EEG Imaginary Body Kinematics Regression

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Introduction

- Brain-Computer Interface (BCI)
- Applications:
  - Manipulation of external devices (e.g. wheelchairs)
  - For communication in disabled people
  - Rehabilitation robotics
  - Diagnosis and prediction of diseases (e.g. Parkinson's disease, Seizure, Epilepsy)
  - Games
- Invasive vs Noninvasive
  - Electrocorticography
    - Fifer et al. (2012)
  - Electroencephalography
    - Mcfarland & Wolpaw (2011)

Background

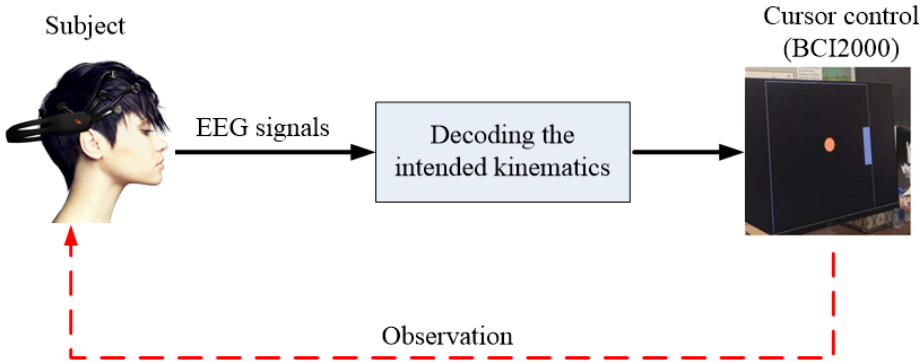
Invasive

Noninvasive

- Sensorimotor Rhythms (SMR)
- Steady-State Visual Evoked Potential (SSVEP)
- Imagined Body Kinematics
  - Continuous decoding the kinematic parameters during imaginary movements of one body part
  - Short time of training
  - Natural imaginary movement
  - Smoother controller system
  - Possibility of developing a generalized decoder
  - Eliminating Subject dependency

Research Objective and Setup

- Objective: Improve the training model accuracy of a noninvasive BCI system based on extracted information from EEG signals and through imagined body kinematics
- Setup
  - Emotiv EPOC for recording EEG signals
  - BCI2000 for cursor visualization and data collectection
  - Matlab/Python for processing



Training

- Automated cursor movement on computer monitor in 1D
- Subject imagines following movement with dominant hand
- 10 trials
  - 5 horizontal
  - 5 vertical
- 1 minute each
- Cross validation between trials

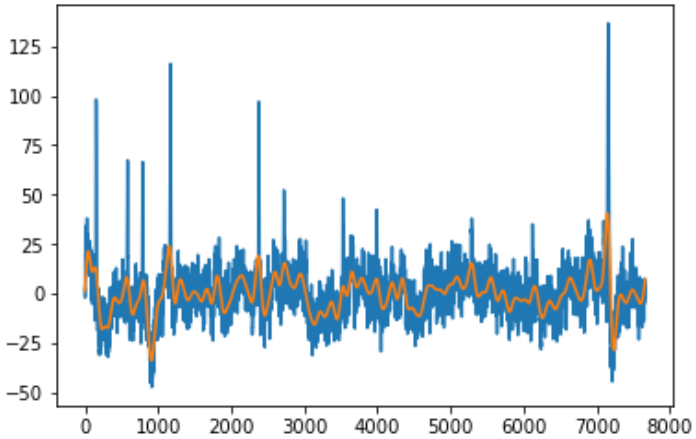
Data

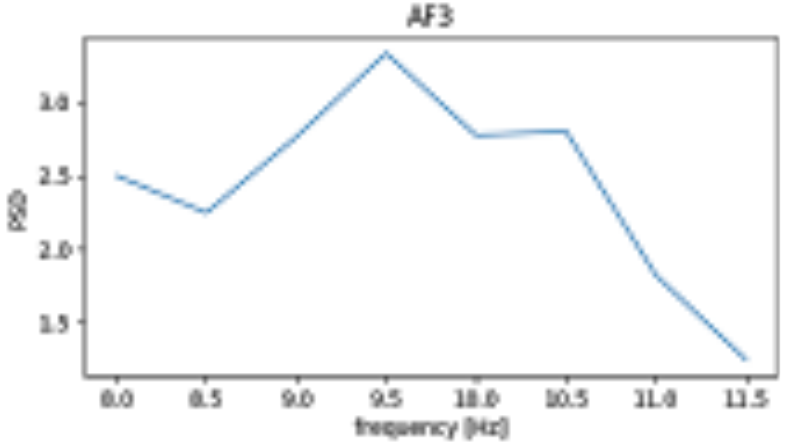
- 35 Subjects
- 10 trials each (5 vertical/5 horizontal)
- 14 channels each
- 12 million rows total

