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
  [033835bb] JLD2 v0.4.38
⌅ [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 To see why use `status --outdated`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
```

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

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

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

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

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

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	-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, [illegible]	[-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, [illegible]	[-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

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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
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
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,	[-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,	[-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

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

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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
	-0.758759, -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 -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, [illegible]	[-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 -0

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Row	X[Hand tip l] Array…	Y[Hand tip l] Array…	Z[Hand tip l] Array…	X[Hand tip r] Array…	Y[Hand tip r] Array…	Z[Hand tip r] Array…	X[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 -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 -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,	[-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,	[-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 -0

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Row	X[Hand tip l] Array…	Y[Hand tip l] Array…	Z[Hand tip l] Array…	X[Hand tip r] Array…	Y[Hand tip r] Array…	Z[Hand tip r] Array…	X[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 -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

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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
	-0.453205, -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

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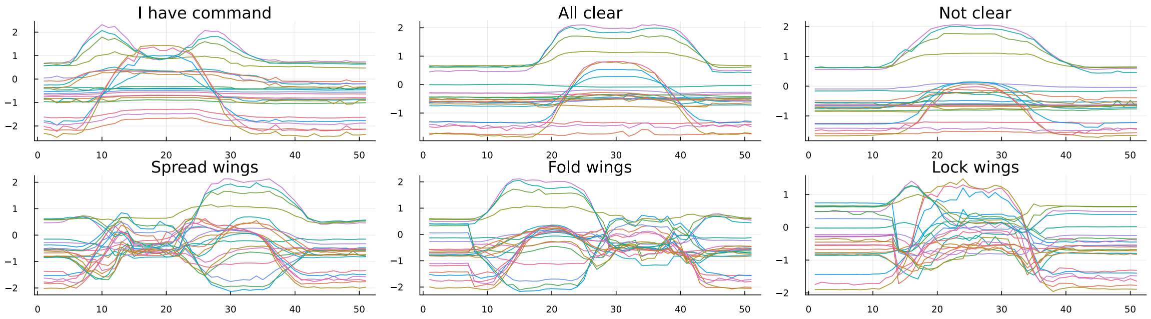
Row	X[Hand tip l] Array…	Y[Hand tip l] Array…	Z[Hand tip l] Array…	X[Hand tip r] Array…	Y[Hand tip r] Array…	Z[Hand tip r] Array…	X[A
360	[-0.553245, -0.551704, -0.548044, -0.544929, -0.546446, -0.546651, -0.554797, -0.580788, -0.634431, -0.679319 … -0.605506, -0.606554, -0.662612, -0.709257, -0.727722, -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 [7]:

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

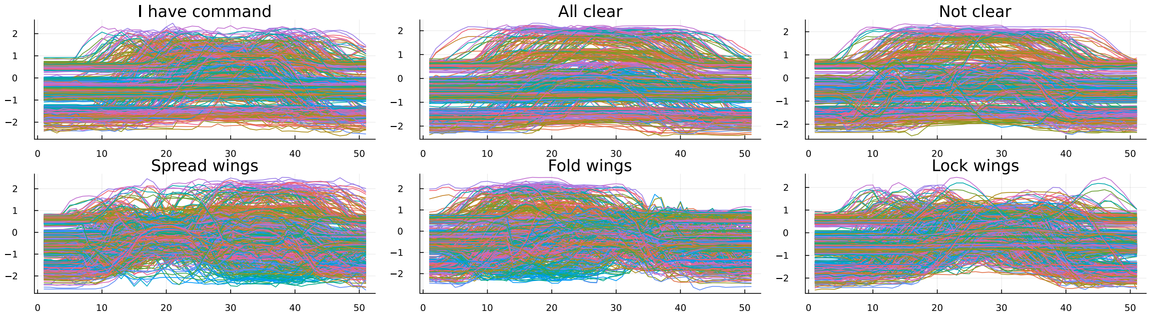
Out[7]:



In [36]:

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

Out[36]:



In [9]:

```
# Randomly split the data: 20% training, 80% testing
N = nrow(X)
perm = randperm(Random.MersenneTwister(1), N)
                                    rm[1:round(Int, N*.2)], perm[round(Int, N*.2)+1:en
```

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```
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 CART decision 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)

# Training fails!
@time fit!(dt_mach; rows=train_idxs)

report(dt_mach).print_tree()
```

```
┌ 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, …), …).
  3.769835 seconds (7.21 M allocations: 448.771 MiB, 4.41% gc time, 99.63% c
ompilation time)
```

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```
MethodError: no method matching round(::Vector{Float64}; sigdigits::Int64)

Closest candidates are:
  round(::Union{Float16, Float32, Float64}, ::RoundingMode{:ToZero}) got uns
upported keyword argument "sigdigits"
   @ Base float.jl:392
  round(::Union{Float16, Float32, Float64}, ::RoundingMode{:Down}) got unsup
ported keyword argument "sigdigits"
   @ Base float.jl:393
  round(::Union{Float16, Float32, Float64}, ::RoundingMode{:Up}) got unsuppo
rted keyword argument "sigdigits"
   @ Base float.jl:394
  ...


Stacktrace:
 [1] #print_tree#109
   @ ~/.julia/packages/DecisionTree/0Dw1P/src/DecisionTree.jl:238 [inlined]
 [2] print_tree
   @ ~/.julia/packages/DecisionTree/0Dw1P/src/DecisionTree.jl:231 [inlined]
 [3] #print_tree#107
   @ ~/.julia/packages/DecisionTree/0Dw1P/src/DecisionTree.jl:198 [inlined]
 [4] print_tree(tree::DecisionTree.Root{Vector{Float64}, UInt32}, depth::Int
64, indent::Int64; sigdigits::Int64, feature_names::Nothing)
   @ DecisionTree ~/.julia/packages/DecisionTree/0Dw1P/src/DecisionTree.jl:2
01
 [5] print_tree (repeats 2 times)
   @ ~/.julia/packages/DecisionTree/0Dw1P/src/DecisionTree.jl:200 [inlined]
 [6] (::MLJDecisionTreeInterface.TreePrinter{DecisionTree.Root{Vector{Float6
4}, UInt32}})()
   @ MLJDecisionTreeInterface ~/.julia/packages/MLJDecisionTreeInterface/cIW
Ga/src/MLJDecisionTreeInterface.jl:20
 [7] top-level scope
   @ In[11]:7
```

In [29]:

```
# All instances have the same length
length.(X)
```

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Out[29]: 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[Elbow l]	Y[Elbow l]
	Int64	Int64	Int64	Int64	Int64	Int64	Int64	Int64
1	51	51	51	51	51	51	51	51
2	51	51	51	51	51	51	51	51
3	51	51	51	51	51	51	51	51
4	51	51	51	51	51	51	51	51
5	51	51	51	51	51	51	51	51
6	51	51	51	51	51	51	51	51
7	51	51	51	51	51	51	51	51
8	51	51	51	51	51	51	51	51
9	51	51	51	51	51	51	51	51
10	51	51	51	51	51	51	51	51
11	51	51	51	51	51	51	51	51
12	51	51	51	51	51	51	51	51
13	51	51	51	51	51	51	51	51
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
349	51	51	51	51	51	51	51	51
350	51	51	51	51	51	51	51	51
351	51	51	51	51	51	51	51	51
352	51	51	51	51	51	51	51	51
353	51	51	51	51	51	51	51	51
354	51	51	51	51	51	51	51	51
355	51	51	51	51	51	51	51	51
356	51	51	51	51	51	51	51	51
357	51	51	51	51	51	51	51	51
358	51	51	51	51	51	51	51	51
359	51	51	51	51	51	51	51	51
360	51	51	51	51	51	51	51	51

In [13]:

```
# Maybe let's unwind the temporal axis?
X_static = Matrix(X)
cols = []
for i_var in 1:size(X_static, 2)
    var_unroll = hcat(X_static[:,i_var]...)
                                          var_unroll))
```

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```
end
X_static = DataFrame(cols, ["$n[$i]" for n in names(X) for i in 1:51])
```

Out[13]: 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 [14]:

