Understanding user interactivity for immersive communications and its impact on QoE

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A massive thanks to

Silvia Rossi (UCL)

.. the Phd Student behind this work

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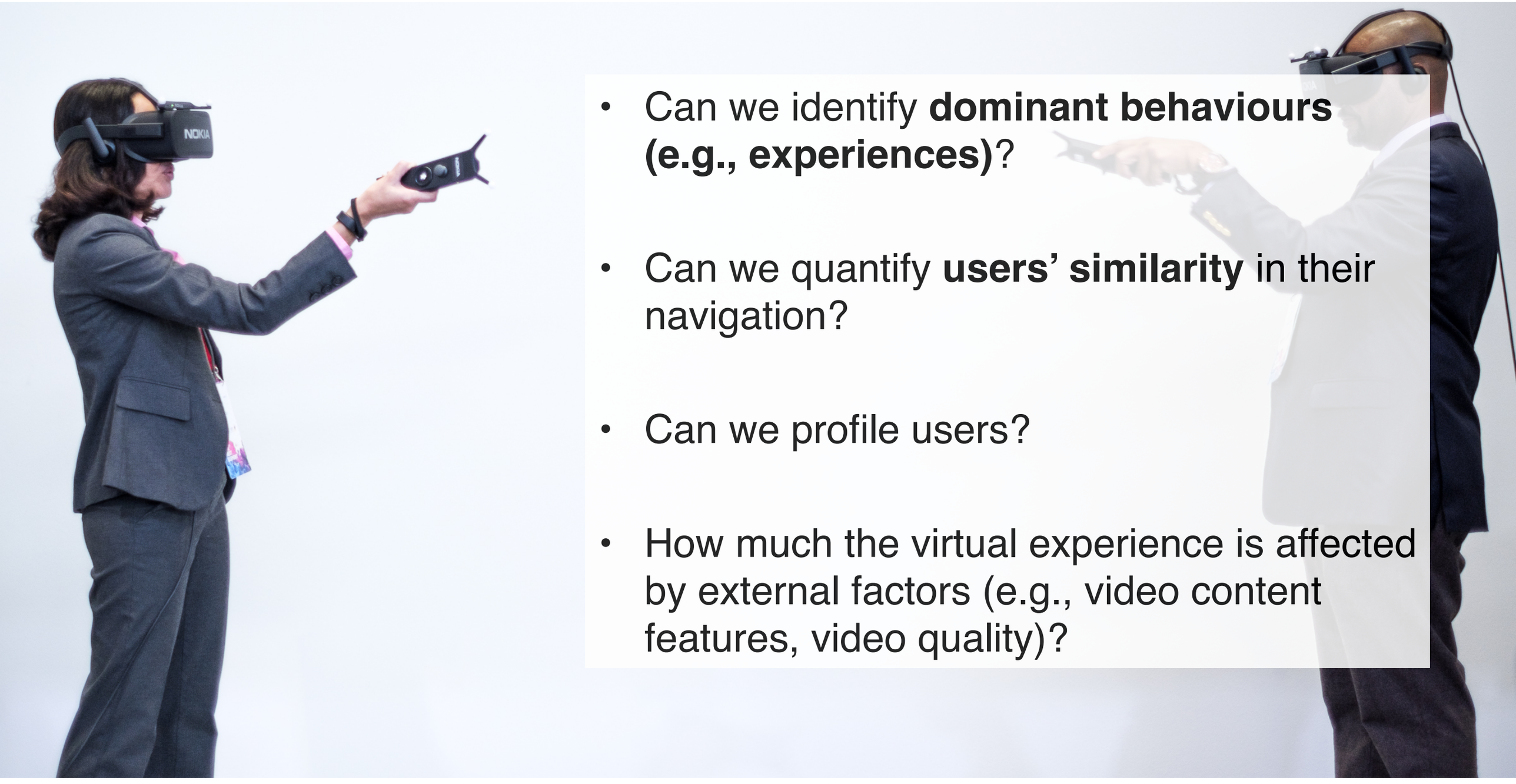


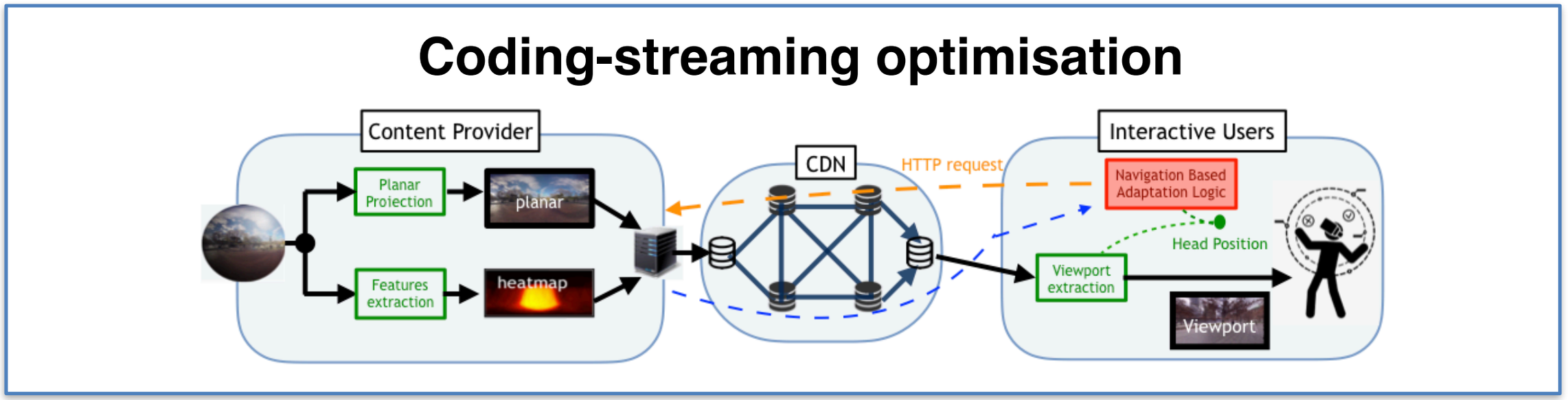
- Can we identify **dominant behaviours (e.g., experiences)**?
- Can we quantify **users' similarity** in their navigation?
- Can we profile users?
- How much the virtual experience is affected by external factors (e.g., video content features, video quality)?

How to assess/ define quality of experience in immersive realities?

How do we actually behave in immersive realities?

Image Credit: https://upload.wikimedia.org/wikipedia/commons/0/04/Mobile_World_Congress_2017_%2838277560286%29.jpg

Why?



VR therapists

Live performance

Mu Mu et al, “User attention and behaviour in virtual reality encounter”, 2020
WHIST, AoE 2019

Do we have good tools already to study users' behaviour?

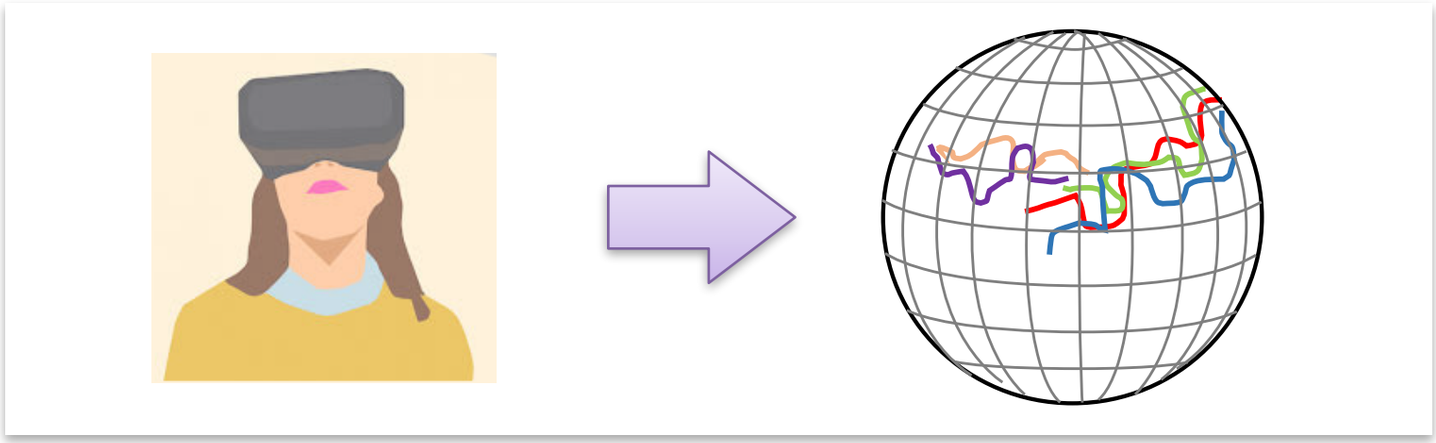
User Behaviour Analysis in VR system

Traditional metrics

- Angular velocity
- Frequency of fixation
- Mean exploration angles
- Heat map

Do these metrics fully capture users' behaviour?

