2020 年度　修士課程最終発表会

M23

VR 環境における視線の空間および過渡分布の数理解析に関する研究

Mathematical Analysis of Eye-gaze Space and Transient Distributions on VR Environment

Akira HIRAI

Micheletto Laboratory
Graduate School of Nanobioscience,
Yokohama City University, Yokohama, Japan

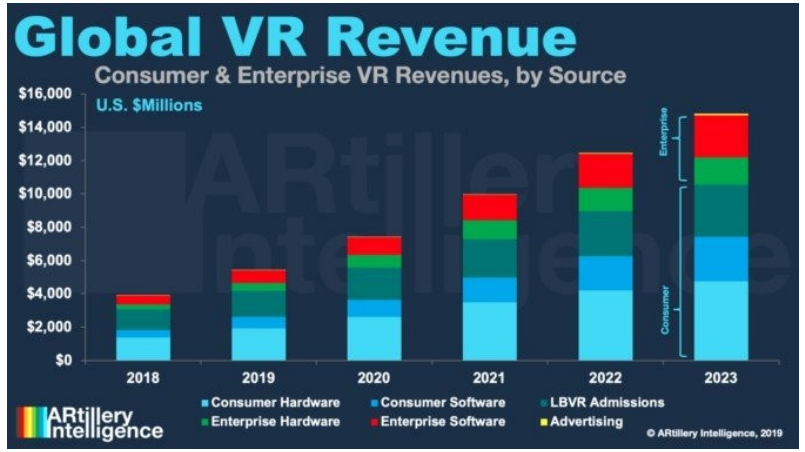
YCU 横浜市立大学

Outline

1. **Introduction**
   - Background
   - Motivation
2. **Experiment and Results**
   - Searching target on test pattern
   - Clustered by K-Means and Elbow method
   - Classify using Probability Ellipse and Reaction time
   - Transient Analysis by Fourier Transformation
   - Neural Network Analysis of Fourier Transformed Data
3. **Discussion**
4. **Summary**

Introduction

Background



Issues

What's the relationship between eye-gaze moving and perception ?

What's the mechanism of VR sickness ?

The VR market is expected to grow significantly in the future

Motivation and Methodology

Motivation

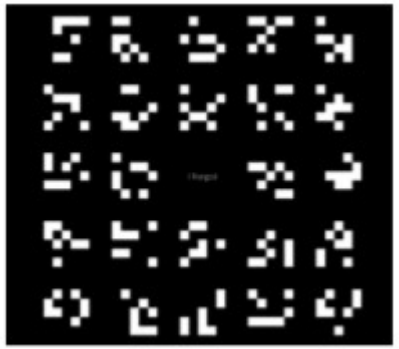
My interest

VR Sickness

Transient Analysis

Eye-Gaze Space Analysis

Visual Search

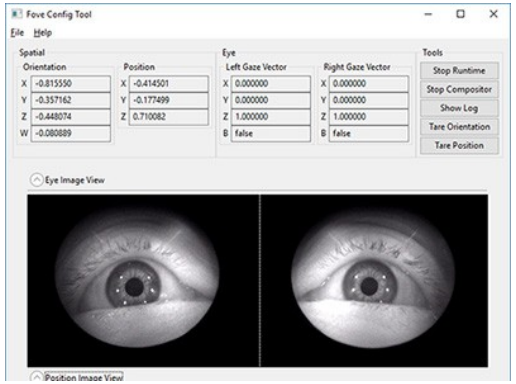


At Micheletto Lab

Methodology

FOVE 0 VR

Eye-gaze tracking system



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Searching target on test pattern

Target

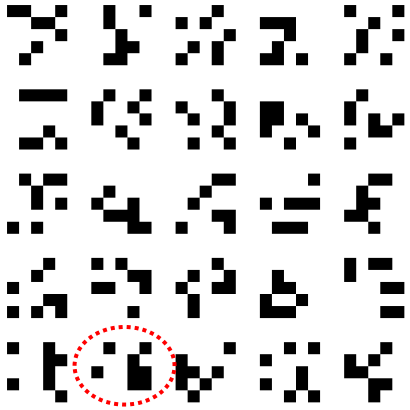
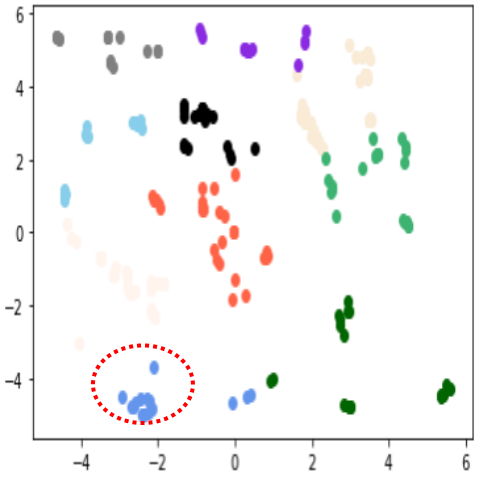


Fig. 1. Test pattern

Eye-gaze tracking data



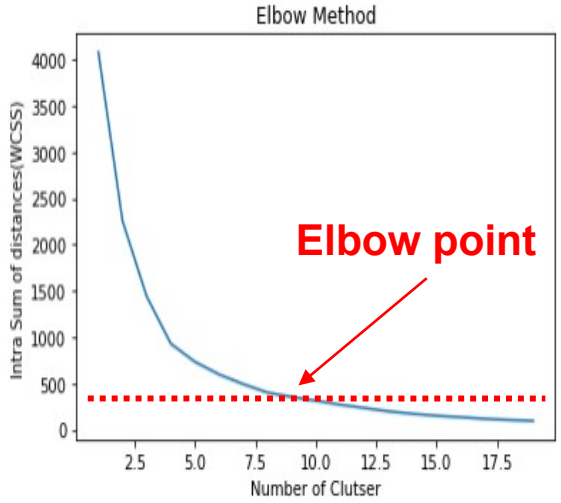


Fig.2. Clustered by K-Means and Elbow method

Clustering

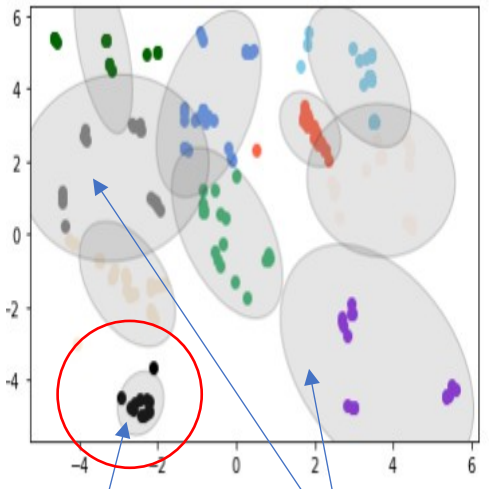


Fig.3. Clustered result

Clustered by K-Means and Elbow method

K-Means method

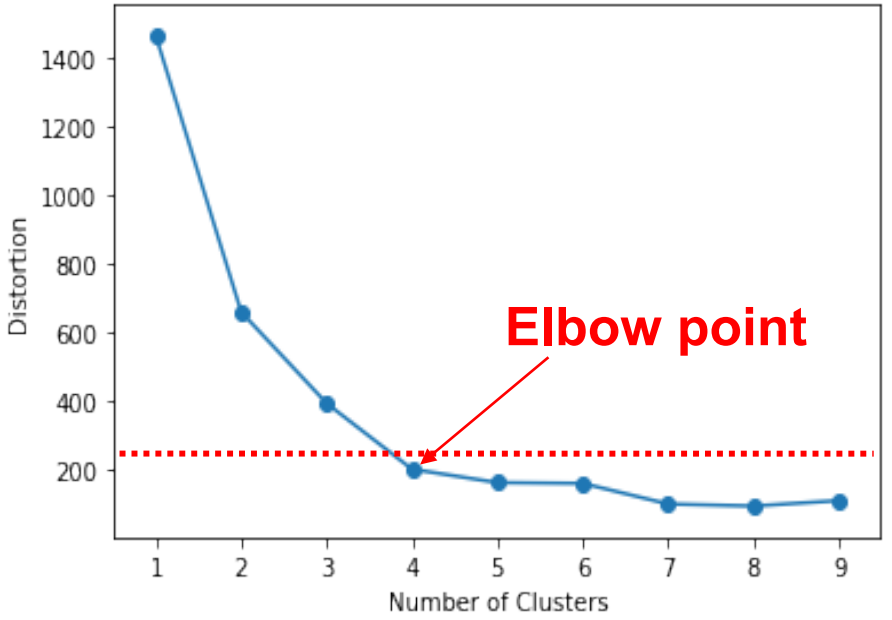
Clustered data using given number of clusters

