Lab 7

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#Rcpp

We will get some experience with speeding up R code using C++ via the Rcpp package.

First, clear the workspace and load the Rcpp package.

```
pacman::p_load(Rcpp)
```

Create a variable n to be 10 and a vaiable Nvec to be 100 initially. Create a random vector via rnorm Nvec times and load it into a Nvec x n dimensional matrix.

```
n<- 10
Nvec <-100
X= matrix(data=rnorm(Nvec*n), nrow=Nvec)
head(X)</pre>
```

```
##
              [,1]
                          [,2]
                                     [,3]
                                                 [,4]
                                                            [,5]
##
  [1,] -0.68978143
                   1.16685579
                               0.69746817
                                           0.02710038
                                                      0.04175333
                                                                  1.6092540
        0.20013438 -0.08385234 -0.02012739
                                          0.77688223 -0.16661927
        0.05717207 -0.3821346
## [3,]
                                          0.83416245
## [4,] -0.12866176 -1.48243590
                              0.19525074
                                                      0.32567324
                                                                 1.8240664
## [5,] -0.33259300 0.99989871
                               0.52231764
                                          0.92348737 -0.51634274
## [6,] -0.99837910 -0.53275508 0.94897928 -0.68467839 -0.75048532
##
             [,7]
                         [,8]
                                    [,9]
                                              [,10]
        0.6540923
                  2.03696558 -0.94744568 -0.7756266
## [1,]
## [2,] -0.4755381 -0.24871469 -0.23079676
                                         1.8946037
## [3,]
        3.2234681 0.08046676 0.51644378 -0.6496923
## [4,]
        1.2160436 -0.12566820
                              0.51930931
                                         0.3617756
## [5,]
        0.2653940 1.18999409
                              2.02601121
                                         1.3991946
## [6,] -1.0952557 -0.52533511
                              0.05062882 -0.7524438
```

Write a function all_angles that measures the angle between each of the pairs of vectors. You should measure the vector on a scale of 0 to 180 degrees with negative angles coerced to be positive.

```
angle <- function(u,v){
   acos(sum(u*v)/sqrt(sum(u^2)*sum(v^2))) * 180/ pi
}
all_angles <- function(X){
   A <-matrix(NA, nrow = nrow(X), ncol = nrow(X))
   for(i in 1: (nrow(X)-1)){
      for(j in (i+1): nrow(X)) {
            A[i,j] = angle (X[i,],X[j,])
            }
      }
      A</pre>
```

}
all_angles(X

##		[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]
##	[1,]		92.33756		-	69.27226	92.70577	49.29352	71.10291
##	[2,]	NA		109.34015				98.20901	76.90253
##	[3,]	NA	NA				127.00575		63.60421
##	[4,]	NA	NA	NA		63.57406	97.12296	97.06139	69.97169
##	[5,]	NA	NA	NA	NA		100.80675	71.09219	35.95769
##	[6,]	NA	NA	NA	NA	NA	NA	78.41906	116.96709
##	[7,]	NA	NA	NA	NA	NA	NA	NA	72.59298
##	[8,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[9,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[10,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[11,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[12,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[13,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[14,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[15,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[16,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[17,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[18,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[19,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[20,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[21,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[22,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[23,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[24,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[25,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[26,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[27,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[28,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[29,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[30,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[31,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[32,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[33,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[34,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[35,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[36,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[37,]	NA		NA			NA	NA	NA
##	[38,]	NA	NA	NA	NA		NA	NA	NA
##	[39,]	NA	NA	NA	NA		NA NA	NA	NA NA
##	[40,]	NA	NA	NA NA	NA		NA NA	NA	NA NA
## ##	[41,]	NA	NA	NA NA	NA		NA NA	NA	NA NA
	[42,]	NA NA	NA NA	NA NA	NA NA		NA NA	NA NA	NA NA
##	[43,]	NA NA	NA NA	NA NA	NA NA		NA NA	NA NA	NA NA
## ##	[44,]	NA NA	NA NA	NA NA	NA NA		NA NA	NA NA	NA NA
## ##	[45,] [46,]	NA NA	NA NA	NA NA	NA NA		NA NA	NA NA	NA NA
##	[47,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
##	[48,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
##	[49,]	NA	NA	NA	NA	NA	NA	NA	NA

##	[50,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[51,]	NA	NA	NA	NA NA	NA NA	NA	NA	NA NA
##	[52,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[53,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[54,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[55,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[56,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[57,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[58,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[59,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[60,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[61,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[62,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[63,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[64,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[65,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[66,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[67,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[68,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[69,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[70,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[71,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[72,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[73,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[74,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[75,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[76,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[77,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[78,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[79,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[80,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[81,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[82,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[83,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[84,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[85,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[86,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[87,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[88,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[89,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[90,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[91,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[92,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[93,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[94,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[95,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[96,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[97,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[98,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[99,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[100,]	NA	NA F 407	NA	NA	NA .	NA	NA .	NA
##	F4 7	[,9]	[,10]	[,11]				[,14]	[,15]
##	[1,]	73.34311		123.66947		3998 78.3			.27490
##	[2,]	97.56888	00.0456/	106.49232	125.22	235/ 101.2	25305 91.	00238 93	.52719

	F0 7				44 50005			
##	[3,]	97.95718		105.53102	41.79065	72.65327	67.68658	39.85239
##		117.19347			93.35554	85.57380	72.06063	91.32782
##	[5,]	103.89594	64.39138	125.28859	114.24892	76.82546	100.51926	89.59021
##	[6,]	90.79076	105.54113	64.29234	114.01206	95.30581	78.75511	130.69183
##	[7,]	63.66836	102.01309	129.19344	91.13614	74.72414	103.45830	118.74876
##	[8,]	99.17169	76.32468	127.29339	89.02129	82.25206	100.59282	69.89345
##	[9,]	NA	86.48299	110.95442	81.93477	73.24319	105.26103	84.82574
##	[10,]	NA		114.32928		67.74741	77.12789	64.74378
##	[11,]	NA	NA	NA		120.04982	90.78158	98.90111
##	[12,]	NA	NA	NA	NA	66.13718	73.34488	63.32962
##	[13,]	NA NA	NA NA	NA NA	NA NA	NA	70.05635	73.84374
##	[14,]	NA	NA NA	NA NA	NA NA	NA NA	70.00000 NA	80.90066
##	[15,]	NA	NA	NA	NA	NA	NA	NA
##	[16,]	NA	NA	NA	NA	NA	NA	NA
##	[17,]	NA	NA	NA	NA	NA	NA	NA
##	[18,]	NA	NA	NA	NA	NA	NA	NA
##	[19,]	NA	NA	NA	NA	NA	NA	NA
##	[20,]	NA	NA	NA	NA	NA	NA	NA
##	[21,]	NA	NA	NA	NA	NA	NA	NA
##	[22,]	NA	NA	NA	NA	NA	NA	NA
##	[23,]	NA	NA	NA	NA	NA	NA	NA
##	[24,]	NA	NA	NA	NA	NA	NA	NA
##	[25,]	NA	NA	NA	NA	NA	NA	NA
##	[26,]	NA	NA	NA	NA	NA	NA	NA
##	[27,]	NA	NA	NA	NA	NA	NA	NA
##	[28,]	NA	NA	NA	NA	NA	NA	NA
##	[29,]	NA	NA	NA	NA	NA	NA	NA
##	[30,]	NA	NA	NA	NA	NA	NA	NA
##	[31,]	NA NA	NA NA	NA NA	NA	NA NA	NA NA	NA NA
##	[32,]	NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
##	[33,]	NA	NA	NA	NA	NA	NA	NA
##	[34,]	NA	NA	NA	NA	NA	NA	NA
##	[35,]	NA	NA	NA	NA	NA	NA	NA
##	[36,]	NA	NA	NA	NA	NA	NA	NA
##	[37,]	NA	NA	NA	NA	NA	NA	NA
##	[38,]	NA	NA	NA	NA	NA	NA	NA
##	[39,]	NA	NA	NA	NA	NA	NA	NA
##	[40,]	NA	NA	NA	NA	NA	NA	NA
##	[41,]	NA	NA	NA	NA	NA	NA	NA
##	[42,]	NA	NA	NA	NA	NA	NA	NA
##	[43,]	NA	NA	NA	NA	NA	NA	NA
##	[44,]	NA	NA	NA	NA	NA	NA	NA
##	[45,]	NA	NA	NA	NA	NA	NA	NA
##	[46,]	NA	NA	NA	NA	NA	NA	NA
##	[47,]	NA	NA	NA	NA	NA	NA	NA
##	[48,]	NA	NA	NA	NA	NA	NA	NA
##	[49,]	NA	NA	NA	NA	NA	NA	NA
##	[50,]	NA	NA	NA	NA	NA	NA	NA
##	[51,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA
##	[52,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
##	[53,]	NA NA	NA NA	NA NA		NA NA	NA NA	NA NA
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##	[54,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA
##	[55,]	NA	NA	NA	NA	NA	NA	NA
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##	[57,]	NA	NA	NA	NA	NA	NA	NA
##	[58,]	NA	NA	NA	NA	NA	NA	NA
##	[59,]	NA	NA	NA	NA	NA	NA	NA
##	[60,]	NA	NA	NA	NA	NA	NA	NA
##	[61,]	NA	NA	NA	NA	NA	NA	NA
##	[62,]	NA	NA	NA	NA	NA	NA	NA
##	[63,]	NA	NA	NA	NA	NA	NA	NA
##	[64,]	NA	NA	NA	NA	NA	NA	NA
##	[65,]	NA	NA	NA NA	NA	NA	NA	NA
	[66,]	NA NA						
##			NA	NA	NA	NA	NA	NA
##	[67,]	NA	NA	NA	NA	NA	NA	NA
##	[68,]	NA	NA	NA	NA	NA	NA	NA
##	[69,]	NA	NA	NA	NA	NA	NA	NA
##	[70,]	NA	NA	NA	NA	NA	NA	NA
##	[71,]	NA	NA	NA	NA	NA	NA	NA
##	[72,]	NA	NA	NA	NA	NA	NA	NA
##	[73,]	NA	NA	NA	NA	NA	NA	NA
##	[74,]	NA	NA	NA	NA	NA	NA	NA
##	[75,]	NA	NA	NA	NA	NA	NA	NA
##	[76,]	NA	NA	NA	NA	NA	NA	NA
##	[77,]	NA	NA	NA	NA	NA	NA	NA
##	[78,]	NA	NA	NA	NA	NA	NA	NA
##	[79,]	NA	NA	NA	NA	NA	NA	NA
##	[80,]	NA	NA	NA	NA	NA	NA	NA
##	[81,]	NA	NA	NA	NA	NA	NA	NA
##	[82,]	NA	NA	NA	NA	NA	NA	NA
##	[83,]	NA	NA	NA	NA	NA	NA	NA
##	[84,]	NA	NA	NA	NA	NA	NA	NA
##	[85,]	NA	NA NA	NA	NA	NA	NA NA	NA
##	[86,]	NA	NA	NA NA	NA	NA	NA	NA
		NA NA						
##	[87,]		NA NA	NA NA	NA	NA NA	NA	NA NA
##	[88,]	NA	NA	NA	NA	NA	NA	NA
##	[89,]	NA	NA	NA	NA	NA	NA	NA
##	[90,]	NA	NA	NA	NA	NA	NA	NA
##	[91,]	NA	NA	NA	NA	NA	NA	NA
##	[92,]	NA	NA	NA	NA	NA	NA	NA
##	[93,]	NA	NA	NA	NA	NA	NA	NA
##	[94,]	NA	NA	NA	NA	NA	NA	NA
##	[95,]	NA	NA	NA	NA	NA	NA	NA
##	[96,]	NA	NA	NA	NA	NA	NA	NA
##	[97,]	NA	NA	NA	NA	NA	NA	NA
##	[98,]	NA	NA	NA	NA	NA	NA	NA
##	[99,]	NA	NA	NA	NA	NA	NA	NA
##	[100,]	NA	NA	NA	NA	NA	NA	NA
##		[,16]	[,17]	[,18]	[,19]	[,20]	[,21]	[,22]
##	[1,]	100.57486	70.47671	92.92571	85.02748	80.81049	71.64746	99.79455
##	[2,]	97.60597		109.26206	69.19103	40.07312		124.95574
##		119.45762			116.97812	120.23541	68.07483	77.28325
##	[4,]	87.14486	69.02930	91.69686	85.20734	84.33235	92.48073	77.96128
##		104.11620	94.52208	70.10700	79.75532	64.61584		101.54072
##	[6,]	47.07836	80.06671	74.36373	68.95320	78.15532	89.93439	68.50103
##	[7,]	85.42112	87.01535	91.70107	90.35266	88.90134		101.53257
##		128.55574		71.78080	94.14046	84.19915	95.83114	91.14451
##	[9,]	102.07061	69.02925	95.75026	95.79790	92.91924	03.94526	101.01323

