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Modeling Sequential Decision Making in Engineering Systems Design

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Abstract

We develop a framework to cluster designers with similar sequential design behaviors. Using the framework, we not only identify the designers who have similar design sequences but also their mostly occurred design patterns. Moreover, we aim to predict future design sequences based on designers' performed actions. To achieve this objective, we adopt deep recurrent neural networks (RNNs). In addition to the prediction of next design sequences, deep RNNs can also be used to test the utility of different clustering methods.

Research Motivation

- Design is sequential in nature and has great impact on final design outcomes.
- Designers iteratively and sequentially take decision to explore the design space in a design process.
- In-depth understanding of the sequential behavior would help to discover beneficial design heuristics.
- Accurate prediction of design sequences is also vital to the design automation.

Research Questions

1. What are the common sequential decision-making patterns in engineering systems design?
2. How to computationally model and predict designers' sequential design decisions?

Research Platform

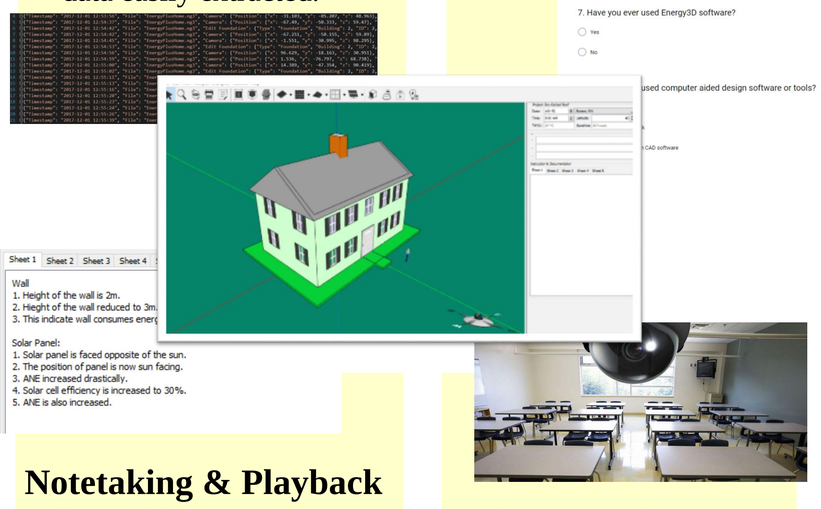
- Energy3D is a tool that enables Data-Driven Design (D^3) research.
- Energy3D provide fine-grained design process data with a lens of high resolution.
- Data can be collected in unobtrusive way, i.e., designers are not aware of data collection.
- We use Energy3D as a platform in our research.

JSON data:

- The JSON file contains every actions with detailed information.
- The standard format of JSON makes the targeted data easily extracted.

Questionnaire:

- Questionnaire can also be added to collect designers' demographics information.



Notetaking & Playback

- Energy3D has built-in notetaking option which can be used to collect data.
- Playback option enable to trace back designers performed actions.

Video recording:

- Video can be recorded while designers performing design.
- The video can be used as a protocol study.

Figure 1: Features and data collection methods with Energy3D

Ongoing Research

Research question 1

The proposed framework:

