Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

Fabien Danieau

Advisors: Anatole Lécuyer, Philippe Guillotel, Julien Fleureau, Nicolas Mollet and Marc Christie

Audiovisual Experience

- Evolution of the audiovisual experience
  - Improving the Quality of Experience (QoE)
  - Focused on images and sound
  - Next step: sense of touch? (Haptic)

A trip to the moon.
Méliès, 1902.

The jazz singer.
Crosland, 1927.

The wizard of oz.
Fleming, 1939.

Avatar.
Cameron, 2009.

Haptics and Audiovisuals

- Haptics already used in VR
- Early results on haptics for AV
  - Haptics may enrich user experience
    [O'Modhrain and Oakley 2003]
  - New medium to express content
    [Magnenat 2006]
  - New field of study: Haptic-AudioVisuals
    [El-Saddik 2007]

Virtual reality setup *[Cirio2011]*

4D cinema setup

- **How to augment audiovisuals with haptic feedback?**

Challenges

How to integrate haptic effect into a film production **workflow**?

How to **design** and **add** haptic effects to AV content?

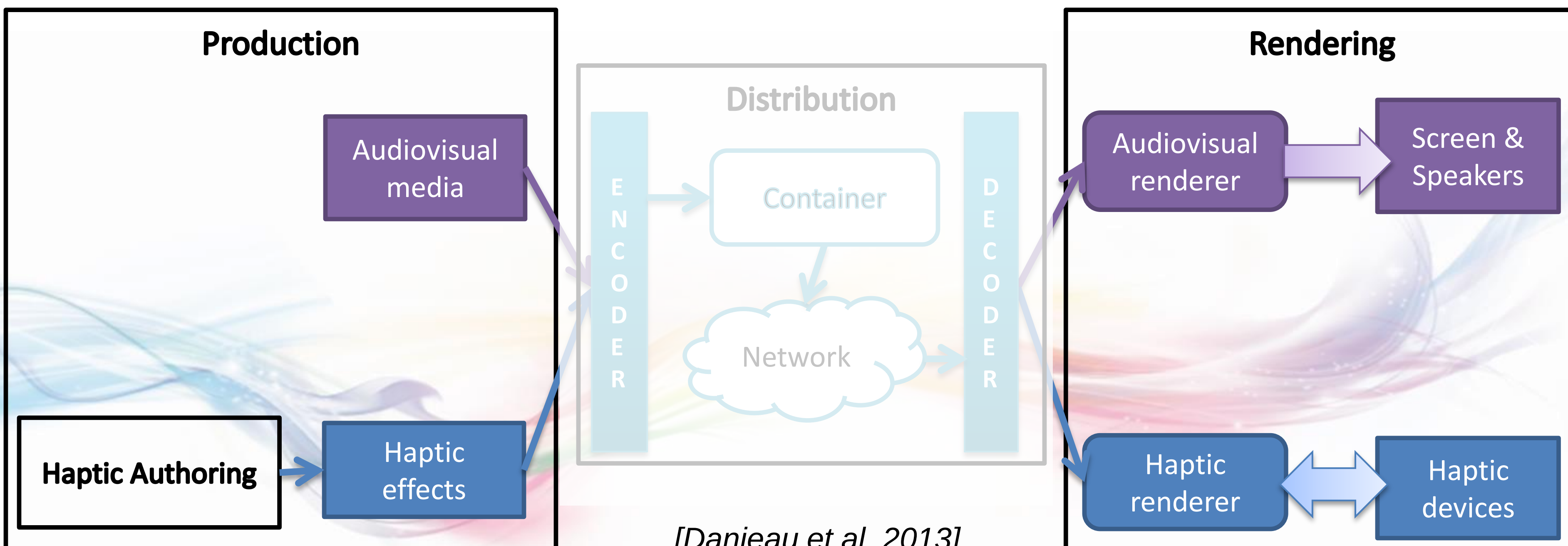
How to **render** haptic effects in video viewing settings?

Audiovisual experience

How to **evaluate** the influence of haptic effects on the AV experience?

Workflow for adding haptic effects to audiovisuals

- Based on architecture for video streaming *[Wu et al. 2001]*
- Three steps
  - Production
  - Distribution
  - Rendering

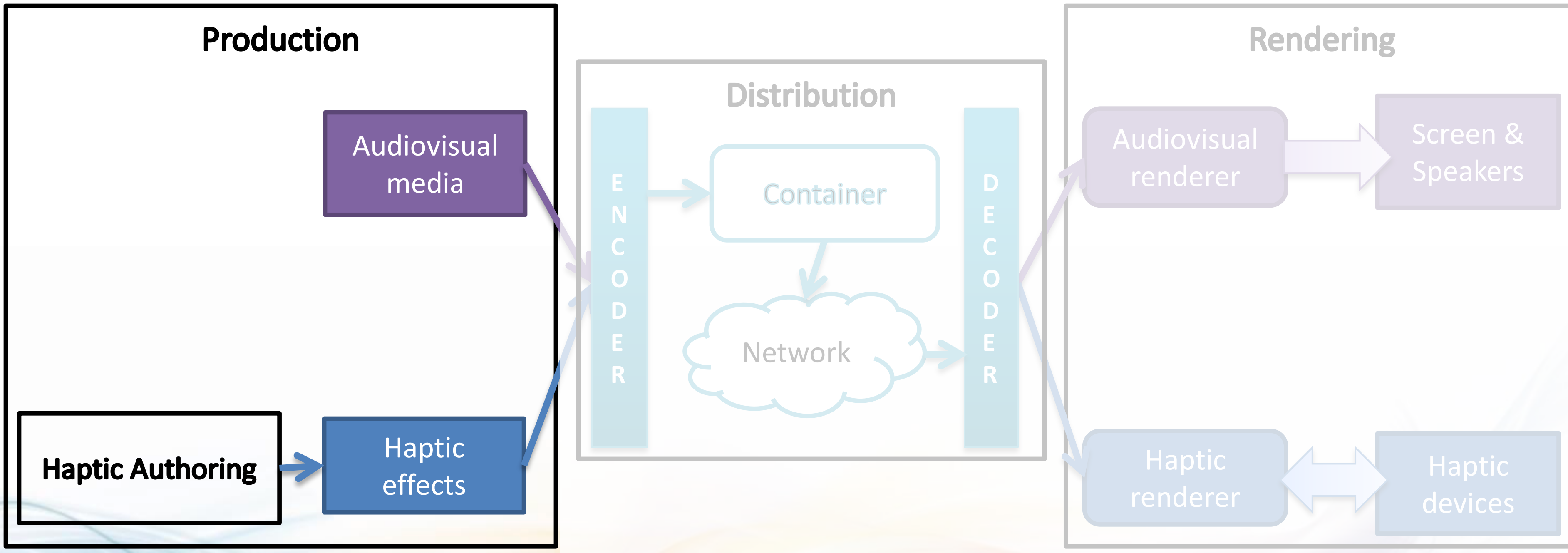


[Danieau et al. 2013]

Outline

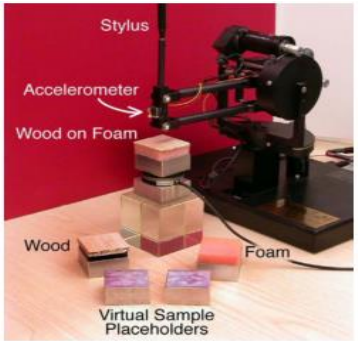
- State-of-the-Art of the Haptic-Audiovisuals
  - Production of haptic effects
  - Rendering of haptic effects
- Contributions
  - Production of haptic effects
  - Rendering of haptic effects
- Conclusion / Perspectives