шш	[10]	07 46051	77 52014	00 61531	67 06500	66 10007	61 51000	100 21010
##	[10,]	97.46051	77.53914	89.61531		66.18007		108.31210
##	[11,]	71.03643	91.75595	76.75692		100.09458		56.48894
##	[12,]		107.97736		124.33198		76.59198	72.52949
##	[13,]		100.35037		111.02853			86.30010
##		68.60131		105.75947	96.30227	90.53471		82.22979
##	-	132.89942			110.41248		77.77197	83.36792
##	[16,]	NA	87.40614	95.53864	77.67220	94.72231	83.91104	81.93367
##	[17,]	NA	NA	111.80387	57.17938	65.26895	70.40954	94.99469
##	[18,]	NA	NA	NA	88.30861	98.41860	106.76028	50.44621
##	[19,]	NA	NA	NA	NA	62.19444	67.84992	88.25028
##	[20,]	NA	NA	NA	NA	NA	90.27703	122.74042
##	[21,]	NA	NA	NA	NA	NA	NA	90.99882
##	[22,]	NA						
##	[23,]	NA						
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##	[30,]	NA						
##	[31,]	NA						
##	[32,]	NA						
##	[33,]	NA						
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##	[42,]	NA						
##	[43,]	NA						
##	[44,]	NA						
##	[45,]	NA						
##	[46,]	NA						
##	[47,]	NA						
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##	[64,]	NA						
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##	[79,]	NA						
##	[80,]	NA						
##	[81,]	NA NA	NA NA	NA NA	NA NA	NA NA	NA NA	NA
##	[82,]	NA NA	NA NA	NA	NA NA	NA	NA NA	NA
##	[83,]	NA NA	NA NA	NA	NA NA	NA	NA NA	NA
##	[84,]	NA NA						
##	[85,]	NA NA						
##								
	[86,]	NA NA	NA NA	NA	NA NA	NA	NA NA	NA
##	[87,]	NA						
##	[88,]	NA						
##	[89,]	NA						
##	[90,]	NA						
##	[91,]	NA						
##	[92,]	NA						
##	[93,]	NA						
##	[94,]	NA						
##	[95,]	NA						
##	[96,]	NA						
##	[97,]	NA						
##	[98,]	NA						
##	[99,]	NA						
##	[100,]	NA						
##								[,29]
##	[1,]							
##		91.10352						
##	[3,]						94.31673	
##	[4,]	85.14511	60.99014	118.75812	87.81669	113.77591	116.47883	112.48833
##	[5,]	61.58788						
##		96.31185						
##		81.08880					110.76744	76.90954
##	[8,]	57.54745	106.08075	127.36889	77.16537	90.75217	126.92628	91.06173
##		120.46127						
##	[10,]	74.93796	127.85813	114.90399	106.49480	97.41909	101.94320	
##		111.52649						
##	[12,]	77.42755	72.32792	104.21597	57.01035	81.10446	75.31655	92.73144
##	[13,]	73.95934	87.53655	114.55366	95.81553	95.39739	86.73460	104.24465
##	[14,]	72.53591	70.01566	120.85756	109.28837	97.37312	74.10657	100.22831
##	[15,]	85.11558	105.32351	122.01215	70.60267	109.01396	95.87083	84.05991
##	[16,]	85.17603	63.34449	72.98182	127.05638	87.05639	56.78172	110.23770

шш	[47]	105 60750	00 05040	07 71050	00 40004	00 67065	100 10010	FO 17201
##		125.60750	89.95040	87.71058			123.19340	59.17391
##	[18,]	82.84510	87.05614		109.81120		92.40255	99.78847
##	[19,]		104.09658		110.43045		107.98426	59.15867
##	[20,]		119.31788		115.93636		109.15383	80.89565
##	[21,]	80.22555	94.05531	96.53480	91.97442	92.10438	97.66591	55.41563
##	[22,]	90.35886	53.66112	99.45007		132.22238		94.70910
##	[23,]	NA			107.63377	75.17451		107.47778
##	[24,]	NA	NA	85.45299		112.14920		115.50684
##	[25,]	NA	NA	NA	86.29073	79.39623	78.59187	76.98681
##	[26,]	NA	NA	NA	NA		114.81115	71.40097
##	[27,]	NA	NA	NA	NA	NA	78.96858	84.07512
##	[28,]	NA	NA	NA	NA	NA		116.97698
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##	[2,]	64.21428	95.57946	94.98124		107.13613		59.62168
##	[3,]	127.34946	67.29386	79.15884	115.15684		103.22844	90.00549
##	[4,]	70.48184		101.67645		118.12681		83.03773
##	[5,]	89.88633		106.44475	93.56570		104.80169	71.21449
##	[6,]				103.22544			104.91646
##		97.88193						
##		119.78887						76.84553
##	- • -	106.47017						
##	-	88.57169					101.81412	79.76221
##	[11,]	76.83236	110.21112	60.64478	67.34085	74.92974	91.94366	120.99691
##	-	125.52970						
##	-	96.05569						75.86985
##	-	73.57853						
##		124.26664						
##		52.41253						
##		67.74661						
##		107.63987						
##		76.06194						
##	-	58.64956						
##		91.17304						
##		106.77948						
##	[23,]	106.09051	72.09944	107.49863	119.74584	92.09776	104.42710	85.16758