The objective function

$$\sum_{i=1}^{K} \sum_{x \in X_i} \left\| x - \mu_i \right\|^2$$

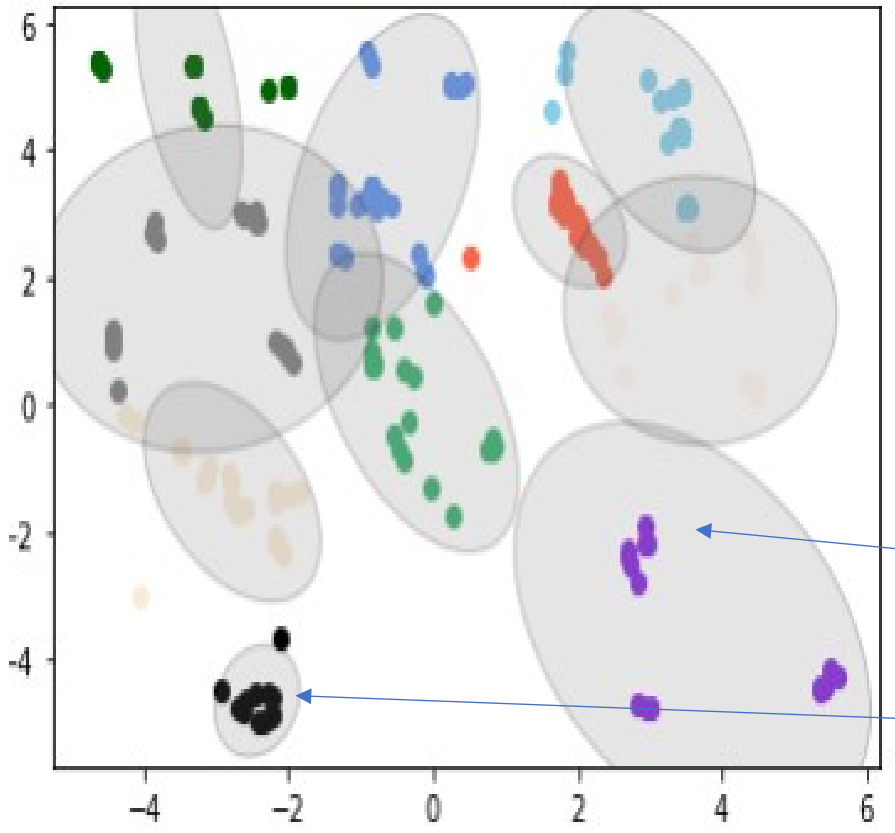
Elbow method

Optimization of number of clusters using calculation of distortion

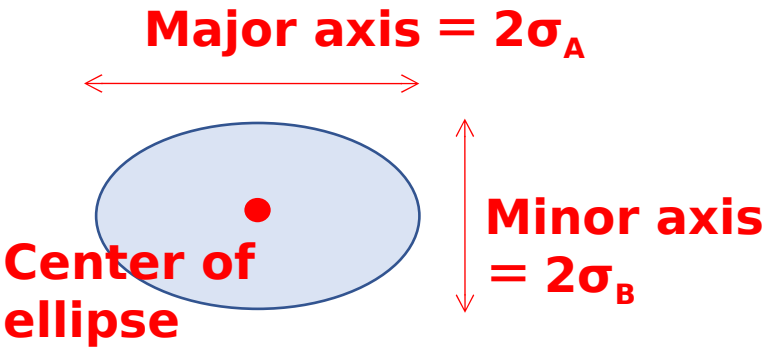


Probability Ellipse

Clarify parameters on “Probability Ellipse” to characterize clusters



Reaction time to find the target τ_R= 16.1 sec.



	中心座標	$2\sigma_A$	$2\sigma_B$
Searching	(3.59, -3.56)	7.01	4.26
Stare	(-2.43, -4.65)	1.78	1.15

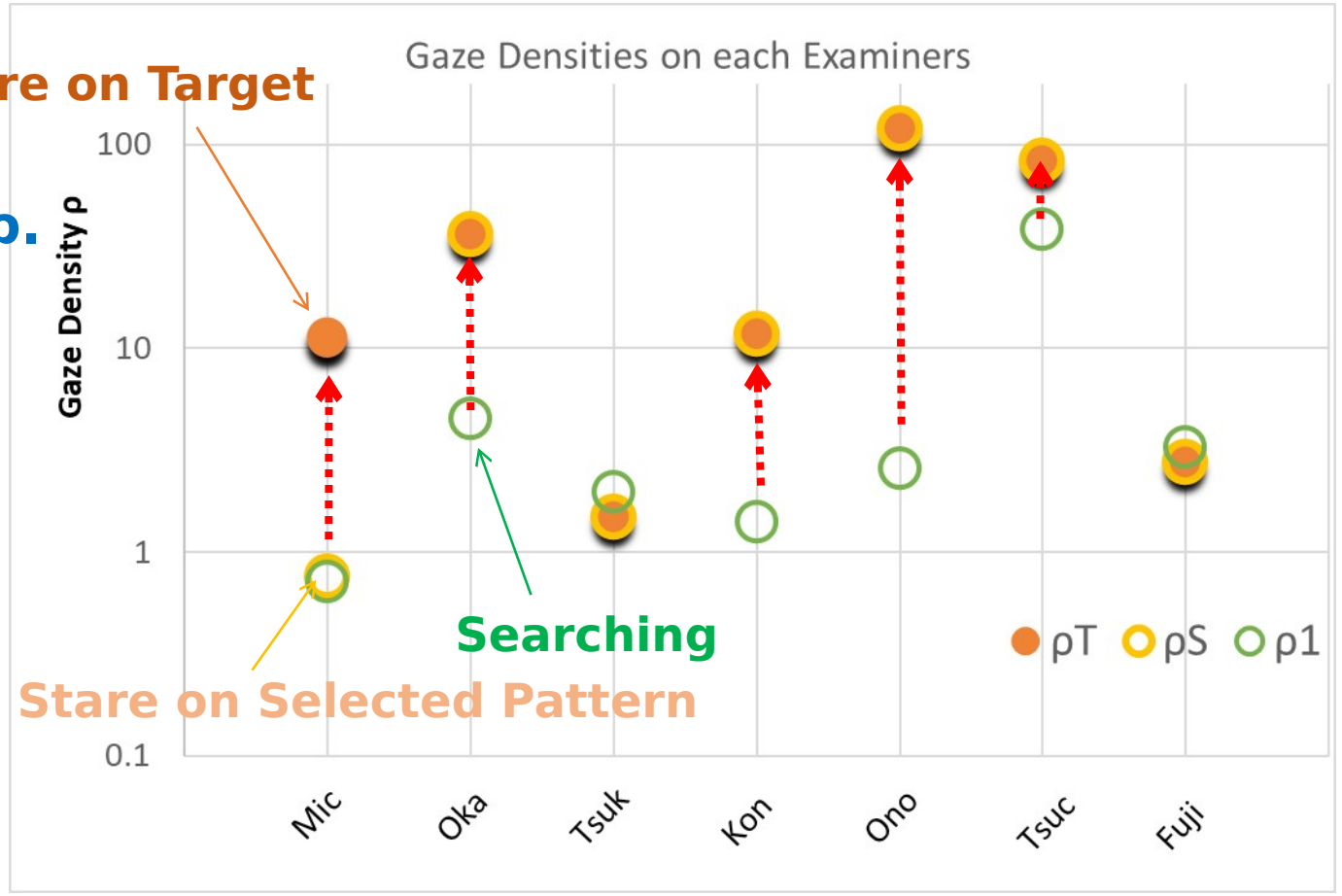
Gaze-search Result

Characterization of Gaze-search

Characterization of "Stare" and "Search" by key-parameter ρ.