Production of Haptic Effects

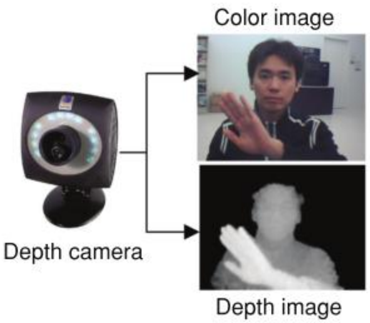


Production of Haptic Effects

- Capture devices
  - Force sensors / Accelerometers
    - *[MacLean 96]*
    - *[O'Modhrain and Oakley 2003]*
    - *[Brady et al. 2002]*
  - Depth Camera / 3D trackers
    - *[McDaniel et al. 2005]*
- Automatic extraction
  - Visual / Audio
    - *[Ur Rheman 2008]*
    - *[Rasool and Sourin 2011]*
    - *[Chi et al. 2008]*
    - *[Lee et al. 2013]*
  - Metadata
    - *[Yamaguchi et al. 2006]*
- Manual authoring
  - *[Enriquez and MacLean 2003]*
  - *[Gaw et al. 2006]*
  - *[Rahman et al. 2006]*
  - *[Ryu et al. 2008]*

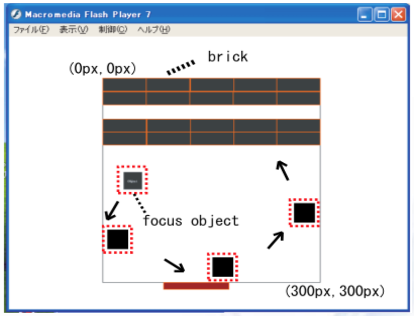


[Kuchenbecker et al. 2005]



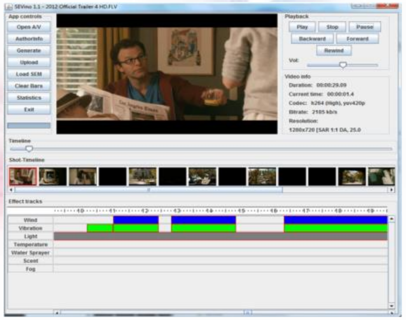
[Cha et al. 2009]

[Rasool and Sourin 2011]



[Yamaguchi et al. 2006]

[Waltl2013]



[Kim et al.2010]

Production of Haptic Effects

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    [MacLean 96]
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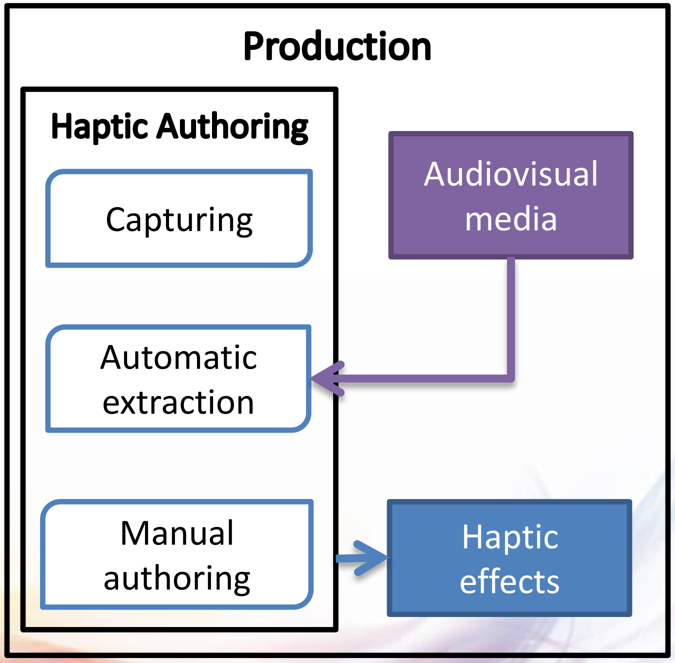
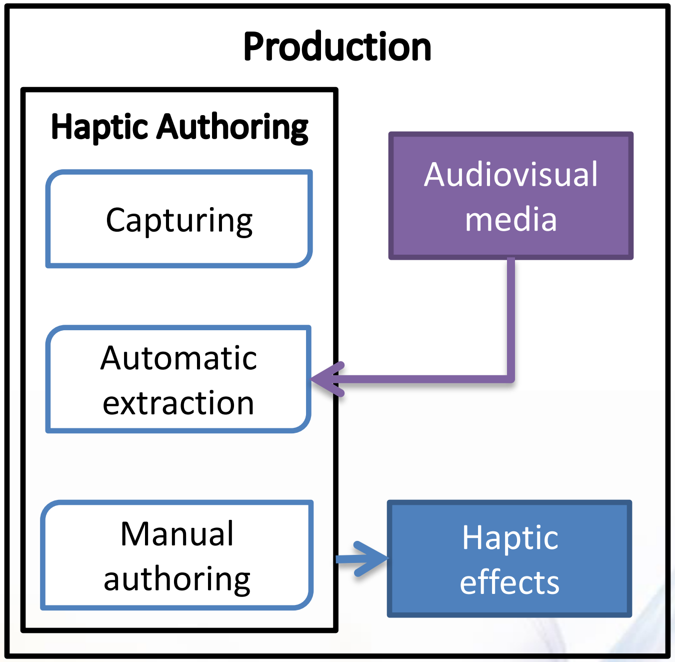


Production: limitations

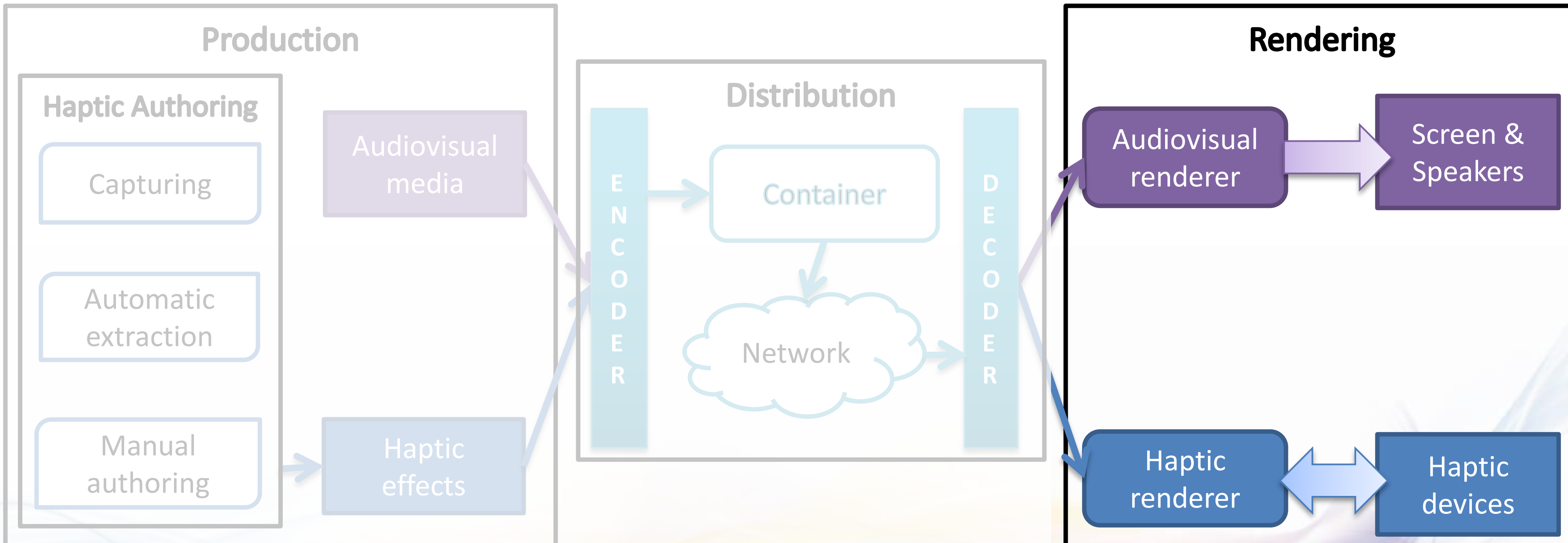
1. Creation of effects is difficult
   - Capture: synchronization between sensor and AV content
   - Automatic extraction: restricted to specific configurations
   - Manual : hard to design complex effects