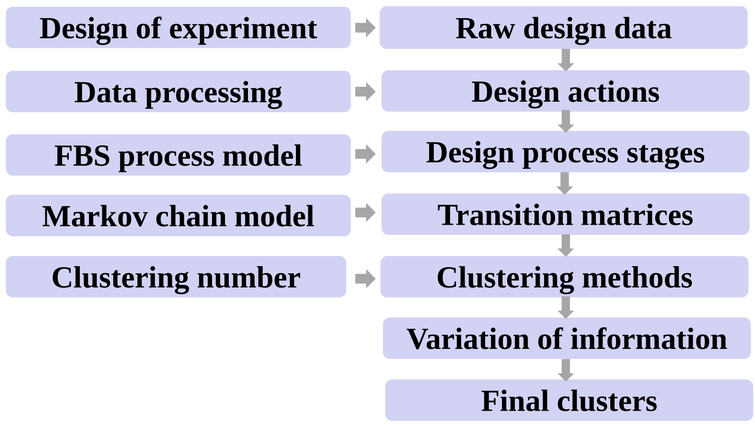


Figure 2: Flow chart of the proposed framework

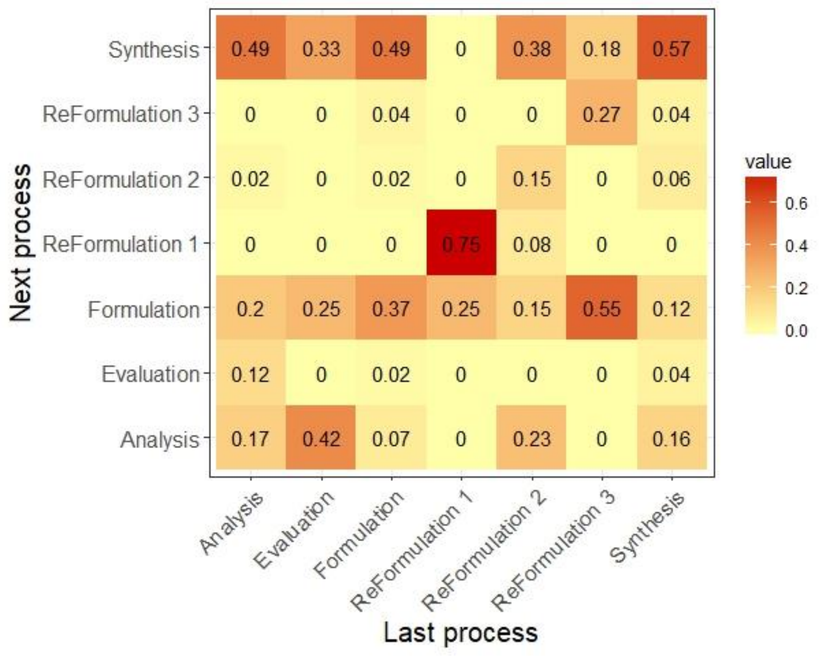


Figure 3: The Markov transition probability matrix of seven design process stages which are defined by the Function-Behavior-Structure process model [1]

Clustering methods:

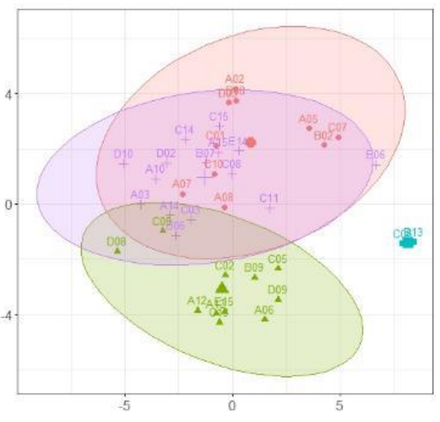


Figure 4.a: K-means clustering [2]

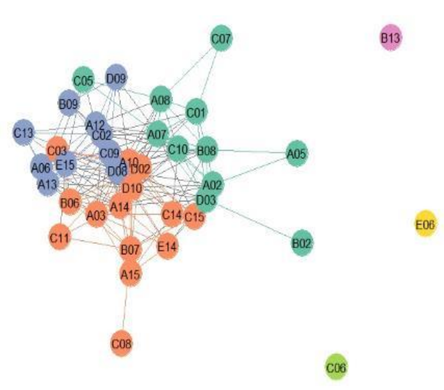


Figure 4.b: Network-based clustering [3]

From the analysis, we found that the most common sequential patterns are *Synthesis→Synthesis* and *Reformulation→Formulation*.

Research question 2

Neural Network:

- We use long short term memory (LSTM) [4], a special type of recurrent neural network to predict the next design stage.
- Recurrent neural network takes sequences as input data.
- Each design process stage is converted into a one hot vector.
- Combining the one-hot vectors, a matrix is formed which is actually the input of the neural network.

