Quantitative Evaluation of Manufacturing Visualization via Data Fusion

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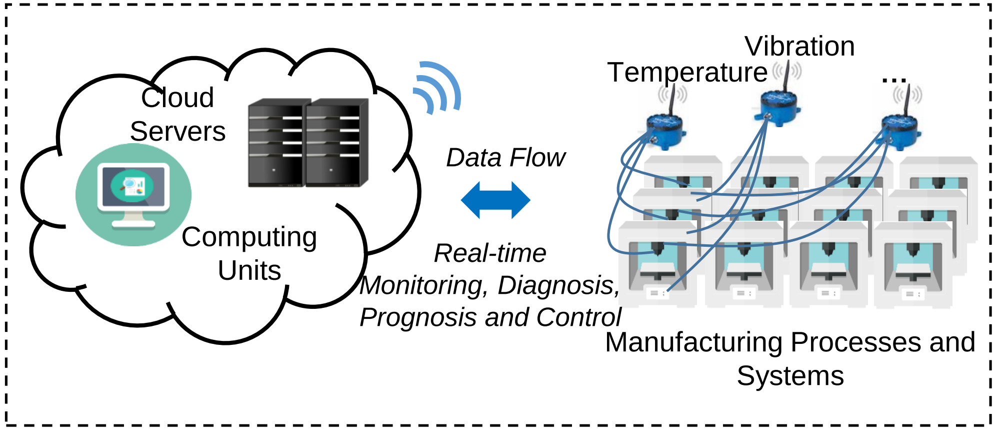
Outline

- **Introduction**
- User Study
- Feature Extraction and Regularized Linear Regression
- Results and Discussion
- Summary and Future Works

See references for figures in the notes

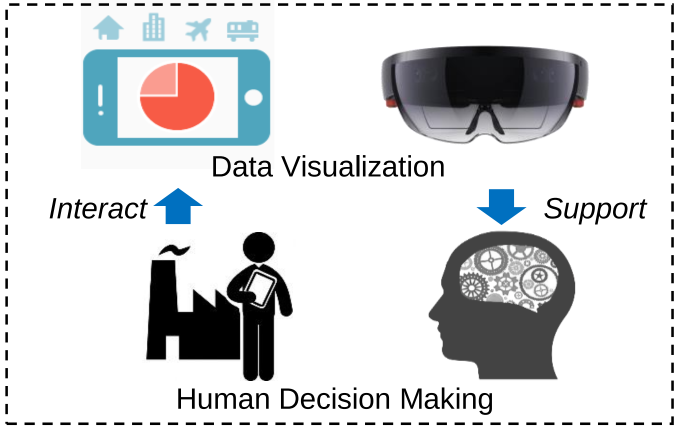
Motivation and Objective



Manufacturing Data Analytics and Sensor Network
(Chen, Sun, & Jin, 2016; Sun, Huang, & Jin, 2017)

Effectiveness?

Efficiency?



Human-Machine Collaboration
(Chen & Jin, 2017)