Our Main Goal



To design metrics and methodologies to analyse users' behaviour in 360-degree videos aiming at

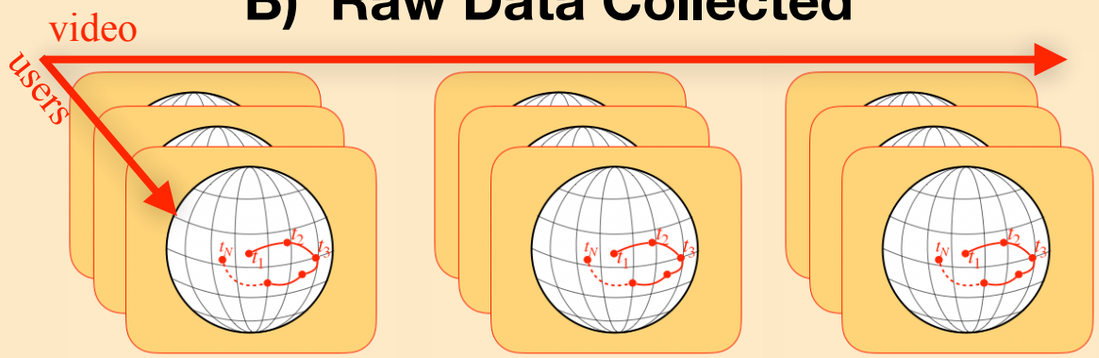
- identifying **dominant behaviours** of immersive navigation
- **quantifying similarities** across contents and across users
- analysing and **quantify** the **level of interaction** of the user with the content

User Behaviour Analysis in VR system

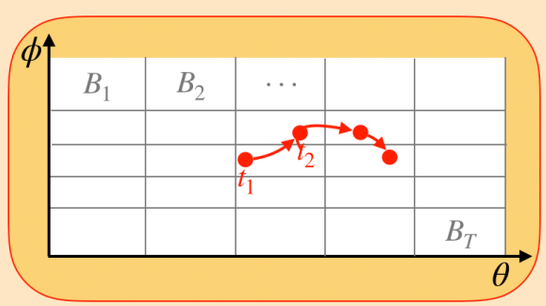
UCL

A) Experiments

B) Raw Data Collected

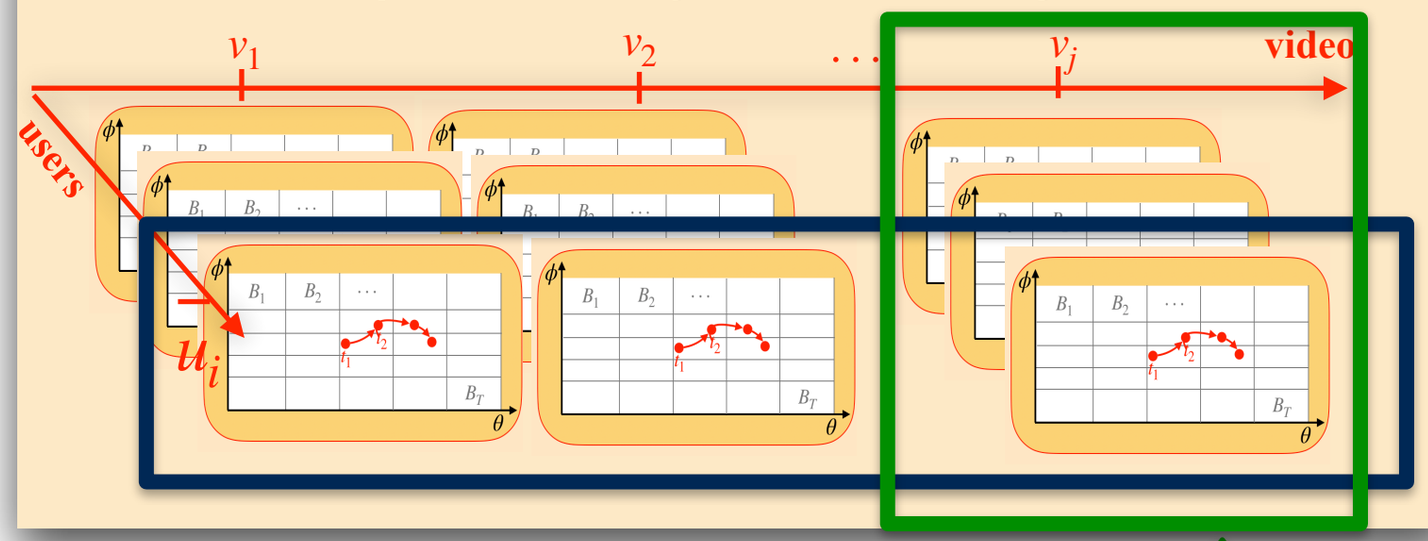


C) Pre-Processing



$u_i = < (x_1, t_1), \ldots, (x_n, t_n) >$

D) User's Trajectories Analysis



Intra-user behaviour analysis:

To characterise the navigation of each user over time against different video contents.

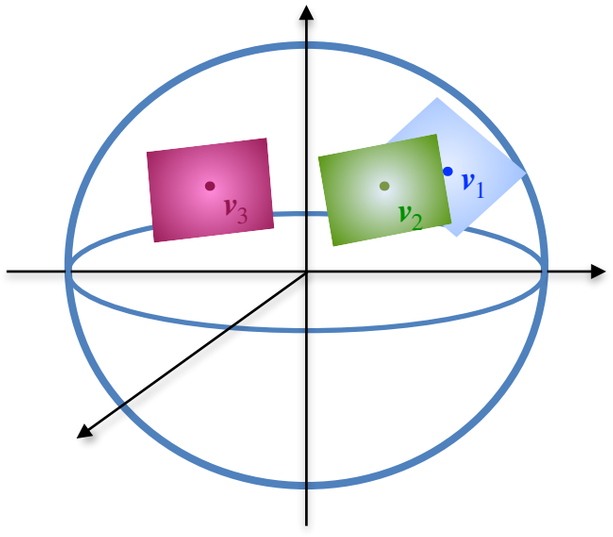
Actual Entropy
Fixation map Entropy

Inter-user behaviour analysis

To study the behaviour of a single user in correlation with others in the same content.

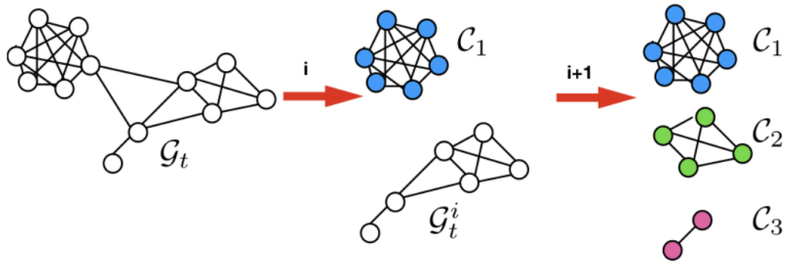
User Affinity Index

User Navigation in 3-DoF



Distance between **viewport centres** as proxy of viewport overlap [1]

Distance as metric to assess user similarity



Clique-based clustering to detect user with similar behaviour (**looking at the same viewport**)