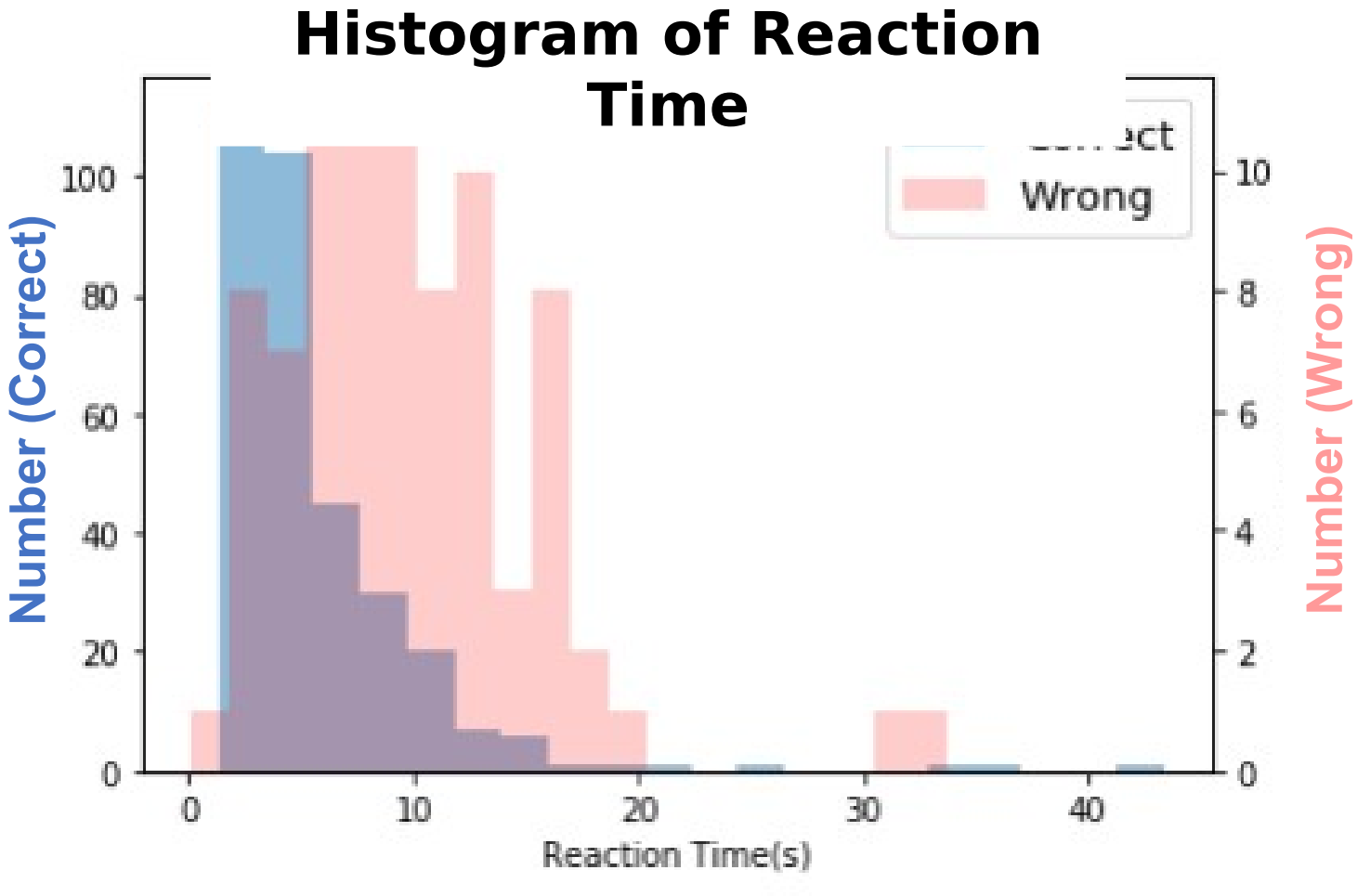
Gaze Density

$$\rho = \frac{\text{Gaze Points}}{\pi\sigma_A\sigma_B}$$

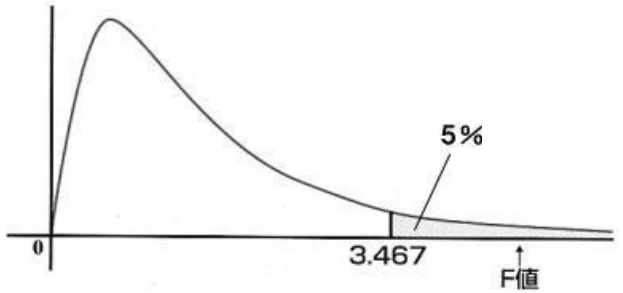


Reaction Time

Relationship between Searching and Reaction Time



F distribution



F test ： P value

0.0235 < 0.05

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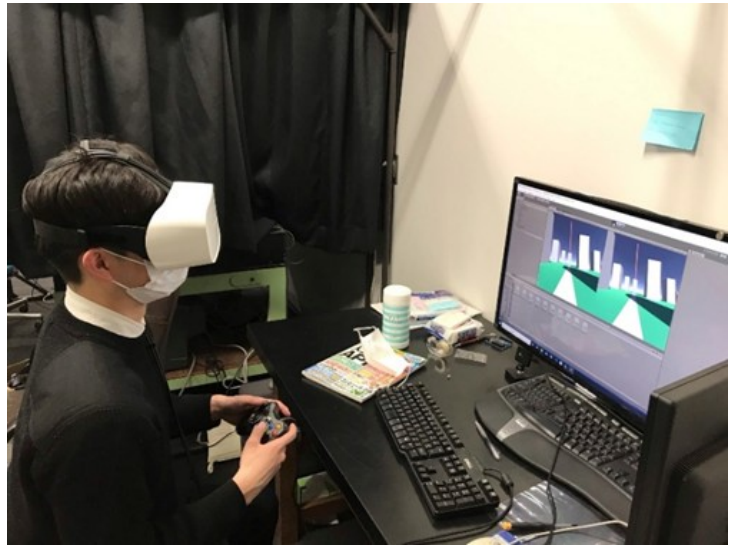
VR Sickness Test

