

Supplementary Materials

EventDTW: An Improved Dynamic Time Warping Algorithm for Aligning Biomedical Signals of Nonuniform Sampling Frequencies

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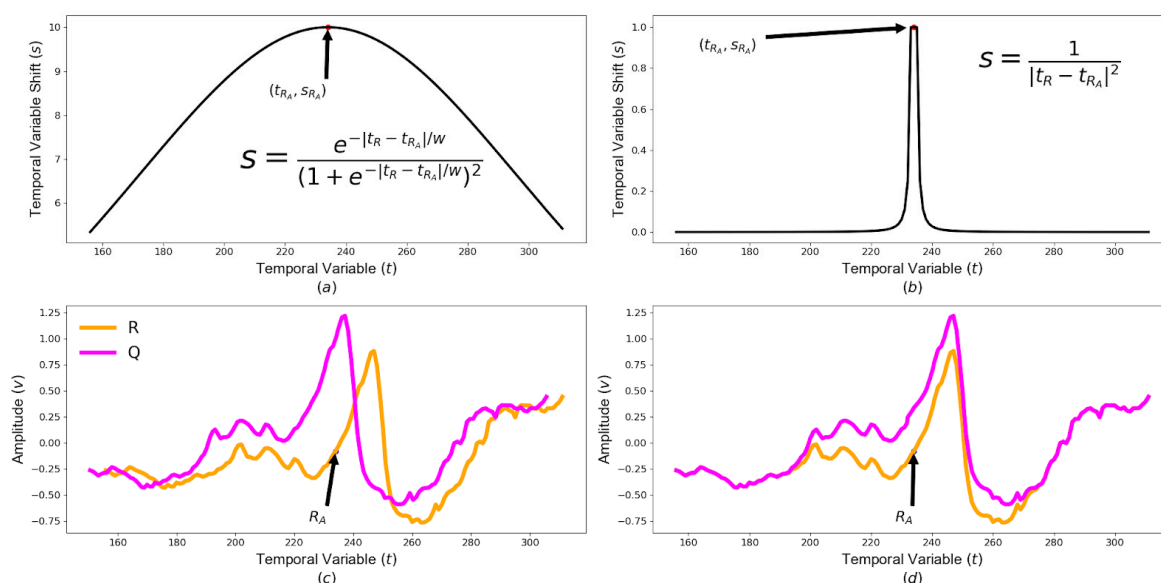


Figure S1. Comparison between temporal variable shift functions

Figure 1. (a) (b) Temporal variable shift function designed based on the derivative of sigmoid function and inverse square distance function. (c) (d) Part of signal near anchor point in Beef dataset from UCR Time Series Classification Archive warped based on (a) and (b)

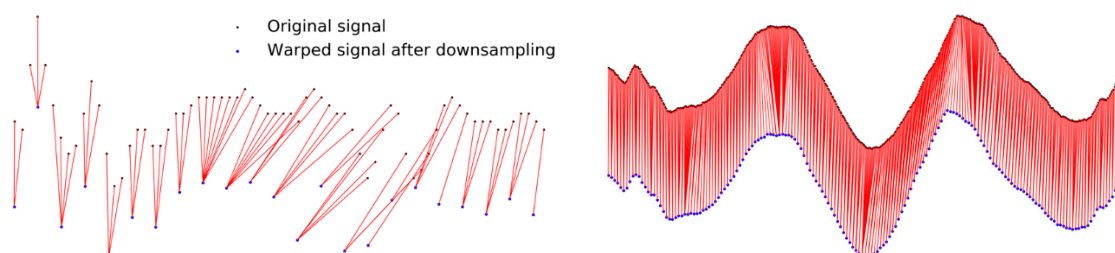


Figure S2. Examples in which eDTW perform worse than DTW.