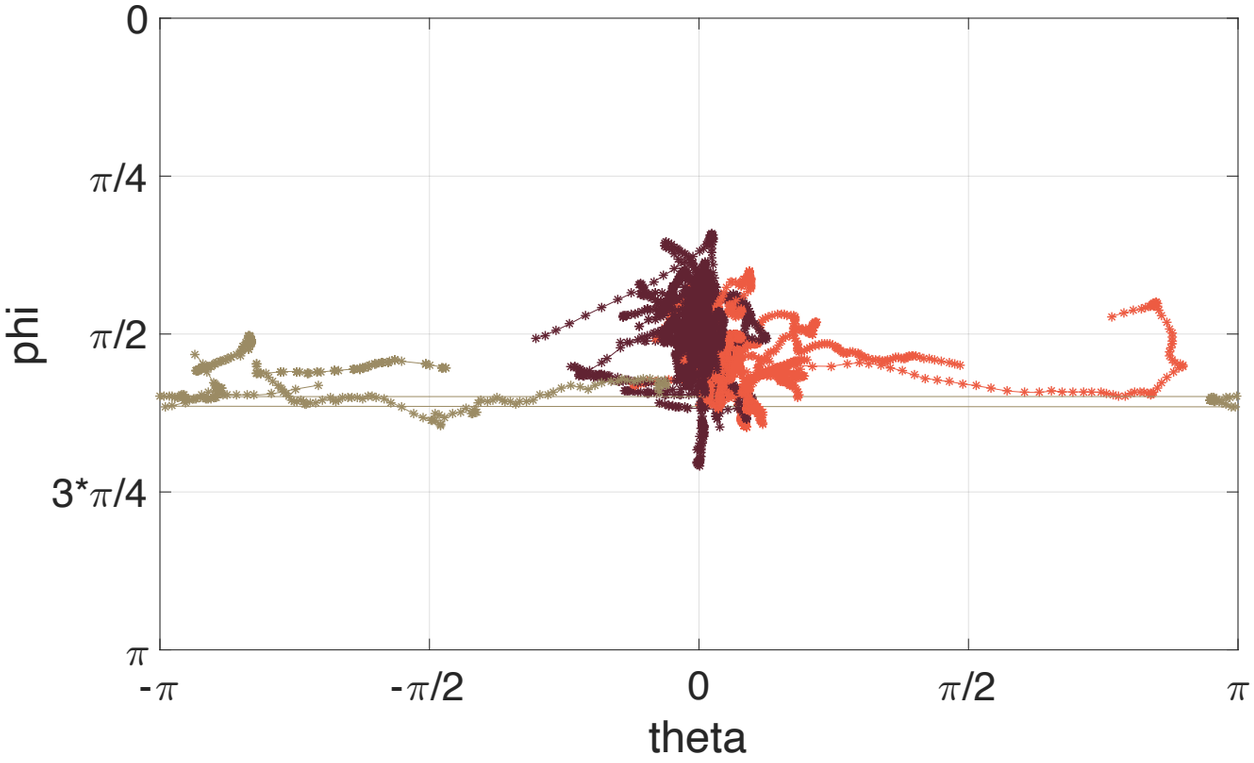
Affinity metric

$$UAI = \frac{\sum_{i=1}^{C} x_i \cdot w_i}{\sum_{i=1}^{C} w_i}$$

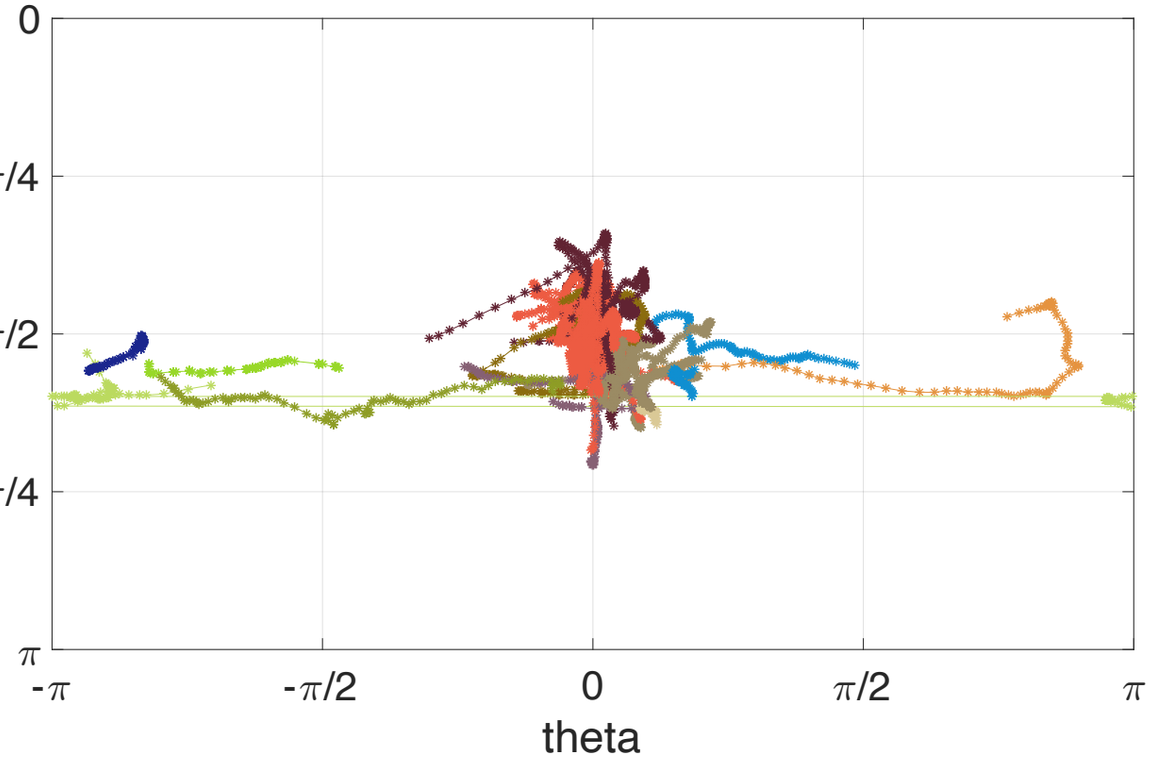
- C: number of clusters detected in a frame by the clique-clustering
- x_i: % of users in cluster i
- w_i: number of users in cluster i

[1] S. Rossi, F. De Simone, P. Frossard, and L. Toni. 2019. **Spherical Clustering of Users Navigating 360° Content.** In IEEE International Conference on Acoustics, Speech and Signal Processing.

