What You Pay Is What You Get

Economics of Quality of Experience in Fixed and Mobile Telecommunications

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Agenda

- Introduction
- From QoS to QoE
- Towards Fundamental Laws of QoE
- A Fixed Point Model for QoE-based Charging
- User Trial Evidence
- Conclusions & Outlook

From Quality-of-Service to Quality-of-Experience

A Brief History of Service Quality

- Early definitions of Quality-of-Service
  - *"collective effect of service performance which determines the degree of satisfaction of a user of the service"* [ITU-T Rec. E.800, 1994]
  - *"a set of qualities related to the collective behavior of one or more objects"* [ISO/IEC 13236, 1998]
  - *"used to define the network's capability to meet the requirements of users and applications"* [Kilkki, 1999]
- 10 years later…
  - *"ability of the network to provide a service at an assured service level"* [Soldani, 2006]
  - *"capability of a network to provide better service to selected network traffic … described by the following parameters: delay and jitter, loss probability, reliability, throughput and delivery time"* [Markaki, 2007]

Some Approaches Towards QoE

- QoE as a buzzword extension:

  „QoE has been defined as an extension of the traditional QoS in the sense that QoE provides information regarding the delivered services from an end-user point of view" [Lopez et al. 2006]

- QoE as a usability metric:

  "QoE is how a user perceives the usability of a service when in use – how satisfied he/she is with a service in terms of, e.g., usability, accessibility, retainability and integrity" [Soldani 2006]

- QoE as a hedonistic concept:

  "QoE describes the degree of delight of the user of a service, influenced by content, network, device, application, user expectations and goals, and context of use" [Dagstuhl Seminar May 2009]

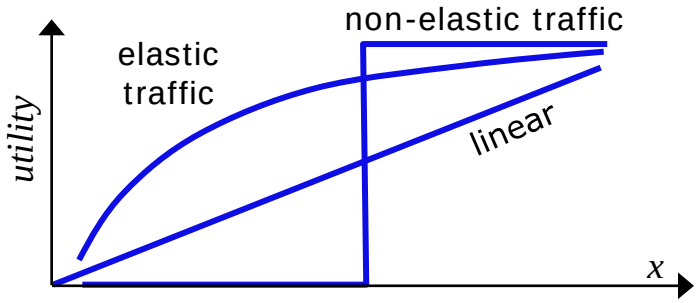
- QoE as the ultimate answer to life, universe and everything:

  "Quality of Experience includes everything that really matters" [Kilkki@LinkedIn 2008]

Towards Fundamental Laws of QoE

Utility vs QoE

- Basic question: what is the „value“ of a resource/service for the end customer?

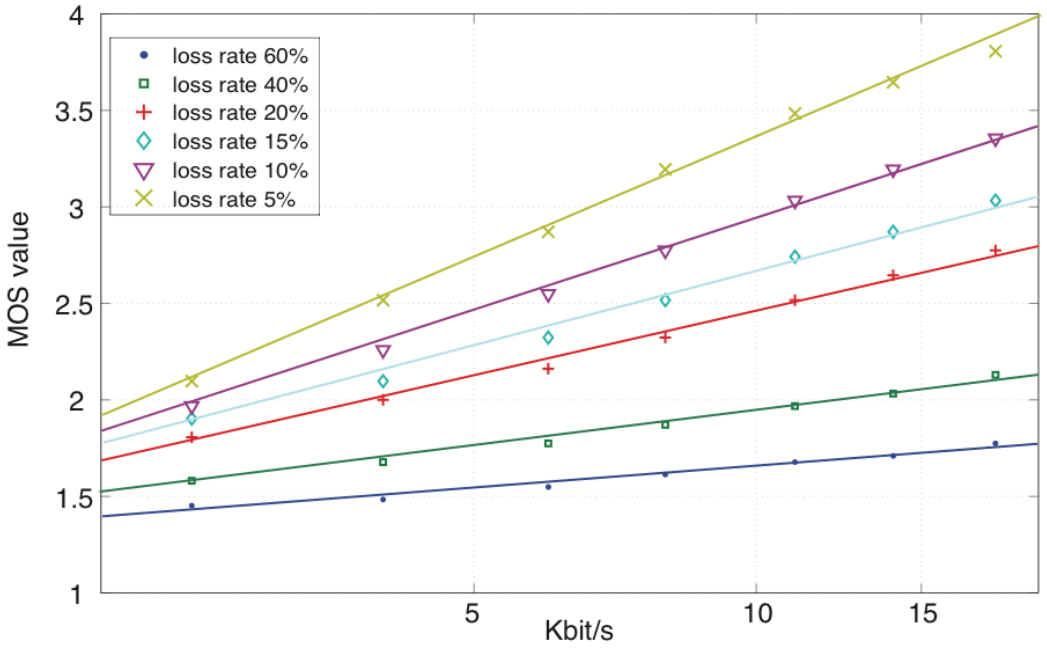


- Formal answer in microeconomics:
  $u_i(x)$:= utility function for customer i to receive service x
- Usual assumptions: monotonically increasing, concave, ...
- Typical candidate: logarithm function
  - mathematically feasible
  - many nice properties, e.g. proportional fairness (Kelly et al.)