sub	H/V	trial	posX	posY	AF3	F7	F3	FC5	T7	P7	O1	O2	P8	T8	FC6	F4	F8	AF4	vol
SoheilB	H	1	2046	2047	2.6118	16.583	-6.0334	-1.0284	8.3647	-6.3642	-8.0171	-5.4992	-10.207	-5.4653	-14.298	-10.188	-15.045	-22.201	-0.15625
SoheilB	H	1	2046	2047	-2.0416	12.659	-8.5144	-5.9059	2.9563	-8.8454	-9.2852	-8.7106	-17.87	-18.082	-19.582	-13.624	-17.852	-24.096	-0.15625
SoheilB	H	1	2046	2047	10.823	19.365	2.625	-0.95381	4.9331	0.40383	-5.4473	0.83103	-11.607	-12.221	-6.6745	-1.8286	-6.4066	-8.2475	-0.15625
SoheilB	H	1	2046	2047	19.962	22.883	10.961	1.4144	7.2904	5.0127	-2.9964	7.0874	-6.9255	-2.2559	1.5866	7.9904	0.03677	-0.90293	-0.15625
SoheilB	H	1	2046	2047	18.28	22.552	13.188	0.82313	7.047	1.2093	-3.6332	2.0584	-8.7876	0.057505	-0.9211	7.9882	-2.8258	-5.9083	-0.15625
SoheilB	H	1	2046	2047	18.576	25.85	13.695	1.8304	7.387	-3.6896	-8.7162	-5.438	-10.173	-3.5671	-3.4477	5.2993	-7.5064	-10.164	-0.15625
SoheilB	H	1	2046	2047	25.576	31.571	14.786	3.7998	6.6175	-6.4211	-17.408	-9.4667	-12.26	-10.461	-5.1832	3.8787	-10.085	-9.8709	-0.15625
SoheilB	H	1	2046	2047	32.429	34.746	18.268	6.8122	5.2167	-3.4175	-19.607	-10.616	-15.448	-13.012	-5.8673	7.4101	-6.1348	-4.7161	-0.15625
SoheilB	H	1	2046	2047	34.277	34.484	22.449	9.7628	6.2446	1.7528	-11.349	-7.1529	-12.53	-5.0042	1.2907	17.098	5.7678	4.3836	-0.15625
SoheilB	H	1	2046	2047	33.127	33.725	24.108	9.5312	7.6565	-1.7005	-4.1335	-1.1005	-3.3167	5.8663	12.52	23.88	17.667	9.1226	-0.15625
SoheilB	H	1	2046	2047	32.367	32.831	22.638	6.236	7.6018	-9.0785	-4.709	1.8478	3.3523	11.933	16.439	23.404	20.409	6.2867	-0.15625
SoheilB	H	1	2046	2047	28.79	26.731	17.054	0.71783	5.9575	-8.4725	-6.135	2.6204	3.7284	12.856	12.425	19.752	13.279	3.4819	-0.15625
SoheilB	H	1	2046	2047	20.776	18.731	10.076	-4.498	1.0068	-5.3214	-4.8139	2.5918	0.83793	6.9713	8.1043	13.487	4.8711	3.631	-0.15625
SoheilB	H	1	2046	2047	20.092	24.048	13.029	0.076558	0.44429	-4.4935	-3.5773	2.7123	1.2476	2.8463	8.6648	10.077	6.7349	4.9273	-0.15625
SoheilB	H	1	2046	2047	30.369	40.004	24.124	13.017	12.609	-0.04507	-2.5613	8.2692	9.2366	13.26	13.495	15.59	16.766	7.3276	-0.15625
SoheilB	H	1	2046	2047	32.328	42.072	22.601	14.463	22.034	2.0854	-4.5408	13.857	15.456	24.856	15.374	17.413	18.191	4.4983	-0.15625
SoheilB	H	1	2046	2047	19.503	27.278	7.6588	1.4819	14.266	-6.4391	-13.182	6.4261	8.6169	18.034	9.6653	6.8286	7.8581	-6.1522	-0.15625
SoheilB	H	1	2046	2047	11.084	18.708	0.87778	-5.2839	4.2167	-14.799	-19.726	-6.2647	-4.6681	3.6359	2.9438	-1.3786	1.6392	-13.088	-0.15625
SoheilB	H	1	2046	2047	14.17	23.568	5.6561	0.13673	5.0571	-12.316	-14.414	-7.4935	-10.409	1.6472	2.735	0.32597	5.4097	-11.707	-0.15625
SoheilB	H	1	2046	2047	19.431	29.688	10.872	5.8593	8.4921	-4.1542	-5.0111	-3.098	-6.1457	9.4531	7.2453	2.7538	9.6012	-8.932	-0.15625
SoheilB	H	1	2046	2047	25.226	31.701	16.007	7.176	9.3759	1.525	-2.5176	-3.581	0.51747	13.763	11.014	5.8392	10.601	-5.6902	-0.15625
SoheilB	H	1	2045	2047	29.999	31.251	20.76	6.7065	11.137	1.5723	-4.115	-2.6185	2.1706	12.297	12.372	13.734	13.457	-1.7045	-0.15625
SoheilB	H	1	2045	2047	27.089	30.553	20.718	7.744	12.754	0.044938	-3.4907	3.819	1.0616	10.776	13.302	20.133	17.877	0.64061	-0.15625
SoheilB	H	1	2045	2047	19.422	31.34	17.888	10.071	12.029	0.53726	-2.5825	6.2711	1.8607	8.4965	13.105	19.266	15.498	2.3848	-0.15625
SoheilB	H	1	2045	2047	15.285	28.545	14.632	6.8581	8.3526	-3.0716	-5.2808	-0.14487	-1.3857	1.0047	7.0304	13.083	4.7636	0.81357	-0.15625