2. Limited use of haptic effects in AV context
   - Only physical events

- **Need for novel approach for producing haptic effects**
- **Explore the potential of haptics for AV**

Rendering of Haptic Effects

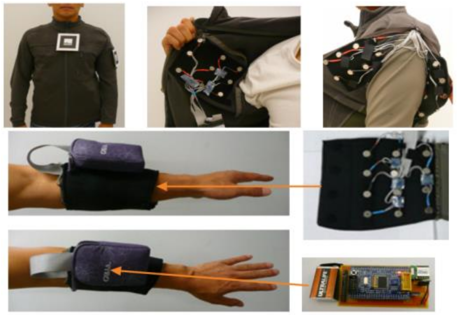


Rendering of Haptic Effects

- Wearable devices
  - Vibrations

    [Lee et al. 2005]

    [Lemmens et al. 2009]



[Rhaman et al. 2010]

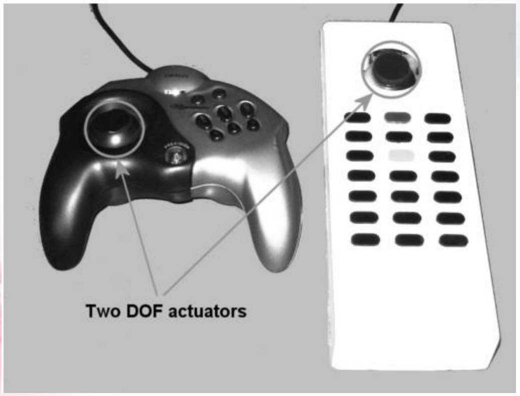
[Kim et al. 2010]

- Handheld devices
  - Vibrations

    [Ur Rhéman et al. 2008]
  - Force-feedback

    [Yamaguchi et al. 2006]

[Alexander et al. 2011]

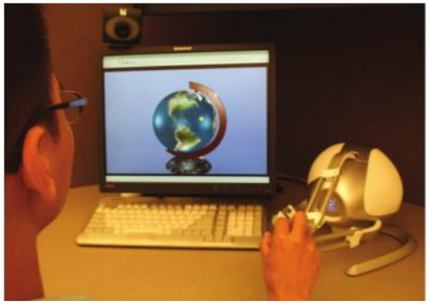


[O'Modhrain and Oakley 2010]

Rendering of Haptic Effects

- Desktop Devices
  - Force-feedback

    [Hoshi et al. 2010]
    [Gaw et al. 2006]
    [Kim et al. 2011]



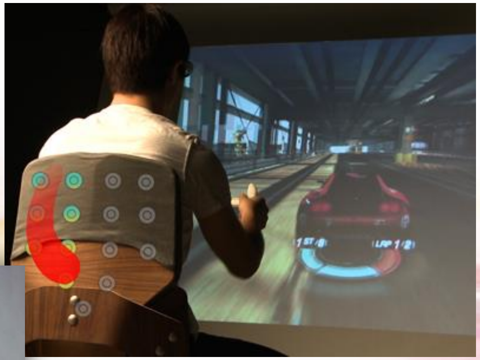
[Cha et al. 2009]

[Sodhi et al. 2013]

- Haptic seats
  - Vibrations

    [Dijk et al. 2010]
    [Israr and Poupyrev 2011]
  - Motion

    [DBox]



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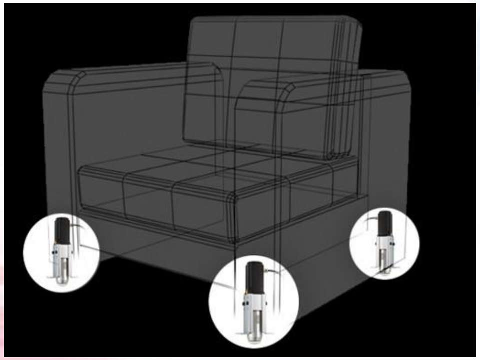
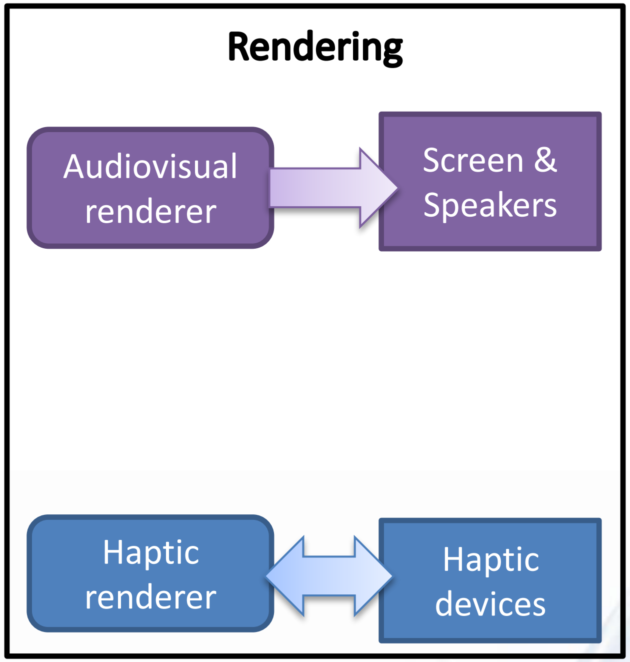


[DBox]

