0.871592 | 0.871904 | -0.614831 |
| **350** | -0.391091 | -1.24245 | -0.649191 | 0.429929 | -0.759488 |
| **351** | -0.294253 | -1.21454 | -0.883526 | 0.727772 | -0.610082 |
| **352** | -0.149389 | -1.0713 | -0.864521 | 0.560025 | -0.542136 |
| **353** | -0.423029 | -1.19482 | -1.04728 | 0.938631 | -0.554863 |
| **354** | -0.26923 | -1.38106 | -0.871616 | 0.453254 | -0.792699 |
| **355** | -0.342298 | -1.4574 | -0.950301 | 1.01039 | -0.930284 |
| **356** | -0.134113 | -1.10602 | -0.824465 | 0.750383 | -0.467471 |
| **357** | 0.097314 | -1.13352 | -1.00926 | 0.985647 | -0.620846 |
| **358** | -0.191882 | -1.13238 | -0.680037 | 0.579504 | -0.473543 |
| **359** | -0.323847 | -1.13138 | -0.822845 | 0.649077 | -0.54487 |
| **360** | -0.196397 | -1.13002 | -0.815892 | 0.803101 | -0.52948 |

In [20]:

```
# Bind data to learning algorithm
dt_mach_features = machine(model, X_features, y)

# Train!
@time fit!(dt_mach_features; rows=train_idxs);
```

```
# report(dt_mach_features).print_tree()

# Compute accuracy
yhat = predict_mode(dt_mach_features; rows=test_idxs)
acc = MLJ.accuracy(yhat, y[test_idxs])
println("Accuracy: $(acc)")
```

```
  0.060928 seconds (151.84 k allocations: 10.592 MiB, 95.50% compilation tim
e)
Accuracy: 0.6076388888888888
[ Info: Training machine(DecisionTreeClassifier(max_depth = -1, …), …).
```

In [21]:

```
feature_importances(dt_mach_features)
```

Out[21]:

```
72-element Vector{Pair{Symbol, Float64}}:
      Symbol("max(Z[Wrist l])") => 0.39197281914934023
     Symbol("mean(Z[Thumb l])") => 0.18132225305149968
      Symbol("max(X[Elbow r])") => 0.1674106890097206
      Symbol("min(Z[Elbow l])") => 0.04649458245137584
     Symbol("mean(Y[Thumb l])") => 0.039423017278086676
      Symbol("min(X[Thumb r])") => 0.02890204377675993
   Symbol("min(X[Hand tip l])") => 0.028357357678726745
      Symbol("max(X[Elbow l])") => 0.027751246591978567
      Symbol("max(X[Wrist l])") => 0.026023637734944746
      Symbol("max(X[Wrist r])") => 0.02471299742179882
   Symbol("min(Y[Hand tip r])") => 0.022598081318570357
      Symbol("min(X[Elbow r])") => 0.015031274537197794
  Symbol("mean(X[Hand tip l])") => 0.0
                                 ⋮
      Symbol("max(Y[Thumb l])") => 0.0
      Symbol("min(Y[Thumb l])") => 0.0
      Symbol("max(Z[Thumb l])") => 0.0
      Symbol("min(Z[Thumb l])") => 0.0
     Symbol("mean(X[Thumb r])") => 0.0
      Symbol("max(X[Thumb r])") => 0.0
     Symbol("mean(Y[Thumb r])") => 0.0
      Symbol("max(Y[Thumb r])") => 0.0
      Symbol("min(Y[Thumb r])") => 0.0
     Symbol("mean(Z[Thumb r])") => 0.0
      Symbol("max(Z[Thumb r])") => 0.0
      Symbol("min(Z[Thumb r])") => 0.0
```

In [22]:

```
using ModalDecisionTrees

# Instantiate the learning algorithm
mdt_model = ModalDecisionTree(; relations = :IA7);
```

In [23]:

```
# Bind data to learning algorithm
mach = machine(mdt_model, X, y)

# Train!
@time fit!(mach; rows=train_idxs)
```

```
[ Info: Precomputing logiset...
[ Info: Training machine(ModalDecisionTree(max_depth = nothing, …), …).
```

```
114.965140 seconds (888.64 M allocations: 46.538 GiB, 11.95% gc time, 44.92%
compilation time)
```

Out[23]:

```
trained Machine; caches model-specific representations of data
  model: ModalDecisionTree(max_depth = nothing, …)
  args:
    1:  Source @660 ⏎ Table{AbstractVector{AbstractVector{Continuous}}}
    2:  Source @460 ⏎ AbstractVector{Multiclass{6}}
```

In [24]:

```
# Compute accuracy
yhat = predict_mode(mach; rows=test_idxs)
MLJ.accuracy(yhat, y[test_idxs])
```