Clean Up

- Raw signal contains a lot of noise
- Low pass filter + ICA to filter signal
- Band pass filter to isolate frequency ranges of interest



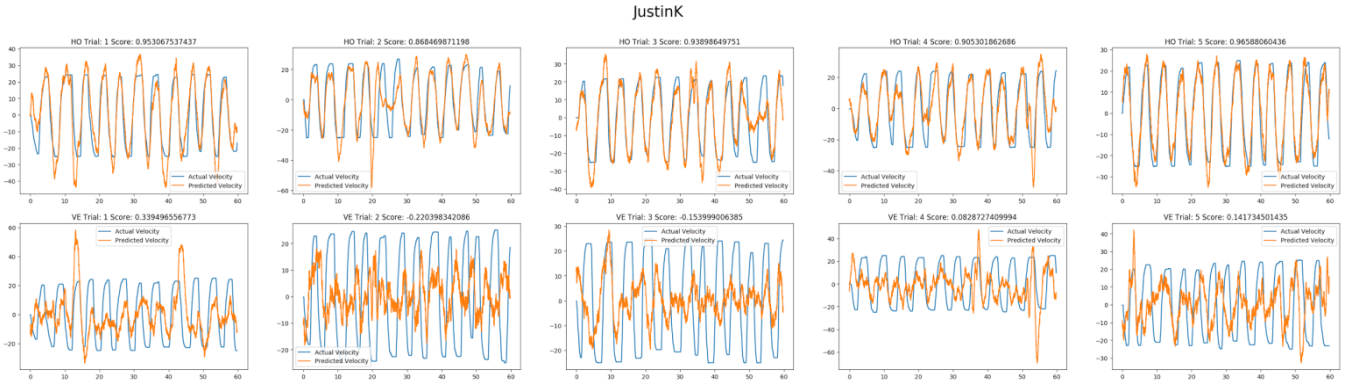


Features

- 13 points in memory
- Power spectral density in 3 frequency ranges
  - Alpha
  - Beta
  - Mu
- Coefficients Generated by a Classification Model
  - Predicts if velocity will be positive or negative

Training, Testing, and Results

- Models are trained on linear and nonlinear algorithms
  - Linear Regression, Kernel Ridge, Adaboost
- Test with trial wise cross-validation
  - 1 trial left out as test 4 used for training, rotate
  - Scored using the average correlation of the two curves over five windows



1-D Movement Classification

Formalized Problem

Input

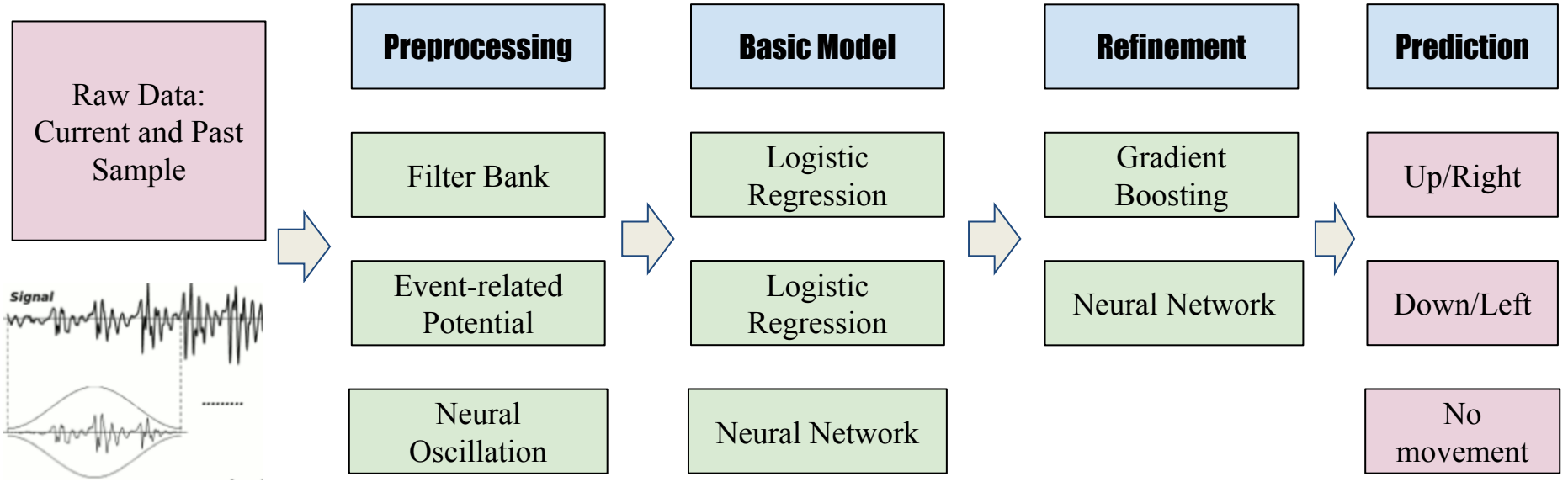
- EEG data (time series) with 128 Hz and 14 channels