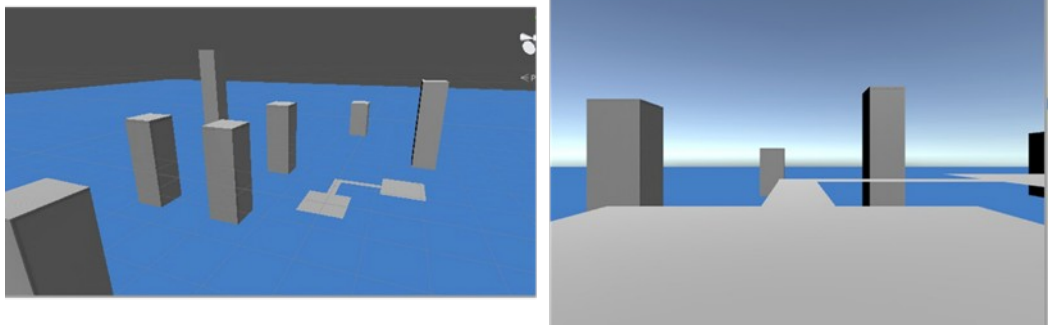
Transient Analysis on Game Style Test



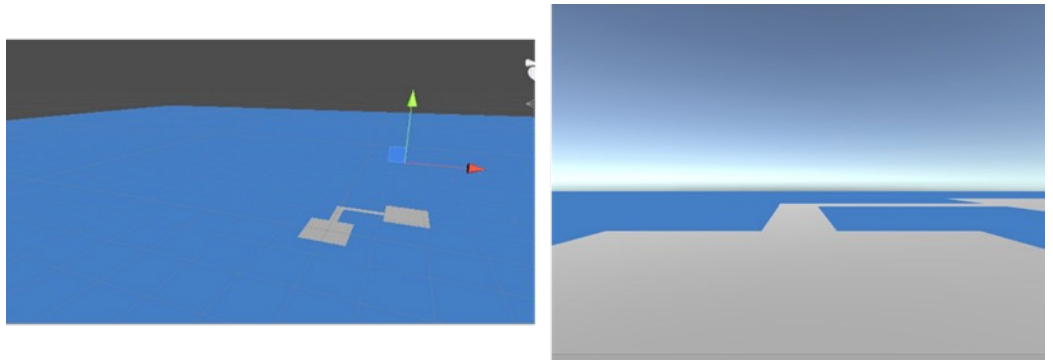
Game Style Test

Stage-1
w/o Shake

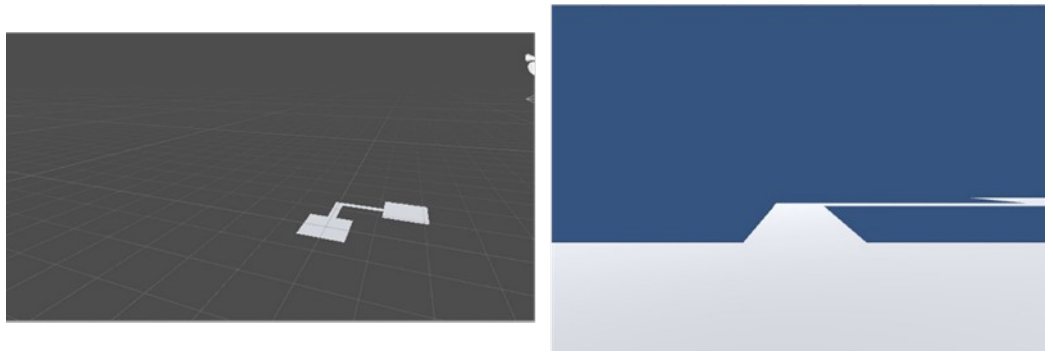
Stage-2
w Shake



Stage-3
w Shake



Stage-4
w Shake

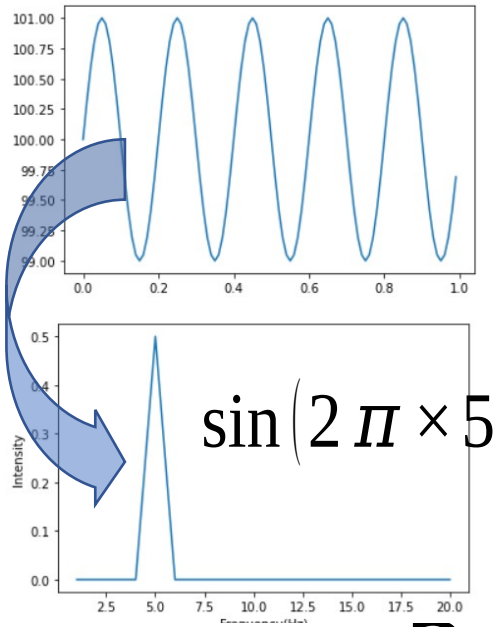


Fourier Transform

$$F(\omega)=\int_{-\infty}^{\infty} f(t)e^{-2\pi i\omega t}\,dt$$

The Gaze data is obtained as ().

Fourier Transform of any frequency is



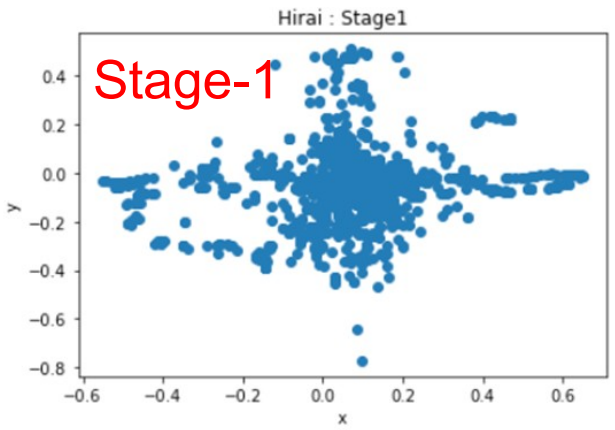
$$\sin(2\pi\times 5t)+Constant$$

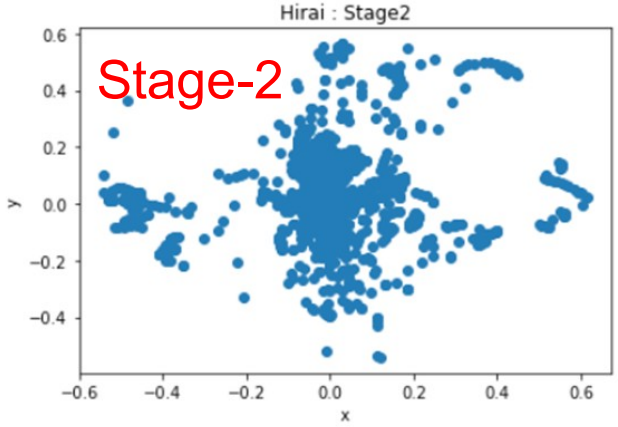
$$F(\omega)=\frac{1}{N}\sum_{k}^{k\in N} x_k e^{-2\pi i\omega t_k}$$

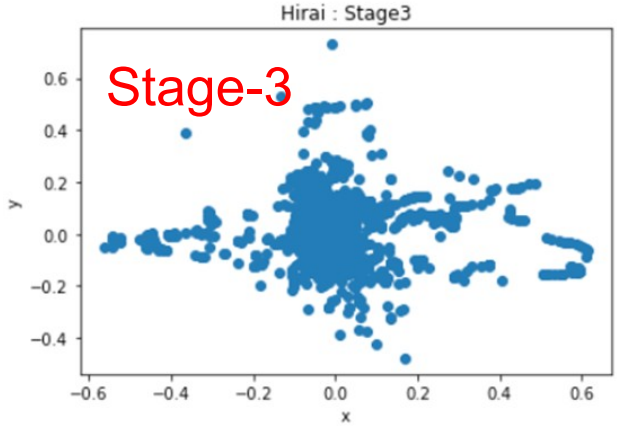
Constant is not affecting Fourier Transform