Table S1. The Error Rate and Singularity Score for 84 datasets from the UCR Time Series Classification Archive

	Event DTW	Event DTW	DT W	DT W	shape DTW	shape DTW	dDT W	dDT W
	ER	SS	ER	SS	ER	SS	ER	SS
50words_TRAIN	0.0102 04	5.5828 89	0.010 882	5.860 42	0.0283 69	13.567 41	0.023 171	7.586 778
Adiac_TRAIN	0.0045 37	0.8666 67	0.004 547	0.901 149	0.0715 97	21.577 01	0.085 32	23.41 825
ArrowHead_TRAIN	0.0148 35	11.336 6	0.013 953	11.11 402	0.0443 97	20.522 09	0.030 228	13.20 623
Beef_TRAIN	0.0087 9	9.7908 32	0.009 682	11.14 829	0.0205 16	22.331 62	0.012 517	8.499 793
BeetleFly_TRAIN	0.0023 33	1.4455 88	0.002 362	1.537 941	0.0192 45	18.751 37	0.020 132	22.50 025
BirdChicken_TRAIN	0.0065 04	4.8133 36	0.005 525	3.907 878	0.0316 49	40.24	0.031 255	25.01 438
Car_TRAIN	0.0068 38	5.6540 83	0.006 723	5.026 461	0.0443 03	83.417 01	0.036 464	34.14 809
CBF_TRAIN	0.0266 74	6.2917 99	0.026 674	6.291 799	0.0985 68	38.939 68	0.056 078	8.672 222
ChlorineConcentration_TRAIN	0.0131 65	3.9655 56	0.013 143	3.931 616	0.0955 89	36.772 12	0.052 783	7.167 475
Coffee_TRAIN	0.0060 84	4.2469 42	0.005 857	4.172 206	0.0227 21	12.225 26	0.016 917	7.493 684
Computers_TRAIN	0.1353 13	267.08 2	0.135 313	267.0 82	0.1642 72	306.25 88	0.132 968	256.4 508
CinC_ECG_torso_TRAIN	0.0048 52	7.7979 6	0.007 242	9.029 677	0.0565 61	243.36 84	0.004 813	8.396 662
Cricket_X_TRAIN	0.0086 3	4.7845 67	0.008 586	4.772 567	0.0321 68	18.998 67	0.019 02	6.622 278
Cricket_Y_TRAIN	0.0143 77	6.8389 56	0.014 199	6.737 623	0.0359 16	21.348	0.018 684	7.438 389
Cricket_Z_TRAIN	0.0160 24	5.6445 53	0.015 97	5.660 553	0.0455 66	32.701	0.019 071	7.252 578
DiatomSizeReduction_TRAIN	0.0069 54	3.9045 6	0.004 073	0.995 623	0.0726 93	65.670 72	0.077 625	35.92 303
DistalPhalanxOutlineAgeGroup_TRAIN	0.0122 05	3.4256 41	0.010 513	3.487 179	0.0729 23	7.1128 21	0.050 256	5.979 487
DistalPhalanxOutlineCorrect_TRAIN	0.0139 49	3.8051 28	0.011 487	3.911 538	0.0744 1	7.2666 67	0.049 077	5.911 538