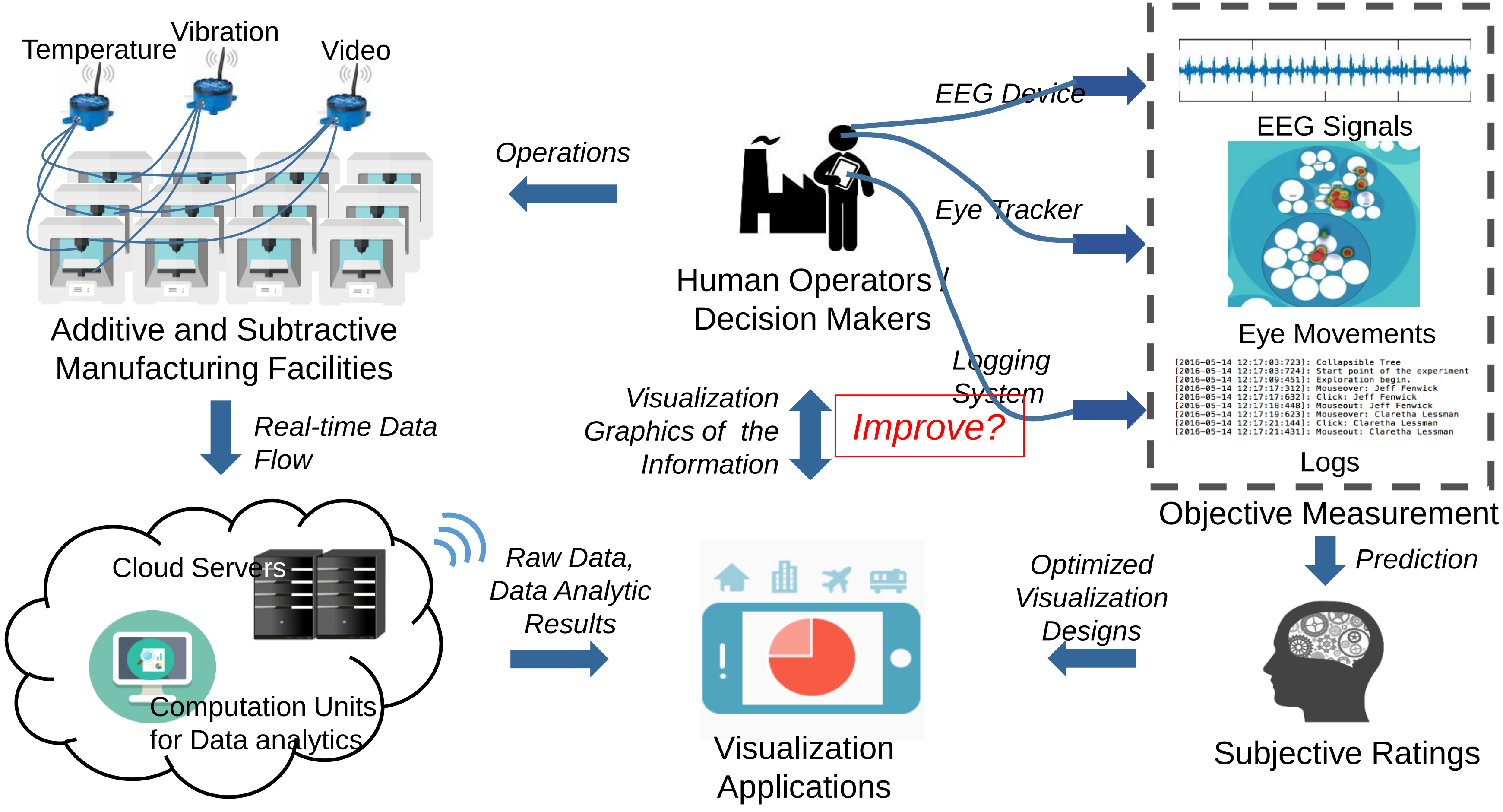
- **Motivation**

  Heterogeneous data and complex analytics results make it cognitive challenging for manufacturing users (e.g., engineers and operators) to obtain information and insights in collaboration with manufacturing data analytics.

- **Objective**

  To bridge the gap between the high demand of new data visualization tools and the low efficiency of user-centered evaluating processes.

Challenges and Approach



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Related Works (Information Visualization)

- **Formats of Information Visualization**
  - Static visualizations (DeLamarter, 1986; Rohrer et al., 1997)
  - Interactive designs to visualize high dimensional, large-sample and dynamic data sets (Wegman, 1990; Carlis and Konstan, 1998; Van Ham et al., 2004; Wills, 1997)
  - Virtual reality to immerse the users in the virtual world of data visualization (Bryson, 1996)
  - Augmented reality to mix up the real world and visualization graphics (Azuma, 1997)
- **Application of VR and AR-based visualization**
  - Medical science (Bichlmeier et al., 2007; Hansen et al., 2010)
  - Education (Billinghurst, 2002; Kaufmann, 2003)
  - Industry (Doil et al., 2003; Nee et al., 2012)
  - Smart manufacturing data analytics (Chen et al., 2016)

Related Works (Visualization Evaluation)

- Qualitative Evaluation
  - Field observation (Isenberg et al., 2008) and laboratory observation (Hilbert et al., 2000);
  - Heuristic evaluation, formative usability test and summative evaluation (Hix et al., 1999);
  - Longitudinal study for entire visualization and analysis process (Saraiya et al., 2006);
  - Pluralistic walkthrough (Bias, 1994) and cognitive walkthrough (Rieman et al., 1995);
  - Limitations: Lacking unobtrusive data collection during users' interaction with visualizations; lacking online visualization evaluation in a timely manner.
- Quantitative Evaluation
  - Controlled experiment (e.g., randomized experiments, A/B testing, treatment testing) (Willett et al., 2007; Cohavi et al., 2009);
  - Performance models (e.g., GMOS, Fitt's Law) (Bowman et al., 2002);
  - Automated usability evaluation to use software facilities to record relevant information about the user and the system (Lvory et al., 2001);
  - Limitations: Lacking subjective measures to indicate users' perception, cognition, and preferences.