Results - Clustering of Trajectories

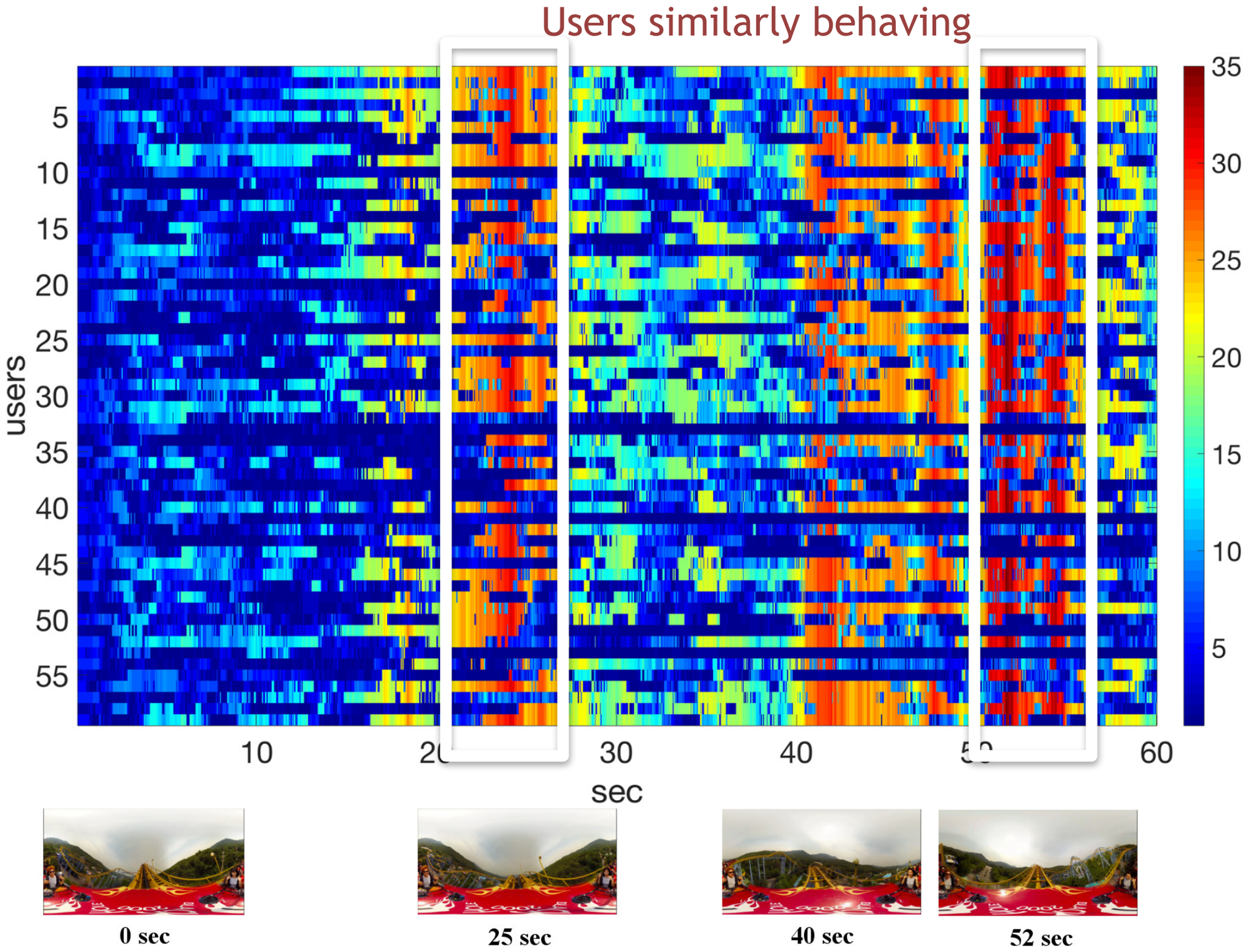


Spectral clustering of trajectories



Proposed Clique-Based clustering

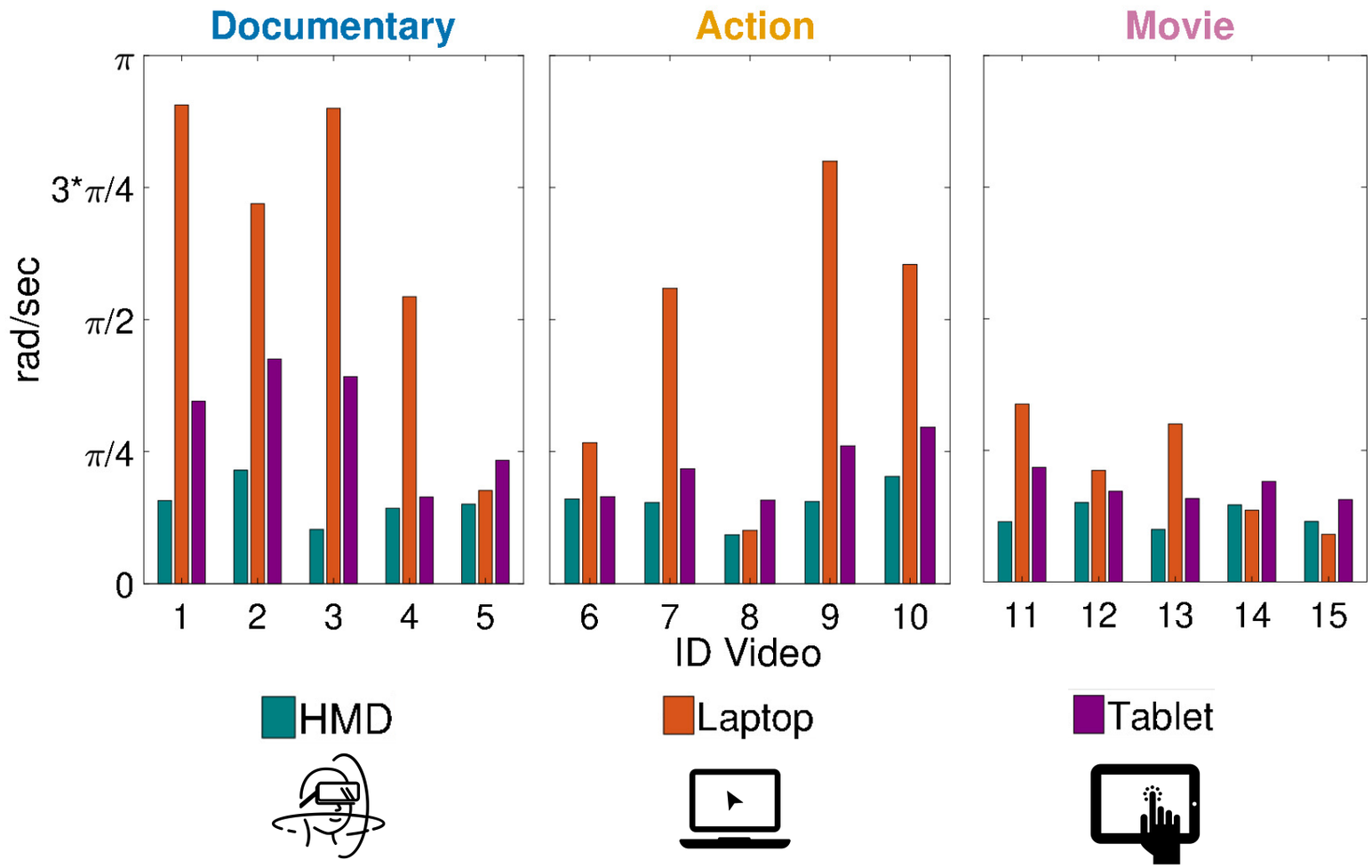
Analysis based on Clusters



(a) Rollercoaster video

Viewport angular velocity

Users' behaviour changes not only based on the video **content categories** but also on the selected **viewing devices**



- Users dynamically navigate more the content with laptop
- Movie are explored slower with all devices
- HMD has the lowest speed across devices and video categories

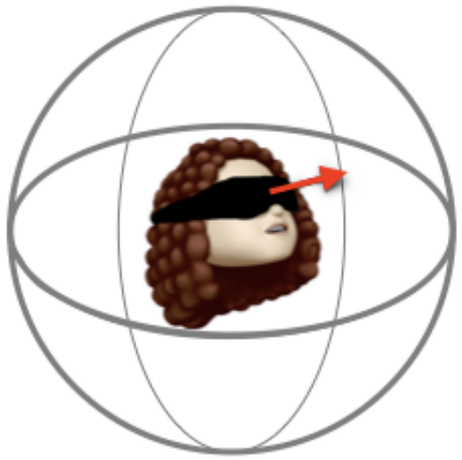
Take Home Message

- In contents with no main focus of attention, users experience a low affinity, which is interestingly not perturbed by the viewing device.

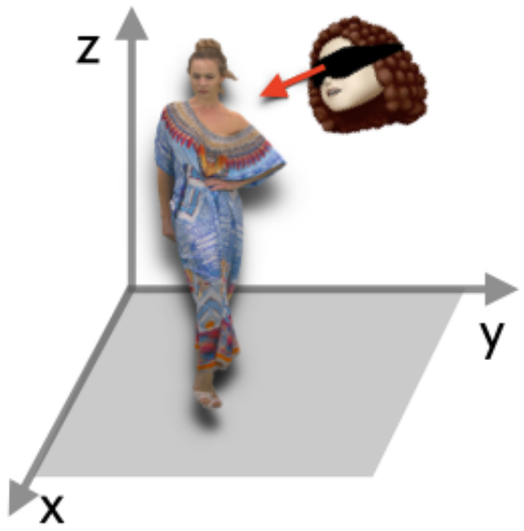
- Users tend to explore content characterised by a dominant focus of attention in a very similar way.

- In content with a main focus of attention, the user affinity is strongly related to the selected viewing device. In particular, the HMD leads to quite similar navigation among users.