Rendering: limitations

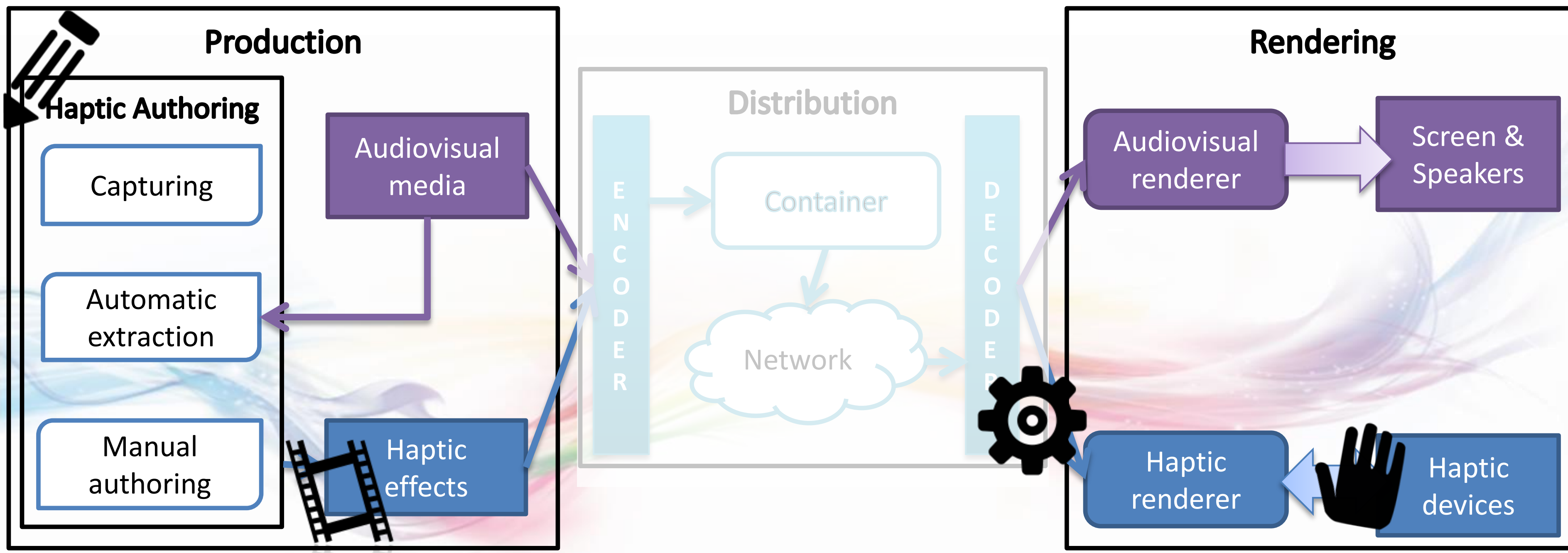
1. Lack of devices adapted to a passive AV experience
   - Wearable / Handheld / Desktop: not adapted, weak effects
   - Seats: cumbersome, expensive
2. Few works on haptic rendering for HAV
   - Haptic effects designed for one specific device



- **Need for dedicated haptic devices for AV settings**
- **Need for haptic rendering for HAV content**