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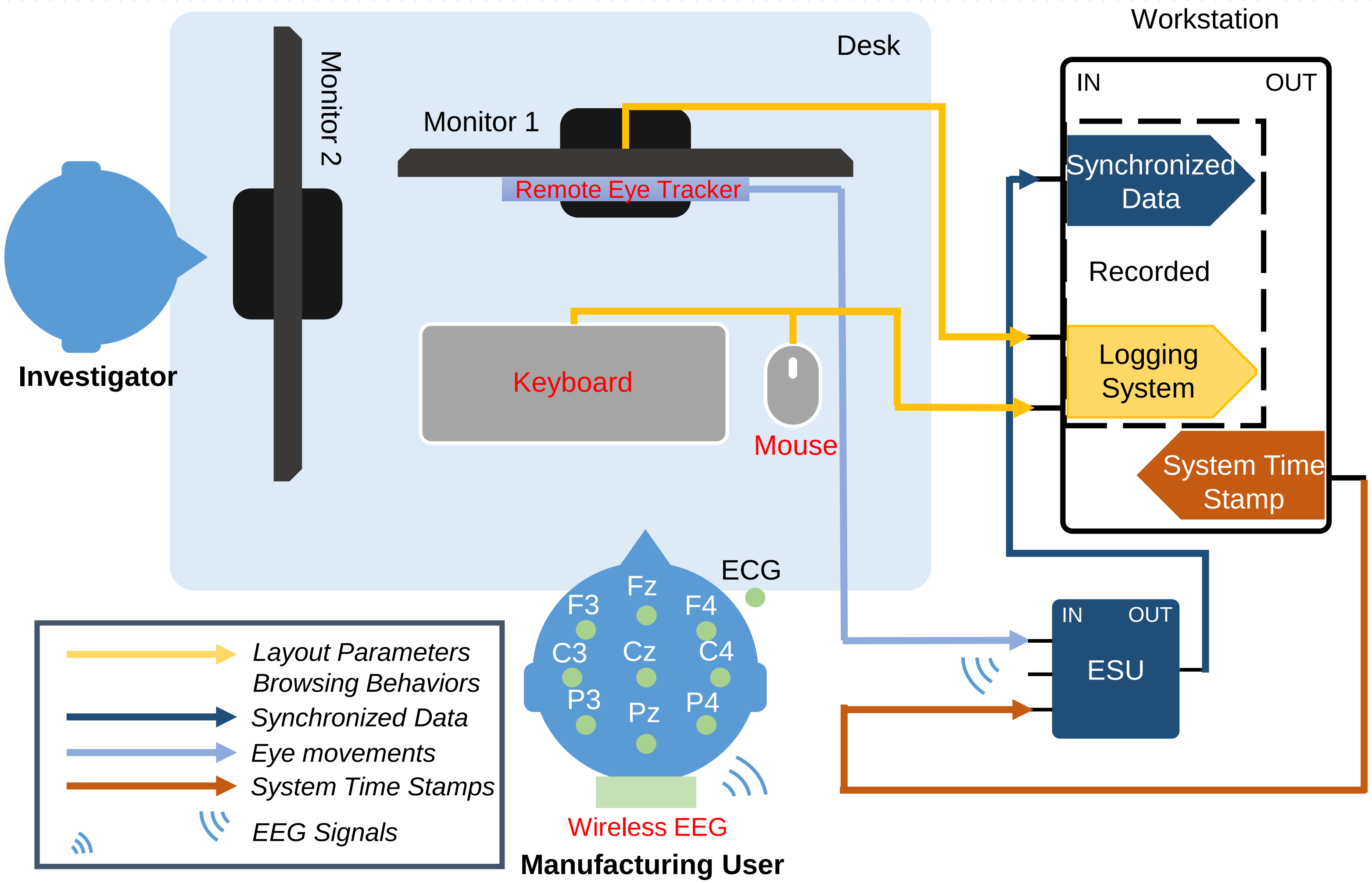
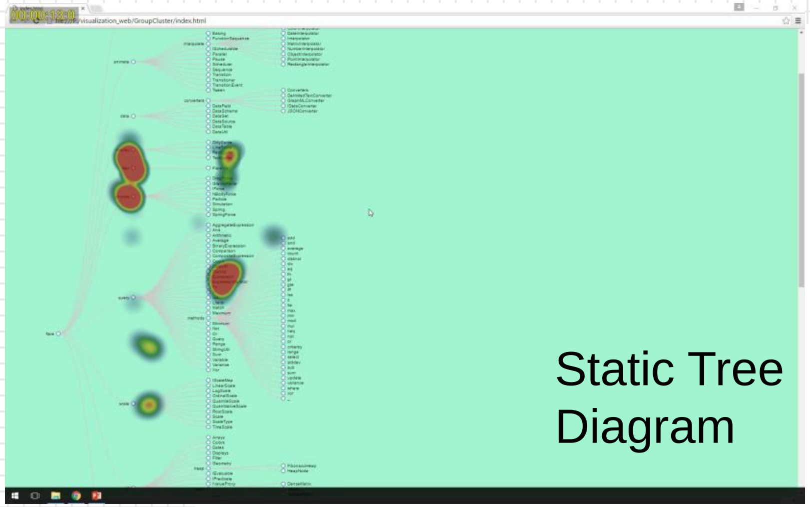
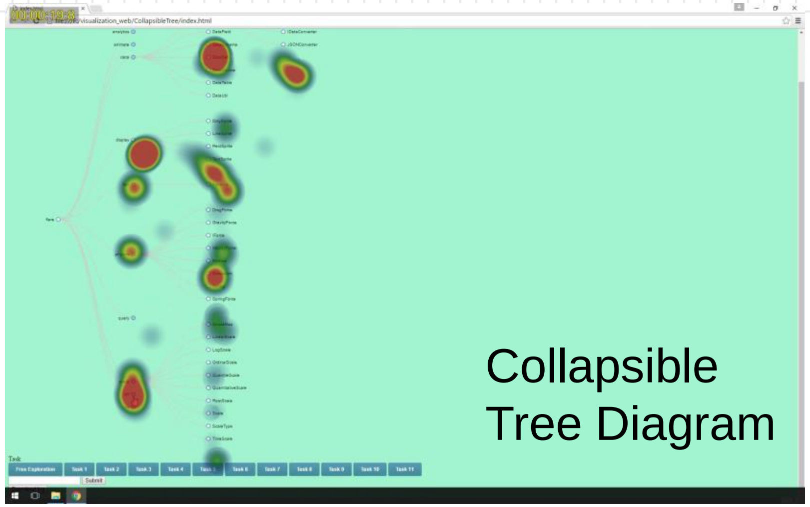
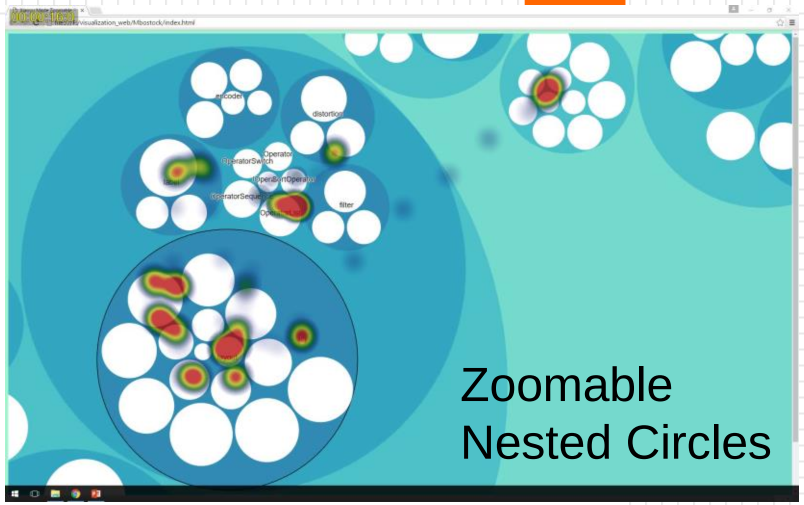
Experimental Setup



Three Visualization Designs for Evaluation







Static Node-link Tree Diagram: full names and hierarchical relationships were mapped to the circles, texts and edges, respectively.