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

```julia

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

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, …), …).
  0.857494 seconds (1.21 M allocations: 93.284 MiB, 5.28% gc time, 95.00% co
mpilation time)
Feature 73 < -1.244 ?
├─ Feature 790 < 1.396 ?
    ├─ 3 : 12/12
    └─ Feature 499 < 1.055 ?
        ├─ Feature 1005 < -1.419 ?
            ├─ 1 : 16/16
            └─ 5 : 4/4
        └─ Feature 70 < -1.848 ?
            ├─ 3 : 1/1
            └─ 5 : 5/5
└─ Feature 380 < -0.02374 ?
    ├─ Feature 680 < -0.3382 ?
        ├─ 4 : 13/13
        └─ Feature 295 < -0.4847 ?
            ├─ 4 : 1/1
            └─ 6 : 7/7
    └─ Feature 170 < 0.461 ?
        ├─ 6 : 1/1
        └─ 2 : 12/12
Accuracy: 0.59375
```

In [37]:
```julia
println(names(X_static)[73])
println(names(X_static)[790])
```

```
Y[Hand tip l][22]
X[Wrist r][25]
```

In [16]:
```julia
feature_importances(dt_mach_static)
```

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```
Out[16]: 1224-element Vector{Pair{Symbol, Float64}}:
          Symbol("Y[Hand tip l][22]") => 0.3919728191493403
             Symbol("X[Wrist r][25]") => 0.15879837719523981
             Symbol("Y[Elbow l][23]") => 0.15430650160975126
             Symbol("Y[Wrist l][17]") => 0.08149246071839794
             Symbol("Y[Thumb l][36]") => 0.0787799819908887
             Symbol("X[Elbow r][40]") => 0.06189215649217878
          Symbol("X[Hand tip r][17]") => 0.02775124659197857
          Symbol("Z[Hand tip r][40]") => 0.02372646104198667
          Symbol("Y[Hand tip l][19]") => 0.02127999521023807
           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 [17]: X_mean = DataFrame(mean.(Matrix(X)), ["mean($n)" for n in names(X)])
```

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Out[17]: 360×24 DataFrame *335 rows omitted*

Row	mean(X[Hand tip l])	mean(Y[Hand tip l])	mean(Z[Hand tip l])	mean(X[Hand tip r])	mean(Y[Ha tip r])
	Float64	Float64	Float64	Float64	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 [18]:

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

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

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```julia
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)")
```

```
  0.011851 seconds (11.21 k allocations: 831.303 KiB, 89.43% compilation tim
e)
Feature 20 < -1.249 ?
├─ Feature 23 < -0.7454 ?
    ├─ Feature 14 < -1.301 ?
        ├─ Feature 16 < 1.062 ?
            ├─ Feature 20 < -1.76 ?
                ├─ 3 : 2/2
                └─ 
            └─ Feature 3 < -0.6793 ?
                ├─ 1 : 10/10
                └─ 
        └─ 5 : 4/4
    └─ Feature 13 < -0.4633 ?
        ├─ Feature 19 < -0.753 ?
            ├─ 5 : 1/1
            └─ 3 : 10/10
        └─ 4 : 2/2
└─ Feature 1 < -0.4318 ?
    ├─ Feature 11 < -0.4122 ?
        ├─ Feature 8 < -0.4618 ?
            ├─ Feature 21 < -0.6537 ?
                ├─ 6 : 4/4
                └─ 2 : 1/1
            └─ 2 : 11/11
        └─ Feature 18 < -0.4754 ?
            ├─ 4 : 1/1
            └─ 6 : 4/4
    └─ 4 : 11/11
Accuracy: 0.5798611111111112
```