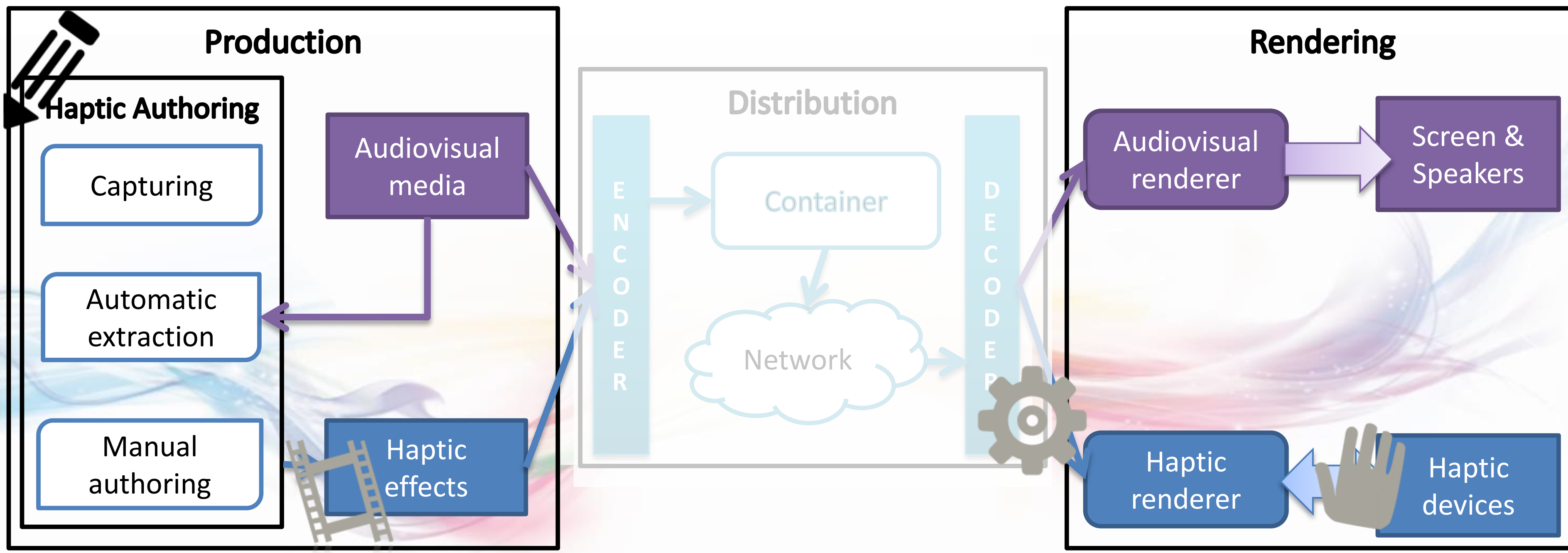
Thesis Objectives

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography



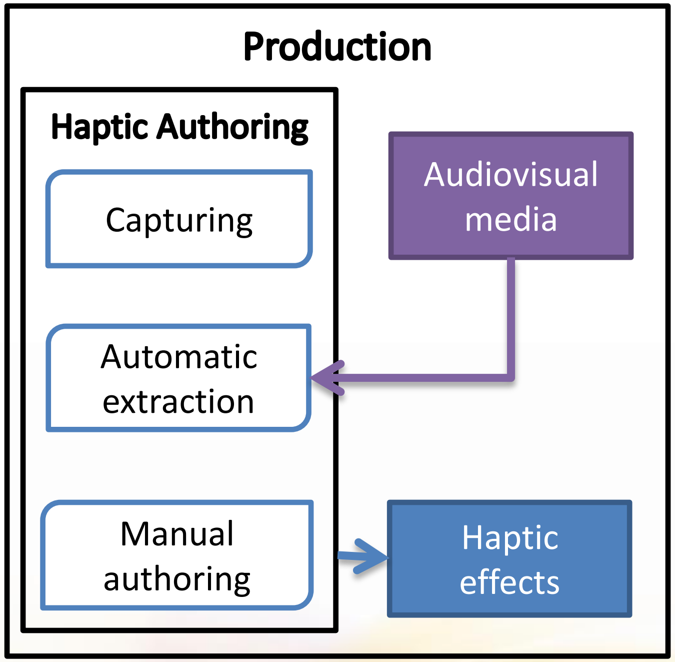
Contribution #1

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography



Current solution for producing haptic effects

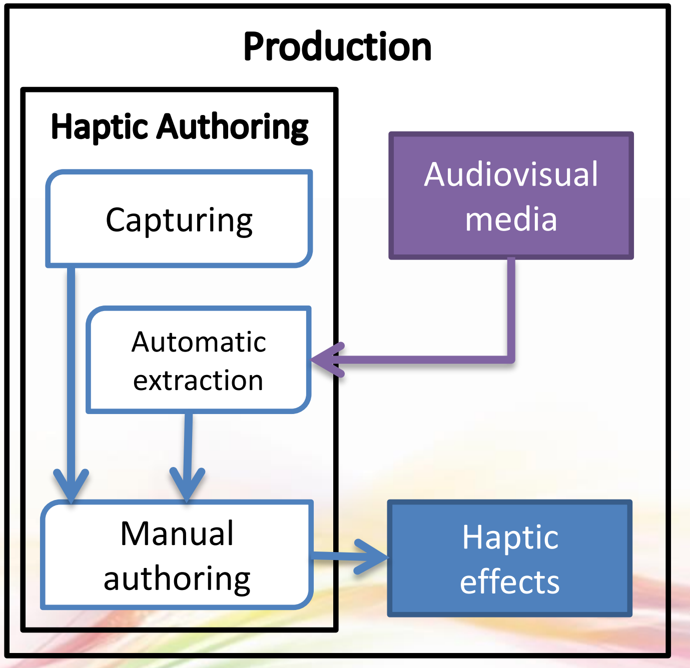
- 3 different techniques



- **Objective: novel approach for producing effects**

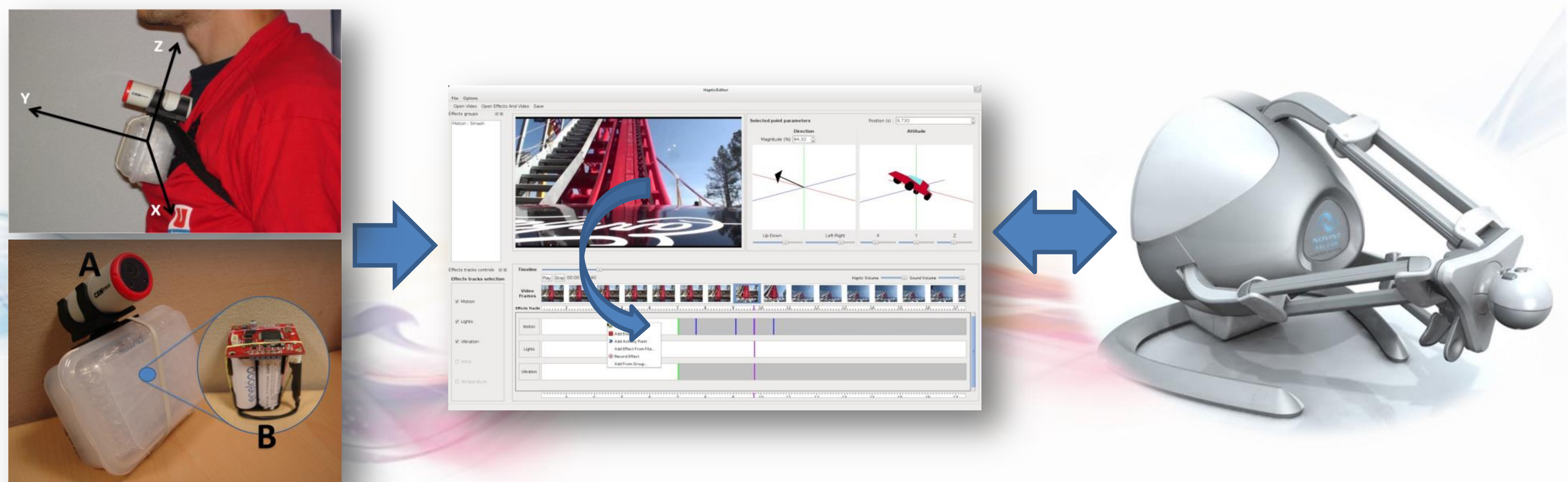
New framework for producing haptic effects

- Approach: combine the 3 techniques



New framework for producing haptic effects

- Proof-of-Concept
  - Capture of motion data
  - Manual edition thanks to force-feedback device
  - Automatic extraction of vibration effects
  - Preview of haptic effects



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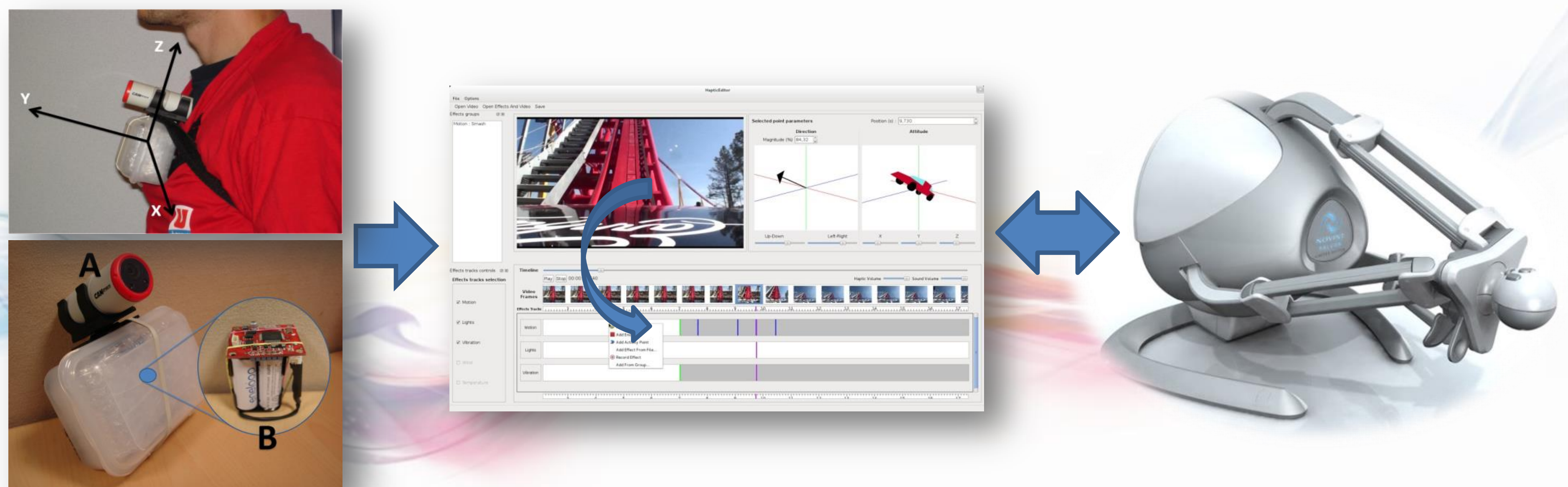
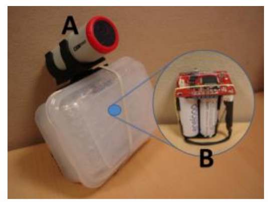


PoC Details

- Capture device
  - Camera
  - IMU: linear acceleration (A)



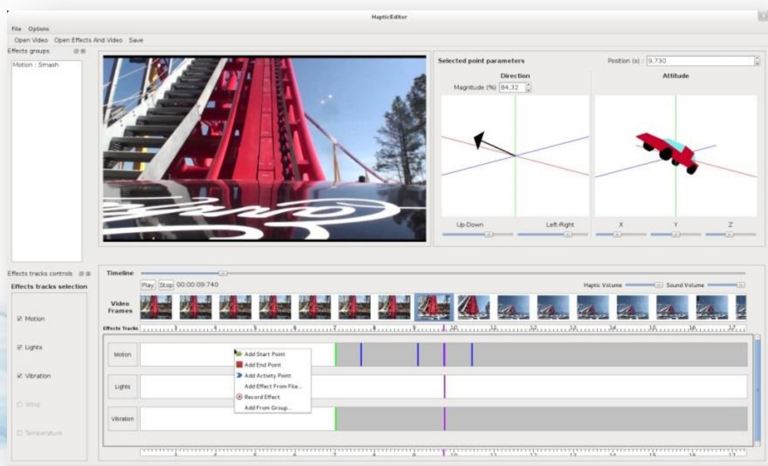
- Preview of effects
  - Signal processing
    - Synchro with AV (haptic clap)
    - Low pass filtering
    - Gravity removal
  - Haptic Rendering