- But: isn‘t there a better justification??
- Inspiration: recent results from QoE evaluations

Example 1: VoIP Quality under PSQA

- Rubino et al.: Pseudo-Subjective Quality Assessment (PSQA)
  - learning tool for QoE of multimedia applications
  - basic approach: Random Neural Networks
- Scenario: Speex codec, bitrates varying from 2.4 to 24.8 kbps

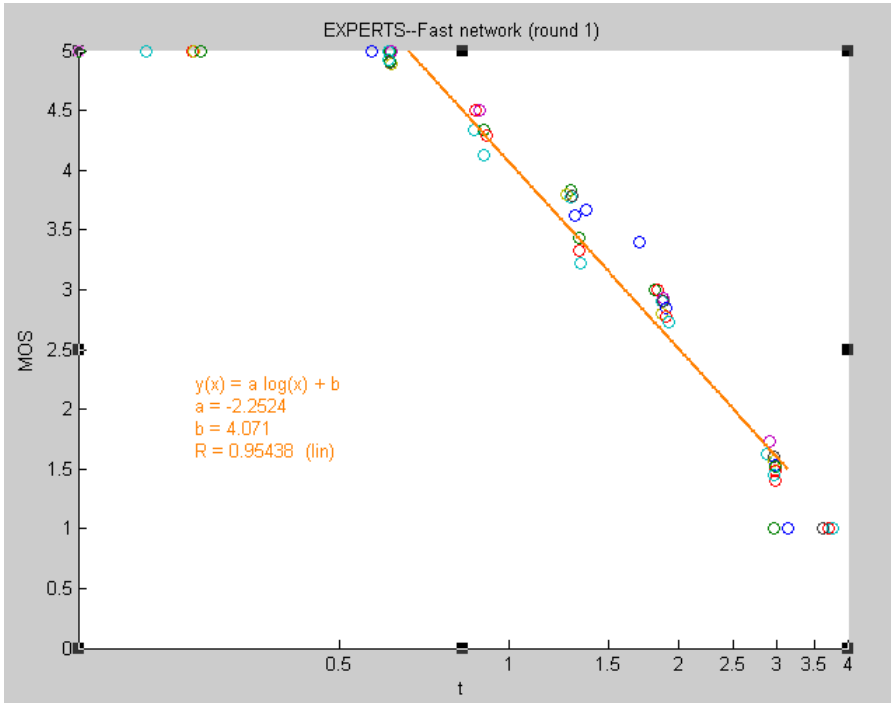


[Rubino et al. 2007]

Example 2: QoE for Web Browsing

- Ibarrola, Liberal et al.: Web QoE under IP network latency
  - two-step web browsing task: access search page + results page
  - network conditions varied from very slow to very fast

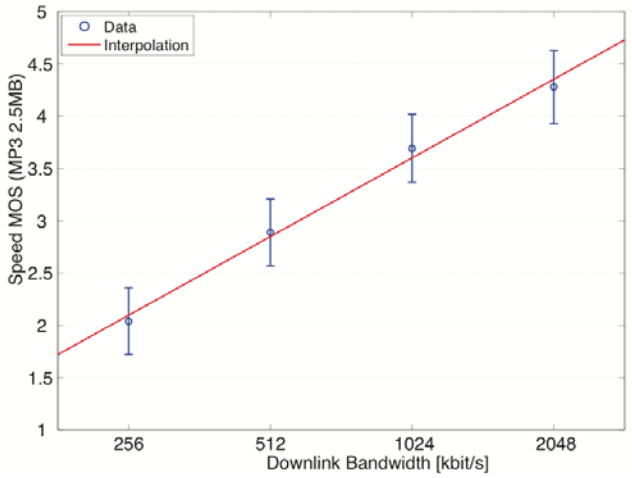
- Result: end user satisfaction depends logarithmically on total session time (waiting time as function of network latency)

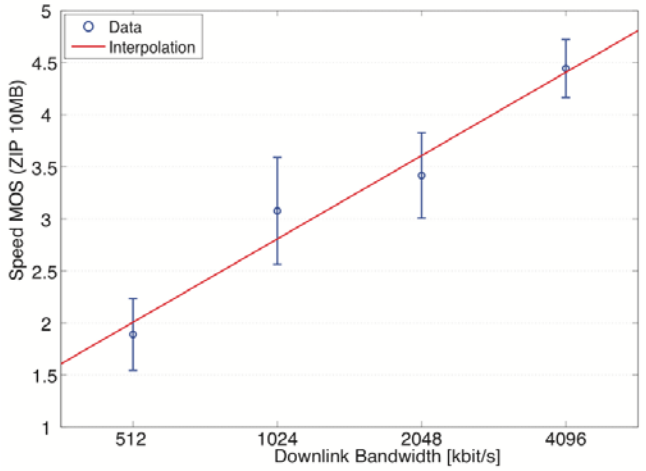


[Ibarrola, Liberal 2009]

