Modeling of Cognitive Bias of Video Viewing Users based on Quantum Decision Making

Natsumi Nishizawa, Tatsuya Otoshi, Masayuki Murata

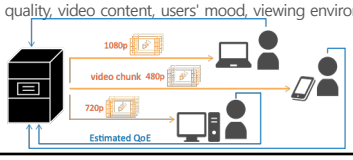
Graduate School of Information Science and Technology,
Osaka University

2021/01/12

1

Video Streaming and QoE Estimation

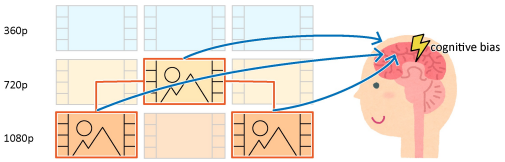
- **The popularity of video streaming distribution**
  - Congestion or poor network quality
  - Need to improve satisfaction with limited network resources
    - Bitrate control should be adapted to how users feel
    - Demand for estimation the satisfaction level of users
- **Use QoE (Quality of Experience) to express the satisfaction level**
  - QoE: the subjective evaluation of the service experience by users
    - Factor: network quality, video content, users' mood, viewing environment, etc.



2

For More Accurate QoE Estimation

- **Cognitive biases arise while watching videos**
  - Cognitive bias: irrational decisions including statistical and memory errors
  - example: the QoE differs whether users selected the video quality or not [1]
    - users believe that the video quality selected by themselves is better than the one chosen automatically
  - Previous QoE models do not consider cognitive bias

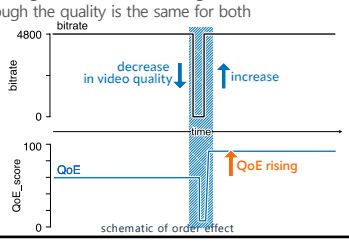


[1] A. Sackl, P. Zwickl, S. Egger-Lampl, and P. Reichl, "The role of cognitive dissonance for QoE evaluation of multimedia services," 2012 IEEE GlobecomWorkshops, GC Wkshps 2012, pp.1352–1356, February 2012

3

Cognitive Bias to be Modeled

- **Order Effect during Video Streaming**
  - The order that information is presented can make a difference in decision-making
  - For watching videos
    - Rebuffering occurs from the highest bitrate and returns to it again
    - the QoE is higher after the rebuffering than before, even though the quality is the same for both



4

Goal and Approach

Goal

Representing cognitive bias with image quality change in the QoE model of video viewers

Approach

- **Build a QoE model including cognitive bias with QDM (Quantum Decision Making)**
- **Simulate the QoE of streaming video viewers**
  - Use dataset with videos, bitrate, and QoE scores
  - Compare the estimated QoE with the QoE score of the dataset to evaluate the accuracy of the model

5

Overview of the Proposed Method

- **Build the QoE model with QDM**
  - QDM: Model human cognitive states by mapping them to quantum states
  - Decision-making is probabilistic in nature
    - QDM represents context-dependent uncertainty in decision-making
    - Use quantum mathematics to account for entanglement in decision-making naturally
    - Capable of comprehensive modeling of various cognitive biases
- **The process of modeling the QoE with QDM**
  1. Apply QDM to the QoE of video viewers
  2. Modeling temporal changes in cognitive states
     - Modeling the anchoring effect
  3. Implementing the order effect into the QoE model

6

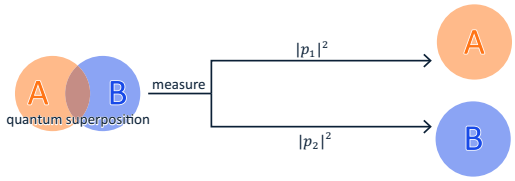
Quantum State and State Changes

7

- **Quantum state: source on Hilbert space $|\psi\rangle \in \mathcal{H}$**
- **Quantum superposition and destruction**
  - state superposition $|\psi\rangle$: a linear combination of $|\psi_1\rangle$ and $|\psi_2\rangle$
    - p_1, p_2 : probability amplitude

$$|\psi\rangle = p_1|\psi_1\rangle + p_2|\psi_2\rangle$$

  - destruction of state superposition: Observation determines either $|\psi_1\rangle$ or $|\psi_2\rangle$



7

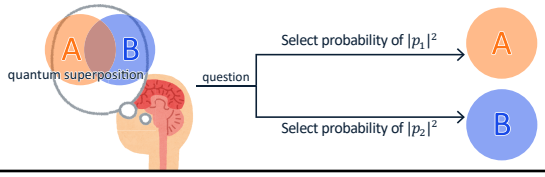
Cognitive State and Decision Making

8

- **Cognitive state: quantum state $|\psi\rangle \in \mathcal{H}$**
- **Decision Making**
  - Assume a decision making to choose option $\{A, B\}$
  - When the choice is undecided: quantum superposition
    - Choose option A with a probability of $|p_1|^2$ and option B with a probability of $|p_2|^2$

$$|\psi\rangle = p_1|A\rangle + p_2|B\rangle \ (p_1, p_2: \text{probability amplitude})$$