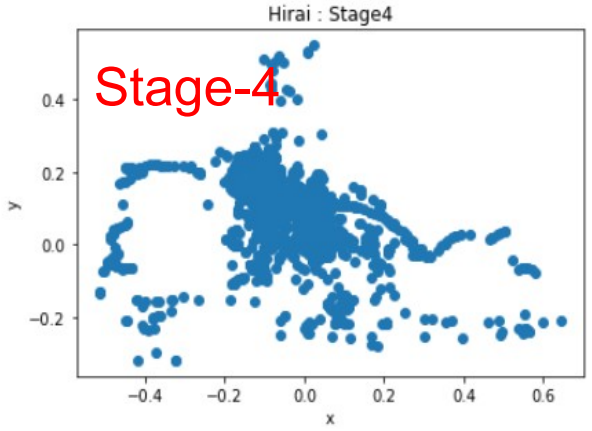
Transient Analysis

Transient Analysis by Fourier Transformation

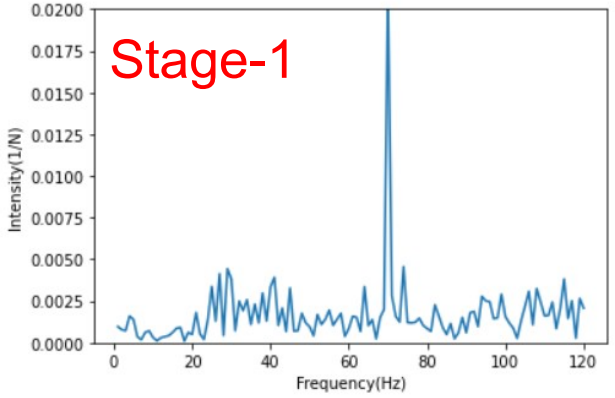


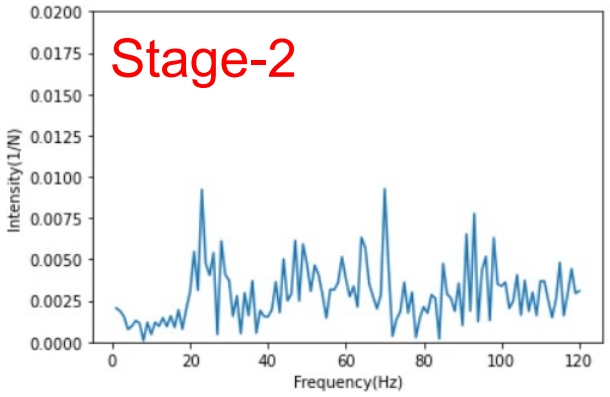


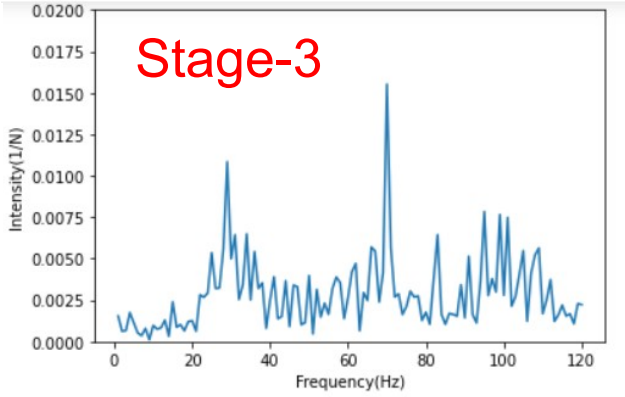


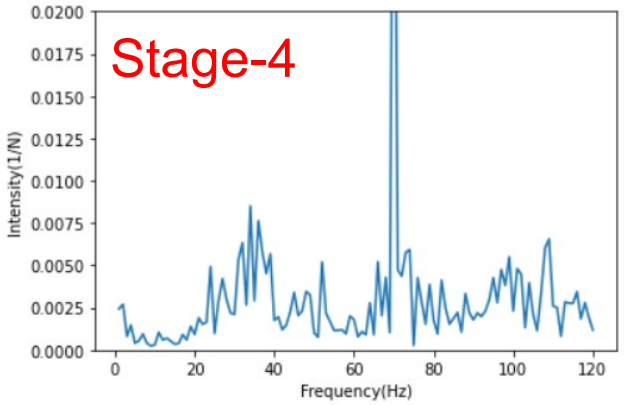


Fourier Transformation of x-axis eye-moving





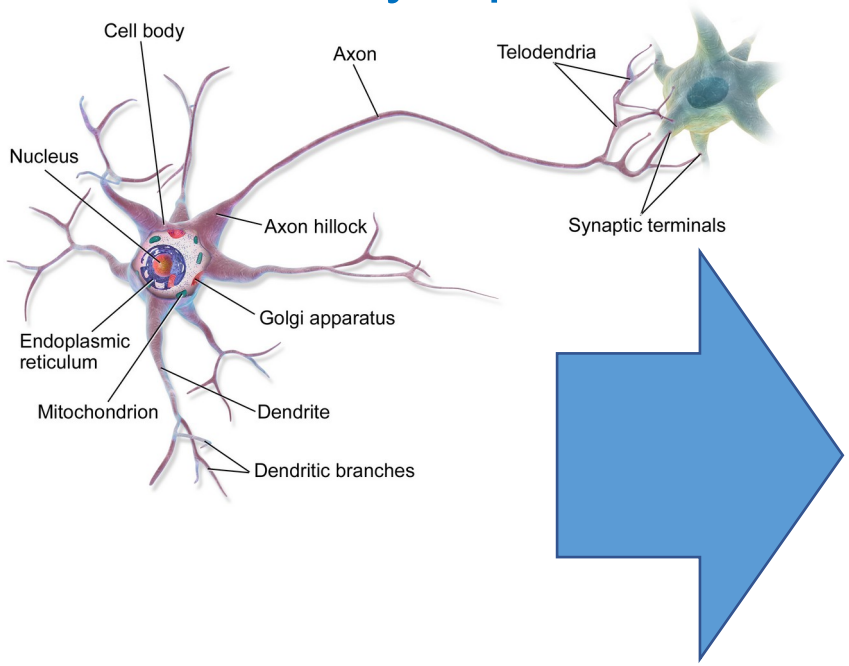




Neural Network(1)

Neuron

Neuron with synapse



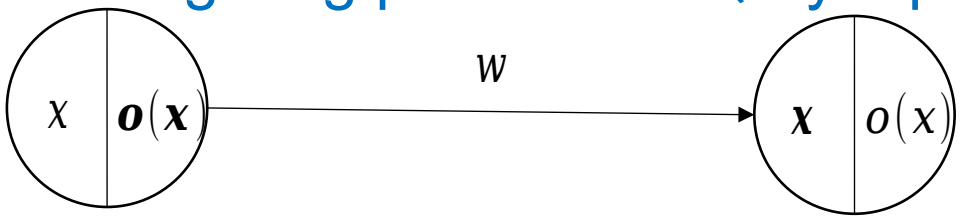
Active function ： Sigmoid function

$$o(x)=\frac{1}{1+e^{-x}}$$

$$o'(x)=o(x)(1-o(x))$$

Neurons connect and disconnect synapses (strengthening and weakening weighting)

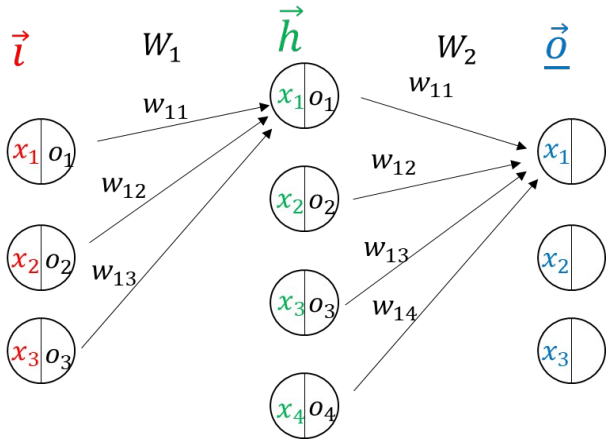
Weighting parameter （Synapse）



$$x=w\cdot o(x)$$

Neural Network(2)

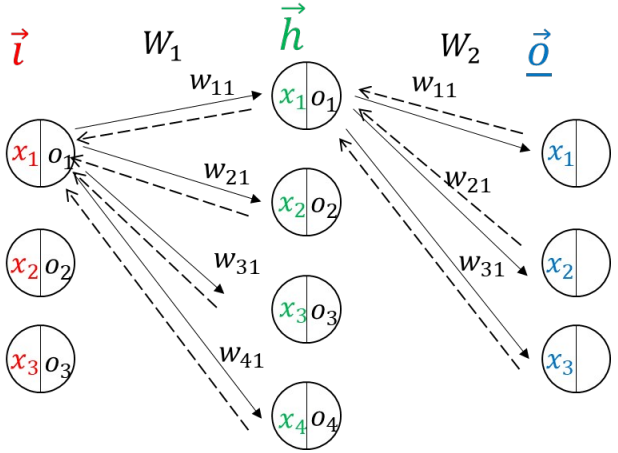
Neural Network Analysis of Fourier Transformed Data



$$\vec{h} = W_1 o(\vec{i})$$
$$\vec{o} = W_2 o(\vec{h})$$

$$o(x) = \frac{1}{1+e^{-x}}$$

$$o'(x) = o(x)\big(1 - o(x)\big)$$



$$W \leftarrow W + \eta \frac{\partial E}{\partial W}$$

Examinee H

```
Stg-1 [[944.   0.  39.  17.]
Stg-2  [  0. 974.  16.  10.]
Stg-3  [  0.   0. 988.  12.]
Stg-4  [  1.   5.  20. 974.]]
      accuracy: 97.0%
```

Examinee F

```
Stg-1 [[  4. 565. 364.  67.]
Stg-2  [ 39. 163. 701.  97.]
Stg-3  [ 64. 187. 488. 261.]
Stg-4  [  0. 521. 449.  30.]]
      accuracy: 17.1%
```

Examinee T

```
Stg-1 [[ 36. 216. 314. 434.]
Stg-2  [117. 421. 422.  40.]
Stg-3  [ 25.  73. 902.   0.]
Stg-4  [  0. 614. 371.  15.]]
      accuracy: 34.4%
```

Examinee O

```
Stg-1 [[ 60. 633. 284.  23.]
Stg-2  [148. 636. 211.   5.]
Stg-3  [166. 720.  48.  66.]
Stg-4  [116. 658.  92. 134.]]
      accuracy: 21.9%
```

Examinee M

```
Stg-1 [[245.  38. 182. 535.]
Stg-2  [  0. 524. 174. 302.]
Stg-3  [  3.  44. 934.  19.]
Stg-4  [  1.  90.  63. 846.]]
      accuracy: 63.7%
```