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

In [19]:
```julia
feature_importances(dt_mach_mean)
```

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```
Out[19]: 24-element Vector{Pair{Symbol, Float64}}:
             Symbol("mean(Y[Thumb l])") => 0.3556033147199974
          Symbol("mean(X[Hand tip l])") => 0.13499663752164212
             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[Wrist l])") => 0.043933318313957734
             Symbol("mean(X[Thumb l])") => 0.026377918698496972
             Symbol("mean(Z[Wrist r])") => 0.019694995497722176
             Symbol("mean(Z[Thumb l])") => 0.019694995497722176
          Symbol("mean(Z[Hand tip r])") => 0.015031274537197794
          Symbol("mean(Y[Hand tip l])") => 0.0
          Symbol("mean(X[Hand tip r])") => 0.0
          Symbol("mean(Y[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(Z[Wrist l])") => 0.0
             Symbol("mean(Y[Wrist r])") => 0.0
             Symbol("mean(X[Thumb r])") => 0.0
             Symbol("mean(Z[Thumb r])") => 0.0
```

```
In [20]: 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"]])
```

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Out[20]: 360×72 DataFrame *335 rows omitted*

Row	mean(X[Hand tip l]) Float64	max(X[Hand tip l]) Float64	min(X[Hand tip l]) Float64	mean(Y[Hand tip l]) Float64	max(Y[Hand tip l]) 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 [21]:

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

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

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```
# 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)")
```

```
  0.058000 seconds (151.85 k allocations: 10.589 MiB, 95.36% compilation tim
e)
Accuracy: 0.6215277777777778
```

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

In [22]:

```
feature_importances(dt_mach_features)
```

Out[22]:

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

In [23]:

```
using ModalDecisionTrees

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

In [24]:

```
# 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, …), …).
```

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```
102.039333 seconds (888.92 M allocations: 46.554 GiB, 10.71% gc time, 43.99%
compilation time)
```

```
Out[24]:  trained Machine; caches model-specific representations of data
            model: ModalDecisionTree(max_depth = nothing, …)
            args:
              1:  Source @965 ⏎ Table{AbstractVector{AbstractVector{Continuous}}}
              2:  Source @752 ⏎ AbstractVector{Multiclass{6}}
```

```
In [25]:  # Compute accuracy
          yhat = predict_mode(mach; rows=test_idxs)
          MLJ.accuracy(yhat, y[test_idxs])
```

```
Out[25]:  0.7847222222222222
```

```
In [26]:  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 [27]:  # 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
```

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```
▣ ⟨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 [35]:

```
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]")
    print("IF\t")
    antd = antecedent(rule)
    consq = consequent(rule)
    println(SoleLogics.experimentals.formula2natlang(antd; threshold_digits
    print("THEN\t")
    println(consq)
end
```

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```
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]
IF      ∃ interval where ((min[V1] ≥ 0.43) and (∃ interval where ((min[V13]
< -1.54) and (∃ preceding, partially overlapping interval where (min[V1] ≥
0.43)))))
THEN    ▣ Spread wings


[2]
IF      (∃ interval where ((min[V1] ≥ 0.43) and (∃ interval where (min[V13]
< -1.54)))) and (∀ intervals (whenever min[V1] ≥ 0.43 holds, also ∀ interval
s (whenever min[V13] < -1.54 holds, also ∀ preceding, partially overlapping
intervals (min[V1] < 0.43))))
THEN    ▣ Fold wings


[3]
IF      (∃ interval where (min[V1] ≥ 0.43)) and (∀ intervals (whenever min[V
1] ≥ 0.43 holds, also ∀ intervals (min[V13] ≥ -1.54)))
THEN    ▣ Lock wings


[4]
IF      (∃ interval where (min[V5] ≥ 0.85)) and (∀ intervals (min[V1] < 0.4
3))
THEN    ▣ I have command


[5]
IF      ((∃ interval where ((min[V3] ≥ -0.62) and (min[V5] < -1.85))) and (∀
intervals (min[V1] < 0.43))) and (∀ intervals (min[V5] < 0.85))
THEN    ▣ All clear


[6]
IF      (((∃ interval where (min[V3] ≥ -0.62)) and (∀ intervals (min[V1] <
0.43))) and (∀ intervals (min[V5] < 0.85))) and (∀ intervals (whenever min[V
3] ≥ -0.62 holds, also min[V5] ≥ -1.85))
THEN    ▣ Not clear


[7]
IF      ((∀ intervals (min[V1] < 0.43)) and (∀ intervals (min[V5] < 0.85)))
and (∀ intervals (min[V3] < -0.62))
THEN    ▣ All clear
```