DistalPhalanxTW_TRAIN	0.0433 33	7.7282 05	0.041 846	7.728 205	0.0946 15	8.5230 77	0.070 667	10.80 855
Earthquakes_TRAIN	0.0907 3	62.455 09	0.090 73	62.45 509	0.1968 42	139.06 79	0.130 171	95.34 793
ECG200_TRAIN	0.0189 18	3.5343 75	0.019 153	3.580 208	0.0533 94	11.383 33	0.061 492	10.41 076
ECG5000_TRAIN	0.0181 64	4.4372 46	0.017 681	4.222 754	0.0524 48	15.797 1	0.047 746	15.54 614
ECGFiveDays_TRAIN	0.0125 42	3.8266 67	0.012 727	3.900 741	0.0386 7	10.969 63	0.033 333	7.963 21
ElectricDevices_TRAIN	0.3170 36	93.394 44	0.317 036	93.39 444	0.2388 44	70.608 33	0.449 227	126.5 423
FaceAll_TRAIN	0.0149 5	2.6599 48	0.013 972	2.595 866	0.0990 77	30.021 71	0.036 656	3.734 884
FaceFour_TRAIN	0.0103 35	6.7777 83	0.010 335	6.777 783	0.0163 09	8.9813 22	0.011 449	5.137 644
FacesUCR_TRAIN	0.0118 31	3.5251 94	0.011 886	3.562 403	0.0820 97	18.954 26	0.029 42	3.810 853
FISH_TRAIN	0.0104 6	8.7627 9	0.009 443	8.022 411	0.0526 24	63.724 24	0.057 795	52.70 938
FordA_TRAIN	0.0019 69	1.7285 14	0.001 976	1.755 02	0.0111 84	7.8618 47	0.006 685	3.274 096
FordB_TRAIN	0.0019 58	1.7402 28	0.001 978	1.775 569	0.0096 52	5.7220 88	0.006 557	3.044 177
Gun_Point_TRAIN	0.0227 48	7.5181 11	0.018 054	6.551 444	0.0572 24	20.066 67	0.058 286	15.10 686
Ham_TRAIN	0.0061 54	5.2239 97	0.006 226	5.385 069	0.0112 81	7.7734 27	0.007 799	3.451 282
HandOutlines_TRAIN	0.0032 92	3.8203 19	0.002 961	1.249 506	0.1704 16	1658.3 68	0.047 254	204.0 377
Haptics_TRAIN	0.0057 66	9.2026 62	0.005 596	9.573 793	0.0224 67	94.020 7	0.013 308	21.43 163
Herring_TRAIN	0.0058 74	4.7372 65	0.006 563	4.756 971	0.0465 37	62.710 59	0.027 619	27.26 876
InlineSkate_TRAIN	0.0058 91	21.970 75	0.005 884	21.96 285	0.1121 27	641.46 84	0.008 277	11.42 907
InsectWingbeatSound_TRAIN	0.0184 97	8.3596 25	0.024 949	9.783 654	0.0307 24	11.045 88	0.023 604	7.670 211
ItalyPowerDemand_TRAIN	0.0625	5.4458 33	0.062 5	5.445 833	0.1815 48	8.55	0.152 381	5.984 722
LargeKitchenAppliances_TRAIN	0.2256 83	421.71 7	0.238 333	434.0 703	0.2226 41	483.93 51	0.190 877	364.6 064