Collapsible Node-link Tree Diagram: after a click on the node, the corresponding branch can be expanded or collapsed, which provides users with filtered information.

Zoomable Nested Circles: The nodes are mapped to circles. Hierarchical levels are represented by different level of packs and interactive field of views. By clicking on an interested circle, the circle will be zoomed in/out with more details on children circles inside it.

Data set to be visualized: hierarchical data of human resources in three companies

Open source library D3.js is used for creating three visualization designs. Codes are in HTML and javascript and are deployed on web browser.

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Pre-defined Tasks

Task 1	**Free Exploration**		**Explore the visualization design in three minutes.**
Task 2	Predefined Tasks	Type 1	Find a given name* in level 1**.
Task 3			Find a given name in level 1.
Task 4			Find a given name in level 2.
Task 5			Find a given name in level 2.
Task 6			Find a given name in level 3.
Task 7			Find a given name in level 3.
Task 8		Type 2	Find a given name in level 2 and click on the direct parent***.
Task 9			Find a given name in level 3 and click on the direct parent.
Task 10		Type 3	Count the total number children of two given names in level 1.
Task 11			Count the total number children of two given names in level 2.
Task 12			Count the total number children of two given names in level 3.

* Every given name differs from each other.
** Level is defined by the distance between the node and the root in a hierarchical data set.
*** Direct parent node is defined as the directly linked nodes in higher level.

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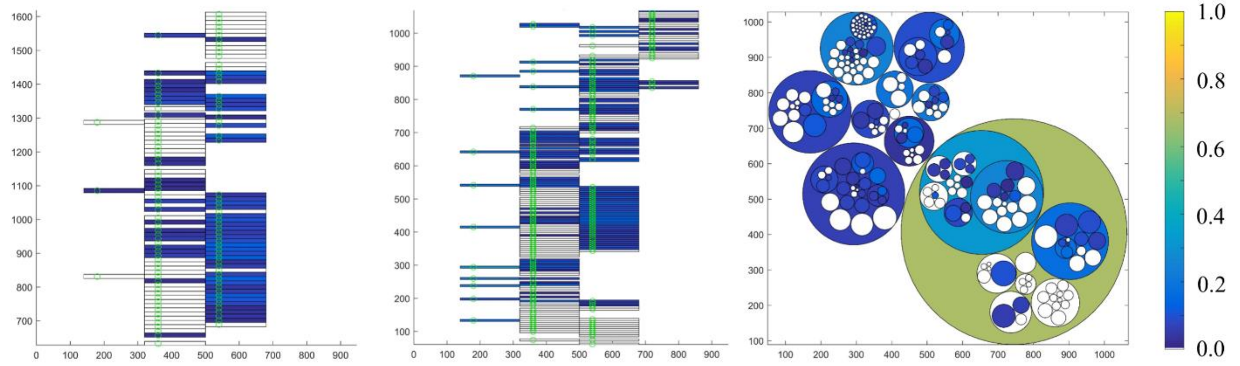
Data Collection and Feature Extraction

iFFT (Doyle et al., 1974) to obtain five bands in time domain (s_{raw}); Personalized feature standardization (Wang et al., 2016) $s_{scaled} = \frac{s_{raw}-B_l}{B_u-B_l}$.

		...racker		
10 Channels *	Time stamps	Trajectory	Time stamps	...time	...me ...ps



* 10 EEG cha...

** Mouse eve...

Mean va... energy, ... skewnes...

Line length: $L = \sum_{k=2}^{N} |s_{scaled}(k - ...$

Mean of nonlinear energy operator: $\frac{1}{N-2}\sum_{k=2}^{N-1} s_{scaled}(k)^2$ ...

Wavelet ene...

Mean value and standard deviation of tim... eye hits within...

Mean value deviation of...

Mean value and standard deviation of tim... mouse hits wit...

Mean value and standard deviation of reading paths

Data	EEG Signals			Eye Movements				
Features	Stat. features (6)**	Morpho-logical Features (2)	Time-freq. features (1)	AOIs related features (2)	Distance related features (2)	AOIs related features (2)	Distance related features (2)	Task features (2)
Number	450			4		6		

* Features of EEG signals were extracted from Delta, Theta, Alpha, Beta, and Gamma bands (5 bands) of ECG, Fz, F3, F4, Cz, C3, C4, POz, P3, P4 channels (10 channels), respectively. Hence in total 10 channels × 5 bands × (6 statistical features + 2 morphological features + 1 time-frequency features) = 450 features were extracted from EEG signals.