Example 3: QoE for Mobile Broadband

- FTW Project ACE: Advancing the Customer Experience
- Goal: predict user satisfaction with a service based on traffic data from a passive network monitoring tool
- File download scenario: users download single MP3 and ZIP files at different network speeds (256 – 4096 kbps)
- Result: logarithmic dependencies between bandwidth and MOS

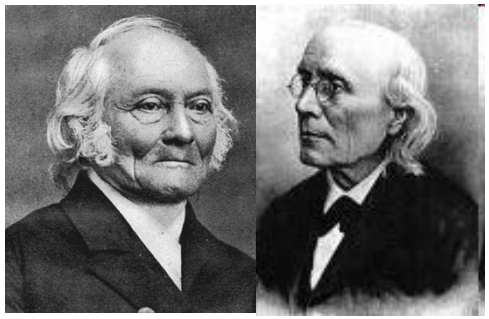




[R., Tuffin, Schatz 2011]

QoE Laws of Weber-Fechner Type

- Once upon a time (in fact 1834): E. Weber, G. Fechner and the birth of psychophysics



- Idea: operation of human sensory system based on „just noticeable differences“
- Formally: differential perception dP proportional to relative change dS/S of physical stimulus

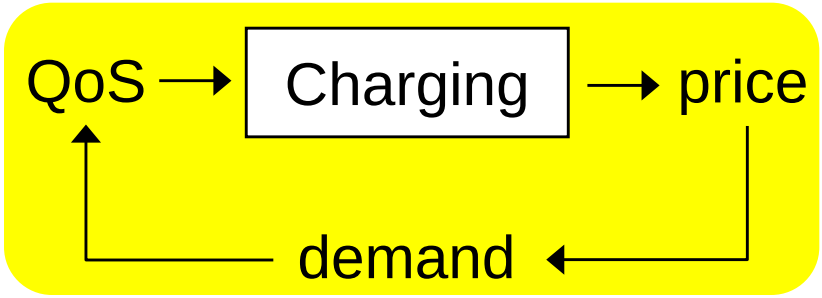
$$dP = k \cdot \frac{dS}{S} \quad \Rightarrow \quad P = k \cdot \log \frac{S}{S_0}$$

- Well-known principle for human vision, hearing, smelling, touching, even numerical cognition…
- Conclusion: initial evidence for validity also in ICT context

[R., Egger, Schatz, D‘Alconse 2010]

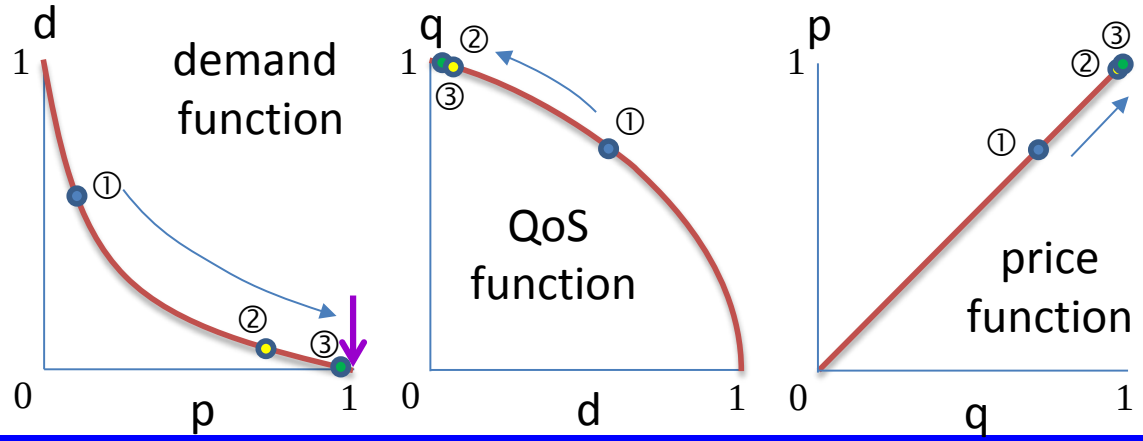
A Fixed Point Model for QoE-Based Charging

