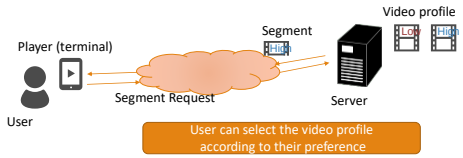
Implementation of Quantum Decision-Making Based Recommendation Method for Adaptive Bitrate Streaming

TATSUYA OTOSHI, MASAYUKI MURATA

GRADUATE SCHOOL OF INFORMATION SCIENCE AND TECHNOLOGY, OSAKA UNIVERSITY

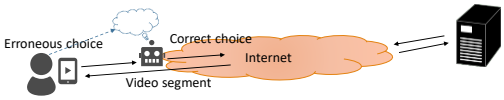
Dynamic Adaptive Streaming

- Switch the rate according to the situation
  - Ex) Low bitrate for the low network throughput
- MPEG-dash (Dynamic Adaptive Streaming over HTTP)
  - Video server retains the multiple video profiles
  - Video divided into segments at regular intervals
  - Player dynamically selects the profile on the user terminal



QoE Control by Agent

- Your own choice
  - Choose something close to what you want
  - Include errors that people easily make
- Agent collects the user's choice
  - Corrects mistakes while respecting the user's wishes



How to model users' wishes and mistakes?

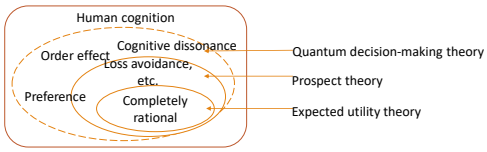
QoE Modeling and Challenges

- Quality of experience(QoE) Model[1],Etc
  - Quantify user's satisfaction for video streaming
  - Factor is basically only the communication quality
- Psychological Effect on QoE
  - User's behavior includes cognitive bias
- Ex) Cognitive dissonance
  - Users prefer what they select[2]

[1] T. Yamazaki, T. Miyoshi, M. Eguchi, and K. Yamori, "A service quality coordination model bridging QoS and QoE," in IEEE 20th International Workshop on Quality of Service (IWQoS). IEEE, 2012, pp. 1-4.
[2] Sackl, A., Zwickl, P., Egger, S., & Reichl, P. , "The role of cognitive dissonance for QoE evaluation of multimedia services," *in Proceedings of GLOBECOM Workshops*, 2012.

Purpose and approach

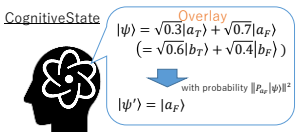
- Purpose
  - Modeling user's behavior, including psychological effects
  - Guiding the user to correct selection
- Approach
  - Modeling user by Quantum Decision Making[3], etc.
  - Induce appropriate selection based on the model



[3] J. M. Yearsley and J. R. Busemeyer, "Quantum cognition and decision theories: A tutorial," Journal of Mathematical Psychology, vol. 74, pp. 99 (116, 2016, foundations of Probability Theory in Psychology and Beyond.

Quantum Decision Making

- Probabilistic decision based on cognitive status
- Cognitive status is modeled as a quantum state
  - Cognitive status changes after decision-making

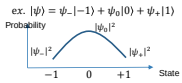


Decision Making

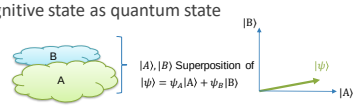
Question: A Is True? Answers: A is False (with Probability70%)

Quantum State

- Defined
  - Quantum state : $|\psi\rangle \in \mathcal{H}$
  - $\mathcal{H}$ is the complex Hilbert Space
- Superposition
  - $|\psi\rangle = \psi_1|\psi_1\rangle + \psi_2|\psi_2\rangle$
  - $|\psi_1|^2, |\psi_2|^2$: Probability Amplitude

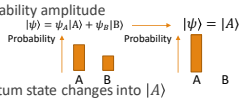


- Cognitive state as quantum state

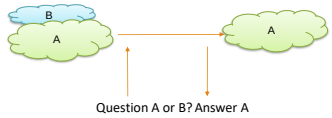


Quantum Observation

- Observation value is obtained by quantum observation
  - Probability of getting value A is probability amplitude
  - $P(A|\psi) = \left||A\rangle\langle A|\psi\rangle\right|^2$

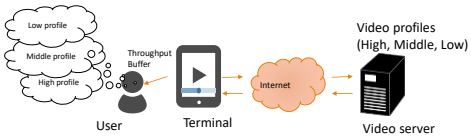


- Convergence of probability
  - When value A is observed, the quantum state changes into $|A\rangle$
  - If you do the same measurement immediately after observing A
- Decision making as a quantum observation



User model by Quantum decision making

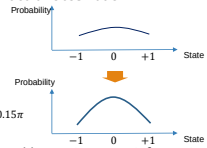
- Cognitive status
  - Superposition of available video profiles
  - $|\psi\rangle = \psi_H|q_H\rangle + \psi_M|q_M\rangle + \psi_L|q_L\rangle$
- Decision Making
  - $P(a_i|\psi_i)$: The probability to select the image quality a_i