Out[24]:

```
0.7847222222222222
```

In [25]:

```
report(mach).printmodel(true; show_metrics = true)
```

```
▣ ⟨G⟩min[X[Hand tip l]] ≥ 0.428173
├✔ ⟨G⟩(min[X[Hand tip l]] ≥ 0.428173 ∧ ⟨G⟩min[X[Wrist l]] < -1.536833)
│├✔ ⟨G⟩(min[X[Hand tip l]] ≥ 0.428173 ∧ ⟨G⟩(min[X[Wrist l]] < -1.536833 ∧
⟨A̅O̅⟩min[X[Hand tip l]] ≥ 0.428173))
││├✔ Spread wings : (ninstances = 8, confidence = 1.0, coverage = 1.0)
││└✘ Fold wings : (ninstances = 12, confidence = 1.0, coverage = 1.0)
│└✘ Lock wings : (ninstances = 14, confidence = 1.0, coverage = 1.0)
└✘ ⟨G⟩min[Y[Hand tip r]] ≥ 0.847021
 ├✔ I have command : (ninstances = 14, confidence = 0.93, coverage = 1.0)
 └✘ ⟨G⟩min[Z[Hand tip l]] ≥ -0.62357
  ├✔ ⟨G⟩(min[Z[Hand tip l]] ≥ -0.62357 ∧ min[Y[Hand tip r]] < -1.850843)
  │├✔ All clear : (ninstances = 4, confidence = 0.75, coverage = 1.0)
  │└✘ Not clear : (ninstances = 7, confidence = 1.0, coverage = 1.0)
  └✘ All clear : (ninstances = 13, confidence = 0.92, coverage = 1.0)
```

In [26]:

```
# Access model
tree = report(mach).model

# Extract the corresponding ruleset
ruleset = listrules(tree; use_shortforms = true);

# Print ruleset
printmodel.(ruleset; show_metrics = false, threshold_digits = 2, variable_na
▣ ⟨G⟩((min[X[Hand tip l]] ≥ 0.43) ∧ ⟨G⟩((min[X[Wrist l]] < -1.54) ∧ ⟨A̅O̅⟩(min
[X[Hand tip l]] ≥ 0.43)))  ➡  Spread wings

▣ ⟨G⟩((min[X[Hand tip l]] ≥ 0.43) ∧ ⟨G⟩(min[X[Wrist l]] < -1.54)) ∧ [G]((min
[X[Hand tip l]] ≥ 0.43) → ([G]((min[X[Wrist l]] < -1.54) → ([A̅O̅](min[X[Hand
tip l]] < 0.43)))))  ➡  Fold wings

▣ ⟨G⟩(min[X[Hand tip l]] ≥ 0.43) ∧ [G]((min[X[Hand tip l]] ≥ 0.43) → ([G](mi
n[X[Wrist l]] ≥ -1.54)))  ➡  Lock wings

▣ ⟨G⟩(min[Y[Hand tip r]] ≥ 0.85) ∧ [G](min[X[Hand tip l]] < 0.43)  ➡  I have
command

▣ ⟨G⟩((min[Z[Hand tip l]] ≥ -0.62) ∧ (min[Y[Hand tip r]] < -1.85)) ∧ [G](min
[X[Hand tip l]] < 0.43) ∧ [G](min[Y[Hand tip r]] < 0.85)  ➡  All clear

▣ ⟨G⟩(min[Z[Hand tip l]] ≥ -0.62) ∧ [G](min[X[Hand tip l]] < 0.43) ∧ [G](min
[Y[Hand tip r]] < 0.85) ∧ [G]((min[Z[Hand tip l]] ≥ -0.62) → (min[Y[Hand tip
r]] ≥ -1.85))  ➡  Not clear

▣ [G](min[X[Hand tip l]] < 0.43) ∧ [G](min[Y[Hand tip r]] < 0.85) ∧ [G](min
[Z[Hand tip l]] < -0.62)  ➡  All clear
```

In [27]:

```
first_rule = ruleset[1]
first_antd = antecedent(first_rule)

println("First formula, translated:")
println(SoleLogics.experimentals.formula2natlang(first_antd; threshold_digit

println()
println("All formulas, translated:")

for (i_rule, rule) in enumerate(ruleset)
    println()
    println("[$i_rule]")
    antd = antecedent(rule)
    println(SoleLogics.experimentals.formula2natlang(antd; threshold_digits
end
```

```
First formula, translated:
∃ interval where ((min[V1] ≥ 0.43) and (∃ interval where ((min[V13] < -1.54)
and (∃ preceding, partially overlapping interval where (min[V1] ≥ 0.43)))))

All formulas, translated:

[1]
∃ interval where ((min[V1] ≥ 0.43) and (∃ interval where ((min[V13] < -1.54)
and (∃ preceding, partially overlapping interval where (min[V1] ≥ 0.43)))))


[2]
(∃ interval where ((min[V1] ≥ 0.43) and (∃ interval where (min[V13] < -1.5
4)))) and (∀ intervals (whenever min[V1] ≥ 0.43 holds, also ∀ intervals (whe
never min[V13] < -1.54 holds, also ∀ preceding, partially overlapping interv
als (min[V1] < 0.43))))


[3]
(∃ interval where (min[V1] ≥ 0.43)) and (∀ intervals (whenever min[V1] ≥ 0.4
3 holds, also ∀ intervals (min[V13] ≥ -1.54)))


[4]
(∃ interval where (min[V5] ≥ 0.85)) and (∀ intervals (min[V1] < 0.43))


[5]
((∃ interval where ((min[V3] ≥ -0.62) and (min[V5] < -1.85))) and (∀ interva
ls (min[V1] < 0.43))) and (∀ intervals (min[V5] < 0.85))


[6]
(((∃ interval where (min[V3] ≥ -0.62)) and (∀ intervals (min[V1] < 0.43))) a
nd (∀ intervals (min[V5] < 0.85))) and (∀ intervals (whenever min[V3] ≥ -0.6
2 holds, also min[V5] ≥ -1.85))


[7]
((∀ intervals (min[V1] < 0.43)) and (∀ intervals (min[V5] < 0.85))) and (∀ i
ntervals (min[V3] < -0.62))
```

Loading [MathJax]/extensions/Safe.js