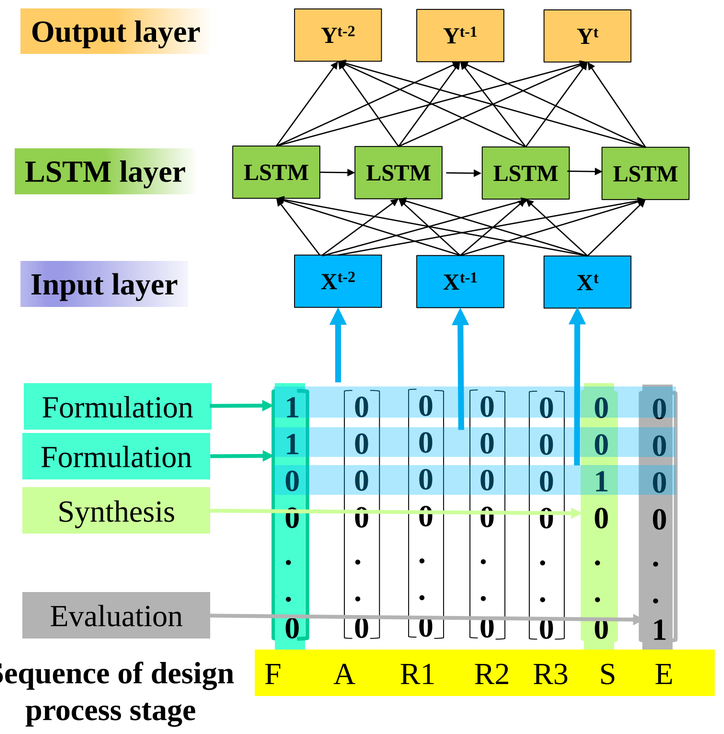


Figure 5: Neural network structure with input data

Prediction accuracy:

With the neural network, we get the training accuracy **58.09%** and testing accuracy **58.04%**, respectively.

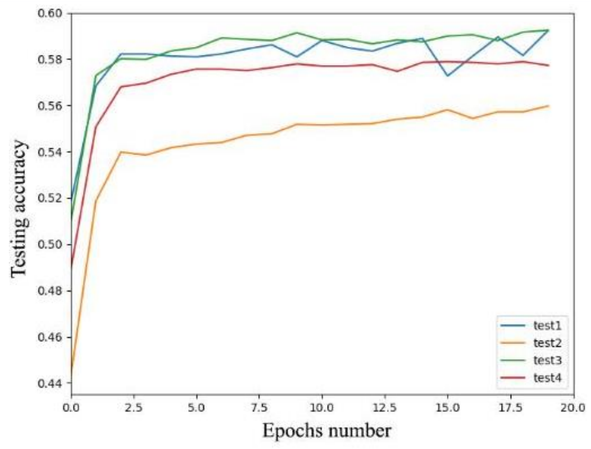


Figure 6: Testing accuracy with four-fold validation

Future Work

- We plan to add the cluster information as a static data into the neural network structure to combine the dynamic sequential data for improving the prediction accuracy.
- We will compare the prediction accuracy of different cluster methods to validate their clustering performance.
- The further step of this research is to leverage the reinforcement learning as a core implementation of design automation.

References

[1] Gero, J. S., 1990. "Design prototypes: a knowledge representation schema for design".AI magazine,11(4), p. 26.
[2] James, G., Witten, D., Hastie, T., and Tibshirani, R., 2013. An introduction to statistical learning, Vol. 112. Springer.
[3] Schaeffer, S. E., 2007. "Graph clustering".Computer science review,1(1), pp. 27–64.
[4] Hochreiter, Sepp, and Jürgen Schmidhuber. "Long short-term memory." Neural computation 9.8 (1997): 1735-1780.

Acknowledgement

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