Lighting2_TRAIN	0.0393	34.133	0.039	34.12	0.0637	85.229	0.022	26.93
	89	64	383	924	74	51	598	007
Lighting7_TRAIN	0.0377	24.332	0.037	24.26	0.0861	58.451	0.038	19.22
	81	91	799	75	43	22	263	487
MALLAT_TRAIN	0.0063	16.271	0.007	17.35	0.0112	29.381	0.009	12.21
	18	45	074	355	37	28	914	429
Meat_TRAIN	0.0099	9.3774	0.023	24.43	0.0385	44.208	0.015	7.028
	33	42	93	881	29	65	473	596
MedicalImages_TRAIN	0.0496	6.1227	0.049	6.159	0.0971	15.391	0.111	8.955
	84	95	874	158	59	25	269	387
MiddlePhalanxOutlineAgeGroup_TRAIN	0.0157	3.8615	0.011	3.788	0.0630	6.6974	0.055	6.6
	44	38	333	462	77	36	949	
MiddlePhalanxOutlineCorrect_TRAIN	0.0155	3.6705	0.011	3.648	0.0603	6.5743	0.056	6.292
	38	13	692	718	08	59	718	308
MiddlePhalanxTW_TRAIN	0.0514	8.7076	0.046	8.574	0.0806	8.2205	0.084	12.77
	36	92	821	359	67	13	051	949
MoteStrain_TRAIN	0.0180	3.6924	0.017	3.625	0.0879	10.273	0.077	12.46
	78	6	549	794	19	81	954	27
NonInvasiveFatalECG_Thorax1_TRAIN	0.0241	31.587	0.024	31.36	0.0237	48.173	0.010	8.795
	54	02	419	622	02	87	018	235
NonInvasiveFatalECG_Thorax2_TRAIN	0.0197	34.786	0.025	36.96	0.0311	60.854	0.012	10.31
	92	82	406	413	71	68	43	33
OliveOil_TRAIN	0.0111	11.439	0.011	11.41	0.0161	20.398	0.008	5.795
	79	6	111	995	7	24	658	497
OSULeaf_TRAIN	0.0034	2.0059	0.003	2.024	0.0226	21.610	0.020	18.84
	08	08	41	276	15	8	507	976
PhalangesOutlinesCorrect_TRAIN	0.0156	3.5474	0.012	3.557	0.0627	7.1230	0.053	6.526
	41	36	308	692	69	77	795	923
Phoneme_TRAIN	0.0019	2.8996	0.001	2.871	0.0642	71.371	0.004	3.612
	29	17	919	204	61	75	492	47
Plane_TRAIN	0.0065	2.1715	0.006	2.149	0.0424	10.922	0.039	10.05
	31	28	413	306	05	22	303	185
ProximalPhalanxOutlineAgeGroup_TRAIN	0.0117	2.7692	0.010	2.974	0.0635	5.9384	0.054	7.938
	95	31	821	359	9	62	769	462
ProximalPhalanxOutlineCorrect_TRAIN	0.0113	2.6205	0.010	2.815	0.0644	5.8717	0.054	7.779
	85	13	154	385	1	95	103	487
ProximalPhalanxTW_TRAIN	0.0584	9.5487	0.056	9.574	0.0858	8.0564	0.089	15.18
	1	18	718	359	97	1	385	291
RefrigerationDevices_TRAIN	0.0159	33.311	0.015	33.31	0.0097	14.792	0.012	29.13
	83	8	983	846	5	5	315	746
ScreenType_TRAIN	0.0975	181.86	0.097	181.8	0.1233	250.14	0.088	153.2
	35	84	535	684		28	251	955

ShapeletSim_TRAIN	0.0087 99	6.5848 06	0.008 783	6.573 561	0.2958 09	474.68 51	0.035 95	10.95 385
ShapesAll_TRAIN	0.0056 61	2.5473 53	0.005 2	1.976 046	0.0453 94	55.756 08	0.063 887	64.40 488
SmallKitchenAppliances_TRAIN	0.1202 23	258.48 07	0.120 223	258.4 807	0.0939 27	192.38 71	0.106 317	227.2 055
SonyAIBORobotSurfaceII_TRAIN	0.0369 84	5.3761 9	0.036 984	5.376 19	0.1177 78	14.080 95	0.117 778	10.25 82
SonyAIBORobotSurface_TRAIN	0.0225 3	5.9376 81	0.022 134	5.676 812	0.0769 43	7.9971 01	0.067 984	7.894 203
StarLightCurves_TRAIN	0.0145 78	14.896 06	0.015 22	14.14 699	0.0441 39	91.663 74	0.017 614	20.92 2
Strawberry_TRAIN	0.0113 83	5.5610 68	0.011 244	5.631 154	0.0239 59	12.547 86	0.016 311	6.247 721
SwedishLeaf_TRAIN	0.0069 11	1.7460 32	0.006 059	1.491 27	0.0481 61	13.974 6	0.051 878	13.52 553
Symbols_TRAIN	0.0169 87	7.7205 07	0.017 791	9.298 748	0.0759 14	100.05 72	0.046 397	34.80 104
synthetic_control_TRAIN	0.0625 44	7.28	0.062 544	7.28	0.2596 49	46.913 33	0.138 158	8.677 778
ToeSegmentation1_TRAIN	0.0108 54	5.8339 79	0.010 547	5.649 74	0.0213 85	9.8239 13	0.015 823	5.723 896
ToeSegmentation2_TRAIN	0.0098 74	6.1923 24	0.009 789	6.283 65	0.0171 66	12.023 98	0.013 551	6.346 54
Trace_TRAIN	0.0418 19	18.075 6	0.043 105	18.35 202	0.1036 1	76.228 57	0.037 106	13.45 072
TwoLeadECG_TRAIN	0.0104 94	3.0246 91	0.010 446	3.054 321	0.0517 09	9.5530 86	0.052 754	9.432 099
Two_Patterns_TRAIN	0.0279 52	8.6986 77	0.027 952	8.698 677	0.0666 86	19.564 29	0.042 741	10.46 111
UWaveGestureLibraryAll_TRAIN	0.0087 34	18.784 47	0.008 785	18.91 981	0.0099 82	19.462 86	0.009 238	19.35 495
uWaveGestureLibrary_X_TRAIN	0.0223 08	15.393 84	0.023 526	16.17 375	0.0371 31	28.426 09	0.033 404	21.95 961
uWaveGestureLibrary_Y_TRAIN	0.0266 79	19.495 31	0.028 178	20.89 332	0.0363 1	25.039 05	0.030 916	22.38 201
uWaveGestureLibrary_Z_TRAIN	0.0234 52	16.788 6	0.023 245	16.94 094	0.0404 49	28.322 22	0.030 351	20.46 337
wafer_TRAIN	0.0673 74	21.930 05	0.067 442	21.74 761	0.0908 3	22.914 77	0.075 524	23.94 341
Wine_TRAIN	0.0198 14	9.8925 57	0.019 825	9.913 07	0.0277 33	9.5282 05	0.053 979	26.71 275