Predict

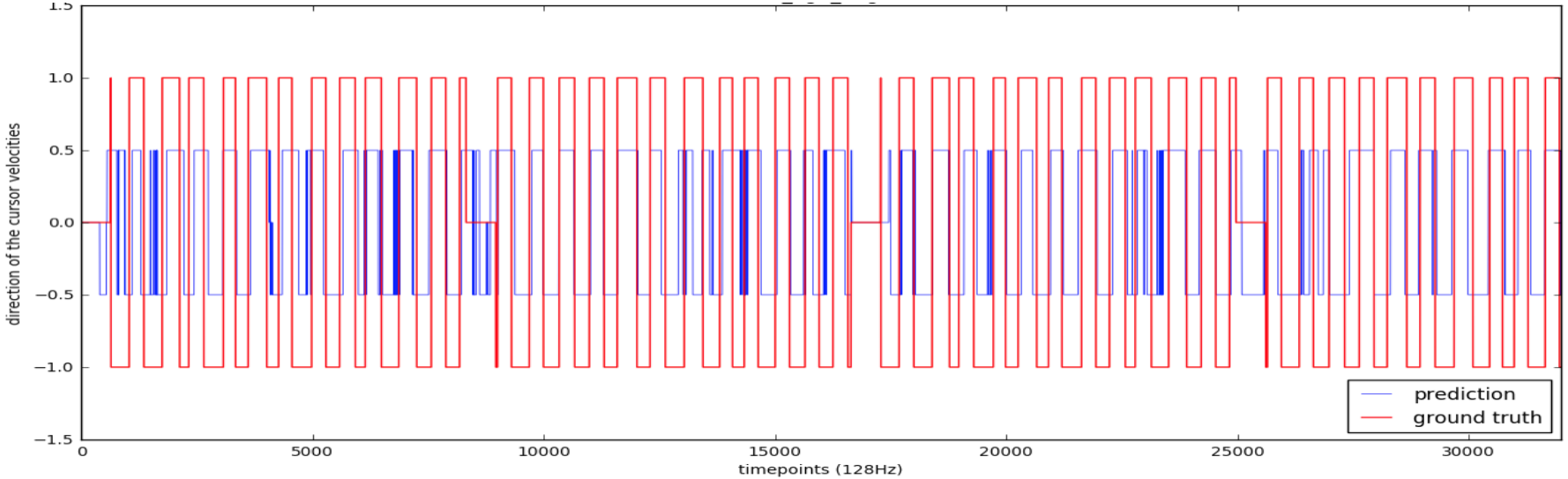
The cursor movement direction at any given time point