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##	[24,] [25,]	72.92522	68.30005	95.87363	92.19292	98.84513		106.87654
##	[26,]	73.94135	93.59967	79.70909	60.11268	91.81917		115.84755
##		120.39607	81.28056	70.67077		107.12014	84.30687	92.15859
##	[27,]	96.15323			103.10536		82.72461	69.94586
##	[28,]	83.41339	88.48249	79.76035	92.88910	66.24449	85.25717	90.70771
##	[29,]		116.55188	94.94871		104.65023		113.85749
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## ##	[50,]	NA NA						
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##	[1,]	89.67959	80.65048	63.23385	96.97574	89.82281	89.65805	92.49987
##	[2,]	103.56207	48.38491	76.80821	83.05666	79.65975	122.63790	95.39184
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##	[4,]	100.57789	74.76906	82.75085	114.85721	55.58101	113.60588	96.62349
##	[5,]	77.98058	67.29485	78.50736	106.17580	90.81282	107.32711	75.71954
##	[6,]	75.94341	101.26762	119.41243	97.67501	92.76096	122.07767	70.51553
##	[7,]	81.07661	66.68857	91.28582	97.91687	90.62512	98.34989	94.47474
##	[8,]	99.57314	78.87468	64.40329	124.43225	83.64508	78.75711	84.10929
##	[9,]	102.18780	68.25816	69.68745	76.18606	76.61225	78.27479	125.74484
##	[10,]	89.30293	67.38583	84.34971	87.49356	77.74747	87.65270	83.47324
##	[11,]	87.20442	133.72197	106.30875	86.99243	98.29511	99.57012	73.77506
##	[12,]	99.72413	96.35100	96.33628	100.79935	68.40012	45.40578	113.42439
##	[13,]	66.03137	70.55624	99.98128	86.84854	72.89159	78.86020	107.82407
##	[14,]	99.64062	85.94462	106.85102	104.64102	66.24583	84.16246	94.51597
##	[15,]	110.28357	97.68296	59.35424	98.26975	77.49808	40.19878	104.67588
##	[16,]	56.74373	89.08976	150.42785	78.08042	90.26505	123.83225	77.19724
##	[17,]	120.47637	68.22809	70.24546	94.85844	55.42019	112.35737	105.39221
##	[18,]	67.89917	116.86359	88.42893	108.78202	96.95514	88.63000	68.56466
##	[19,]	91.81847	93.41998	95.73748	101.34009	86.43454	114.89745	52.40600
##	[20,]	98.13135	67.69845	75.11621	83.13554	100.38347	121.69965	79.32037
##	[21,]	99.46210	93.28706	91.86067	101.21691	75.60344	68.27372	78.42862
##	[22,]	91.17778	128.01931	98.16292	127.33535	69.65381	82.81922	78.93080
##	[23,]	75.46301	87.86059	115.97261	113.63304	95.12118	80.58655	63.37022
##		83.26834						93.39667
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##		119.85390						
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##		66.92182						
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##		73.20171						
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##	[31,]	61.78026		100.72429	76.54623	92.19680	82.20336	95.17983
##	[32,]		117.23026	71.19786		104.07105	68.57100	93.67004
##	[33,]	78.44378	92.87417	86.46417	61.56842		108.45169	90.36050
##	[34,]		114.26078	82.52458		122.24020	71.89343	87.15190
##	[35,]	92.48914	79.60102	96.42829	95.49084	68.72440		113.05115
##	[36,]	95.68956	45.91466	77.38783	73.29228	90.08072	97.65825	123.52641
##	[37,]	NA	98.12379	125.66948	63.45968	123.11268	105.44439	66.61949
##	[38,]	NA	NA	85.56053	79.78803	66.65798	111.60276	
##	[39,]	NA	NA	NA	97.04471	82.42791	71.62999	110.99366
##	[40,]	NA	NA	NA	NA	120.61881	97.95743	103.17213
##	[41,]	NA	NA	NA	NA	NA	91.61469	119.73616
##	[42,]	NA	NA	NA	NA	NA	NA	97.24350
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                                                      96.95496 100.43911 127.52665
                                                                           91.47256
##
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                                                     93.40504 100.96701
##
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                                                      84.16186
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                                                                           88.81150
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                                                     70.33379 138.82302
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##
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##
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                                                                95.48989
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     [7,]
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##
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##
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##
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##
    [53,]
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                                                           61.44199
                                                                     98.41258
##
          93.66053 90.52640 101.44227 98.80792 36.22691
                                                           81.75888 108.54169
##
    [55,]
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                    90.78650
                             69.60195 100.77454 82.04931
                                                           81.28824 84.64846
    [56.]
          90.35020
                    78.28573
                              71.25550 73.25230
                                                 76.84246
                                                           90.62432 119.09735
##
          83.25146 107.32547
                              85.32630 96.17649 99.07753
##
    [57,]
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    [58,]
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                                                           90.59601
##
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                    65.57328 65.85745 126.93362 73.52872
                                                           76.79928
##
    [60,] 116.29795
                                                                     79.19428
          76.20768 93.51770 85.13939 99.23678 48.66136
                                                           91.23430
##
    [61,]
                                                                     89.32839
          71.71597 105.62542 89.52728 63.29024 115.19153
##
    [62,]
                                                           78.99017
                                                                     89.24652
##
    [63,]
          83.79997 109.73220 125.69910 84.96915 73.49066
                                                           77.55403
                                                                     93.60777
##
    [64,]
          92.42032 66.45159 96.57514 126.38520 79.88056
                                                           70.42308
                                                                     65.16731
          96.18357
                   73.51055 80.49992 62.71992 78.57262
##
    [65,]
                                                           96.15601
                                                                     95.02183
    [66,] 118.40312 69.94311 113.76965 115.12401 84.77254
                                                           81.50891
                                                                     70.22833
##
##
    [67,]
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                                                           96.90929
                                                                     97.59709
##
    [68.]
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                                                           46.17715
                                                                     77.37787
##
    [69,]
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                                                                     97.63316
##
    [70,]
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                                                                    90.19500
##
    [71,]
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                                                 71.22011 101.92945 116.75122
##
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    [72,]
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    [73,]
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##
##
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    [77,] 104.41484 77.06030 116.84502 92.22966 120.62791
                                                           93.83312
                                                                    74.31986
    [78,] 67.71126
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##
                                                           90.90852
                                                                     81.11260
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##
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##
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##
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##
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                                                                     75.04907
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                                                                     80.37876
##
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    [86,] 91.62332 100.23159 103.40422 58.38501 69.50284 98.49847 116.17920
##
```

```
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                                                             89.43241
                                                                         82.03340
                                                              98.91283
##
    [89,] 87.77031 82.75184 113.80757 117.70120 112.82575
                                                                         69.82401
   [90,] 105.71394 67.89350 63.70732 94.75318 97.76107
                                                              88.45558
##
                                                                         81.88070
    [91,] 60.39093 114.83865 103.15192 72.11576 102.81762
                                                              81.04513
                                                                         97.52396
##
    [92,] 100.43356 95.70529 69.45787 50.48420 102.38216 120.77655 106.40380
    [93.]
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                                                              90.46459 107.14791
##
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##
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##
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##
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##
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##
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    [11,]
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    [13,]
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##
           65.26299
##
    [14,]
    [15,]
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##
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          87.02238
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##
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##
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   [34,] 77.92029
    [35,] 114.70887
##
##
    [36,]
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##
           78.13654
   [37,]
##
    [38,]
           85.94180
   [39,] 75.39051
##
```

```
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##
    [41,] 87.49635
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    [43,] 103.08059
##
##
    [44,] 72.10851
##
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##
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    [47,] 112.27462
##
##
    [48,] 85.46214
##
    [49,] 117.41276
    [50,] 128.54113
##
    [51,] 86.38822
    [52,] 82.54453
##
##
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##
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##
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##
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    [62,]
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##
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##
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    [67,] 85.58530
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    [69,] 58.45886
##
##
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##
    [71,] 90.17372
##
    [72,] 87.05025
##
    [73,] 86.78156
    [74,] 110.55147
##
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##
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##
    [81,] 75.60389
##
    [82,] 73.58756
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##
    [84,] 93.96905
    [85,] 115.67744
##
##
    [86,] 82.82674
##
    [87,] 69.75526
##
    [88,] 99.91288
    [89,] 117.98834
##
##
    [90,] 76.93727
##
   [91,] 78.90357
##
   [92,] 55.84959
##
   [93,] 107.86074
```

```
## [94,] 75.68157

## [95,] 53.01698

## [96,] 76.78718

## [97,] 65.43208

## [98,] 93.47075

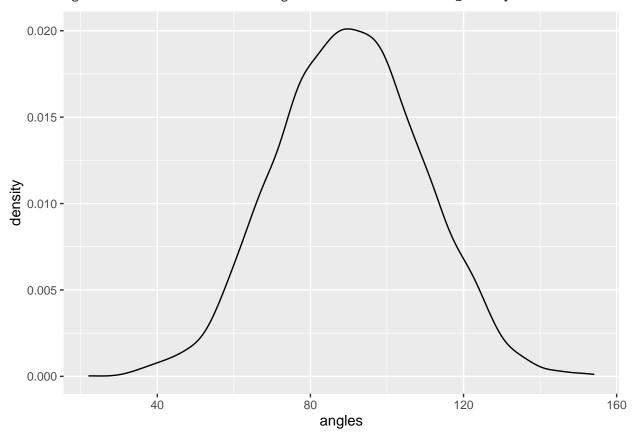
## [99,] 129.70564

## [100,] NA
```

Plot the density of these angles.

```
pacman::p_load(ggplot2)
ggplot(data.frame(angles=c(all_angles(X)))) +
  aes(x=angles) +
  geom_density()
```

Warning: Removed 5050 rows containing non-finite values (stat_density).



Write an Rcpp function all_angles_cpp that does the same thing. Use an IDE if you want, but write it below in-line.