WordsSynonyms_TRAIN	0.0109	4.8720	0.010	4.893	0.0259	15.704	0.024	10.52
	95	93	162	113	8	81	382	63
WormsTwoClass_TRAIN	0.0048	7.0853	0.004	7.002	0.0098	18.741	0.006	10.73
	94	66	828	669	13	33	631	929

Table S2. The Singularity Score for 38 pairs of signals from the biomedical dataset STEP

EventDTW SS	DTW SS	shapeDTW SS	dDTW SS
214.7496	255.9367	6507.57	916.4238
652.0578	706.6031	9763.598	674.9932
207.9946	248.1262	8267.112	585.3234
863.2967	931.8183	9867.111	1840.99
271.7775	307.3894	6588.195	1014.131
312.8843	365.8864	8321.331	1420.998
199.4667	236.4396	5508.966	326.0338
165.706	202.4154	6240.588	521.357
151.0617	174.6621	3823.265	379.7549
726.1928	799.8118	9644.092	764.3193
98.12004	133.1142	5389.097	544.5346
234.3362	280.7707	6500.829	796.0459
210.5184	227.6504	2586.921	357.2649
407.1318	437.6987	5318.644	316.0044
596.9201	631.4459	5006.234	397.1649
827.2896	872.0031	8137.852	752.6112
338.6973	373.6216	5413.265	447.3042
360.1413	384.7664	4580.263	243.7712
567.2219	613.0839	7246.203	486.145
435.1125	458.8609	3372.282	254.1326
331.0873	362.1576	5033.389	527.209
419.9987	470.5904	6728.692	899.2313
476.1483	513.0718	6276.994	670.0777
166.6122	219.0746	9495.696	845.2175
462.5991	505.0618	6496.791	1006.34
179.9846	194.3681	2704.09	99.84207
265.9964	305.0589	6562.5	382.5716
453.4637	492.3472	6104.72	719.726
243.463	267.893	3835.516	214.2897
306.9594	339.4027	5547.813	443.2662
382.8466	411.8045	4633.256	709.9841
171.4716	210.6143	6106.256	1021.483
280.4449	334.315	8565.34	1669.624
1115.824	1161.347	7738.876	1273.979
266.8022	326.4465	8827.358	1065.5

202.3897	232.9697	3577.855	222.8987
740.5745	778.6155	5896.361	273.463
275.5137	310.9087	5592.405	453.0661



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