User Navigation in 6-DoF



(a) 3-DoF



(b) 6-DoF

- The head is the only “interface” for interactivity
- The media is displayed from an *inward* position

- The user has now the freedom to move inside the VR space
- The media is displayed from an *outward* position

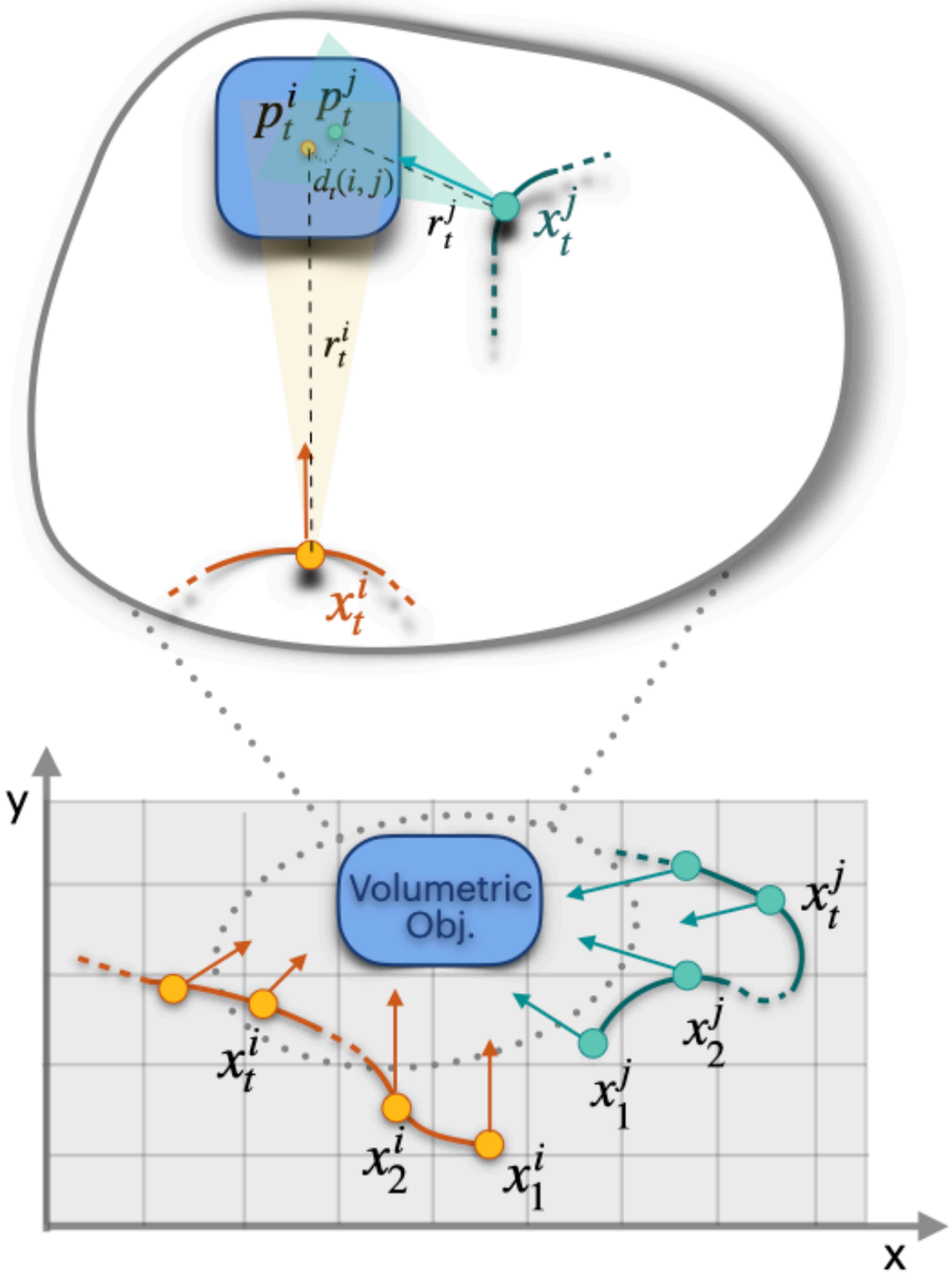
Is the position of viewport center over time enough to identify user behaviour ?

How to assess **user behaviour similarity in 6-DoF**?

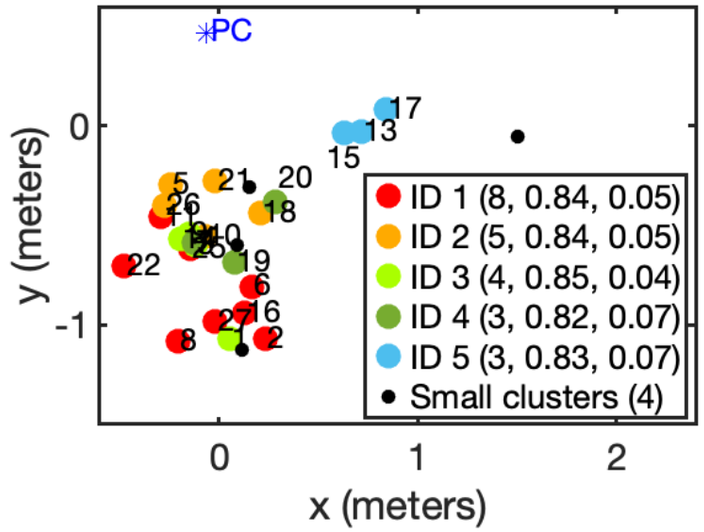
Distance Metrics

To verify if the **overlap ratio** $O_t^{i,j}$ can be substituted with a distance between users, we consider 4 different **distance metrics**:

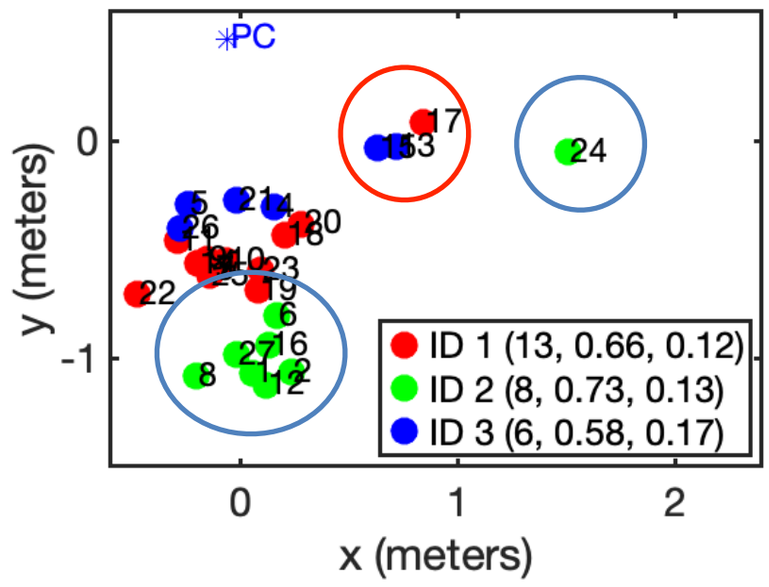
- $L_x^2 \rightarrow$ euclidean distance between x_t^i, x_t^j user positions in the space
- $L_p^2 \rightarrow$ euclidean distance between p_t^i, p_t^j viewport centres on PC
- $G_p \rightarrow$ geodesic distance between p_t^i, p_t^j viewport centres on PC
- $L_p^1 \rightarrow$ cityblock distance between p_t^i, p_t^j viewport centres on PC



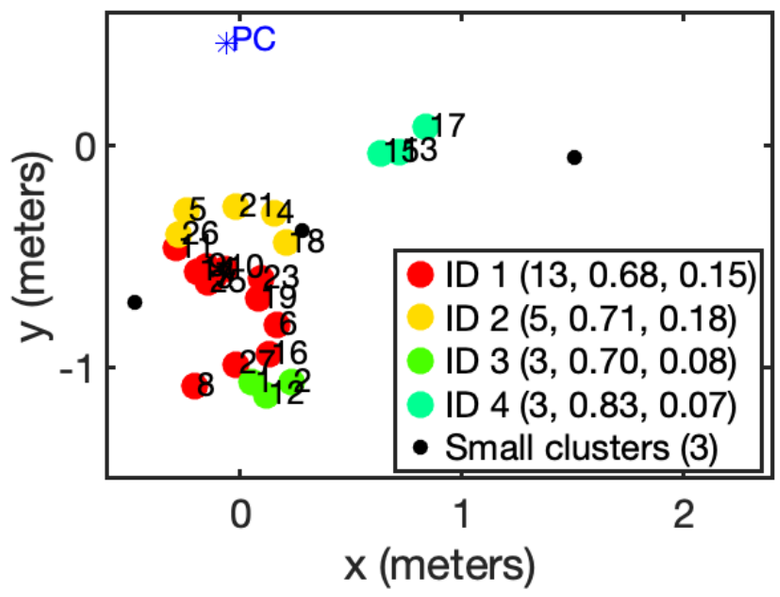
Why do we need a new clustering?