Simple Feedback Model for QoS Charging



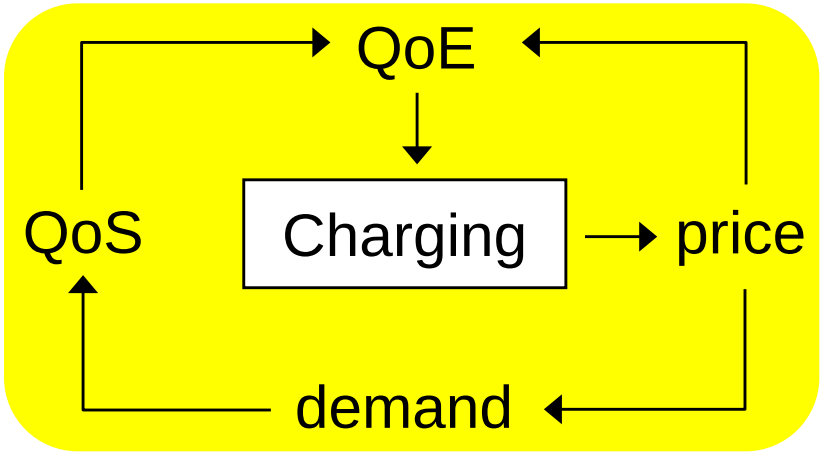
- Characterization by set of recursive functions
  - *Price function* p = p(q)
  - *Demand function* d = d(p)
  - *QoS function* q = q(d)

- Resulting fixpoints: (0,1,0) and (1,0,1)



Model Extension: QoE-based Charging

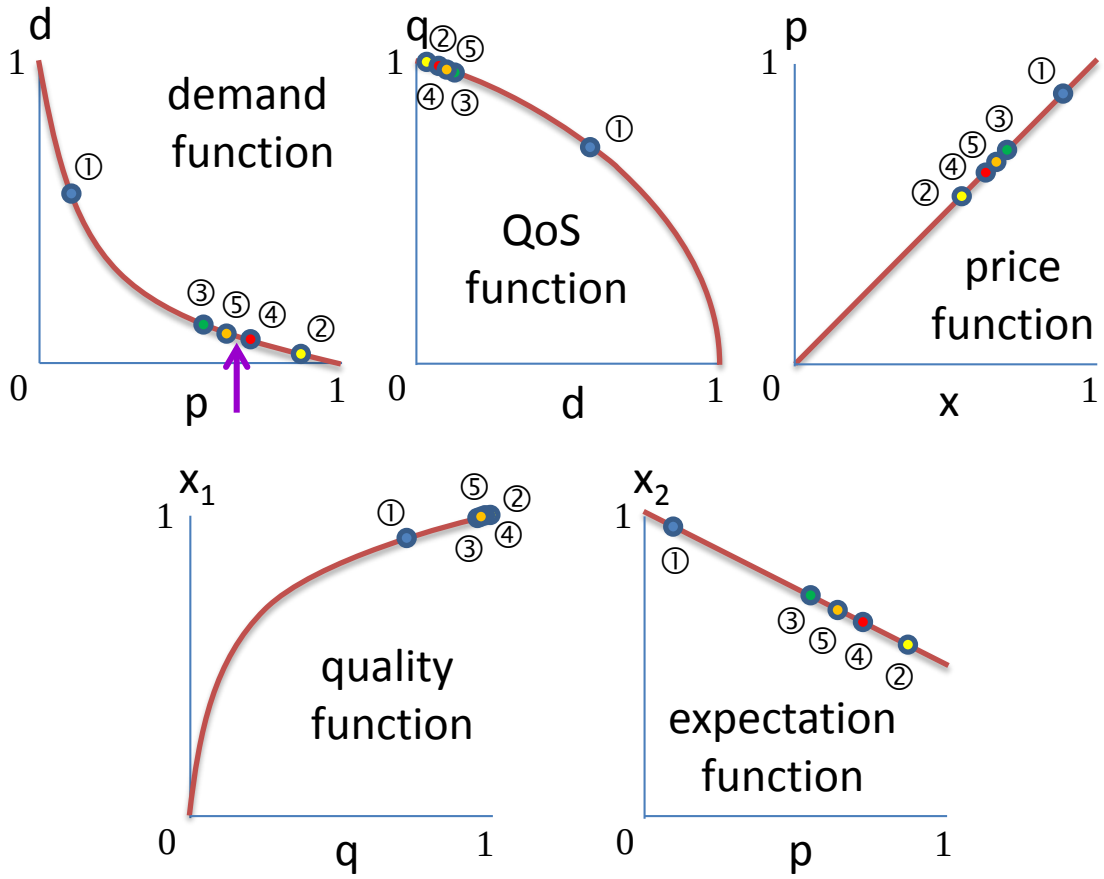
- Wanted: similar model for QoE-based charging



- Extended set of functions:
  - *Price function* $p = p(x)$
  - *Demand function* $d = d(p)$
  - *QoS function* $q = q(d)$
  - *QoE function* $x = x(q, p)$
- Separability assumption $x(q, p) = x_1(q) \cdot x_2(p)$
  - *Quality function x_1 vs Expectation function x_2*