$$F = kA$$

A = linear acceleration
k = scaling constant

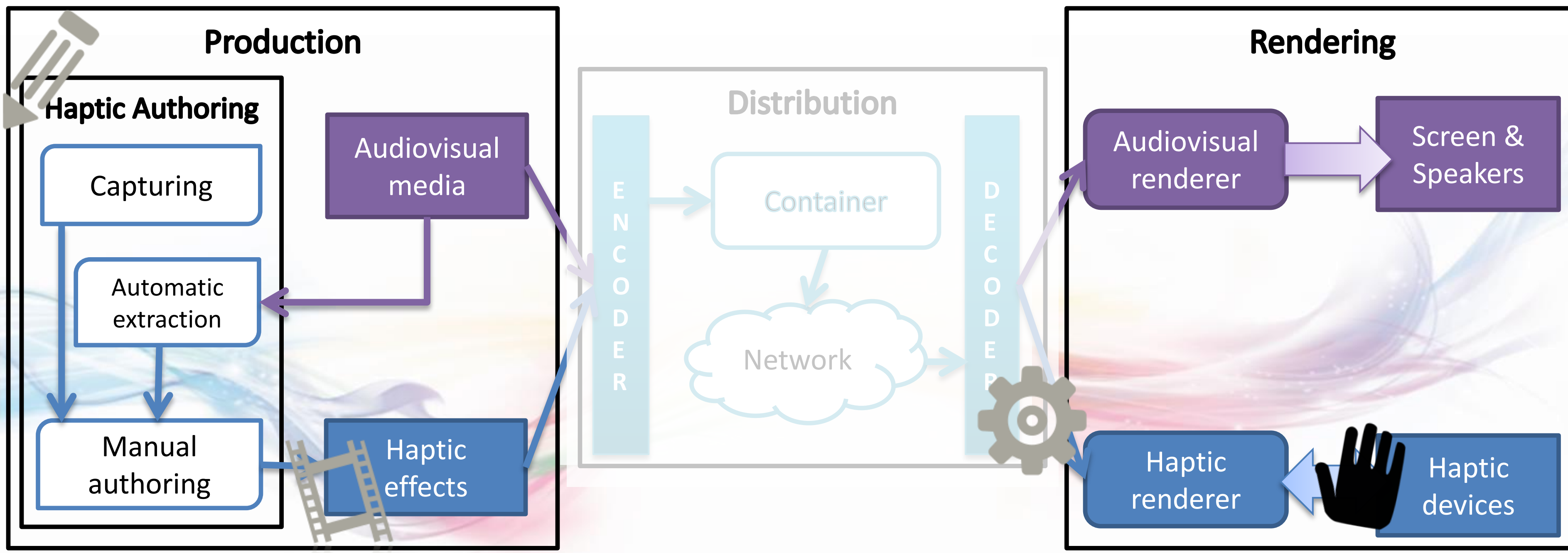
Preliminary Conclusion

- Framework for producing haptic effects: **H-Studio**
  - Capture of motion data
  - Haptic preview of haptic effects
- User study



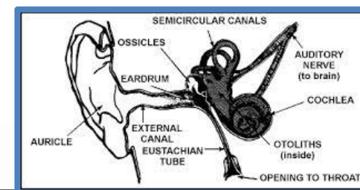
Contribution #2

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography



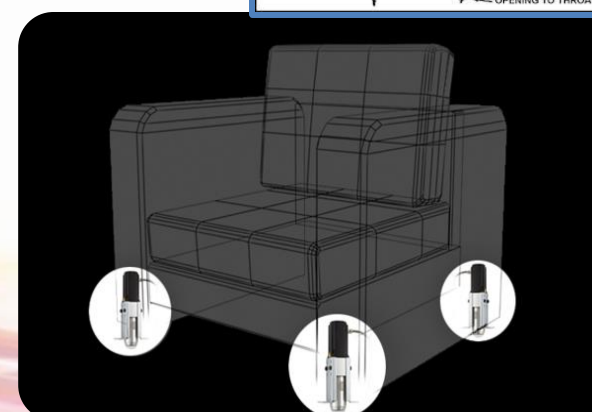
Existing solutions for simulating motion

- Sensation of motion in (home) cinemas
  - Simplified motion platforms
  - Force-feedback based (Haptic motion)
  - Vibration based



[Riecke et al. 2005]

[Lécuyer et al. 2004]
[Ouarti et al. 2014]

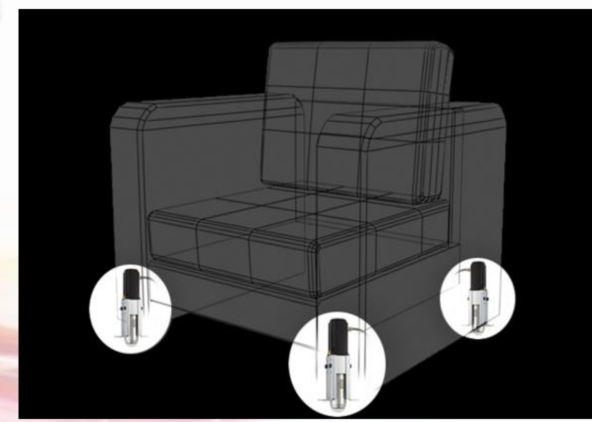


D-box.com

Existing solutions for simulating motion

Sensation of motion

Motion simulator



Haptic motion

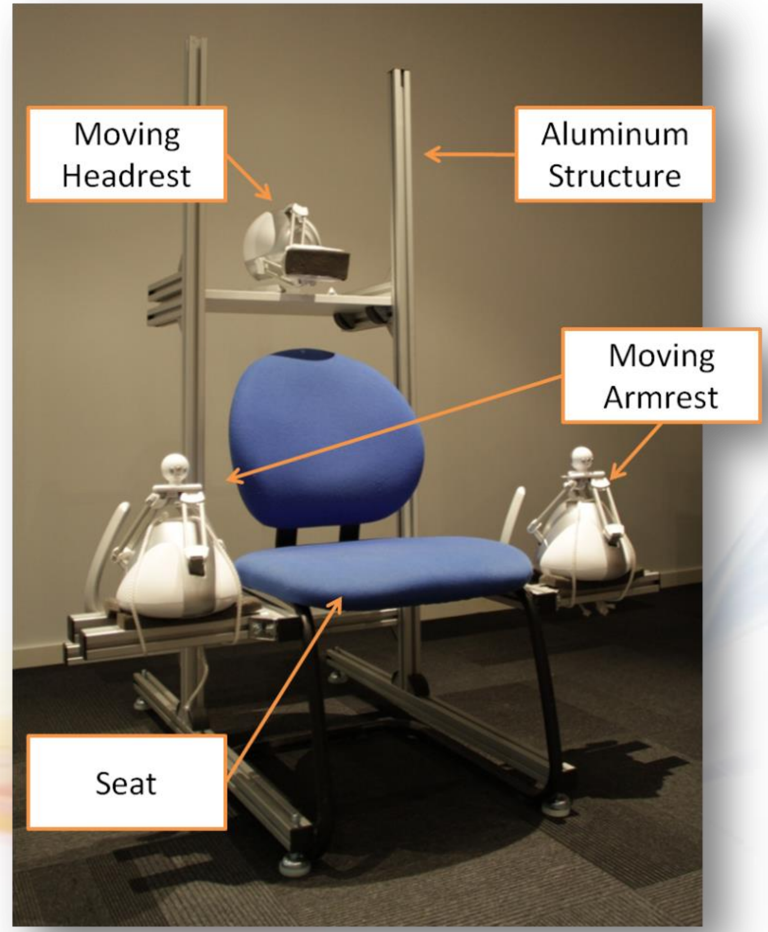
Vibration-based

Complexity

HapSeat

- Sensation of motion induced by force-feedback embedded in a seat
- 3 contact points
  – Hands: haptic motion
  – Head: vestibular system