Analysis Result

Neural Network Analysis and VR sickness

Examinee T, O, F and M

```
Stg-1   [[ 555. 1022.  680. 1743.]
Stg-2    [ 506. 1428. 1071.  995.]
Stg-3    [ 580.  925. 1549.  946.]
Stg-4    [ 437. 1388.  770. 1405.]]
        accuracy: 30.9%
```

Correction rate

Stg-1	**13.9%**
Stg-2	**35.7%**
Stg-3	**38.7%**
Stg-4	**35.1%**

Response of Examinees (Feeling of VR Sickness by Level 0-5)

Examinee	H	T	O	F	M	Ave.
Stg-1	**0**	**0**	**0**	**0**	**0**	**0.0**
Stg-2	**3**	**1**	**2**	**2**	**2**	**2.0**
Stg-3	**2**	**2**	**3**	**2**	**1**	**2.0**
Stg-4	**1**	**2**	**1**	**2**	**1**	**1.4**

→ The Neural Network System detected essential eye movements related VR sickness without individual difference

Discussion(1)

Clustered by K-Means and Elbow method
Classify using Probability Ellipse and Reaction time

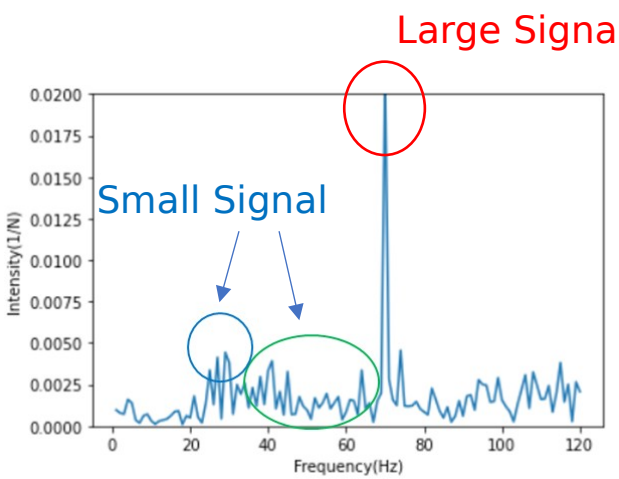
- ✓ We achieved Auto-Clustering using K-Means and Elbow method
- ✓ We also achieved to classify “Stare” and “Searching” by Gaze Density and Reaction Time
- ✓ These analysis methods are first proposed by us

- ✓ We need other approaches for Transient Analysis

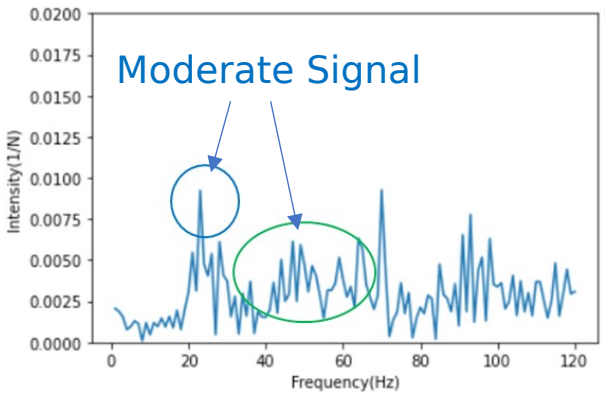
Discussion(2)

Neural Network Analysis and VR sickness

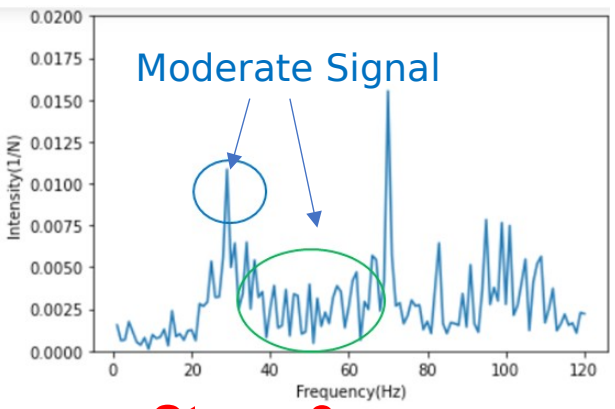
- ✓ Background View and Shaking induces VR sickness
- ✓ Neural Network Analysis of eye-gaze moving can detect essential factors of VR sickness
- ✓ Eye-gaze movement have relationship to VR sickness
- ✓ Further Verification is necessary to determine which Factors cause VR sickness