** Number in the bracket presents the count of features in corresponding group.

Regularized Linear Regression Model

- Notation
  - Data set: $\boldsymbol{X} \in \mathbb{R}^{n \times p}$ (features), $\boldsymbol{y} \in \mathbb{R}^{n}$ (evaluation scores: perceived task complexities collected by questionnaire after performing each task)
  - Coefficient vector: $\boldsymbol{\beta} \in \mathbb{R}^{p}$
  - Error vector: $\boldsymbol{\varepsilon} \in \mathbb{R}^{n}$
  - Tuning parameter: $\lambda > 0$, selected by Bayesian information criterion
- Linear Model:
  - $\boldsymbol{y} = \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$, where $\boldsymbol{\varepsilon}\ i.i.d. \sim N(0, \sigma^2)$
- Estimation:
  - $\widehat{\boldsymbol{\beta}} = \underset{\boldsymbol{\beta}}{\operatorname{argmin}} \left\{ \frac{1}{2} \sum_{i=1}^{n} \left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j \right)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \right\}$
  - Test using a five-fold cross validation

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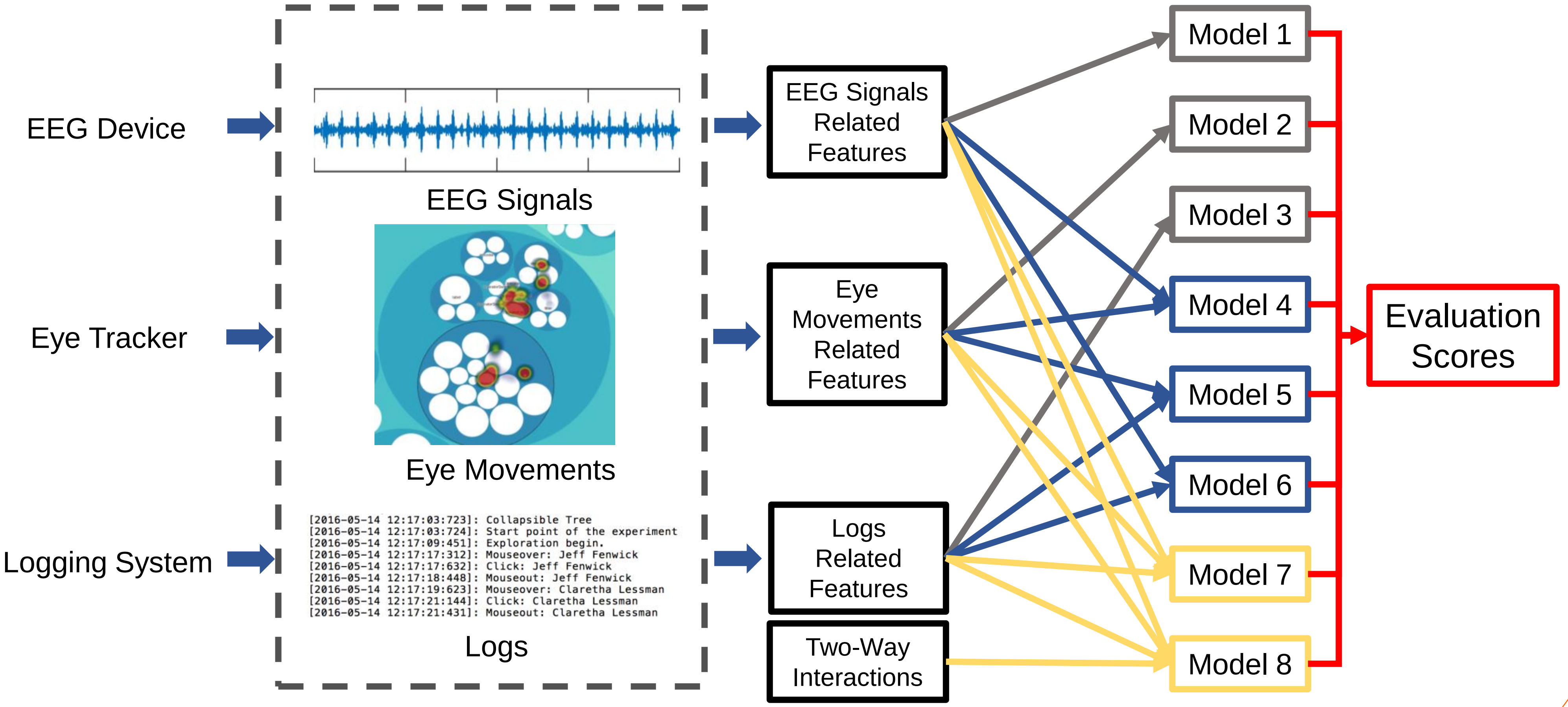
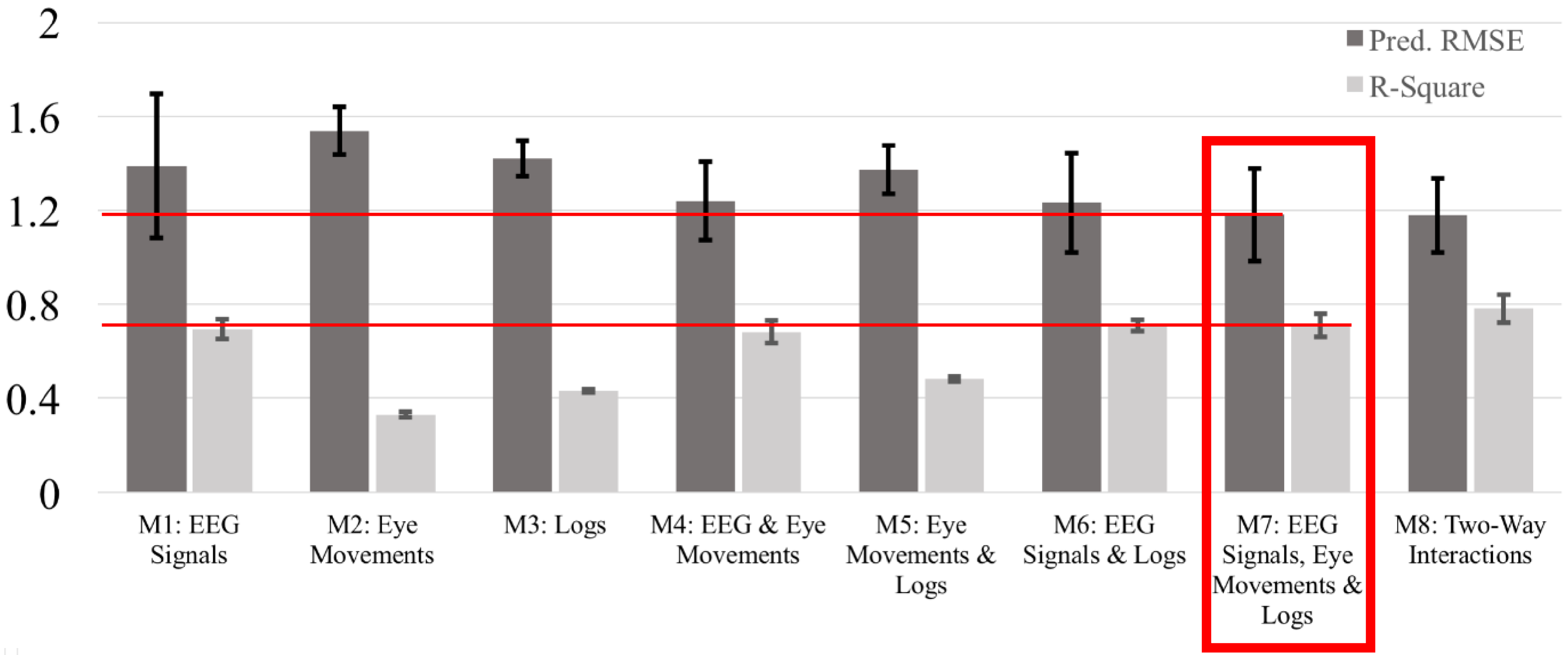
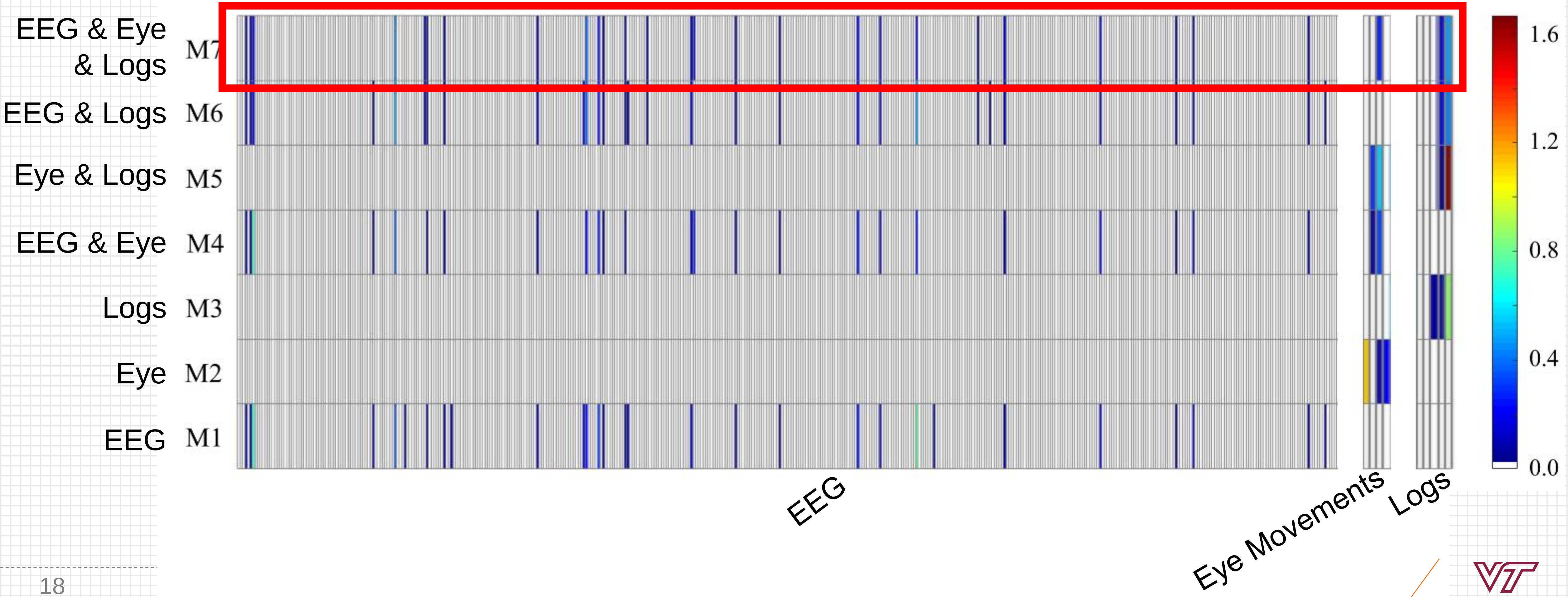
Overview of Study Design