Ground truth clustering (75% overlap threshold)



Clustering from 3DoF (based on viewport center only)



New clustering for 6DoF (taking into account users' position)

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UCL

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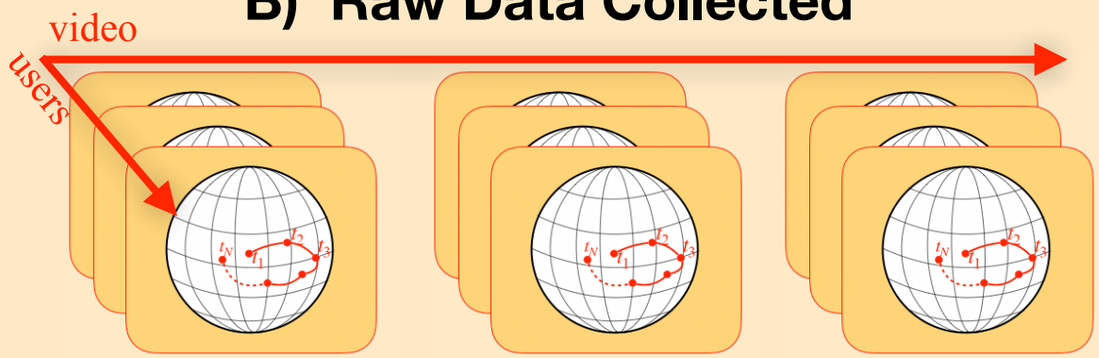

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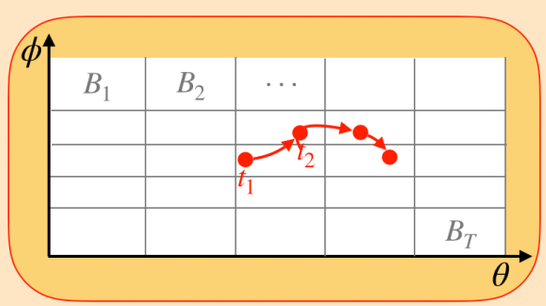

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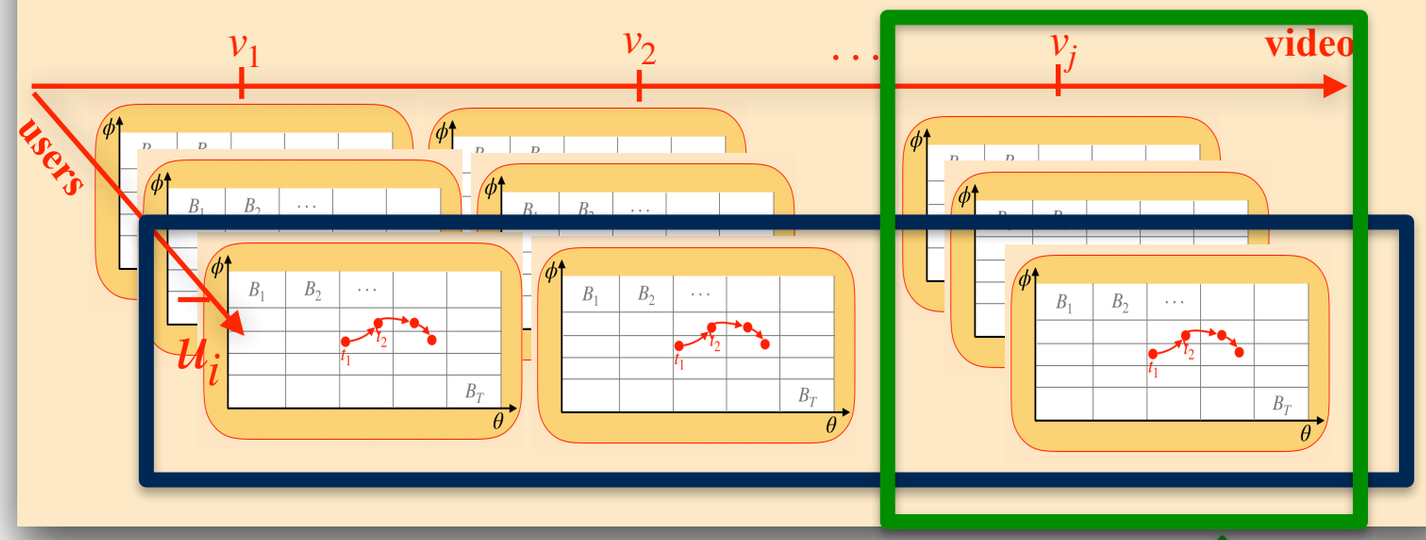

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Fixation map Entropy

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Intra-User behaviour metrics

Entropy

A key quantity in information theory that **measures** the **uncertainty** associated with an event.

$$H(X) = -\sum_{x \in X} p(x) log(p(x))$$

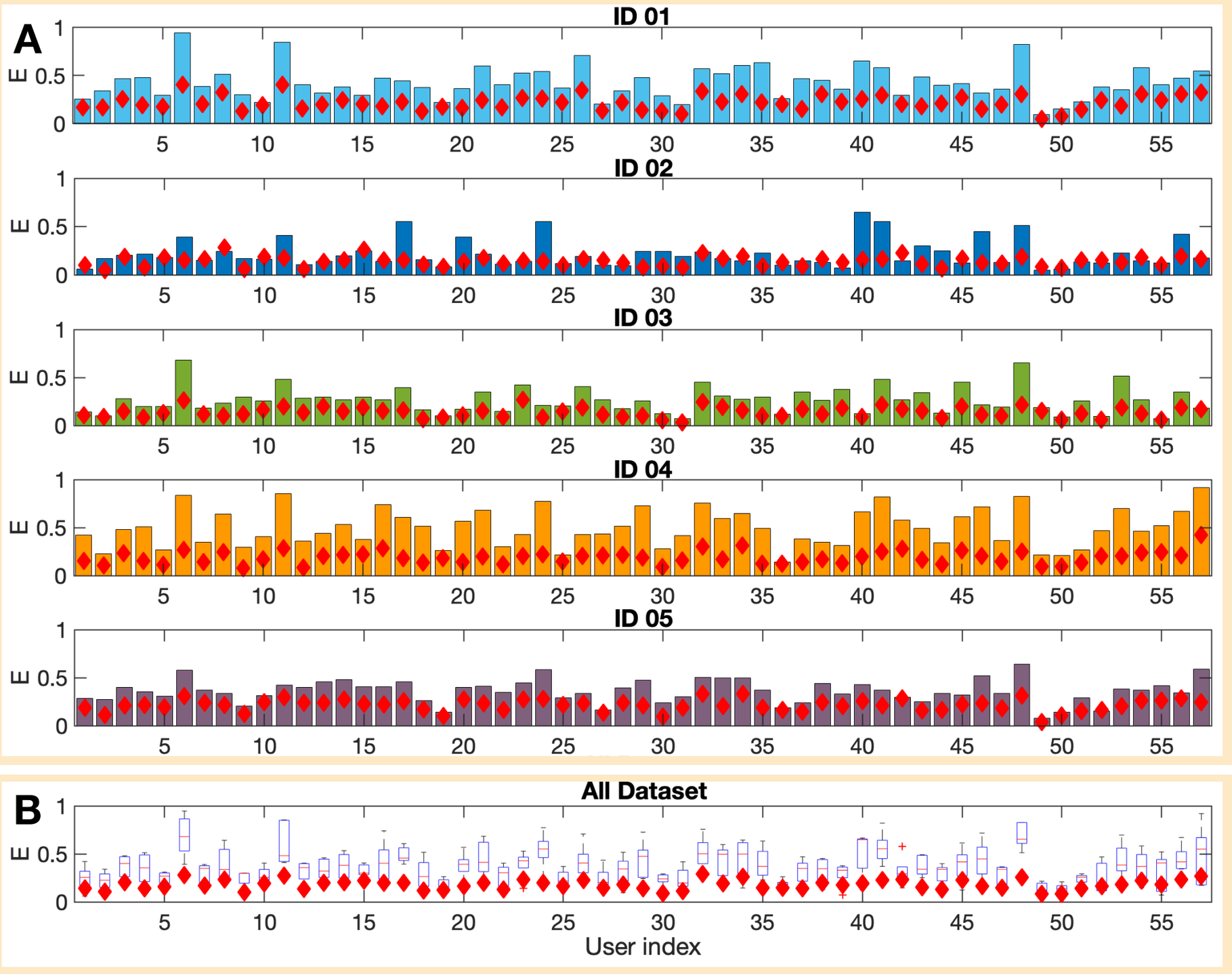
Actual Entropy

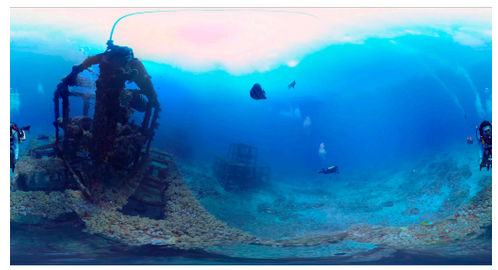
Introduced as a proxy of predictability of human mobility patterns [1], the actual entropy **quantifies** the **information** carried within a given **trajectory**.