- Vertical: Left / Right / No
- Horizontal: Up / Down / No

Overview of Model

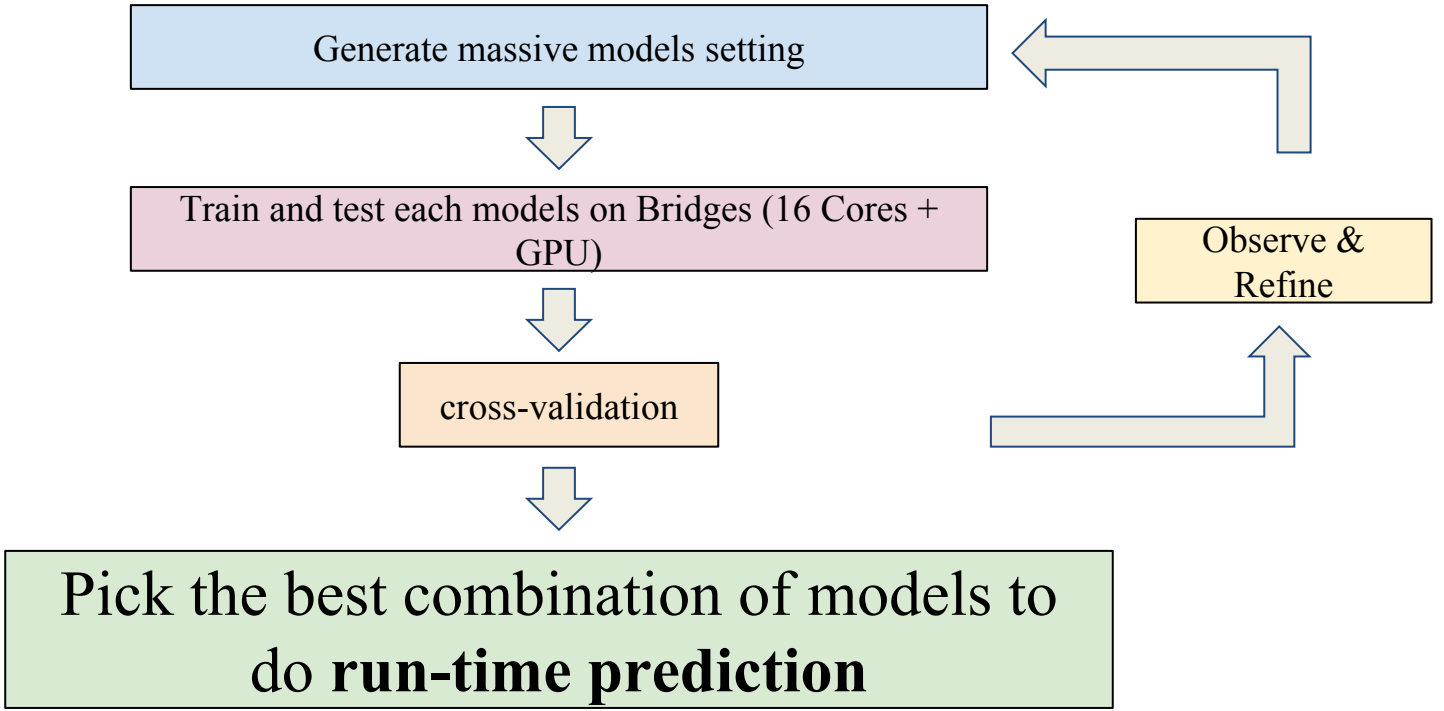


Overview: Results



AUC of **Horizontal** Movement prediction: 92%
AUC of **Vertical** Movement prediction: 74%

Workflow


Generate massive models setting
Train and test each models on Bridges (16 Cores + GPU)
cross-validation
Observe & Refine
Pick the best combination of models to do **run-time prediction**

Preprocessing: Event-related potential

- ERP = The brain response correspond to the event
- The EEG reflects tons of ongoing brain processes
- Any processes other than we want are **noise**
- To maximize the signal-to-noise ratio (SNR)
- Assume $X = D\,A + N.$
- Find the $\hat{A} = \arg\min_{A} \|X - D\,A\|_2^2$

where X = recorded EEG, A = ERP, D is related to event and N = Noise

Preprocessing: Filter Bank

Psychological or Physiological State	Changes in EEG Waves
Concentrated	Suppression of the alpha wave
Deep sleep	Predominance of the delta wave
Vigilant	Generation of beta wave
Recognition of sensory stimuli	Changes in gamma wave

Low freq.

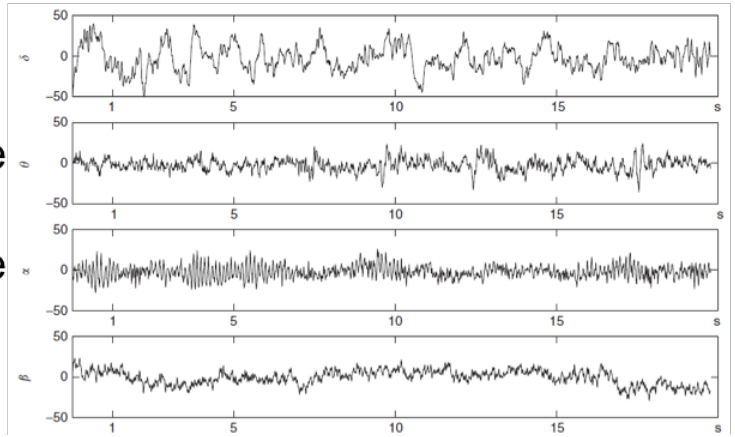
Delta wave

Theta wave

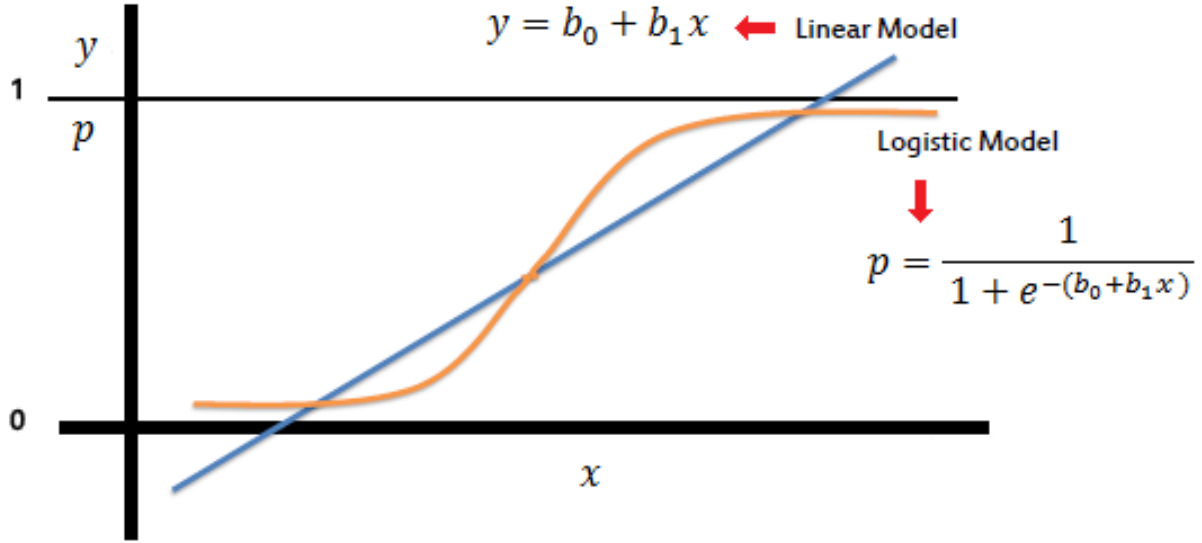
Alpha wave

High freq.