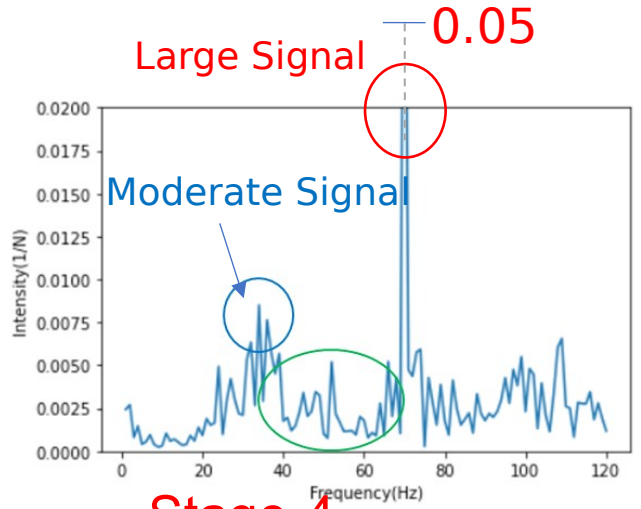
Stage-1



Stage-2



Stage-3



Stage-4

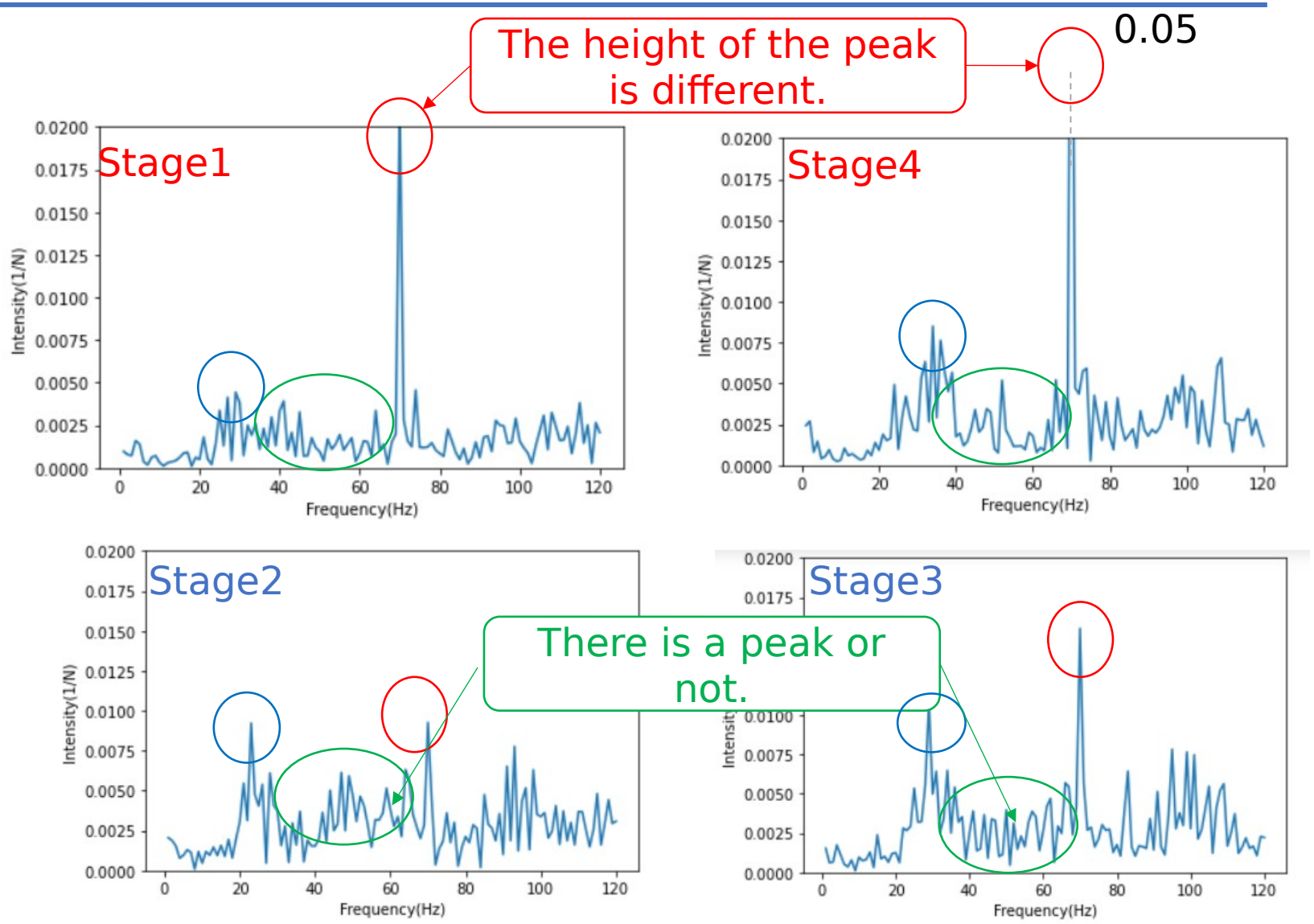
Summary

- We obtained eye-gaze vector and coordinates data on FOVE 0 gaze-tracking platform
- We characterized behavior of the eye-gaze vector and obtained characteristic movements of “Stare” and “Search”
- We proposed key-parameters to characterize gaze-moving
- We also proposed Fourier Transformation and Neural Network technique for Transient gaze-moving analysis
- We obtained positive correlation on results of Neural Network analysis for VR sickness
- I had an oral presentation at VISION 2021 winter conference

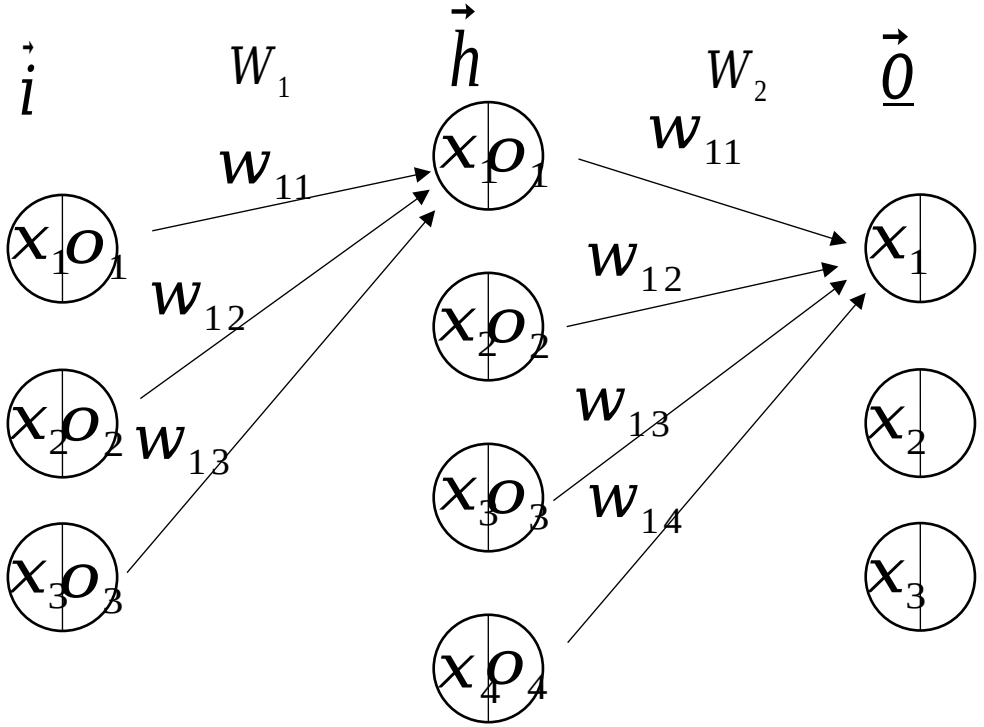
Comparison of the Fourier spectrum

Correlation from 20Hz to 80Hz is important for discrimination

Saccade is 3Hz to 30Hz (VISION 2021 winter conference)



Test （Feedforward)



Active Function : Sigmoid Function

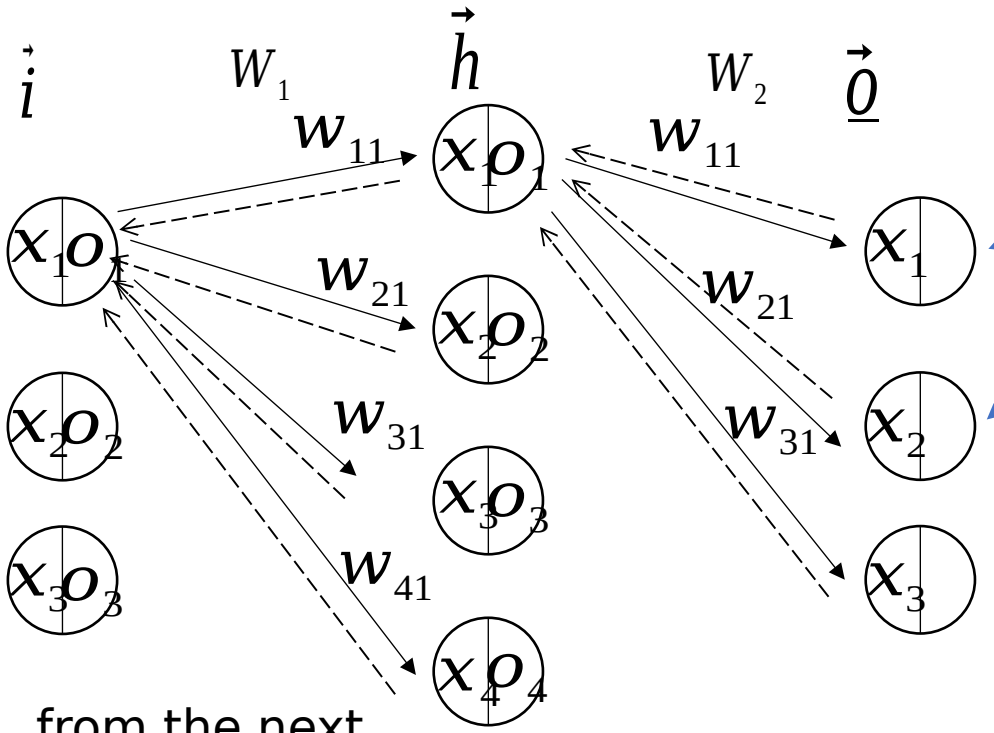
$$o(x)=\frac{1}{1+e^{-x}}$$

$$o'(x)=o(x)(1-o(x))$$

$$\vec{h}=W_1 o(\vec{i})$$

$$\underline{\vec{o}}=W_2 o(\vec{h})$$

Train （Backpropagation）



Error function

$$E = \frac{1}{2}\left|\vec{t} - o(\vec{o})\right|^2$$

Teaching Vector

$$W \leftarrow W + \eta \frac{\partial E}{\partial W}$$

Output to Hidden

$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial E}{\partial o_i} \cdot \frac{\partial o_i}{\partial x_i} \cdot \frac{\partial x_i}{\partial w_{ij}}$$

$$¿ \frac{\partial E}{\partial o_i} \cdot o'_i \cdot o_j$$

$$¿ (t_i - o_i) \cdot o'_i \cdot o_j$$

$$¿ \delta_i \cdot o_j$$

$$\delta_i = \frac{\partial E}{\partial x_i}$$

Hidden to Input （In general)

$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial E}{\partial x_i} \cdot \frac{\partial x_i}{\partial w_{ij}}$$

$$¿ \left(\sum_k \frac{\partial E}{\partial x_k^{next}} \cdot \frac{\partial x_k^{next}}{\partial x_i} \right) \cdot o_j$$

¿ ¿

$$¿ \left(\sum_k \delta_k^{next} \cdot w_{ki}^{next} \cdot o'_i \right) \cdot o_j$$

$$¿ \delta_i \cdot o_j$$

from the next layer

$$\frac{\partial E}{\partial W} = \vec{\delta}\vec{o}^T$$

$$¿ \left(W^{nextT} \overrightarrow{\delta^{next}} \circ \vec{o}' \right) \vec{o}^T$$