Cognitive state update

$q(t)$: Bit rate
$d(t)$: Rebuffering time
s: first buffering time

- Quantum Reinforcement Learning[6]
  - Amplify the probability amplitude of a particular observation
  - $|\psi(t+1)\rangle = Q(x)|\psi(t)\rangle$
    - $Q(x) = (Q_2Q_1(x))^L$
    - $Q_1(x) = I - (1 - e^{i\phi_1})|\pi_x\rangle\langle\pi_x|$
    - $Q_2 = (1 - e^{i\phi_2})|\psi(t)\rangle\langle\psi(t)|$



$|\pi_x\rangle$: Amplified state
$L = F(q_i), \phi_1 = \phi_2 = 0.15\pi$

- User's State Updates
  - Probability of the rational choice is increased by getting more information
  - Amplify the probability of $q_i = \text{argmax}\, F(q_i)$

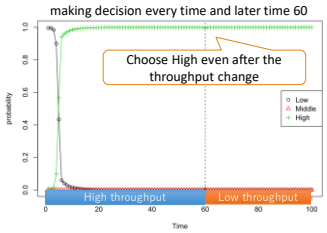
$$F(q) = \sum_t \{q(t) - \lambda|q(t+1) - q(t)| - \lambda_d d(t)\} - \lambda_s s$$

$F(q_i)$:QoE for selecting q_i[7]
(except psychological effects)

[6] J. R. Busemeyer and P. D. Bruza, Quantum models of Cognition and decision. Cambridge University Press, 2012.
[7] x. Yin, A. Jindal, V. Sekar, and B. Sinopoli, "A control-theoretic approach for dynamic adaptive video Streaming over HTTP, "in Proceedings of Sigcomm, 2015, pp. 325-338.

A Model Behavior: Quantum Zeno effect

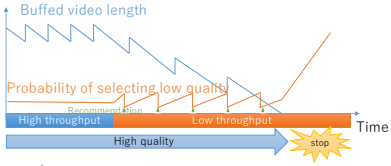
- Choosing the same choice by frequent decision
  - It has been confirmed by the psychological experiment [6]



[6] Yearsley, J., and E. M. Pothos. "Zeno's paradox in decision making."*Proceedings of the Royal Society B* 283.1828 (2016): 20160291.

Challenges and approach in recommendation

- Challenges
  - Frequent recommendation occurs quantum Zeno effect

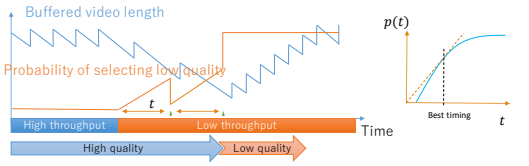


- Approach
  - Waiting until the user's cognitive state changes into the rational decision
  - Consider repeating recommendations

Recommendation Timing Selection

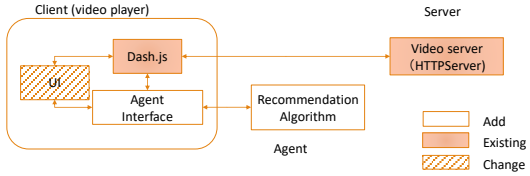
- Minimize the expected time to make the rational choice
  - $minimize_t: E[t \times n] = \frac{t}{p(t)}$

t: Recommendation interval
n: number of required recommendations
$p(t)$: probability to select rational choice



Implementation

- Extend Dash.js to communicate with recommendation agent
  - Notify the agent of the streaming information
  - Follow the instructions of the agent to perform the recommendation

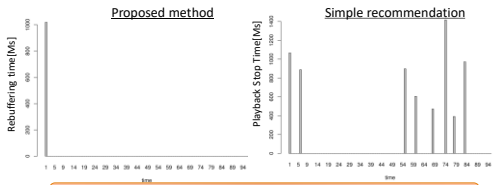


Evaluation environment

- Video
  - Segment Length: 4 seconds
  - Video Profiles: 10 profiles from 200kbps to 12Mbps
- Network
  - Network emulator limits the bandwidth
- User behavior during recommendation
  - Follow the quantum decision-making model
- Comparison with simple recommendation
  - Recommend rational choice every time when the current choice is not rational one

Result

- Throughput is decreased by the network emulator
  - At time 30, throughput changes from 10Mbps to 4Mbps



In the simple recommendation, frequent recommendation causes the quantum Zeno effect and the user cannot select the rational choice.

Summary and future work

- Summary
  - Modeling user's bitrate selection by quantum decision making
  - Proposed a method to perform recommendations in a timely manner
  - Implement the recommendation method in the MPEG-DASH
- Future work
  - Study of the agent placement (Edge or Core)
  - A study of fitting method of quantum decision-making model to user