```
double sum_sqd_u = 0;
    double sum_sqd_v = 0;
    double sum_u_v = 0;
    for (int j = 0; j < p; j++){
        sum_sqd_u += pow(X(i_1, j), 2);
        sum_sqd_v += pow (X(i_2, j), 2);
        sum_u_v += X(i_1, j)* X(i_2, j);
        }
        A(i_1, i_2) = acos(sum_u_v/sqrt(sum_sqd_u*sum_sqd_v)) * (180/ M_PI);
    }
} return A;
}
return A;
}
</pre>
```

##		[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]
##	[1,]	NA	92.33756	86.87351	78.96788	69.27226	92.70577	49.29352	71.10291
##	[2,]	NA	NA	109.34015	63.45660	59.14168	102.25958	98.20901	76.90253
##	[3,]	NA	NA	NA	82.88141	90.99593	127.00575	100.74879	63.60421
##	[4,]	NA	NA	NA	NA	63.57406	97.12296	97.06139	69.97169
##	[5,]	NA	NA	NA	NA	NA	100.80675	71.09219	35.95769
##	[6,]	NA	NA	NA	NA	NA	NA	78.41906	116.96709
##	[7,]	NA	NA	NA	NA	NA	NA	NA	72.59298
##	[8,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[9,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[10,]	NA	NA	NA	NA	NA	NA	NA	NA
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##	[12,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[13,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[14,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[15,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[16,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[17,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[18,]	NA	NA	NA	NA	NA	NA	NA	NA
##	[19,]	NA	NA	NA	NA	NA	NA	NA	NA
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##	[28,]	NA	NA	NA	NA	NA	NA	NA	NA
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##	[82,]	NA							
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##	[97,]	NA	NA	NA	NA	1	NA AV	NA I	NA NA
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##	[99,]	NA	NA	NA	NA	1	I AV	NA I	NA NA
##	[100,]	NA	NA	NA	NA	1	NA AV	NA I	NA NA
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##	[2,]	97.56888	56.64567	106.49232	125.	22357	101.25305	91.00238	93.52719
##	[3,]	97.95718	83.95274	105.53102	41.	79065	72.65327	67.68658	39.85239
##	[4,]	117.19347	84.48477	93.96194	93.	35554	85.57380	72.06063	91.32782
##	[5,]	103.89594	64.39138	125.28859	114.	24892	76.82546	100.51926	89.59021
##	[6,]	90.79076	105.54113	64.29234	114.	01206	95.30581	78.75511	130.69183
##	[7,]	63.66836	102.01309	129.19344	91.	13614	74.72414	103.45830	118.74876
##	[8,]	99.17169	76.32468	127.29339	89.	02129	82.25206	100.59282	69.89345
##	[9,]	NA	86.48299	110.95442	81.	93477	73.24319	105.26103	84.82574
##	[10,]	NA	NA	114.32928	100.	87533	67.74741	77.12789	64.74378
##	[11,]	NA	NA	NA	96.	63217	120.04982	90.78158	98.90111
##	[12,]	NA	NA	NA		NA	66.13718	73.34488	
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##		[,16]	[,17]	[,18]	[,19]	[,20]	[,21]	[,22]
##	-	100.57486	70.47671	92.92571	85.02748	80.81049	71.64746	99.79455
##	[2,]	97.60597	62.63062	109.26206	69.19103	40.07312		124.95574
##	-	119.45762			116.97812			77.28325
##	[4,]	87.14486	69.02930	91.69686	85.20734	84.33235	92.48073	77.96128
##		104.11620	94.52208	70.10700	79.75532	64.61584		101.54072
##	[6,]	47.07836	80.06671	74.36373	68.95320	78.15532		68.50103
##	[7,]	85.42112	87.01535	91.70107	90.35266	88.90134		101.53257
##	-	128.55574		71.78080	94.14046	84.19915	95.83114	91.14451
##	-	102.07061	69.02925	95.75026	95.79790			101.01323
##	[10,]	97.46051	77.53914	89.61531	67.06508	66.18007		108.31210
##	[11,]	71.03643	91.75595	76.75692		100.09458		56.48894
##	[12,]		107.97736		124.33198			72.52949
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##	[14,]	68.60131		105.75947		90.53471		82.22979
##	-	132.89942			110.41248			83.36792
##	[16,] [17,]	NA NA	87.40614	95.53864 111.80387	77.67220	94.72231	83.91104	81.93367 94.99469
##	-	NA NA			57.17938	65.26895	70.40954	50.44621
##	[18,]	NA NA	NA NA	NA NA	88.30861		106.76028 67.84992	
##	[19,] [20,]	NA NA	NA NA	NA NA	NA NA	62.19444 NA		88.25028 122.74042
##	[21,]	NA NA	NA NA	NA NA	NA NA	NA NA	90.27703 NA	90.99882
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76.83236 110.21112
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                                                        74.92974
                                                                    91.94366 120.99691
                                                                    75.91420
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##	[100,]	NA L 073	AN Cool	AN Food	NA L 103	NA C 443	NA L 103	NA L 403
##	F4 7	[,37]	[,38]	[,39]	[,40]	[,41]	[,42]	[,43]
##	-	89.67959		63.23385	96.97574	89.82281		92.49987
##	-	103.56207		76.80821	83.05666		122.63790	95.39184
##	-	108.94092			114.80699		33.17517	98.07895
##	-	100.57789			114.85721		113.60588	96.62349
##	[5,]	77.98058	67.29485	78.50736	106.17580	90.81282	107.32711	75.71954
##	[6,]	75.94341	101.26762	119.41243	97.67501	92.76096	122.07767	70.51553
##	[7,]	81.07661	66.68857	91.28582	97.91687	90.62512	98.34989	94.47474
##	[8,]	99.57314	78.87468	64.40329	124.43225	83.64508	78.75711	84.10929
##	[9,]	102.18780	68.25816	69.68745	76.18606	76.61225	78.27479	125.74484
##	[10,]	89.30293	67.38583	84.34971	87.49356	77.74747	87.65270	83.47324
##	[11,]	87.20442	133.72197	106.30875	86.99243	98.29511	99.57012	73.77506
##	[12,]	99.72413	96.35100		100.79935	68.40012		113.42439
##	[13,]	66.03137	70.55624	99.98128	86.84854	72.89159		107.82407
##	[14,]	99.64062		106.85102		66.24583		94.51597
##		110.28357		59.35424	98.26975	77.49808		104.67588
##	[16,]	56.74373		150.42785	78.08042		123.83225	
##		120.47637		70.24546	94.85844		112.35737	
ıτ Π	L±1,J	120.41001	00.22009	10.24040	J 1.00044	00.42019	112.00101	100.00221

##	[18,]	67.89917	116.86359	88.42893	108.78202	96.95514	88.63000	68.56466
##	[19,]	91.81847	93.41998	95.73748	101.34009	86.43454	114.89745	52.40600
##	[20,]	98.13135	67.69845	75.11621	83.13554	100.38347	121.69965	79.32037
##	[21,]	99.46210	93.28706	91.86067	101.21691	75.60344	68.27372	78.42862
##	[22,]	91.17778	128.01931	98.16292	127.33535	69.65381	82.81922	78.93080
##	[23,]	75.46301	87.86059	115.97261	113.63304	95.12118	80.58655	63.37022
##	[24,]	83.26834	111.20076	105.73822	102.28227	77.49631	98.58612	93.39667
##	[25,]	68.55790	110.10838	100.46246	53.49321	125.98680	100.47656	76.44052
##	[26,]	119.85390	85.59437	55.00740	92.41382	75.67292	59.95444	122.86800
##	[27,]	92.49620	61.38535	103.58587	73.68552	102.26847	88.30972	100.67167
##	[28,]	66.92182	105.98592	138.18188	68.11306	108.37508	86.50080	84.63528
##	[29,]	118.10735	94.63372	64.89339	99.53893	83.78756	70.95727	84.81907
##	[30,]	73.20171	77.65833	105.82500	64.51268	97.39322	138.25795	86.39108
##	[31,]	61.78026	83.24395	100.72429	76.54623	92.19680	82.20336	95.17983
##	[32,]	98.34534	117.23026	71.19786	76.73185	104.07105	68.57100	93.67004
##	[33,]	78.44378	92.87417	86.46417	61.56842	95.38993	108.45169	90.36050
##	[34,]	77.82284	114.26078	82.52458	76.20742	122.24020	71.89343	87.15190
##	[35,]	92.48914	79.60102	96.42829	95.49084	68.72440	90.06123	113.05115
##	[36,]	95.68956	45.91466	77.38783	73.29228	90.08072	97.65825	123.52641
##	[37,]	NA	98.12379	125.66948	63.45968	123.11268	105.44439	66.61949
##	[38,]	NA	NA	85.56053	79.78803	66.65798	111.60276	123.74604
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##	[78,]	NA NA	NA	NA	NA	NA	NA NA	NA
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##		[,44]	[,45]	[,46]	[,47]	[,48]	[,49]	[,50]
##	[1,]	[,44] 66.53988	[,45] 118.43150	[,46] 85.32692	[,47] 100.99697	[,48] 96.95496	[,49] 100.43911	[,50] 127.52665
	[1,] [2,]	[,44] 66.53988 113.34209	[,45] 118.43150 78.39392	[,46] 85.32692 123.15420	[,47] 100.99697 122.56999	[,48] 96.95496 93.40504	[,49] 100.43911 100.96701	[,50] 127.52665 91.47256
##	[1,] [2,] [3,]	[,44] 66.53988 113.34209 80.92493	[,45] 118.43150 78.39392 79.78632	[,46] 85.32692 123.15420 80.95631	[,47] 100.99697 122.56999 59.10644	[,48] 96.95496 93.40504 84.16186	[,49] 100.43911 100.96701 88.03367	[,50] 127.52665 91.47256 88.81150
## ##	[1,] [2,] [3,] [4,]	[,44] 66.53988 113.34209 80.92493 112.93307	[,45] 118.43150 78.39392 79.78632 109.45077	[,46] 85.32692 123.15420 80.95631 120.73921	[,47] 100.99697 122.56999 59.10644 96.70962	[,48] 96.95496 93.40504 84.16186 70.33379	[,49] 100.43911 100.96701 88.03367 138.82302	[,50] 127.52665 91.47256 88.81150 82.52269
## ## ##	[1,] [2,] [3,] [4,] [5,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122
## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613
## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122
## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976 87.59490	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314 95.24388	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870 120.05230	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523 87.57490	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728 102.00632	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989 82.98891	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613 93.87688 76.86640
## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,] [8,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976 87.59490 64.83348	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314 95.24388 78.30555	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870 120.05230 71.10847	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523 87.57490 97.04322	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728 102.00632 98.18971	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989 82.98891 77.10984	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613 93.87688 76.86640 104.48084
## ## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,] [8,] [9,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976 87.59490	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314 95.24388 78.30555 73.45389	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870 120.05230 71.10847 96.53930	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523 87.57490 97.04322 128.64975	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728 102.00632 98.18971 65.43251	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989 82.98891 77.10984 86.93592	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613 93.87688 76.86640 104.48084 107.24788
## ## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,] [8,] [9,] [10,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976 87.59490 64.83348 98.67748 109.53055	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314 95.24388 78.30555 73.45389 85.67372	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870 120.05230 71.10847 96.53930 97.91402	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523 87.57490 97.04322 128.64975 84.94856	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728 102.00632 98.18971 65.43251 78.63565	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989 82.98891 77.10984 86.93592 86.45368	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613 93.87688 76.86640 104.48084 107.24788 75.01535
## ## ## ## ## ## ##	[1,] [2,] [3,] [4,] [5,] [6,] [7,] [8,] [9,] [10,] [11,]	[,44] 66.53988 113.34209 80.92493 112.93307 90.69803 113.67263 72.65976 87.59490 64.83348 98.67748	[,45] 118.43150 78.39392 79.78632 109.45077 109.11295 124.16455 116.47314 95.24388 78.30555 73.45389 85.67372	[,46] 85.32692 123.15420 80.95631 120.73921 120.71228 91.23565 79.22870 120.05230 71.10847 96.53930 97.91402	[,47] 100.99697 122.56999 59.10644 96.70962 115.12051 106.86970 86.60523 87.57490 97.04322 128.64975 84.94856	[,48] 96.95496 93.40504 84.16186 70.33379 94.73958 82.15780 105.01728 102.00632 98.18971 65.43251 78.63565	[,49] 100.43911 100.96701 88.03367 138.82302 94.09133 104.09230 95.48989 82.98891 77.10984 86.93592 86.45368	[,50] 127.52665 91.47256 88.81150 82.52269 88.60122 83.54613 93.87688 76.86640 104.48084 107.24788 75.01535
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##	[46,]	102.91805	36.69848	104.96171	89.96021	86.18458	84.44761	126.72561
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                                                                                [,85]
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                                                                            84.74241
##
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                      74.33144
                                 76.12642
                                           74.86831
                                                      99.02869
                                                                  65.79672
                                                                            65.26637
     [2,]
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                                 67.59802
                                            99.19507
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                                                                 81.07376 105.12200
##
     [3,] 107.34501
##
     [4,]
           67.81346
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                                 87.95296
                                            96.75007 101.89847
                                                                 93.70026
                                                                            89.73482
           34.89426 67.80491 74.64158 85.56596 110.71087
##
     [5.]
                                                                 53.05257
                                                                            73.50923
```

```
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##
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##
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##
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                                                           67.64293
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##
```