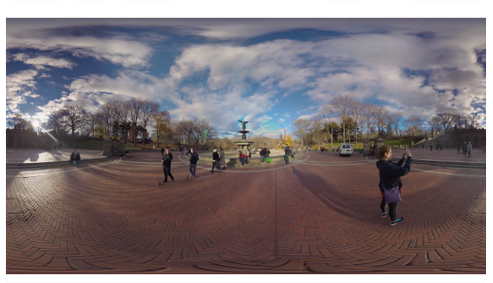
$$H^{act}(X) \approx \left(\frac{1}{n} \sum_{t=1}^{n} \lambda_t \right)^{-1} \log_2(n)$$

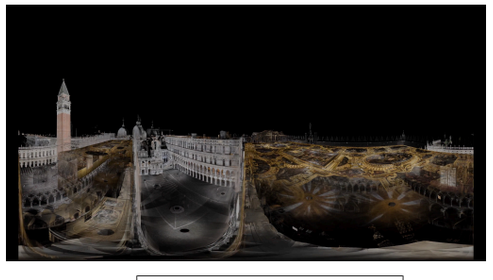
[1] C. Song, Z. Qu, N. Blumm, and A. Barabási. 2010. **Limits of predictability in human mobility**. Science.

Intra-User behaviour analysis





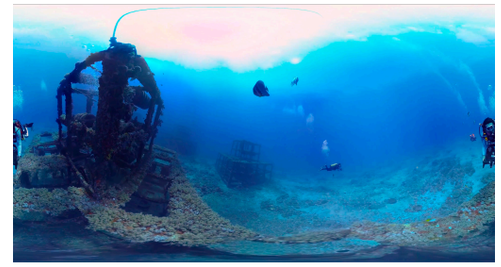


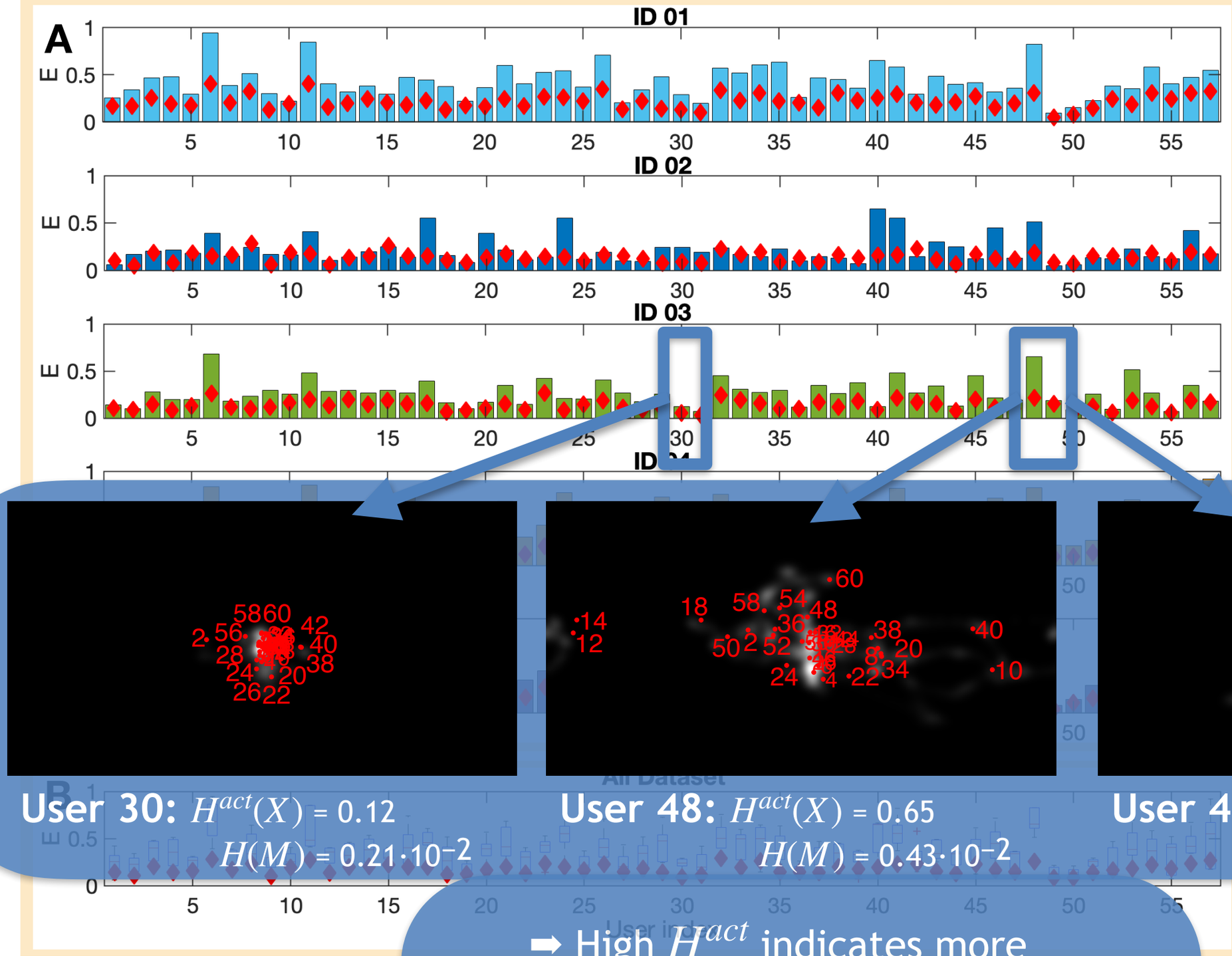


Video ID 01
Video ID 02
Video ID 03
Video ID 04
Video ID 05
H(M)

X. Corbillon, F. De Simone, and G. Simon. 2017. **360-degree video head movement dataset.** In Proceedings of the 8th ACM on Multimedia Systems Conference.