  - When selecting an option: the destruction of quantum superposition



8

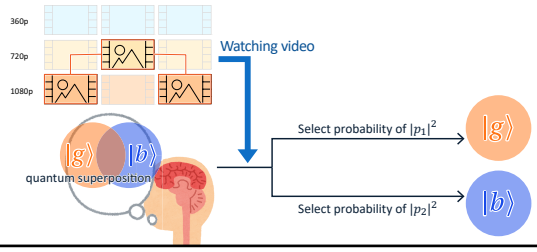
The QoE Model of Video Viewers

9

- **Define the QoE as good $|g\rangle$ and bad $|b\rangle$**
  - Cognitive state of video viewers: State in which $|g\rangle$ or $|b\rangle$ is selected probabilistically

$$|\psi\rangle = p_1|g\rangle + p_2|b\rangle$$

  - QoE: $P(g)$ (Probability of choosing $|g\rangle$)



9

Temporal Changes in Cognitive State

10

- **Introduce a cognitive bias including state change over time into the QoE model**
  - Anchoring Effect: Decision-making that strongly influenced by the information given immediately before
- **Modeling the anchoring effect with QDM**
  - It has been suggested that we use a sampling-like calculation in decision-making
    - Generate a new estimate by probabilistically modifying the current estimate
    - Compare the posterior probability of the new estimate with that of the old estimate and update if it is higher
  - Time evolution in quantum states: Schrodinger equation
    - $\hat{H}$: Hamiltonian, i: imaginary unit, $\hbar$: Dirac's constant

$$i\hbar \frac{d}{dt}|x(t)\rangle = \hat{H}|x(t)\rangle$$

10

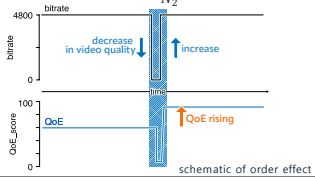
Modeling Order Effect

11

- **The order effect is expressed as the non-commutativity of the operator in QDM**
  - the Hamiltonian depends on the bitrate at the time t
    - $d(t)$: Bitrate on time t, N_1: the threshold of $|g\rangle$ and $|b\rangle$, N_2: Normalization constant

$$\hat{H} = \begin{pmatrix} b & -(a + c(t)) \\ -(a + c(t)) & b \end{pmatrix}$$

$$c(t) = \frac{d(t) - N_1}{N_2}$$



schematic of order effect

11

Evaluation of the QoE model

12

- **Evaluation target**
  - How well our QoE model represents cognitive biases
  - Accuracy of QoE estimation with our QoE model
    - Correlation between the estimated QoE $P(g)'$ and the real QoE
    - Mean square error of $P(g)'$ and the real QoE
- **Evaluation Method**
  - Calculate the QoE score by simulating with a dataset[6]
    - Input bitrate to the model
    - Calculate and output time series of QoE scores per second

[6] N. Eswara et al., "A Continuous QoE Evaluation Framework for Video Streaming Over HTTP," in IEEE Transactions on Circuits and Systems for Video Technology, vol. 28, no. 11, pp. 3236-3250, Nov. 2018.

12

Simulation Environment

13

- **Dataset**
  - Videos (mp4, 36 clips)
    - Edited to include periodic bitrate drops and increases
  - Bitrate
    - Time series values per second
  - QoE score
    - Time series values per second
    - Average QoE score reported by 21 subjects who watched the 36 videos
    - expressed in the range [0,100]

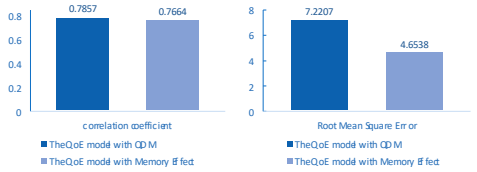
An Example of videos

13

Overview of Results

14

- **QoE estimation accuracy**
  - Compared to the existing QoE model with cognitive bias, Memory Effect [7]
    - Memory Effect: Cognitive bias with time evolution
  - The proposed model showed a higher correlation than the Memory Effect model
  - Mean square error is larger than the Memory Effect model
    - Estimates for intermediate bitrate values are often not accurate



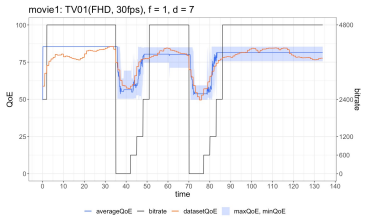
[7] Duc, Tho Nguyen et al. "Modeling of Cumulative QoE in On-Demand Video Services: Role of Memory Effect and Degree of Interest." *Future Internet* 11 (2019): 171.

14

The Simulation Result for a video

15

- **Introducing the anchoring effect in the model can accurately estimate the time series QoE**
  - The behavior of the estimated QoE is similar to the real QoE when the bitrate changes
  - When the bitrate increases gradually, the QoE also increases slowly along with it

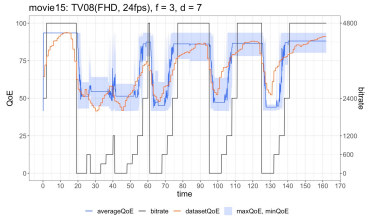


15

The Result for a video with order effects

16

- **The QoE model based on QDM can express the order effect**
  - Rebuffering occurs several times in the video
  - The QoE in the dataset rises gradually each time after rebuffering
  - The estimated QoE also rises gradually



16

Summary and Future Work

17

Summary

- **Developed a QoE model including cognitive bias**
  - Anchoring Effect, Order Effect
- **Evaluated how well the QoE model explains the cognitive bias by simulating it with a video dataset**
  - It can express anchoring and order effects
  - It can estimate the QoE with high accuracy

Future Work

- **Improve the response of the model to instantaneous bitrate changes**
  - It does not deal with these bitrate changes well

17