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                                                                      81.88070
    [91,] 60.39093 114.83865 103.15192 72.11576 102.81762
                                                            81.04513 97.52396
##
    [92,] 100.43356 95.70529 69.45787 50.48420 102.38216 120.77655 106.40380
                NA 122.23095 111.67417 68.84526 112.97896 87.14394 81.41266
##
    [93.]
                                                            90.46459 107.14791
##
    [94,]
                NA
                          NA 80.11855 102.90223 73.94147
##
    [95,]
                NA
                          NA
                                    NA
                                        86.16846 78.52953 99.18490 92.83617
##
    [96,]
                NA
                          NA
                                              NA 107.39945 115.22470 112.63647
                                    NA
##
    [97.]
                          NA
                                     NA
                                                            78.69166 108.52928
                NA
                                              NA
                                                         NA
                NA
##
    [98,]
                          NA
                                     NA
                                              NA
                                                         NA
                                                                   NA 86.62138
    [99,]
                NA
                          NA
                                     NA
                                              NA
                                                        NA
                                                                   NA
                                                                            NA
##
   [100,]
                NA
                          NA
                                     NA
                                              NA
                                                         NA
                                                                   NA
                                                                             NA
##
             [,100]
##
          65.99319
     [1,]
          84.51048
##
     [2,]
##
     [3,]
          77.90511
##
     [4,]
          63.13909
          78.52005
##
     [5,]
##
     [6,]
          97.82168
##
     [7,] 100.15137
##
     [8.]
          89.28846
##
     [9,]
          98.27539
##
    [10,]
          79.42284
##
    [11,]
          98.35024
##
    [12,]
          93.14145
    [13,]
          62.27930
##
    [14,]
          65.26299
##
    [15.]
          75.73070
##
    [16,]
          88.67729
    [17,]
          85.03861
    [18,] 87.02238
##
##
    [19,] 108.18550
##
    [20,] 83.60846
    [21,]
          80.87928
##
    [22,]
          92.80995
##
    [23,]
          98.44394
##
    [24,] 69.03604
##
    [25,] 102.92839
   [26,] 95.57515
##
```

```
[27,] 119.09561
##
    [28,] 100.46579
##
    [29,] 110.59742
    [30,] 62.15980
##
##
    [31,] 52.54052
##
    [32,] 97.54366
##
    [33,]
           94.49460
##
    [34,] 77.92029
##
    [35,] 114.70887
##
           69.26834
    [36,]
    [37,]
           78.13654
##
    [38,]
           85.94180
##
    [39,]
           75.39051
##
    [40,]
           78.84338
##
    [41,]
           87.49635
##
    [42,] 91.05198
##
    [43,] 103.08059
##
    [44,] 72.10851
##
    [45,] 119.25893
    [46,] 80.94849
##
##
    [47,] 112.27462
##
    [48,] 85.46214
    [49,] 117.41276
##
##
    [50,] 128.54113
##
    [51,] 86.38822
    [52,] 82.54453
##
    [53,] 105.42955
##
    [54,] 76.98045
##
    [55,] 78.18214
    [56,] 44.82738
##
##
    [57,] 121.11101
##
    [58,]
          90.93224
##
           93.97013
    [59,]
##
    [60,]
           93.94430
##
    [61,]
           90.16321
##
    [62,] 89.92554
##
    [63,] 95.89457
##
    [64,] 116.54491
##
    [65,] 68.84304
##
    [66,] 116.42135
    [67,] 85.58530
##
    [68,] 96.68509
##
    [69,] 58.45886
##
    [70,] 101.66187
##
    [71,]
           90.17372
##
    [72,] 87.05025
##
    [73,] 86.78156
##
    [74,] 110.55147
##
    [75,] 70.34240
##
    [76,] 82.52590
##
    [77,] 130.13096
##
    [78,] 98.55841
##
    [79,] 96.46605
    [80,] 100.34550
##
```

```
##
    [81,]
           75.60389
##
    [82,]
          73.58756
##
    [83,] 111.58862
    [84,] 93.96905
##
##
    [85,] 115.67744
    [86,]
##
           82.82674
##
    [87.]
           69.75526
##
    [88,]
           99.91288
##
    [89,] 117.98834
##
    [90,]
           76.93727
##
    [91,]
           78.90357
    [92,]
##
           55.84959
##
    [93,] 107.86074
##
    [94,]
           75.68157
##
    [95,]
           53.01698
##
    [96,]
           76.78718
##
    [97,]
           65.43208
    [98,]
           93.47075
    [99,] 129.70564
##
## [100,]
```

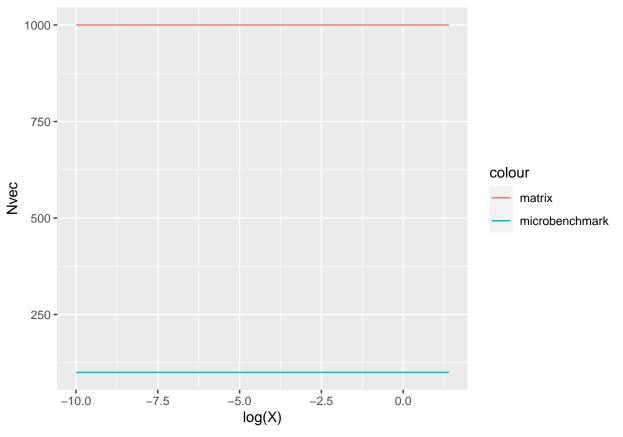
Test the time difference between these functions for n = 1000 and Nvec = 100, 500, 1000, 5000 using the package microbenchmark. Store the results in a matrix with rows representing Nvec and two columns for base R and Rcpp.

```
pacman::p_load(microbenchmark)
n<- 1000
N vec <-100
X= matrix(data=rnorm(Nvec*n), nrow=Nvec)
microbenchmark(all_angles(X),all_angles_cpp(X),times = 10 )
## Unit: milliseconds
##
                              min
                                           lq
                                                    mean
                                                              median
                  expr
                                                                              uq
        all_angles(X) 624.936917 626.010334 634.499838 631.145542 639.917709
##
##
    all_angles_cpp(X)
                         5.478959
                                     5.641084
                                                5.729605
                                                            5.661625
                                                                        5.678334
##
         max neval
##
    654.4513
                10
##
      6.5880
                10
```

Plot the divergence of performance (in log seconds) over n using a line geometry. Use two different colors for the R and CPP functions. Make sure there's a color legend on your plot. We wil see later how to create "long" matrices that make such plots easier.

```
pacman::p_load(ggplot2)
ggplot() + geom_line(aes(y=Nvec, x=log(X), col="microbenchmark")) + geom_line(aes(y=n, x=log(X), col="m
## Warning in log(X): NaNs produced
## Warning in log(X): NaNs produced
## Warning in log(X): NaNs produced
## Warning: Removed 49910 row(s) containing missing values (geom_path).
```

Warning: Removed 49910 row(s) containing missing values (geom_path).



Let Nvec = 10000 and vary n to be 10, 100, 1000. Plot the density of angles for all three values of n on one plot using color to signify n. Make sure you have a color legend. This is not easy.

```
#Nvec =1000
#X<- c()
#for (i in 1:10) {
 # x <- rnorm(Nvec)</pre>
  \#X \leftarrow cbind(X,x)
#}
#angle1 <- all_angle(X)</pre>
#X<- c()
#for (i in 1:100) {
# x < - rnorm (Nvec)
\# X \leftarrow cbind(X,x)
\#angle2 \leftarrow all\_angle(X, 100)
#X<- c()
#for (i in 1:1000) {
 # x<- rnorm (Nvec)
  \#X \leftarrow cbind(X,x)
```

Write an R function nth_fibonnaci that finds the nth Fibonnaci number via recursion but allows you to specify the starting number. For instance, if the sequency started at 1, you get the familiar 1, 1, 2, 3, 5, etc. But if it started at 0.01, you would get 0.01, 0.01, 0.02, 0.03, 0.05, etc.

```
nth_fibonacci <- function(n,start){
  if (n==1 | n== 2) return (start)
  else return (nth_fibonacci (n-1, start)+ nth_fibonacci(n-2,start))</pre>
```

```
nth_fibonacci
}
```

Write an Rcpp function nth_fibonnaci_cpp that does the same thing. Use an IDE if ou want, but write it below in-line.

```
#TODO
```

Time the difference in these functions for $n = 100, 200, \ldots, 1500$ while starting the sequence at the smallest possible floating point value in R. Store the results in a matrix.

```
n<- c(1:15) * 100
timer <- c()
timecpp <- c()</pre>
```

Plot the divergence of performance (in log seconds) over n using a line geometry. Use two different colors for the R and CPP functions. Make sure there's a color legend on your plot.

```
#ggplot()
#geom_line (aes(y= n,x= log (timer),col = "timer")) +
# geom_line (aes(y= n,x= log (timecpp),col = "timercpp")) +
```

Data Wrangling / Munging / Carpentry

Throughout this assignment you can use either the tidyverse package suite or data.table to answer but not base R. You can mix data.table with magrittr piping if you wish but don't go back and forth between tbl_df's and data.table objects.

```
pacman::p_load(dplyr, magrittr, data.table)
```

Load the storms dataset from the dplyr package and investigate it using str and summary and head. Which two columns should be converted to type factor? Do so below.

```
data(storms)
str(storms)
```

```
## tibble[,13] [10,010 x 13] (S3: tbl_df/tbl/data.frame)
            $ name
##
                                                     : chr [1:10010] "Amy" "Amy" "Amy" "Amy" ...
##
            $ year
                                                     : num [1:10010] 1975 1975 1975 1975 ...
                                                     : num [1:10010] 6 6 6 6 6 6 6 6 6 6 ...
            $ month
                                                     : int [1:10010] 27 27 27 27 28 28 28 28 29 29 ...
##
           $ day
##
                                                     : num [1:10010] 0 6 12 18 0 6 12 18 0 6 ...
            $ hour
##
         $ lat
                                                     : num [1:10010] 27.5 28.5 29.5 30.5 31.5 32.4 33.3 34 34.4 34 ...
##
                                                     : num [1:10010] -79 -79 -79 -79 -78.8 -78.7 -78 -77 -75.8 -74.8 ...
        $ long
##
                                                     : chr [1:10010] "tropical depression" "tropical depression "tropical depression" "tropic
## $ category
                                                     : Ord.factor w/ 7 levels "-1"<"0"<"1"<"2"<..: 1 1 1 1 1 1 1 1 2 2 ...
        $ wind
                                                      : int [1:10010] 25 25 25 25 25 25 25 30 35 40 ...
##
                                                     : int [1:10010] 1013 1013 1013 1013 1012 1012 1011 1006 1004 1002 ...
##
            $ pressure
            $ ts diameter: num [1:10010] NA ...
            $ hu_diameter: num [1:10010] NA ...
head(storms)
```

```
## # A tibble: 6 x 13
##
     name
             year month
                           day hour
                                        lat long status
                                                                  category wind pressure
     <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <
                                                                            <int>
                                                                                      <int>
                                       27.5 -79
                                                                               25
                                                                                       1013
## 1 Amy
             1975
                       6
                            27
                                    0
                                                   tropical de~ -1
## 2 Amy
             1975
                       6
                            27
                                    6
                                       28.5 - 79
                                                   tropical de~ -1
                                                                               25
                                                                                       1013
```