Beta wave

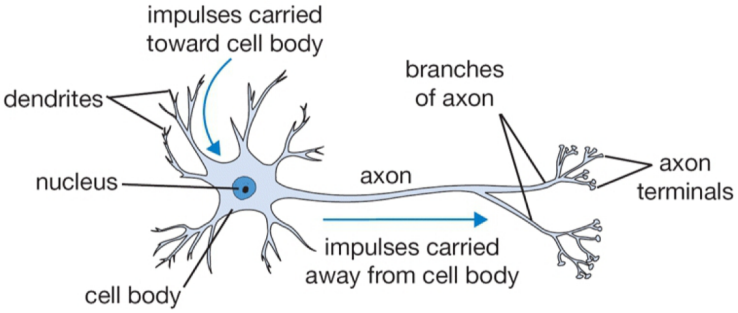


Classifier: Logistic Regression

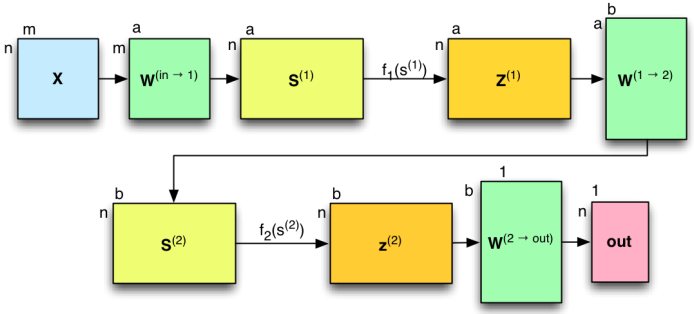


Reference: http://www.saedsayad.com/logistic_regression.htm

Classifier: Neural Network



Represented by matrices (multiplication)



GPU!

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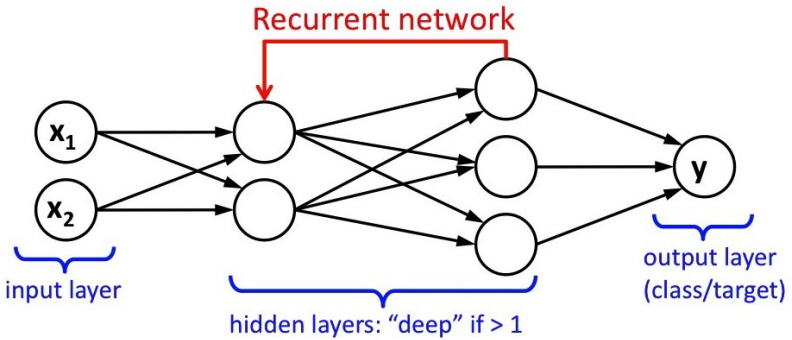
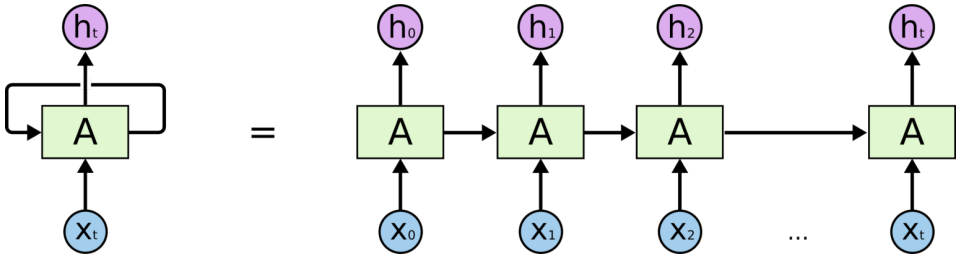
Reference: CUHK IERG4160 (2017 Spring)

http://briandolhansky.com/blog/2014/10/30/artificial-neural-networks-matrix-form-part-5

Another NN: Recurrent Neural Network





Refrence: http://colah.github.io/posts/2015-08-Understanding-LSTMs/

Gradient Boosting

Gradient Boosting = Gradient Descent + Boosting

Adaboost

$$H(x) = \sum_t \rho_t h_t(x)$$

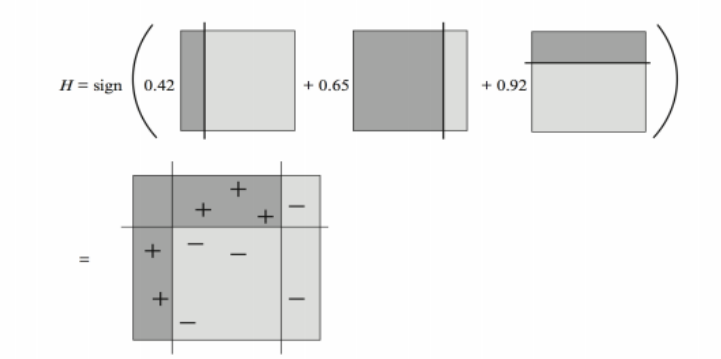


Figure: AdaBoost. Source: Figure 1.2 of [Schapire and Freund, 2012]