Prediction Results



Feature Selection Results



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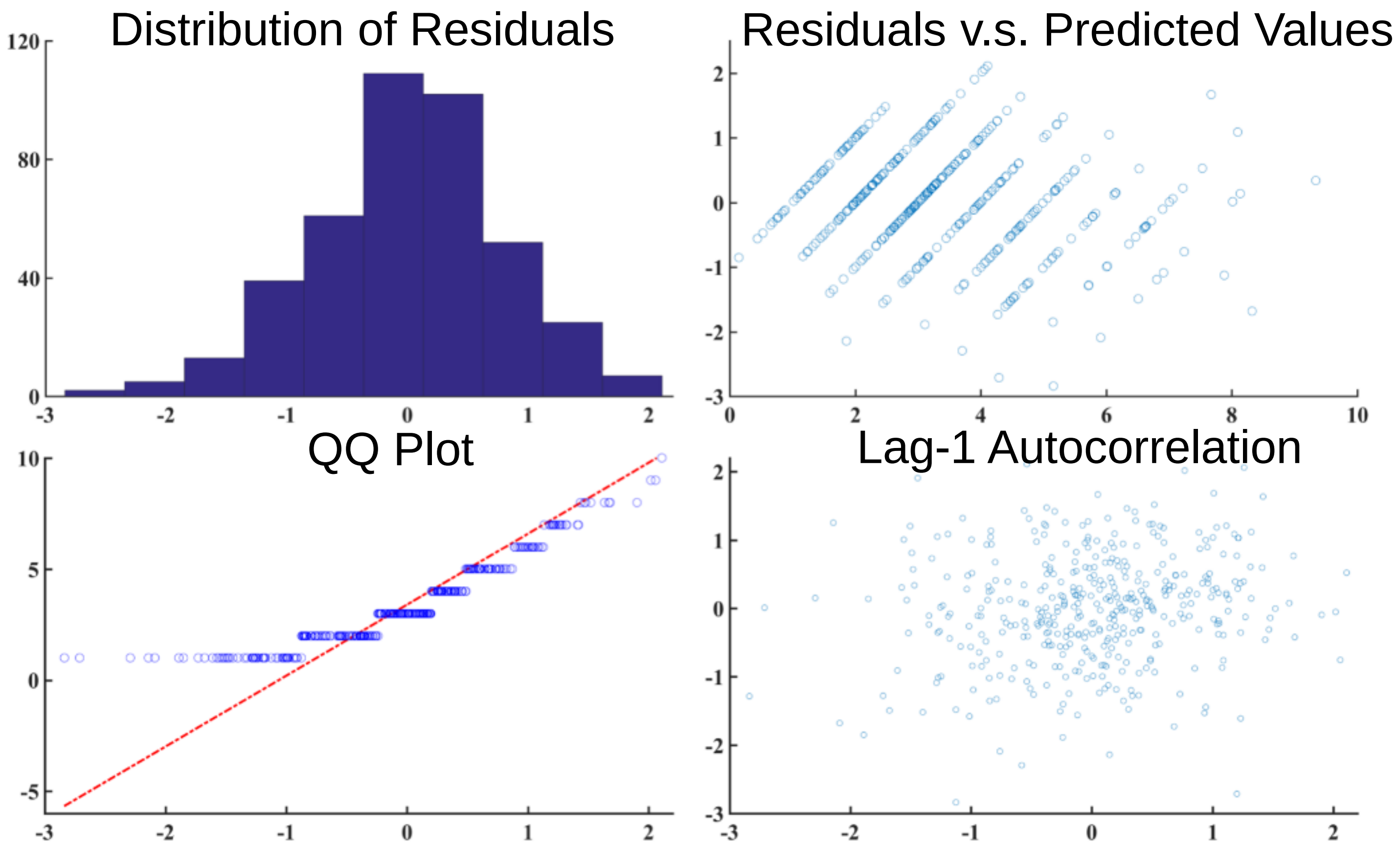
Selected Features

Data	Predictors	Channels	Bands	Features
EEG signals	7	ECG	Delta	entropy
	65	POz	Alpha	wavelet entropy
	94	Fz	Delta	curve length
	103	Fz	Theta	curve length
	107	Fz	Theta	standard deviation
	123	Fz	Beta	skewness
	128	Fz	Gamma	wavelet entropy
	143	Cz	Delta	standard deviation
	148	Cz	Theta	curve length
	182	C3	Delta	wavelet entropy
	187	C3	Delta	entropy
	204	C3	Alpha	skewness
	254	C4	Beta	wavelet entropy
	263	C4	Gamma	wavelet entropy
	278	F3	Delta	standard deviation
	314	F3	Gamma	standard deviation
	353	F4	Gamma	wavelet entropy
	391	P3	Beta	nonlinear energy
Data	Predictors	Features		
Eye movements	453	variance of distance		
Logs	456	variance of distance		
	459	variance of mouse move over/out duration		
	460	task duration		

In literature:

- **Alpha and Gamma bands** of EEG signals are indicators of sustained attentions during performing visual searching tasks (Huang et al., 2007; Ossandón et al., 2012);
- **Statistical, morphological, and time-frequency features** of EEG signals are significantly related to cognitive load (Wang, et al., 2016);
- **Eye movements** are useful physiological data to assess the layouts (Burch et al., 2011) and to capture the patterns of reading paths (Rayner, 2012);
- **Behavioral logs** are indicators of users' attempts and stress conditions (Sun et al., 2014).

Diagnostics



One-Tailed Pairwise T-Test

Alternative Hypothesis	2>1	3>1	3>2	1>2	1>3	2>3
P-values (Evaluation Scores)	0.0003	1.0000	1.0000	0.9997	<0.0001	<0.0001
P-values (Predicted Scores)	<0.0001	1.0000	1.0000	1.0000	<0.0001	<0.0001

* 1, 2, and 3 stands for collapsible node-link tree, static node-link tree, and zoomable nested circles, respectively.
** “>” means that the former design has lower evaluation scores from participants than the latter design does to present the same information.