```
## 3 Amy
            1975
                           27
                                 12
                                     29.5 - 79
                                                 tropical de~ -1
                                                                           25
                                                                                   1013
                     6
                                                                           25
                                                                                   1013
## 4 Amy
            1975
                           27
                                 18
                                     30.5 - 79
                                                 tropical de~ -1
                     6
## 5 Amy
            1975
                           28
                                  0
                                     31.5 -78.8 tropical de~ -1
                                                                           25
                                                                                   1012
            1975
                           28
                                  6 32.4 -78.7 tropical de~ -1
                                                                           25
                                                                                   1012
## 6 Amy
                      6
## # ... with 2 more variables: ts_diameter <dbl>, hu_diameter <dbl>
```

Reorder the columns so name is first, status is second, category is third and the rest are the same.

storms%>%

select(name, status, category, everything())

```
## # A tibble: 10,010 x 13
##
      name status
                         category year month
                                                day hour
                                                             lat long wind pressure
##
      <chr> <chr>
                                  <dbl> <dbl> <int> <dbl> <dbl> <dbl> <int>
                         <ord>
##
  1 Amy
            tropical d~ -1
                                   1975
                                            6
                                                  27
                                                         0
                                                           27.5 - 79
                                                                           25
                                                                                  1013
## 2 Amy
            tropical d~ -1
                                   1975
                                            6
                                                  27
                                                         6
                                                            28.5 -79
                                                                           25
                                                                                  1013
## 3 Amy
            tropical d~ -1
                                   1975
                                            6
                                                  27
                                                        12
                                                            29.5 - 79
                                                                          25
                                                                                  1013
## 4 Amy
                                                  27
                                                            30.5 -79
                                                                          25
                                                                                  1013
            tropical d~ -1
                                   1975
                                            6
                                                        18
## 5 Amy
            tropical d~ -1
                                   1975
                                            6
                                                  28
                                                         0
                                                            31.5 -78.8
                                                                          25
                                                                                  1012
## 6 Amy
                                                  28
                                                            32.4 -78.7
                                                                          25
            tropical d~ -1
                                   1975
                                            6
                                                         6
                                                                                  1012
##
            tropical d~ -1
                                   1975
                                            6
                                                  28
                                                            33.3 -78
                                                                          25
                                                                                  1011
  7 Amy
                                                        12
## 8 Amy
            tropical d~ -1
                                   1975
                                                  28
                                                            34
                                                                 -77
                                                                          30
                                                                                  1006
                                            6
                                                        18
            tropical s~ 0
                                   1975
                                            6
                                                  29
                                                         0
                                                            34.4 -75.8
                                                                          35
                                                                                  1004
## 9 Amy
                                                         6 34
                                            6
                                                                                  1002
## 10 Amy
            tropical s~ 0
                                   1975
                                                  29
                                                                 -74.8
                                                                           40
## # ... with 10,000 more rows, and 2 more variables: ts_diameter <dbl>,
     hu_diameter <dbl>
```

Find a subset of the data of storms only in the 1970's.

hu_diameter <dbl>

##

1 Anita 1977

```
storms %>%
filter(year >= 1970 & year <= 1979)
```

```
## # A tibble: 546 x 13
##
      name
             year month
                                       lat long status
                                                              category wind pressure
                           day hour
##
      <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <
                                                              <ord>
                                                                       <int>
                                                                                 <int>
##
  1 Amy
             1975
                      6
                            27
                                   0 27.5 -79
                                                 tropical d~ -1
                                                                          25
                                                                                  1013
   2 Amy
                            27
                                     28.5 - 79
                                                                          25
##
             1975
                      6
                                   6
                                                 tropical d~ -1
                                                                                  1013
## 3 Amy
             1975
                      6
                            27
                                  12 29.5 -79
                                                 tropical d~ -1
                                                                          25
                                                                                  1013
## 4 Amy
             1975
                      6
                            27
                                  18 30.5 -79
                                                 tropical d~ -1
                                                                          25
                                                                                  1013
## 5 Amy
             1975
                      6
                            28
                                   0 31.5 -78.8 tropical d~ -1
                                                                          25
                                                                                  1012
##
   6 Amy
             1975
                      6
                            28
                                   6
                                      32.4 -78.7 tropical d~ -1
                                                                          25
                                                                                  1012
##
  7 Amy
             1975
                      6
                            28
                                     33.3 -78
                                                 tropical d~ -1
                                                                          25
                                                                                  1011
                                  12
##
  8 Amv
             1975
                      6
                            28
                                     34
                                           -77
                                                 tropical d~ -1
                                                                          30
                                                                                  1006
                                  18
## 9 Amy
                                      34.4 -75.8 tropical s~ 0
                                                                                  1004
             1975
                      6
                            29
                                   0
                                                                          35
                                           -74.8 tropical s~ 0
## 10 Amy
             1975
                      6
                            29
                                   6
                                     34
                                                                          40
                                                                                  1002
## # ... with 536 more rows, and 2 more variables: ts_diameter <dbl>,
```

Find a subset of the data of storm observations only with category 4 and above and wind speed 100MPH and above.

```
storms %>%
  filter(category >= 4 & wind >= 100)

## # A tibble: 416 x 13
## name year month day hour lat long status category wind pressure
```

<ord>

<int>

<int>

<chr> <dbl> <dbl> <int> <dbl> <dbl> <dbl> <chr>

2

9

```
2 Anita 1977
                                      24.2 -97.1 hurricane 5
                                                                        150
                                                                                  926
##
    3 Anita 1977
                                      23.7 - 98
                                                                        120
                                                                                  940
                       9
                             2
                                  12
                                                  hurricane 4
##
    4 David
            1979
                       8
                            28
                                      12.2 -52.9 hurricane 4
                                                                        115
                                                                                  947
##
   5 David 1979
                            28
                                      12.5 -54.4 hurricane 4
                                                                        125
                                                                                  941
                       8
                                   6
##
    6 David
             1979
                       8
                            28
                                  12
                                      12.8 -55.7 hurricane 4
                                                                        130
                                                                                  938
##
    7 David
            1979
                       8
                            28
                                  18
                                      13.2 -56.9 hurricane 4
                                                                        125
                                                                                  941
    8 David
            1979
                       8
                            29
                                   0
                                      13.7 -58
                                                  hurricane 4
                                                                        120
                                                                                  944
##
    9 David 1979
                       8
                            29
                                   6
                                      14.2 -59.2 hurricane 4
                                                                        120
                                                                                  942
## 10 David 1979
                       8
                            29
                                  12
                                      14.8 -60.3 hurricane 4
                                                                        125
                                                                                  938
## # ... with 406 more rows, and 2 more variables: ts_diameter <dbl>,
       hu_diameter <dbl>
```

Create a new feature wind_speed_per_unit_pressure.

```
storms %>%
mutate(wind_speed_per_unit_pressure = wind /pressure)
```

```
## # A tibble: 10,010 x 14
##
              year month
                                 hour
                                          lat long status
                                                                  category
                                                                             wind pressure
                            day
##
      <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <
                                                                            <int>
                                                                  <ord>
                                                                                      <int>
##
    1 Amy
              1975
                        6
                             27
                                     0
                                        27.5 - 79
                                                     tropical d~ -1
                                                                               25
                                                                                       1013
##
              1975
                             27
                                        28.5 - 79
                                                                               25
                                                                                       1013
    2 Amy
                        6
                                     6
                                                     tropical d~ -1
##
    3 Amv
              1975
                        6
                             27
                                        29.5 - 79
                                                     tropical d~ -1
                                                                               25
                                    12
                                                                                       1013
                                    18
##
    4 Amy
              1975
                        6
                             27
                                        30.5 - 79
                                                     tropical d~ -1
                                                                               25
                                                                                       1013
##
    5 Amy
                        6
                             28
                                     0
                                        31.5 -78.8 tropical d~ -1
                                                                               25
              1975
                                                                                       1012
##
    6 Amy
              1975
                        6
                             28
                                     6
                                        32.4 - 78.7 \text{ tropical } d^{-1}
                                                                               25
                                                                                       1012
                        6
                             28
                                        33.3 -78
                                                                               25
##
    7 Amy
              1975
                                    12
                                                     tropical d~ -1
                                                                                       1011
                        6
                             28
                                                                               30
##
    8 Amy
              1975
                                    18
                                        34
                                              -77
                                                     tropical d~ -1
                                                                                       1006
    9 Amy
              1975
                        6
                             29
                                     0
                                        34.4 -75.8 tropical s~ 0
                                                                               35
                                                                                       1004
              1975
                        6
                             29
                                              -74.8 tropical s~ 0
                                                                                       1002
## 10 Amy
                                     6
                                        34
                                                                               40
## # ... with 10,000 more rows, and 3 more variables: ts_diameter <dbl>,
      hu_diameter <dbl>, wind_speed_per_unit_pressure <dbl>
```

Create a new feature: average_diameter which averages the two diameter metrics. If one is missing, then use the value of the one that is present. If both are missing, leave missing.

```
storms %>%
  rowwise() %>%
  arrange(desc(year)) %>%
  mutate (average_diamter= mean (c(ts_diameter,hu_diameter),na.rm=TRUE))
```

```
## # A tibble: 10,010 x 14
## # Rowwise:
##
      name
                                         lat long status
                                                                  category
                                                                            wind pressure
              year month
                            day hour
##
      <chr> <dbl> <dbl> <int>
                                 <dbl> <dbl> <dbl> <chr>
                                                                  <ord>
                                                                            <int>
                                                                                      <int>
##
    1 Ana
              2015
                        5
                              9
                                     6
                                       32.2 -77.5 tropical s~ 0
                                                                               50
                                                                                        998
##
    2 Ana
              2015
                        5
                              9
                                    12
                                        32.5 -77.8 tropical s~ 0
                                                                               50
                                                                                       1001
                                                                                       1001
##
    3 Ana
              2015
                        5
                              9
                                    18
                                        32.7 - 78
                                                    tropical s~ 0
                                                                               45
                        5
##
    4 Ana
              2015
                             10
                                     0
                                        33.1 -78.3 tropical s~ 0
                                                                               45
                                                                                       1001
##
   5 Ana
              2015
                        5
                                        33.5 -78.6 tropical s~ 0
                                                                               40
                                                                                       1002
                             10
                                     6
##
    6 Ana
              2015
                        5
                             10
                                    10
                                        33.8 -78.8 tropical s~ 0
                                                                               40
                                                                                       1002
##
    7 Ana
              2015
                        5
                             10
                                    12
                                        33.9 - 78.8 \text{ tropical s} \sim 0
                                                                               35
                                                                                       1002
##
    8 Ana
              2015
                        5
                             10
                                    18
                                        34.3 - 78.7 \text{ tropical } d^{-1}
                                                                               30
                                                                                       1006
##
                                                                               30
                                                                                       1009
    9 Ana
              2015
                        5
                             11
                                     0
                                        34.7 -78.5 tropical d~ -1
## 10 Ana
              2015
                        5
                                        35.5 -78
                                                    tropical d~ -1
                                                                               30
                                                                                       1010
                             11
                                     6
## # ... with 10,000 more rows, and 3 more variables: ts_diameter <dbl>,
```

```
## # hu_diameter <dbl>, average_diamter <dbl>
```

#finish

For each storm, summarize the maximum wind speed. "Summarize" means create a new dataframe with only the summary metrics you care about.