QoE-based Charging: Fixpoint Model

- Resulting (non-trivial) stable fixpoint:

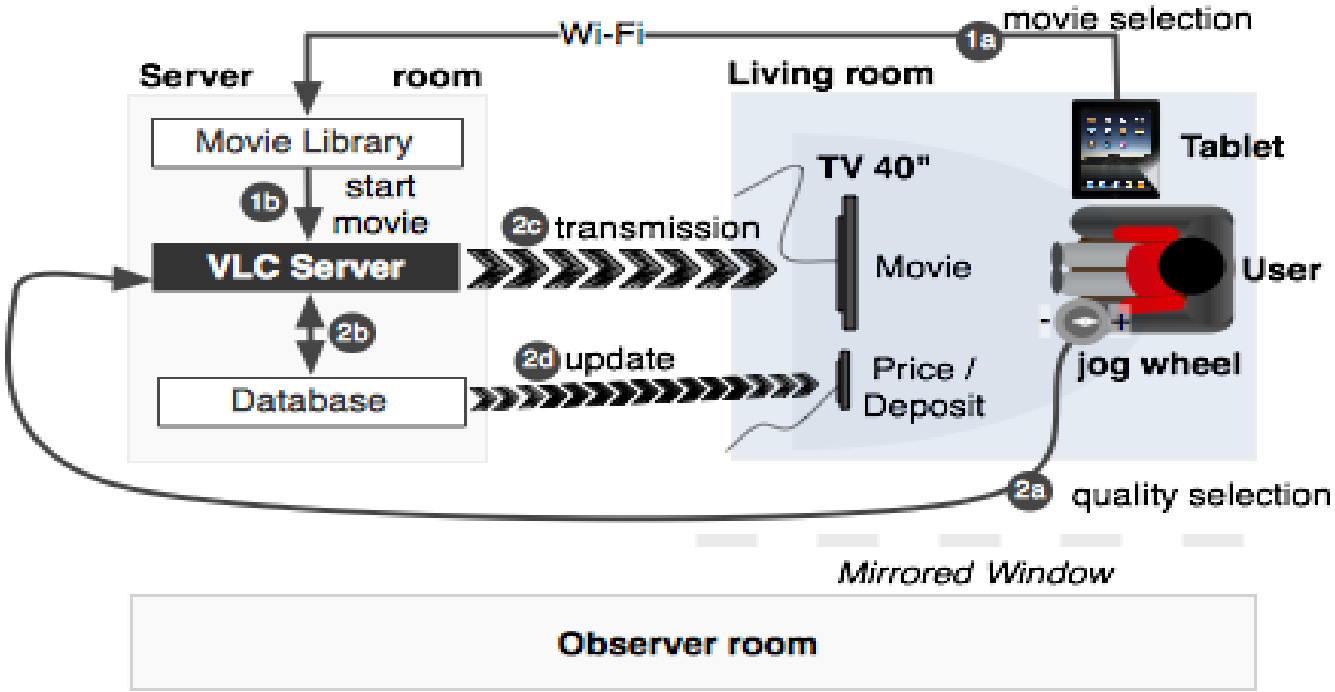


[R., Maillé, Zwickl, Sackl 2013]

Evidence From User Trials

ETICS User Trials

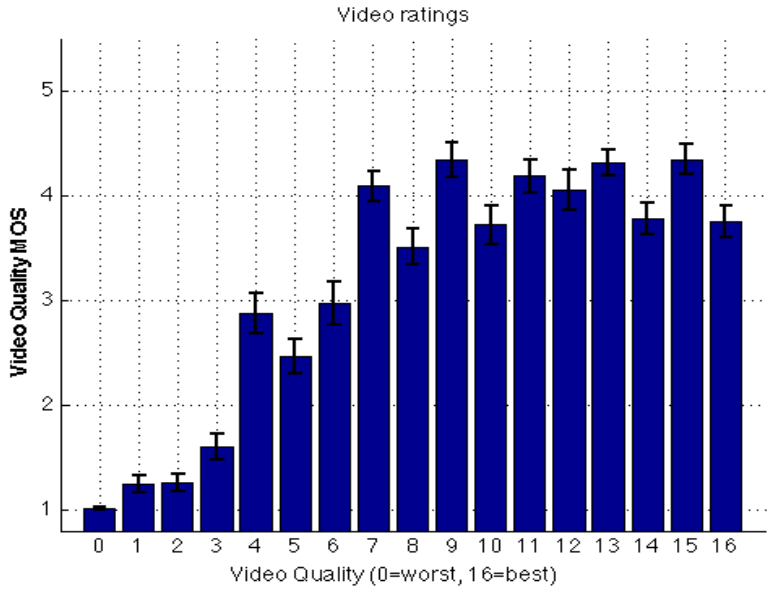
- Idea: investigate the purchase of quality levels based on realtime HD video streams with different bit rates under logarithmic spacing (direct influence on TCP streams)
- Approach:
  - 17+3 quality levels, prices between 0 and 2/3/4 €
  - users receive 10€ which can be spent on quality
- Test setup:



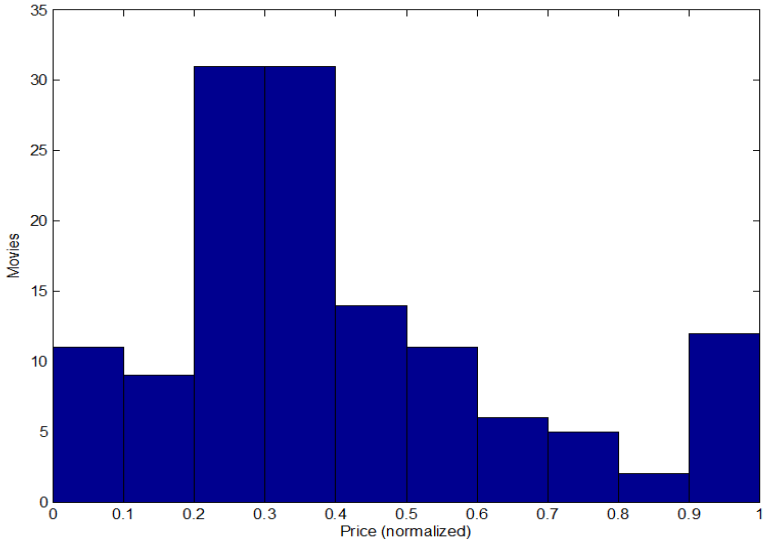
ETICS

Trial Results – Overview

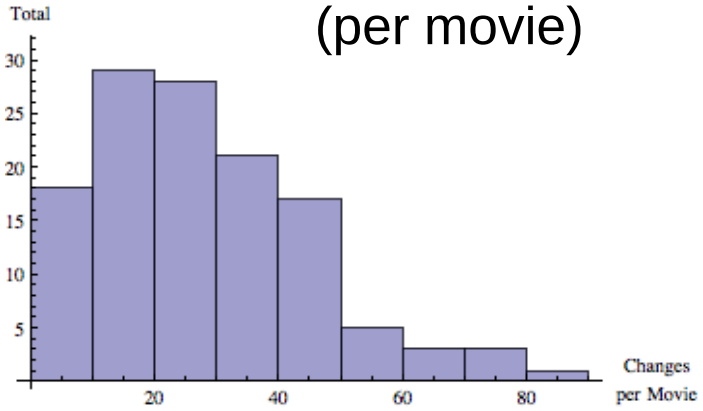
- Ratings of video quality



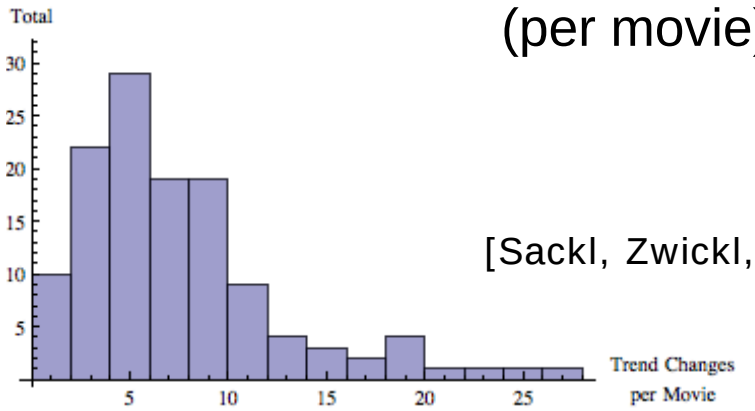
- Distribution of payments



- Price/quality changes (per movie)



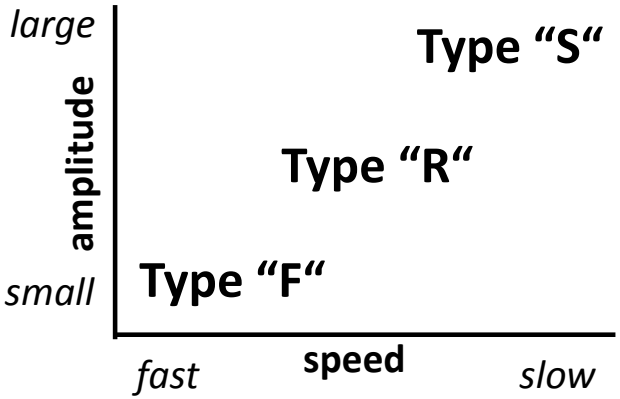
- Changes of price/quality trends (per movie)