Intra-User behaviour analysis



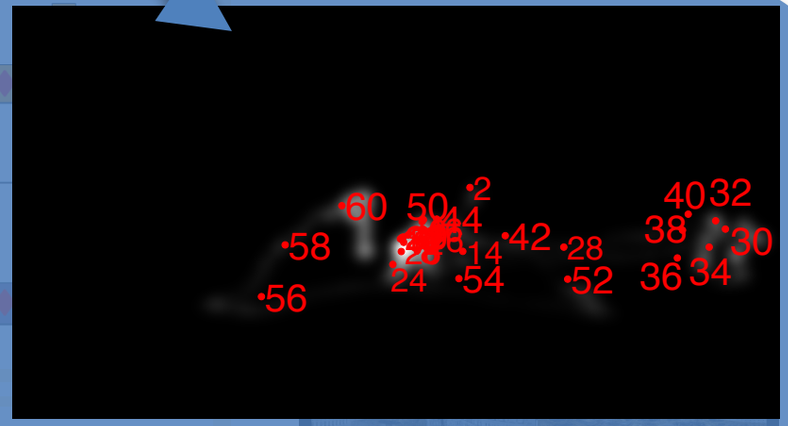


User 30: $H^{act}(X) = 0.12$

$H(M) = 0.21 \cdot 10^{-2}$

User 48: $H^{act}(X) = 0.65$

$H(M) = 0.43 \cdot 10^{-2}$



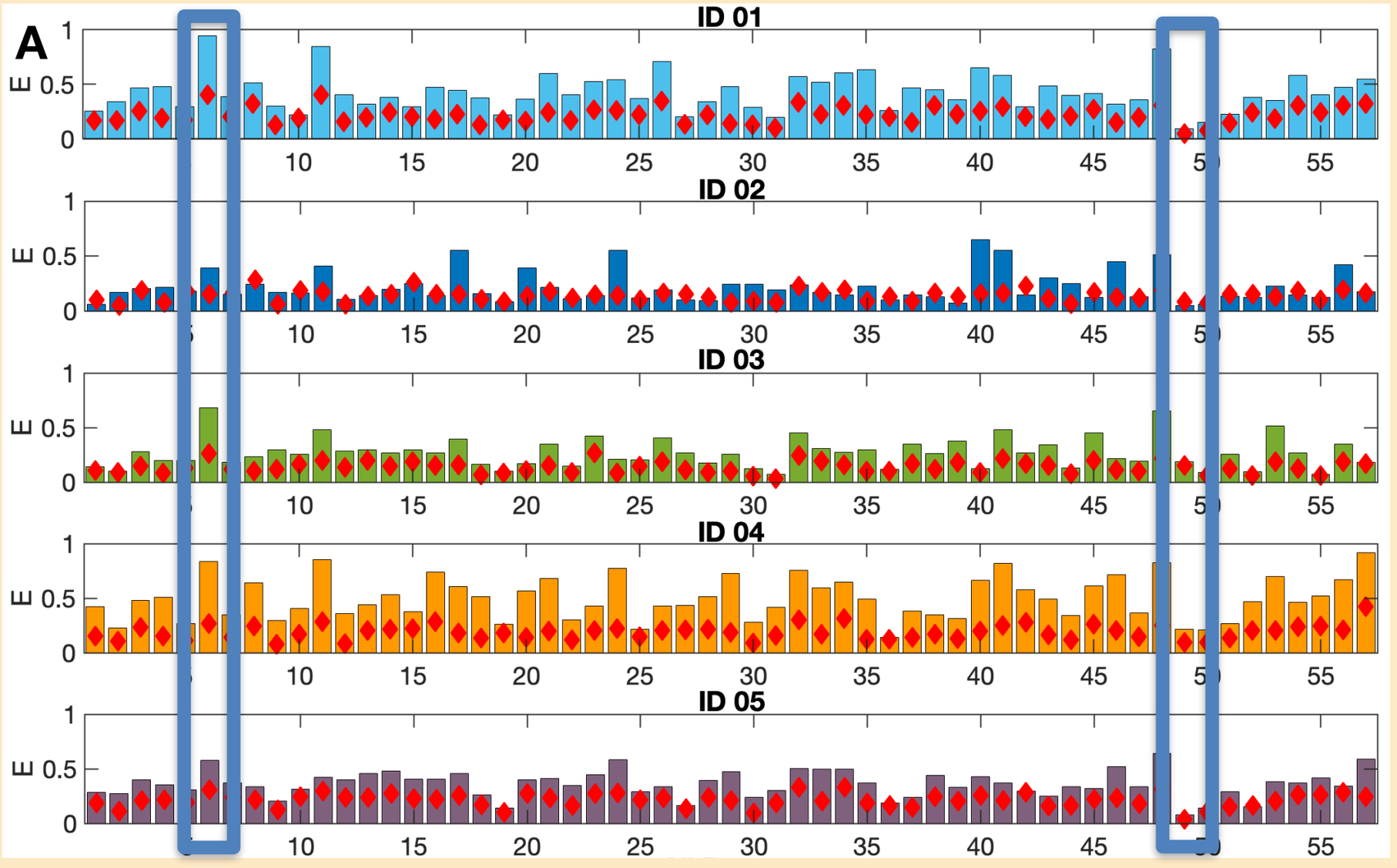
User 49: $H^{act}(X) = 0.28$

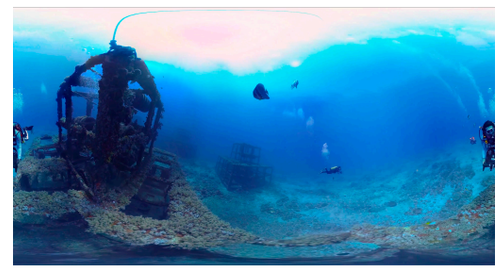
$H(M) = 0.32 \cdot 10^{-2}$

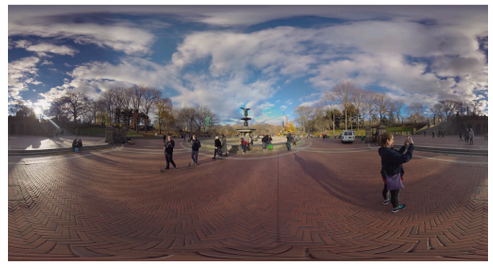
➡ High H^{act} indicates more randomness in the navigation

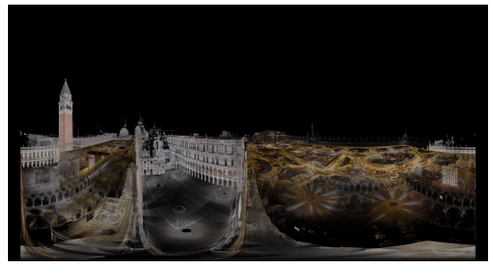
X. Corbillon, F. De Simone, and G. Simon. 2017. **360-degree video head movement dataset.** In Proceedings of the 8th ACM on Multimedia Systems Conference.

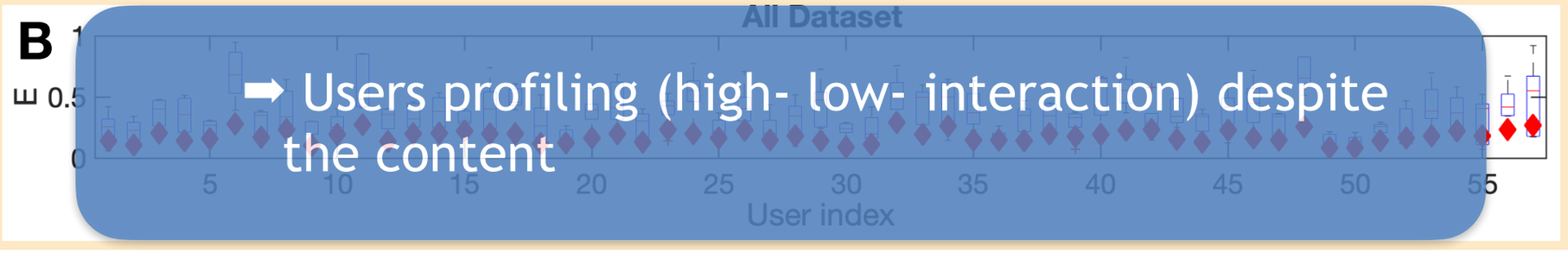
Intra-User behaviour analysis











➡ Users profiling (high- low- interaction) despite the content

Video ID 01
Video ID 02
Video ID 03
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Video ID 05
H(M)

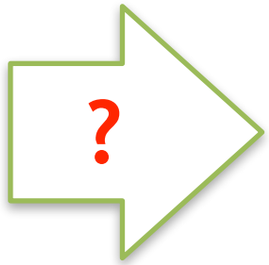
X. Corbillon, F. De Simone, and G. Simon. 2017. **360-degree video head movement dataset.** In Proceedings of the 8th ACM on Multimedia Systems Conference.

Conclusions

- We need to study, understand, and predict users behaviour in immersive tools → **New tools** needed for this study
- Clusters are meaningful if identifying **users looking at the same portion** of content
- Deeper analysis showed us correlation between content-device and level of interactivity
- **User interactivity** can be a good metric for system design and **QoE assessment**

What's the link? (Future Directions)

How do assess/ define quality of experience in immersive realities?



How do we actually behave in immersive realities?

- When studying QoE, should we **focus on dominant behaviours**? (Should we discard outliers?)

- What are the key trajectories/interactions experienced by the users?

- Does quality impact behaviour and QoE in immersive systems?

- Is the similarity in users behaviour related to the quality of the experience?

Thank You! Questions?

Learning and Signal Processing Lab
UCL
https://laspucl2016.com