```
storms %>%
group_by(name) %>%
summarise(max_wind_speed= max(wind,na.rm=TRUE))
```

```
## # A tibble: 198 x 2
##
      name
               max_wind_speed
##
      <chr>
                         <int>
##
    1 AL011993
                           30
##
  2 AL012000
                           25
## 3 AL021992
                           30
## 4 AL021994
                           30
## 5 AL021999
                           30
## 6 AL022000
                           30
## 7 AL022001
                           25
##
   8 AL022003
                           30
## 9 AL022006
                           45
## 10 AL031987
                            40
## # ... with 188 more rows
```

Order your dataset by maximum wind speed storm but within the rows of storm show the observations in time order from early to late.

```
storms %>%
  group_by (name) %>%
  mutate(max_wind_by_storm = max(wind,na.rm =TRUE)) %>%
  select (name, max_wind_by_storm,everything()) %>%
  arrange(desc(max_wind_by_storm),year,month,day,hour)
```

```
## # A tibble: 10,010 x 14
## # Groups:
               name [198]
##
      name
             max_wind_by_sto~ year month
                                                  hour
                                                          lat
                                                              long status
                                                                              category
                                              day
##
                         <int> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dr>
      <chr>
                                                                              <ord>
##
    1 Gilbe~
                           160 1988
                                         9
                                                8
                                                     18
                                                         12
                                                               -54
                                                                     tropica~ -1
##
    2 Gilbe~
                           160 1988
                                         9
                                                9
                                                      0
                                                         12.7 -55.6 tropica~ -1
  3 Gilbe~
                           160 1988
                                                         13.3 -57.1 tropica~ -1
                           160 1988
## 4 Gilbe~
                                         9
                                                9
                                                     12
                                                         14
                                                              -58.6 tropica~ -1
                                         9
                                                9
##
    5 Gilbe~
                           160 1988
                                                     18
                                                         14.5 -60.1 tropica~ 0
## 6 Gilbe~
                           160 1988
                                         9
                                              10
                                                      0
                                                         14.8 -61.5 tropica~ 0
## 7 Gilbe~
                           160 1988
                                         9
                                                              -62.8 tropica~ 0
                                              10
                                                      6
                                                         15
## 8 Gilbe~
                           160 1988
                                         9
                                              10
                                                     12
                                                         15.3 -64.1 tropica~ 0
## 9 Gilbe~
                           160
                               1988
                                         9
                                               10
                                                     18
                                                         15.7 -65.4 tropica~ 0
                                         9
## 10 Gilbe~
                           160 1988
                                               11
                                                      0
                                                        15.9 -66.8 hurrica~ 1
## # ... with 10,000 more rows, and 4 more variables: wind <int>, pressure <int>,
       ts_diameter <dbl>, hu_diameter <dbl>
```

Find the strongest storm by wind speed per year.

```
storms %>%
  group_by(year) %>%
  arrange(year,desc(wind)) %>%
  slice(1)
```

```
## # A tibble: 41 x 13
## # Groups:
                year [41]
##
      name
                year month
                              day hour
                                           lat long status
                                                                category wind pressure
##
      <chr>
                <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dr>
                                                                <ord>
                                                                          <int>
                                                                                   <int>
##
    1 Caroline
                1975
                          8
                                31
                                       0
                                          24
                                                -97
                                                      hurrica~ 3
                                                                            100
                                                                                     973
    2 Belle
                 1976
                          8
                                 9
                                       0
                                          30.9 -75.3 hurrica~ 3
                                                                            105
##
                                                                                     957
    3 Anita
                          9
                                 2
                                          24.2 -97.1 hurrica~ 5
##
                 1977
                                       6
                                                                            150
                                                                                     926
##
    4 Cora
                 1978
                          8
                                 9
                                       0
                                          14
                                                -44.9 hurrica~ 1
                                                                             80
                                                                                     980
##
    5 David
                 1979
                          8
                                30
                                      18
                                          16.6 -66.2 hurrica~ 5
                                                                            150
                                                                                     924
                                                                                     970
##
    6 Ivan
                 1980
                         10
                                6
                                      18
                                          28.1 -31.1 hurrica~ 2
                                                                             90
##
    7 Harvey
                 1981
                          9
                                15
                                       0
                                          28.4 -62.6 hurrica~ 4
                                                                            115
                                                                                     946
                 1982
                          9
                                       0
                                          38.8 -62.3 hurrica~ 4
                                                                            115
                                                                                     950
##
    8 Debby
                                18
##
   9 Alicia
                 1983
                          8
                                18
                                       6
                                          28.9 -95
                                                      hurrica~ 3
                                                                            100
                                                                                     963
## 10 Diana
                 1984
                                          33.9 -77.7 hurrica~ 4
                          9
                                12
                                       0
                                                                            115
                                                                                     949
## # ... with 31 more rows, and 2 more variables: ts_diameter <dbl>,
       hu_diameter <dbl>
```

#select(wind, year)

For each named storm, find its maximum category, wind speed, pressure and diameters. Do not allow the max to be NA (unless all the measurements for that storm were NA).

```
storms %>%
group_by(name) %>% summarise(max_category = max(category),
max_windspeed = max(wind),
max_pressure = max(pressure),
max_diameter_ts = max(ts_diameter),
max_diameter_hu = max(hu_diameter)) %>% na.omit()
## # A tibble: 54 x 6
##
      name max_category max_windspeed max_pressure max_diameter_ts max_diameter_hu
##
      <chr> <ord>
                                   <int>
                                                                  <dbl>
                                                                                   <dbl>
                                                 <int>
##
    1 ALO2~ 0
                                      45
                                                  1008
                                                                   69.0
                                                                                     0
##
    2 AL10~ -1
                                      30
                                                  1013
                                                                    Λ
                                                                                     0
##
    3 A120~ 0
                                      40
                                                                   69.0
                                                                                     0
                                                  1011
##
   4 Andr~ 0
                                      55
                                                  1006
                                                                  207.
                                                                                     0
    5 Beta 3
                                     100
                                                                                    34.5
##
                                                  1007
                                                                  127.
   6 Colin 0
                                                                                     0
##
                                      50
                                                  1013
                                                                  104.
   7 Don
                                      45
                                                  1007
                                                                   69.0
                                                                                     0
   8 Dori~ 0
                                      50
                                                                   80.6
                                                                                     0
##
                                                  1013
  9 Eight -1
                                      30
##
                                                  1009
                                                                    0
                                                                                     0
## 10 Epsi~ 1
                                      75
                                                  1005
                                                                  276.
                                                                                    63.3
## # ... with 44 more rows
```

For each year in the dataset, tally the number of storms. "Tally" is a fancy word for "count the number of". Plot the number of storms by year. Any pattern?

```
data(storms)
storms %>%
group_by(year) %>% summarize(num_storms = n_distinct(name))
```

```
## # A tibble: 41 x 2
## year num_storms
## <dbl> <int>
## 1 1975 3
## 2 1976 2
## 3 1977 3
```

```
##
   5 1979
                     7
##
   6 1980
                     8
##
   7 1981
                     5
##
    8
       1982
                     5
##
  9 1983
                     4
## 10 1984
                    10
## # ... with 31 more rows
For each year in the dataset, tally the storms by category.
storms %>% group_by(year, category) %>% summarise(storms = n())
## `summarise()` has grouped output by 'year'. You can override using the `.groups` argument.
## # A tibble: 233 x 3
               year [41]
## # Groups:
       year category storms
##
      <dbl> <ord>
                      <int>
##
    1 1975 -1
                         30
    2 1975 0
##
                         33
##
   3 1975 1
                         12
##
    4 1975 2
                          9
##
    5 1975 3
                          2
##
   6 1976 -1
                         10
                         20
##
   7 1976 0
  8 1976 1
                         10
##
## 9 1976 2
                          9
## 10 1976 3
                          3
## # ... with 223 more rows
For each year in the dataset, find the maximum wind speed per status level.
storms%>%
  group_by(year,status)%>%
 summarize (max_wind = max(wind))
## `summarise()` has grouped output by 'year'. You can override using the `.groups` argument.
## # A tibble: 123 x 3
## # Groups:
               year [41]
       year status
##
                                 max_wind
      <dbl> <chr>
##
                                    <int>
##
   1 1975 hurricane
                                      100
##
    2 1975 tropical depression
                                       30
    3 1975 tropical storm
##
                                       60
##
   4 1976 hurricane
                                      105
##
   5 1976 tropical depression
                                       30
##
  6 1976 tropical storm
                                       60
##
       1977 hurricane
                                      150
##
  8 1977 tropical depression
                                       30
  9 1977 tropical storm
                                       60
## 10 1978 hurricane
                                       80
## # ... with 113 more rows
```

For each storm, summarize its average location in latitude / longitude coordinates.

##

4 1978

4

```
storms %>% group_by(year, status) %>% summarise(maxwind = max(wind))
## `summarise()` has grouped output by 'year'. You can override using the `.groups` argument.
## # A tibble: 123 x 3
## # Groups:
              year [41]
       year status
                                maxwind
##
##
      <dbl> <chr>
                                  <int>
##
   1 1975 hurricane
                                    100
   2 1975 tropical depression
                                     30
##
      1975 tropical storm
##
   3
                                     60
##
   4 1976 hurricane
                                    105
##
   5 1976 tropical depression
                                     30
##
   6 1976 tropical storm
                                     60
##
   7 1977 hurricane
                                    150
   8 1977 tropical depression
##
                                     30
  9 1977 tropical storm
                                     60
## 10 1978 hurricane
                                     80
## # ... with 113 more rows
```

For each storm, summarize its duration in number of hours (to the nearest 6hr increment).

```
#storms %>% group_by(name) %>% summarise(lats = mean(lats), long = mean(long))
#storms()
```

For storm in a category, create a variable **storm_number** that enumerates the storms 1, 2, ... (in date order). #TO-DO

Convert year, month, day, hour into the variable timestamp using the lubridate package. Although the new package clock just came out, lubridate still seems to be standard. Next year I'll probably switch the class to be using clock.