Experimental Setup

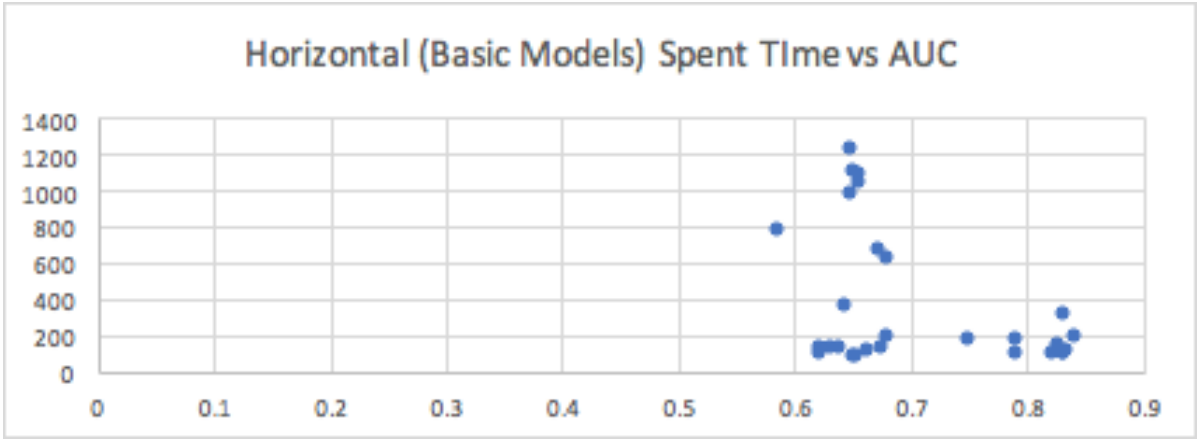
- 12 Subjects' data were used, each of them has 5 trials about horizontal / vertical movements

	1st, 2nd, 3rd trials	4th trial	5th trials
Basic Models	Train Data	Validation	Validation
Refinement	-	2-fold validation	2-fold validation

The computation were run on XSEDE-Bridges 16 Cores + GPU (P100)

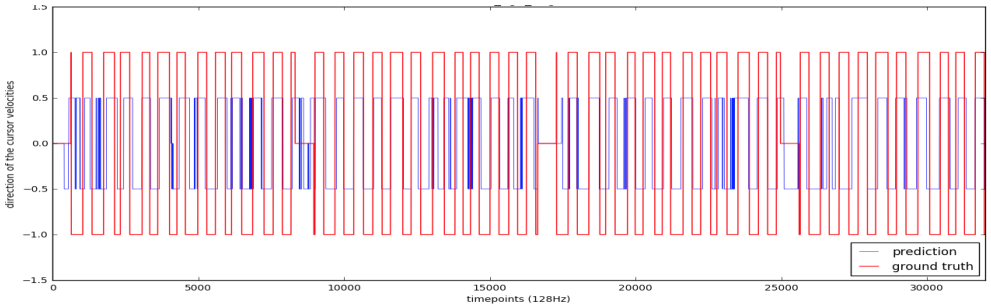
Results: Horizontal (Basic Models)

	Unnamed: 0	AUC	Time
0	FBL	0.842590	181.972919
0	NN_32	0.835308	98.896181
0	NN_64	0.834818	90.139172
0	RNN_FB_delay4000	0.834604	312.028854
0	NN_128	0.834080	89.993732
0	NN_16	0.830884	130.502847
0	NN_256	0.828083	89.038822
0	NN_512	0.823449	91.755990
0	FBLCR_256	0.791780	167.238749
0	FBLCR_All	0.791061	172.708039
0	FBLC_256pts_alex2	0.752158	177.197120
0	CovsERP_Dist_poly	0.680992	612.404152
0	CovsERP_Dist	0.676593	118.485019
0	CovsAlex_7-30Hz_500pts_poly	0.674321	653.031422
0	CovsAlex_7-30Hz_500pts	0.664084	102.315805
0	CovAlex_All	0.657394	1083.693734
0	CovAlex_old_All	0.656820	1032.833952
0	CovsRafal_35Hz_256pts	0.654137	68.562238
0	CovsAlex_35Hz_250pts_poly	0.653636	1099.318186
0	CovsRafal_35Hz_500pts	0.651988	77.257092
0	CovsAlex_35Hz_500pts_poly	0.650604	964.940802
0	CovsAlex_1-15Hz_500pts_poly	0.650267	1216.758358
0	CovsAlex_20-35Hz_500pts_poly	0.644330	357.597696
0	CovsAlex_35Hz_250pts	0.640570	117.760372
0	CovsAlex_1-15Hz_500pts	0.632530	116.162412
0	CovsAlex_20-35Hz_500pts	0.622492	89.197422
0	CovsAlex_35Hz_500pts	0.622180	120.631374
0	FBL_delay100_skip20	0.588445	773.620677



Results: Horizontal (Refine)