- Bonferroni correction compensated significant level: $\alpha = \frac{0.05}{6} \approx 0.0083$.
- Conclusions
  - Static node-link tree is significantly better than the collapsible node-link tree and zoomable nested circles;
  - The predicted scores are as informative as the participants’ evaluation scores.

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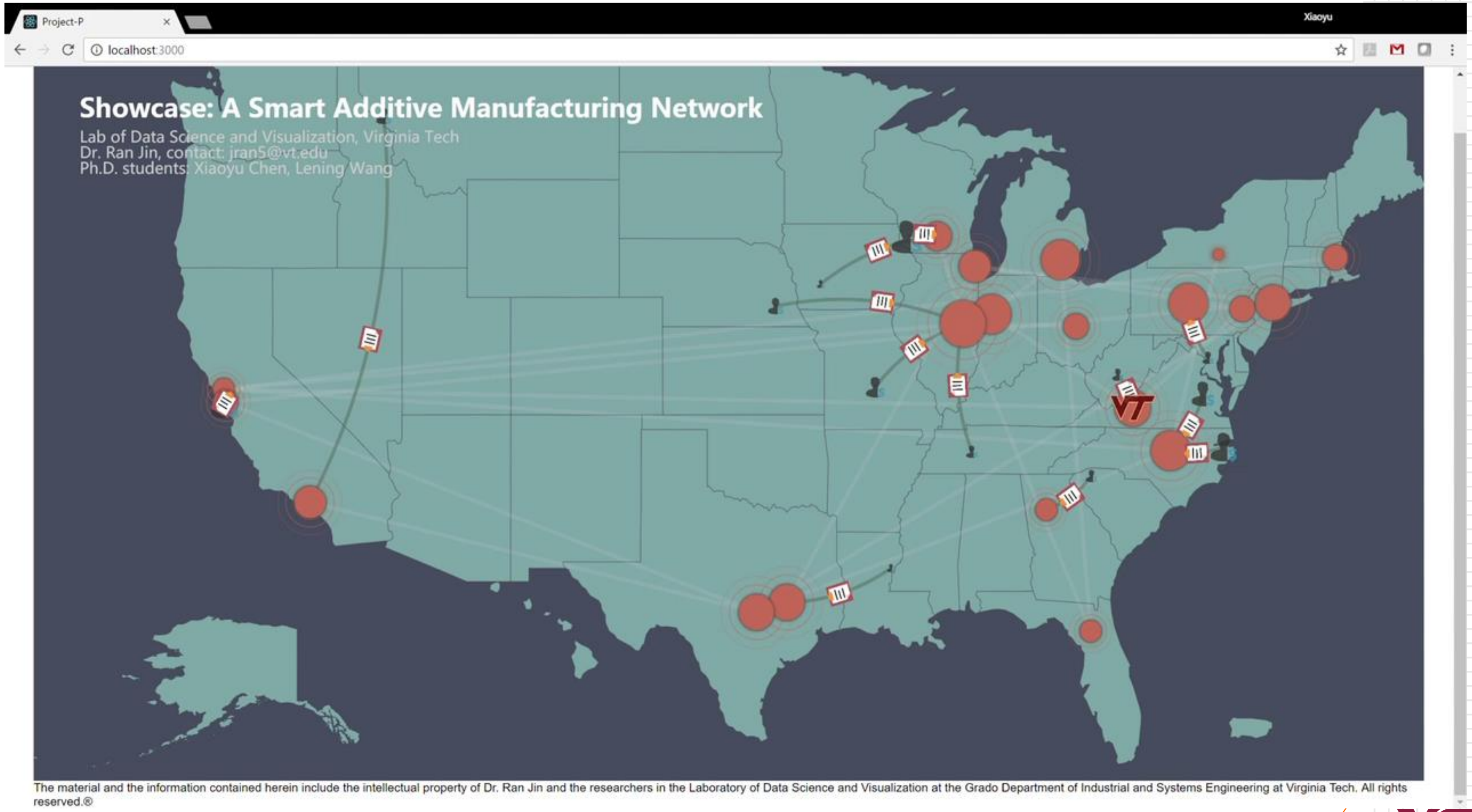
Summaries and Future Works

- **Summaries**
  - Gap exists between the high demand of new data visualization tools and the low efficiency of user-centered designing processes due to the lack of unobtrusive, quantitative and online user-centered evaluation methods;
  - A data fusion method which integrate EEG signals, eye movements, and behavioral logs is proposed to predict the visualization evaluation scores;
  - The prediction results are as informative as users' subjective ratings, thus can be further extended to assist other qualitative evaluation methods in a quantitative manner.
- **Future works**
  - Regression model with multiple responses in an Augmented Reality environment will be investigated;
  - Personalized recommendation via covariates-based extended matrix completion method to recommend visualization designs for new users *(cold-start)* will be developed (under review);
  - Visualization design elements will be considered in the study design and treated as covariates in the model, such that this method can be generalized for various visualization designs.

Visualization of CAMNet

- **120 real and virtual (validated simulation) AM machines**
  - One selective laser melting machine
  - Five fused deposition modeling machines
- **Three-level visualization**
  - Network level: the CAMNet
  - System level: facilities in a center
  - Machine level: single machine



Main References

- Chen, X. and Jin, R., 2017. Statistical modeling for visualization evaluation through data fusion. *Applied ergonomics*, *65*, pp.551-561.
- Chen, X., Lau, N., and Jin, R., 2018. PRIME: A personalized recommendation for information visualization methods via extended matrix completion. *IEEE Transactions on Systems, Man and Cybernetics: Systems*. *Under review*.

Thank you!
Questions?