```
pacman::p_load(lubridate)
storms %>% mutate(timestamp = c(paste(year, month, day, hour, sep = "-")))
```

```
## # A tibble: 10,010 x 14
##
      name
              year month
                                         lat long status
                                                                 category wind pressure
                            day hour
##
      <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <
                                                                           <int>
                                                                                    <int>
##
    1 Amy
              1975
                       6
                             27
                                    0
                                       27.5 -79
                                                    tropical d~ -1
                                                                              25
                                                                                      1013
    2 Amy
              1975
                        6
                             27
                                       28.5 -79
                                                                              25
                                                                                      1013
##
                                    6
                                                    tropical d~ -1
                                    12 29.5 -79
                                                                              25
##
    3 Amy
              1975
                       6
                             27
                                                    tropical d~ -1
                                                                                     1013
##
   4 Amv
              1975
                       6
                             27
                                   18
                                       30.5 - 79
                                                    tropical d~ -1
                                                                              25
                                                                                     1013
                                       31.5 -78.8 tropical d~ -1
                                                                              25
                                                                                      1012
##
    5 Amy
              1975
                       6
                             28
                                    0
##
    6 Amy
              1975
                        6
                             28
                                    6
                                        32.4 -78.7 tropical d~ -1
                                                                              25
                                                                                      1012
##
    7 Amy
              1975
                        6
                             28
                                       33.3 -78
                                                    tropical d~ -1
                                                                              25
                                                                                      1011
                                    12
##
    8 Amy
              1975
                        6
                             28
                                    18
                                       34
                                             -77
                                                    tropical d~ -1
                                                                              30
                                                                                      1006
              1975
                             29
                                    0
                                        34.4 - 75.8 \text{ tropical s} \sim 0
                                                                              35
                                                                                      1004
##
    9 Amy
                        6
## 10 Amy
              1975
                        6
                             29
                                    6
                                        34
                                             -74.8 tropical s~ 0
                                                                              40
                                                                                      1002
## # ... with 10,000 more rows, and 3 more variables: ts_diameter <dbl>,
       hu_diameter <dbl>, timestamp <chr>
```

Using the lubridate package, create new variables day_of_week which is a factor with levels "Sunday", "Monday", ... "Saturday" and week of year which is integer 1, 2, ..., 52.

```
#T0-D0
```

For each storm, summarize the day in which is started in the following format "Friday, June 27, 1975".

$\#T\Omega-D\Omega$

Create a new factor variable decile_windspeed by binning wind speed into 10 bins.

```
bins = range(0:10)
storms %<>% mutate(decile_windspeed = factor(cut(wind, breaks = quantile(wind, bins/10), labels = FALSE
```

Create a new data frame serious_storms which are category 3 and above hurricanes.

```
serious_storms <- storms %>%
filter(category >= 3 )
```

In serious_storms, merge the variables lat and long together into lat_long with values lat / long as a string.

```
serious_storms %<>%
mutate(lat_long = paste(lat, long, sep=" "))
```

Let's return now to the original storms data frame. For each category, find the average wind speed, pressure and diameters (do not count the NA's in your averaging).

```
storms %>% group_by(lat) %>% summarise(average_wind=mean(wind), average_pressure = mean(pressure))
```

```
## # A tibble: 403 x 3
##
        lat average_wind average_pressure
##
       <dbl>
                     <dbl>
                                        <dbl>
##
        7.2
                      25
                                        1010
    1
##
    2
        7.4
                      25
                                        1010
##
    3
        8.3
                      30
                                        1009
                      27.5
##
    4
        8.4
                                        1009
##
    5
                      25
        8.6
                                        1008
##
    6
        8.8
                      25
                                        1010
    7
##
        8.9
                      37.5
                                        1004.
##
    8
         9
                      36.7
                                        1003
##
    9
        9.1
                      35
                                        1004.
## 10
        9.2
                      27.5
                                        1009.
## # ... with 393 more rows
```

storms %>% group_by(long) %>% summarise(average_wind=mean(wind), average_pressure = mean(pressure))

```
## # A tibble: 856 x 3
##
       long average_wind average_pressure
##
      <dbl>
                     <dbl>
                                        <dbl>
##
    1 -109.
                        20
                                         1008
##
    2 -109.
                        20
                                         1008
##
    3 -109
                        20
                                         1008
   4 -109.
##
                        25
                                         1008
##
    5 -109.
                        25
                                         1007
##
    6 -108.
                        25
                                         1007
    7 -108.
                        25
                                         1007
                        25
##
    8 -108
                                         1006
##
    9 -108.
                        25
                                         1006
## 10 -107.
                        25
                                         1005
## # ... with 846 more rows
```

For each named storm, find its maximum category, wind speed, pressure and diameters (do not allow the max to be NA) and the number of readings (i.e. observations).

```
storms %>% group_by(name) %>% summarise(max_wind=max(wind), max_pressure = max(pressure),

max_diam_ts = max(ts_diameter), max_diam_hu = max(hu_diameter)
```

```
## # A tibble: 198 x 5
                max_wind max_pressure max_diam_ts max_diam_hu
##
      name
##
      <chr>
                    <int>
                                  <int>
                                               <dbl>
##
    1 AL011993
                       30
                                   1003
                                                NA
                                                                NA
                       25
##
    2 AL012000
                                   1010
                                                NA
                                                                NA
##
    3 AL021992
                       30
                                   1009
                                                NA
                                                                NA
##
    4 AL021994
                       30
                                   1017
                                                NA
                                                                NA
##
    5 AL021999
                       30
                                   1006
                                                NA
                                                                NA
##
    6 AL022000
                       30
                                   1010
                                                NA
                                                                NA
##
    7 AL022001
                       25
                                   1012
                                                NA
                                                                NA
##
    8 AL022003
                       30
                                   1010
                                                NA
                                                                NA
##
    9 AL022006
                       45
                                   1008
                                                69.0
                                                                 0
## 10 AL031987
                       40
                                   1015
                                                NA
                                                                NA
## # ... with 188 more rows
```

Calculate the distance from each storm observation to Miami in a new variable distance_to_miami. This is very challenging. You will need a function that computes distances from two sets of latitude / longitude coordinates.

```
MIAMI_LAT_LONG_COORDS = c(25.7617, -80.1918)
#TO-DO
```

For each storm observation, use the function from the previous question to calculate the distance it moved since the previous observation.

#T0-D0

For each storm, find the total distance it moved over its observations and its total displacement. "Distance" is a scalar quantity that refers to "how much ground an object has covered" during its motion. "Displacement" is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position.

#T0-D0

For each storm observation, calculate the average speed the storm moved in location.

#T0-D0

For each storm, calculate its average ground speed (how fast its eye is moving which is different from windspeed around the eye).

#T0-D0

Is there a relationship between average ground speed and maximum category attained? Use a dataframe summary (not a regression).

#T0-D0

Now we want to transition to building real design matrices for prediction. This is more in tune with what happens in the real world. Large data dump and you convert it into X and y how you see fit.

Suppose we wish to predict the following: given the first three readings of a storm, can you predict its maximum wind speed? Identify the y and identify which features you need $x_1, ... x_p$ and build that matrix with dplyr functions. This is not easy, but it is what it's all about. Feel free to "featurize" as creatively as you would like. You aren't going to overfit if you only build a few features relative to the total 198 storms.

#T0-D0

Fit your model. Validate it.

```
#T0-D0
```

Assess your level of success at this endeavor.

#TO-DO

The Forward Stepwise Procedure for Probability Estimation Models

Set a seed and load the adult dataset and remove missingness and randomize the order.

```
set.seed(1)
pacman::p_load_gh("coatless/ucidata")
data(adult)
adult = na.omit(adult)
adult = adult[sample(1 : nrow(adult)), ]
```

Copy from the previous lab all cleanups you did to this dataset.

```
#T0-D0
```

We will be doing model selection. We will split the dataset into 3 distinct subsets. Set the size of our splits here. For simplicitiy, all three splits will be identically sized. We are making it small so the stepwise algorithm can compute quickly. If you have a faster machine, feel free to increase this.

```
Nsplitsize = 1000
```

Now create the following variables: Xtrain, ytrain, Xselect, yselect, Xtest, ytest with Nsplitsize observations. Binarize the y values.

```
Xtrain = adult[1 : Nsplitsize, ]
Xtrain$income = NULL
ytrain = ifelse(adult[1 : Nsplitsize, "income"] == ">50K", 1, 0)
Xselect = adult[(Nsplitsize + 1) : (2 * Nsplitsize), ]
Xselect$income = NULL
yselect = ifelse(adult[(Nsplitsize + 1) : (2 * Nsplitsize), "income"] == ">50K", 1, 0)
Xtest = adult[(2 * Nsplitsize + 1) : (3 * Nsplitsize), ]
Xtest$income = NULL
ytest = ifelse(adult[(2 * Nsplitsize + 1) : (3 * Nsplitsize), "income"] == ">50K", 1, 0)
```

Fit a vanilla logistic regression on the training set.

```
logistic_mod = glm(ytrain ~ ., Xtrain, family = "binomial")
```

Warning: glm.fit: fitted probabilities numerically 0 or 1 occurred

and report the log scoring rule, the Brier scoring rule.

```
#T0-D0
```

We will be doing model selection using a basis of linear features consisting of all first-order interactions of the 14 raw features (this will include square terms as squares are interactions with oneself).

Create a model matrix from the training data containing all these features. Make sure it has an intercept column too (the one vector is usually an important feature). Cast it as a data frame so we can use it more easily for modeling later on. We're going to need those model matrices (as data frames) for both the select and test sets. So make them here too (copy-paste). Make sure their dimensions are sensible.

```
#TO-DO
#dim(Xmm_train)
```

```
#dim(Xmm_select)
#dim(Xmm_test)
```

Write code that will fit a model stepwise. You can refer to the chunk in the practice lecture. Use the negative Brier score to do the selection. The negative of the Brier score is always positive and lower means better making this metric kind of like s_e so the picture will be the same as the canonical U-shape for oos performance.

Run the code and hit "stop" when you begin to the see the Brier score degrade appreciably oos. Be patient as it will wobble.

```
#pacman::p_load(Matrix)
#p_plus_one = ncol(Xmm_train)
#predictor_by_iteration = c() #keep a growing list of predictors by iteration
#in_sample_brier_by_iteration = c() #keep a growing list of briers by iteration
#oos_brier_by_iteration = c() #keep a growing list of briers by iteration
#i = 1

#repeat {

#TO-DO

#wrap glm and predict calls with use suppressWarnings() so the console is clean during run

# if (i > Nsplitsize || i > p_plus_one){
# break
# }
#}
```

Plot the in-sample and oos (select set) Brier score by p. Does this look like what's expected?

#T0-D0