  → 6 DoF motion effect
- Suitable for consumer settings



Prototype of the HapSeat

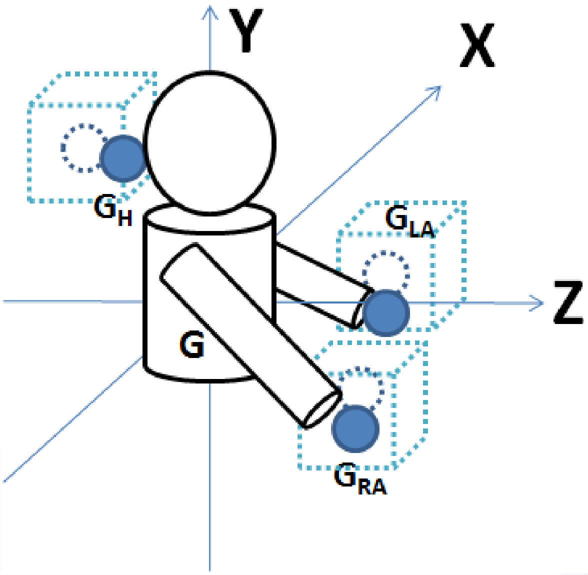
HapSeat

- Video + Motion effects
  - Accelerations (a) + rotational speeds (w)
- How to render motion effects on the HapSeat?
  - **Control model**

HapSeat: Control Model #1

- Physical Model
  - Reproduce acceleration felt by the moving actor

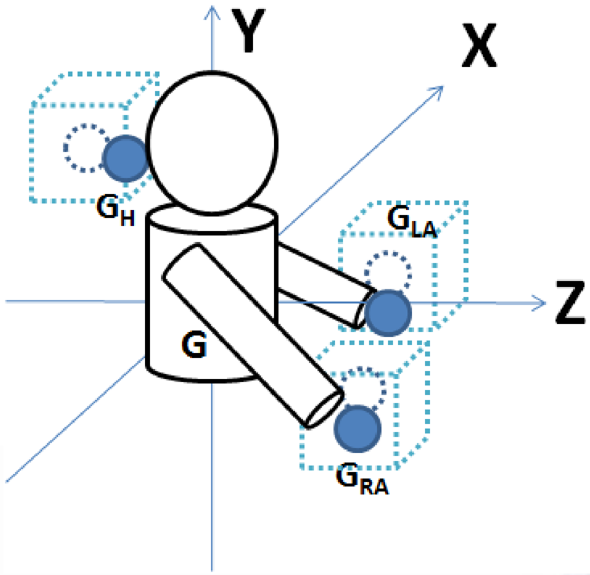
  → Compute acceleration for hands and head from global motion



HapSeat: Control Model #1

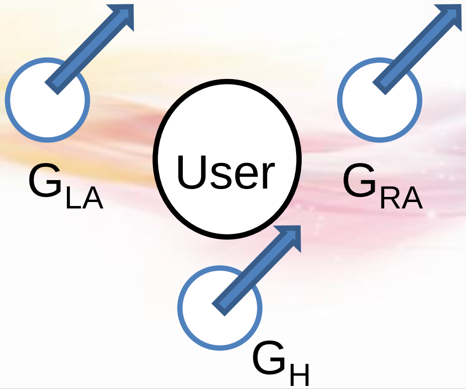
- Physical Model
  - Reproduce acceleration felt by the moving actor

    → Compute acceleration for hands and head from global motion
  - Example:



Motion data = left turn

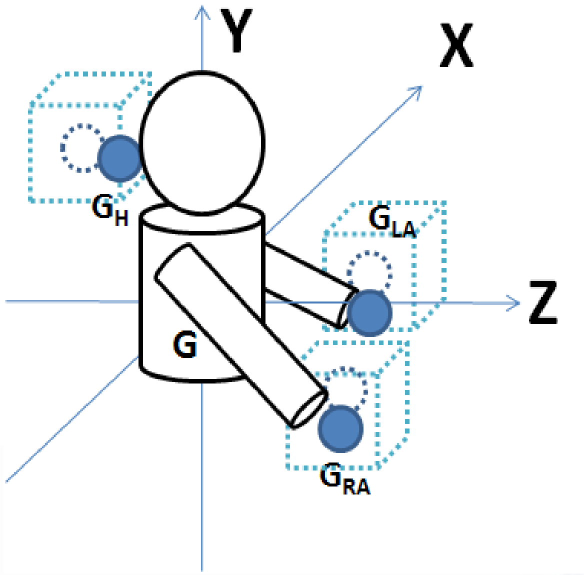
HapSeat – Top View



HapSeat: Control Model #1

- Physical Model
  - Reproduce acceleration felt by the moving actor

  → Compute acceleration for hands and head from global motion
  - Rigid Body Kinematics

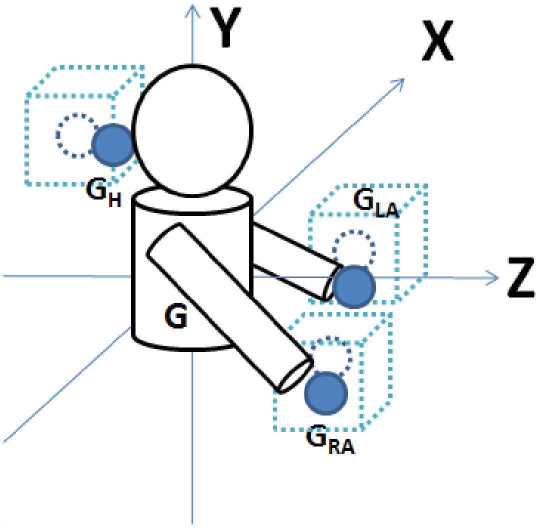


$$\overrightarrow{G_A G'_A} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} \left(a(t) + \frac{dw}{dt}(t) \wedge \overrightarrow{GP_A} + w(t) \wedge \left(w(t) \wedge \overrightarrow{GP_A} \right) \right)$$

P_A = position of the body part (head, hand)
s_x, s_y, s_z = scaling factors

HapSeat: Control Model #2

- Geometrical Model
  - Reproduce position and posture of moving actor during recording



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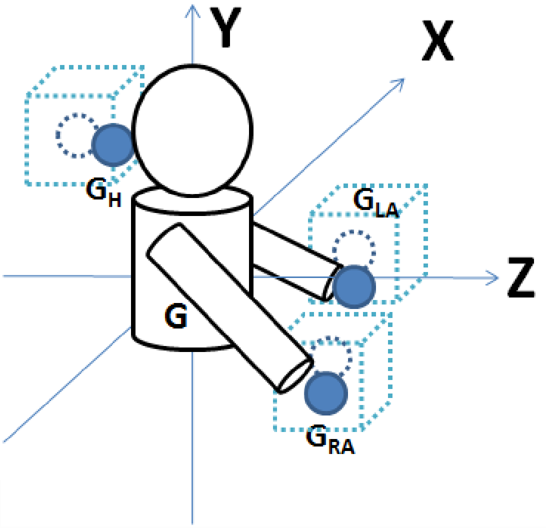
  - Example



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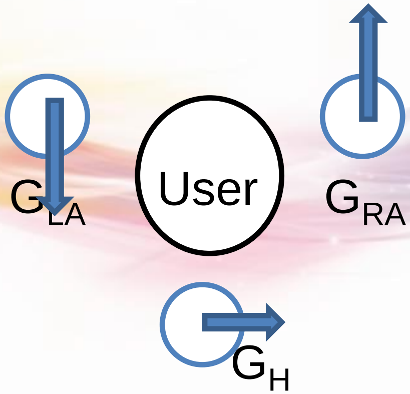