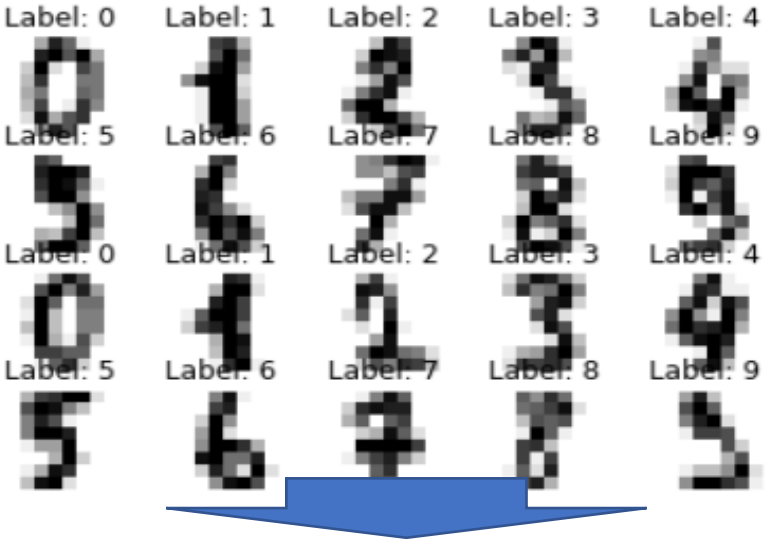
Use

Neural Network is acquiring weighting matrix for minimizing an error function.

Sample Problem(1)

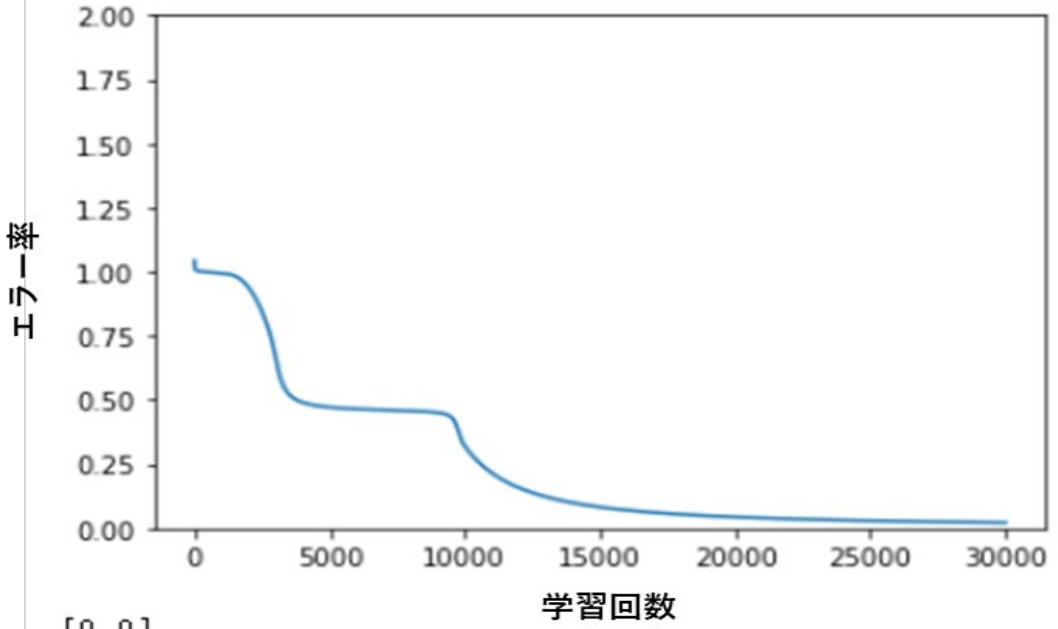
Hand Literature

```
(1797, 8, 8)
```




```
[[178.   0.   0.   0.   0.   0.   0.   0.   0.   0.]
 [  0. 182.   0.   0.   0.   0.   0.   0.   0.   0.]
 [  0.   0. 177.   0.   0.   0.   0.   0.   0.   0.]
 [  0.   0.   0. 183.   0.   0.   0.   0.   0.   0.]
 [  0.   0.   0.   0. 178.   0.   0.   0.   1.   2.]
 [  1.   0.   0.   0.   0. 180.   0.   0.   0.   1.]
 [  0.   0.   0.   0.   0.   0. 181.   0.   0.   0.]
 [  0.   0.   0.   0.   0.   0.   0. 179.   0.   0.]
 [  0.   1.   0.   0.   0.   0.   0.   0. 173.   0.]
 [  0.   0.   0.   1.   0.   0.   0.   0.   0. 179.]]
accuracy: 99.6%
```

XNOR Gate



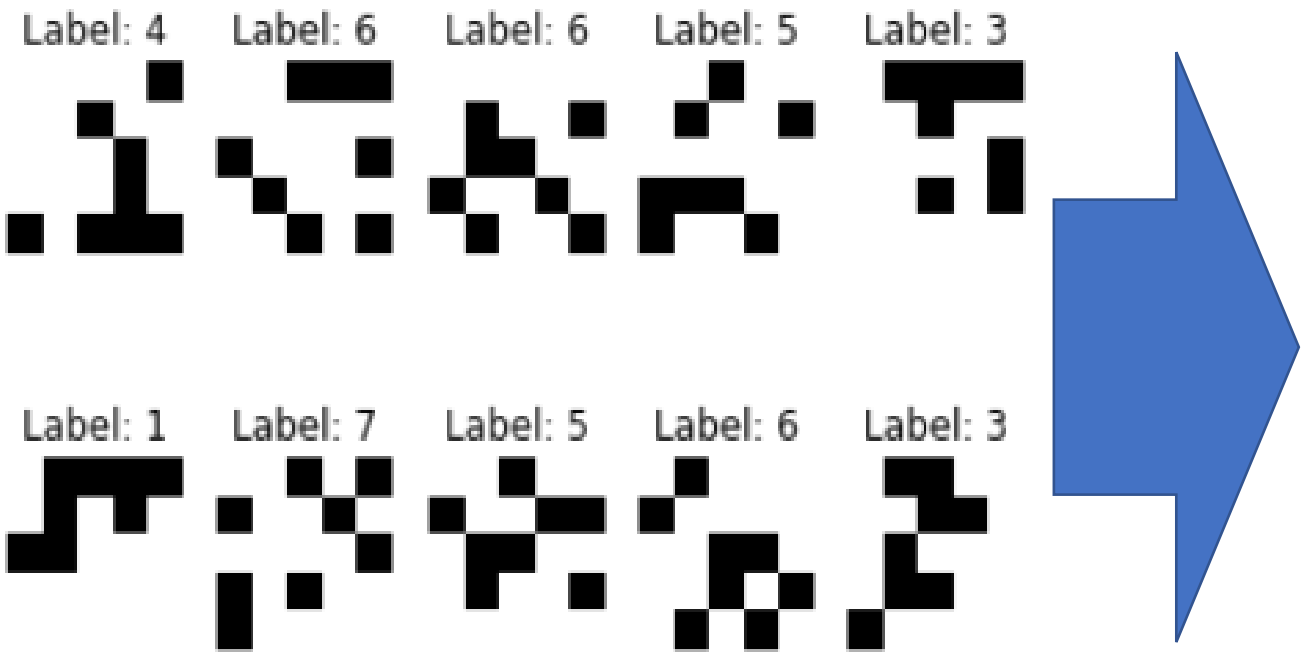

```
[0 0]
[[0.906 0.094]]

[0 1]
[[0.068 0.932]]

[1 0]
[[0.064 0.936]]

[1 1]
[[0.938 0.062]]
```

Sample Problem(2)



Accuracy is 30 to 50%

There is no correlation

Introduction (2)

Motivation

- Analyze map of eye-gaze moving and obtain key parameters to characterize human visual search
- Propose our original mathematical analysis methodologies
- How to get hints of VR Sickness ?

Methodology

- Obtain and analysis eye-gaze tracking data on FOVE 0 VR system using original software
- Clustered by K-Means method and Elbow method
- Classify using Gaze Density and Reaction Time
- Fourier Translation and Neural Network Technique for transient analysis

FOVE 0 VR

Eye-gaze tracking system