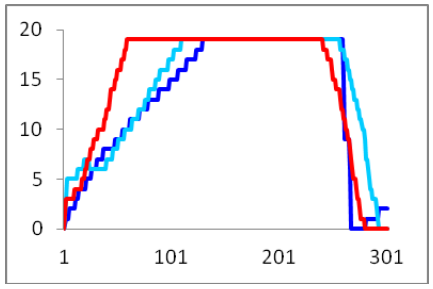
[Sackl, Zwickl, R. 2012]

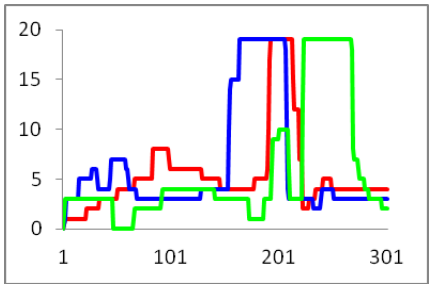
User Classification

- Classification criteria
  - convergence speed
  - convergence amplitude

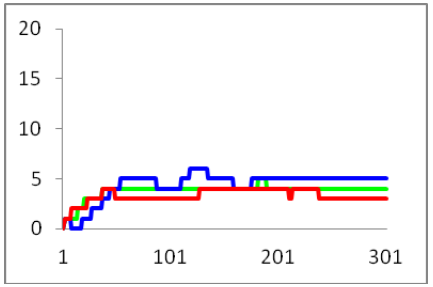


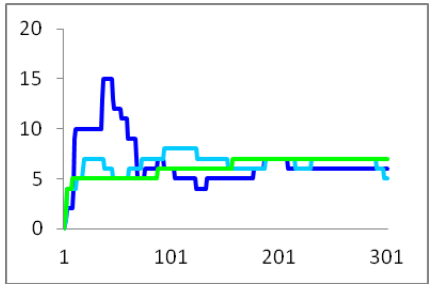
  - Irregular behaviour: ≈15%



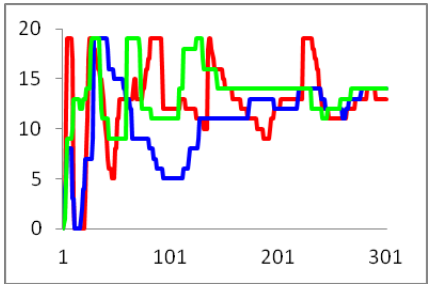


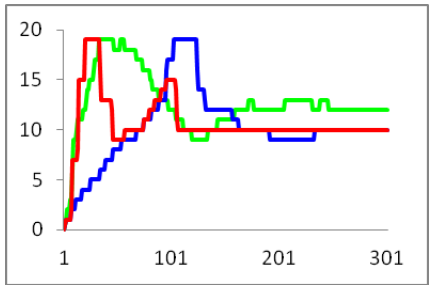
- Typical examples
  - Fast convergence



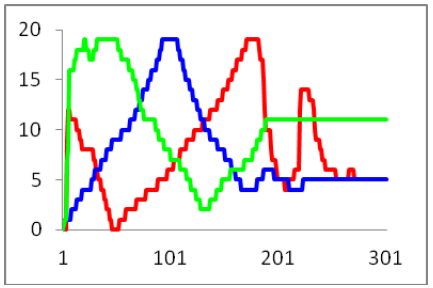


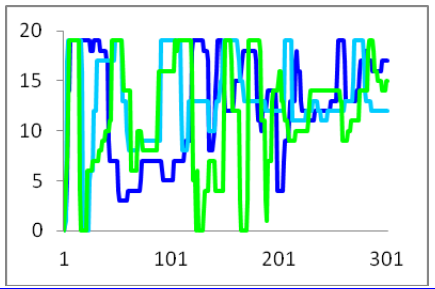
  - Regular convergence





  - Slow convergence





Classification Algorithm

- Fundamental Assumption: individual users follow consistent convergence behaviour
- Metric: Root Square Deviation (RSD)

$$\tilde{\sigma}_i(t) = \sqrt{\left(x_i(t) - \tilde{x}_i\right)^2}$$

convergence value

- Idea: Reference RSD for each class

$$\tilde{\sigma}^F(t) = 3 \cdot \exp(-0.01t)$$

$$\tilde{\sigma}^R(t) = 6 \cdot \exp(-0.007\,t)$$

$$\tilde{\sigma}^S(t) = 9 \cdot \left(1 - t/300\right)$$

Classification Algorithm (cont'd)

- Define: $$\Delta_i^{(k)} = \sqrt{\frac{1}{300}\sum_{t=1}^{300}\left(\tilde{\sigma}_i(t) - \tilde{\sigma}^{(k)}(t)\right)^2}$$

- Classification algorithm:

IF $\Delta_i^{(F)} \le 1$ THEN $i \in F$

ELSE IF $\Delta_i^{(R)} \le 2$ THEN $i \in R$

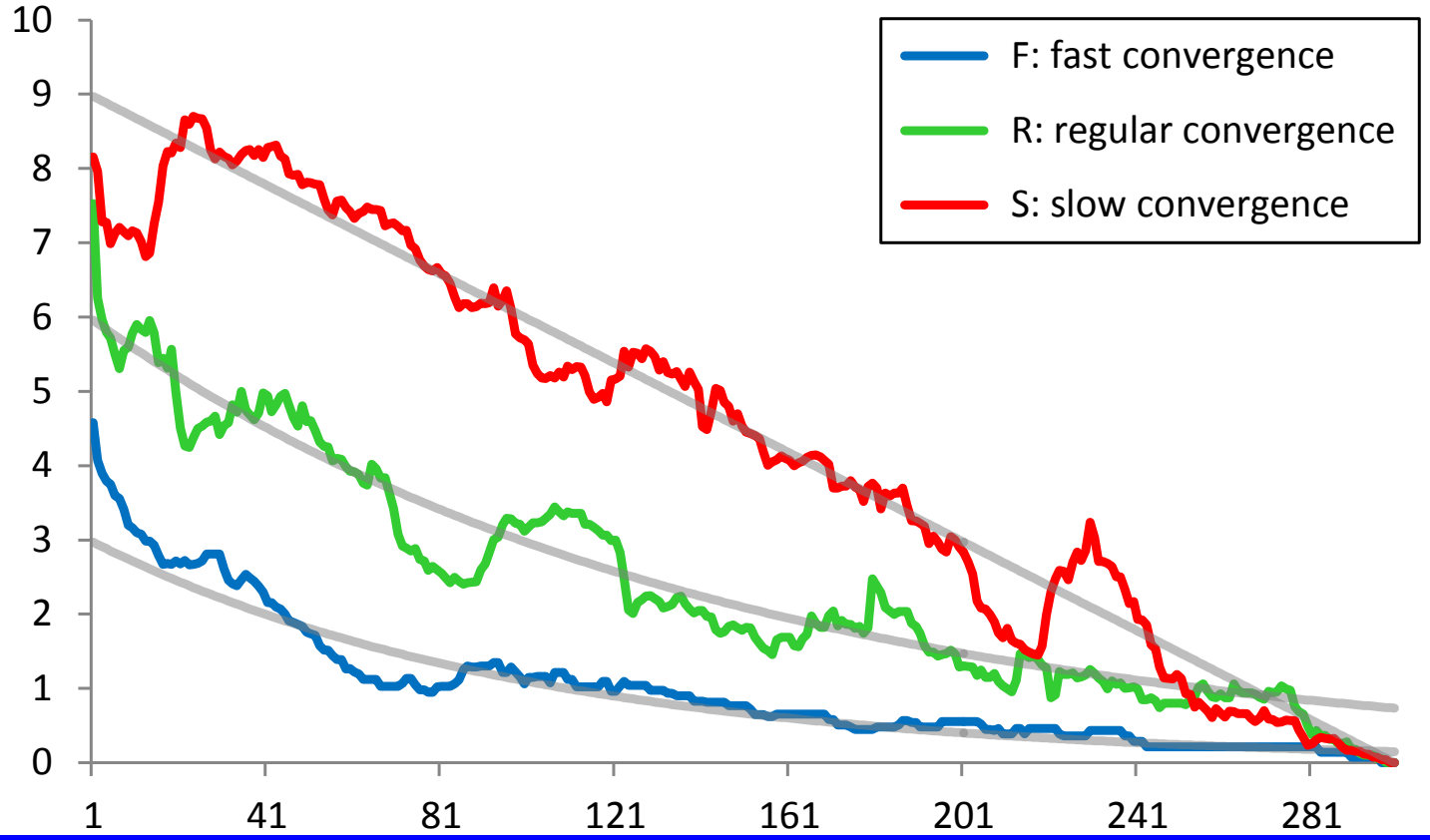
ELSE IF $\Delta_i^{(S)} \le 3$ THEN $i \in S$

ELSE $i \in X$

- Result: 39 out of 40 trial subjects classified successfully (irregular behaviour: ≈15%)

Classification Results

classes	F	R	S	X
Number of users	8	11	15	5
Mean ± standard deviation of $\Delta_i^{(k)}$	0.69 ± 0.16	1.58 ± 0.28	2.58 ± 0.36	8.30 ± 2.91



[R., Maillé, Zwickl, Sackl, 2012]

Summary and Conclusions

What have we learned

- Starting point: transition from QoS to QoE
- Question: consequences for charging
- Charging models: non-trivial fixpoint for QoE-based model
- User trials: perceived quality and acceptance
- Idea: RSD as convergence metric
- Result: efficient user classification algorithm
- Next step:
  - in-depth analysis of user convergence behavior and model quantification
  - extension to related QoE scenarios (mobile broadband, web)
  - investigation of cognitive dissonance phenomena

References and Further Reading

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The End

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Any feedback welcome!