	Unnamed: 0	AUC	Time
0	xgb_longshort_bags_model	0.918678	219.687598
0	xgb_bags	0.917246	44.505239
0	xgb_noCovs	0.914032	18.641206
0	xgb_bags_model	0.913633	249.341032
0	RNN_256_delay4000_allModels_ADAM_bags_model	0.912653	2185.129013
0	RNN_256PR_delay4000_allModels_ADAM_bags_model	0.912417	2195.700831
0	RNN_256_delay2000_allModels_ADAM_bags_model	0.911047	2175.592875
0	xgb_bags_delay	0.911045	448.812827
0	RNN_256_delay4000_allModels_ADAM_bags	0.909810	2146.428794
0	RNN_256_customDelay_allModels_ADAM_bags_model	0.908812	1048.715023
0	xgb_longshort	0.907385	25.947971
0	RNN_256_delay4000_allModels_ADAM_2layers_bags	0.907231	2158.033413
0	RNN_256_delay4000_FBLCRAll_ADAM	0.906253	184.589281
0	xgb_short	0.905916	23.417831
0	xgb_NN_FBL_bags_model	0.905631	113.996028
0	RNN_256PR_delay4000_allModels_ADAM	0.905216	151.410950
0	RNN_256_delay4000_allModels_ADAM_2layers	0.904371	164.942369
0	RNN_256_delay4000_allModels_ADAM	0.903501	166.779580
0	RNN_256_customDelay_allModels_ADAM	0.903034	75.793599
0	xgb_subjects_sub	0.900531	25.345117
0	xgb_NN_FBL	0.899805	8.536120
0	xgb_onlyNN	0.892104	5.638924
0	xgb_NN_FBL_bags	0.879245	23.174044
0	RNN_256_delay4000	0.842177	3852.266719
0	RNN_256_delay4000_FBLCA	0.836923	3890.202207
0	xgb_onlyCovs	0.691169	20.653086



Result: Vertical

	Unnamed: 0	AUC	Time
0	CovsERP_Dist_poly	0.669644	487.399618
0	CovsAlex_1-15Hz_500pts_poly	0.661633	724.974220
0	RNN_FB_delay4000	0.660657	320.613438
0	CovsAlex_1-15Hz_500pts	0.652165	225.277494
0	CovsERP_Dist	0.650005	260.915219
0	CovsRafal_35Hz_256pts	0.646928	280.179943
0	CovsAlex_20-35Hz_500pts_poly	0.646516	217.049680
0	CovsAlex_7-30Hz_500pts_poly	0.644043	252.706750
0	CovsRafal_35Hz_500pts	0.643119	275.645791
0	CovsAlex_35Hz_500pts_poly	0.642127	699.299518
0	FBLCR_All	0.638896	203.199322
0	FBLCR_256	0.638601	178.786031
0	CovsAlex_35Hz_250pts_poly	0.637163	860.897156
0	NN_32	0.633956	107.518679
0	NN_256	0.633861	92.566718
0	CovsAlex_35Hz_250pts	0.633359	241.608241
0	NN_512	0.631083	91.869646
0	NN_64	0.630556	92.625652
0	NN_16	0.630323	130.269898
0	FBL	0.629485	194.645135
0	NN_128	0.629336	91.739161
0	CovAlex_All	0.626050	908.639449
0	FBLC_256pts_alex2	0.625642	211.073688
0	CovAlex_old_All	0.625593	889.716575
0	CovsAlex_35Hz_500pts	0.624196	245.715095
0	CovsAlex_7-30Hz_500pts	0.623102	208.905571
0	CovsAlex_20-35Hz_500pts	0.604611	214.996715
0	FBL_delay100_skip20	0.598033	1367.602588

	Unnamed: 0	AUC	Time
0	xgb_NN_FBL_bags_model	0.723458	131.488834
0	xgb_noCovs	0.714594	18.844718
0	xgb_bags_delay	0.707688	450.176472
0	xgb_longshort_bags_model	0.705651	218.316631
0	xgb_longshort	0.702168	25.889817
0	xgb_short	0.698705	23.303805
0	RNN_256_delay4000_allModels_ADAM_2layers	0.697745	171.210338
0	xgb_subjects_sub	0.696464	25.715433
0	RNN_256_delay4000_allModels_ADAM_bags	0.696216	2190.634941
0	RNN_256PR_delay4000_allModels_ADAM	0.696046	157.041731
0	RNN_256_delay4000_allModels_ADAM_bags_model	0.695849	2259.061960
0	RNN_256_delay4000_FBLCRAll_ADAM	0.695055	190.626488
0	RNN_256PR_delay4000_allModels_ADAM_bags_model	0.694616	2264.915453
0	xgb_onlyNN	0.694058	5.518596
0	xgb_bags	0.693365	45.268314
0	RNN_256_customDelay_allModels_ADAM	0.693143	79.883520
0	RNN_256_delay4000_allModels_ADAM	0.693085	171.961007
0	xgb_NN_FBL	0.692863	8.661242
0	RNN_256_delay4000_allModels_ADAM_2layers_bags	0.690987	2196.073289
0	RNN_256_delay2000_allModels_ADAM_bags_model	0.689881	2255.313206
0	RNN_256_customDelay_allModels_ADAM_bags_model	0.689247	1094.970984
0	xgb_onlyCovs	0.675803	20.528981
0	RNN_256_delay4000_FBLCA	0.667560	4026.971066
0	RNN_256_delay4000	0.666194	4048.248218
0	xgb_NN_FBL_bags	0.665108	23.830886

Next Step:

Next Step

- Convert everything to C to accelerate computation

Goal

- Predict the cursor direction in real-time

Reference

Github: alexandrebarachant/Grasp-and-lift-EEG-challenge
https://github.com/alexandrebarachant/Grasp-and-lift-EEG-challenge