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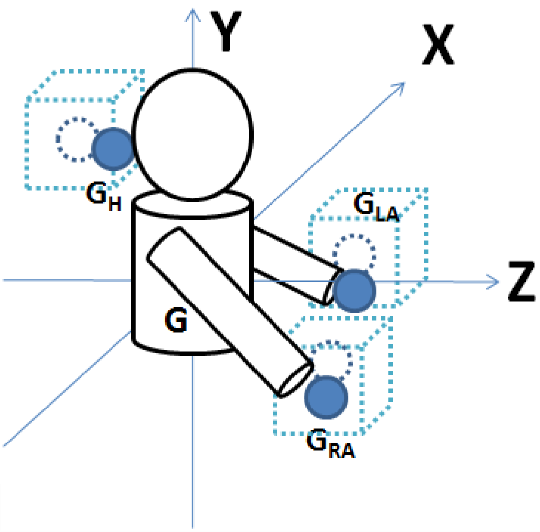


$$\overrightarrow{G_A G'_A} = f(\vec{T}, \vec{R})$$

$$f(\vec{T}, \vec{R}) = \frac{\|\vec{T}\| T + \|\vec{R}\| R}{\|\vec{T}\| + \|\vec{R}\|}$$

$$\vec{T} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} a(t)$$

$$\vec{R} = \left(R_x\left(m_x w_x(t)\right) R_y\left(m_y w_y(t)\right) R_z\left(m_z w_z(t)\right) - I_3\right)\overrightarrow{GP_A}$$

P_A = position of the body part (head, hand)
s_x, s_y, s_z, m_x, m_y, m_z = scaling factors
I_3 = Identity matrix
R_x, R_y, R_z = rotation matrices

User Study

- Objective: study of the influence of the HapSeat on the QoE

- Hypotheses
  - HapSeat provides sensation of motion
  - HapSeat enhances quality of experience

Video 1: real data

Video 2: synthetic data

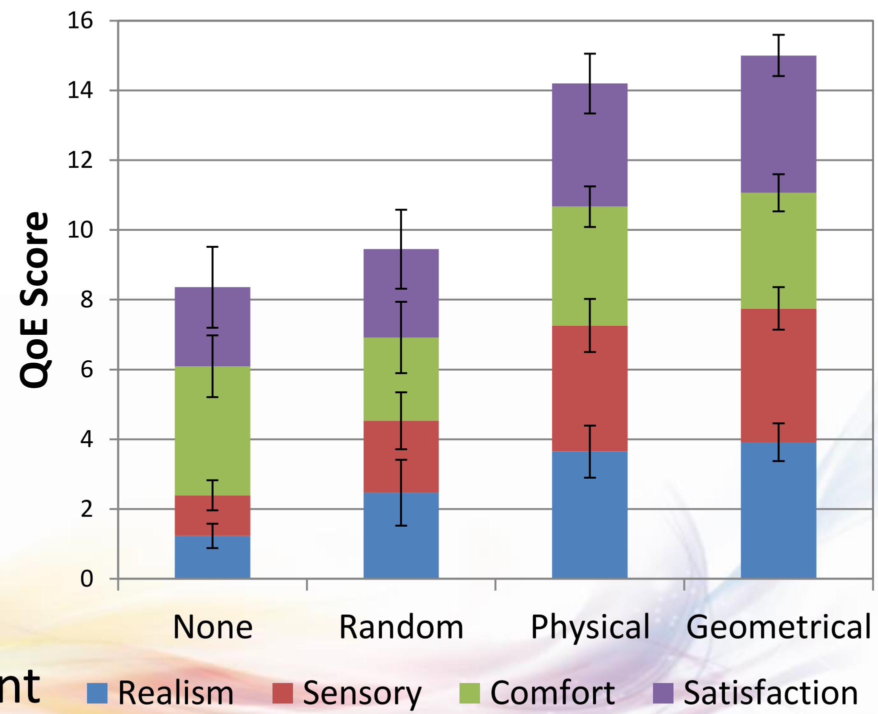
- Variables
  - 2 videos + motion data
  - 4 haptic conditions
    Physical Model, Geometrical Model, Random, None.

- Measure
  - QoE Questionnaire:
    Realism, Sensory, Satisfaction, Comfort

- 17 Participants
  - Age: 36.1 (SD 11.1)

User Study: Results

- Statistical analysis
  - Friedman anova
  - Wilcoxon tests
- HapSeat enhances QoE
  - Physical Model ≈ Geometrical Model **>** Random ≈ None
  - Realism, Sensory and Satisfaction factors improved
  - Comfort is constant
- Discussion
  - Comfort: head movement should be different than hands movement
  - No difference between models: need videos with more rotations



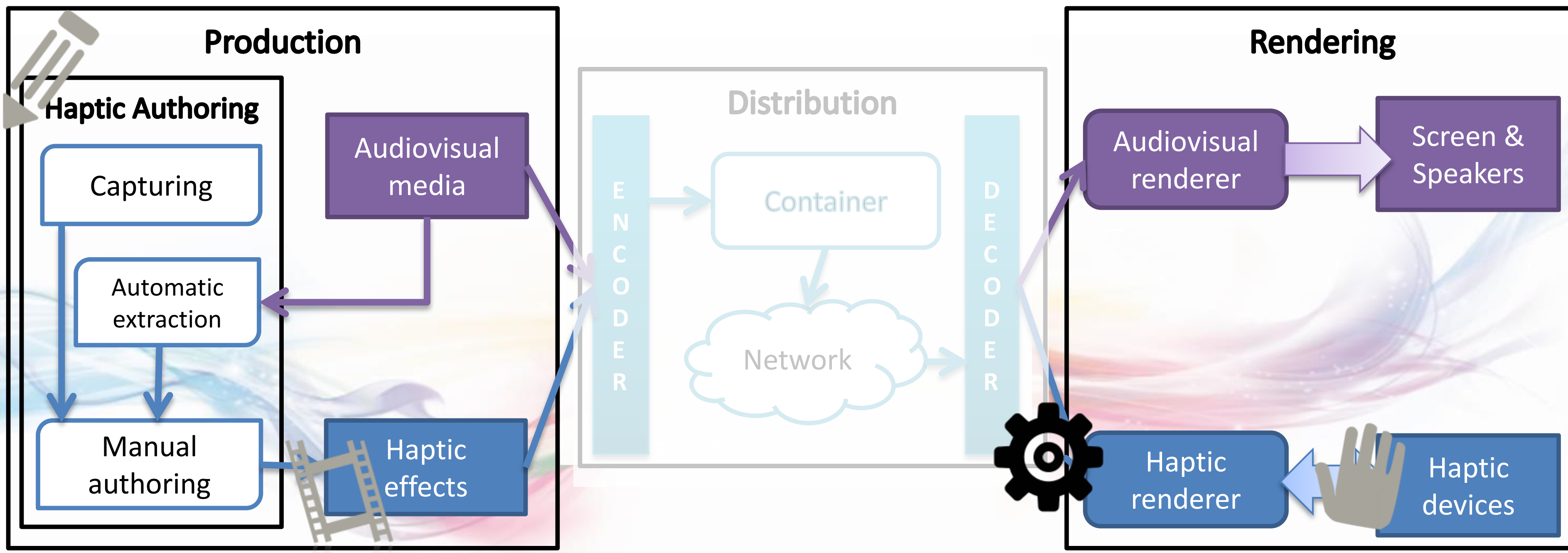
Preliminary Conclusion

- Haptic device for simulating 6DoF motion effects
  - HapSeat: 3 force-feedback devices
  - 2 control models: Physical and Geometrical

- User Study
  - Provides sensation of motion
  - Improves the video viewing experience

Contribution #3

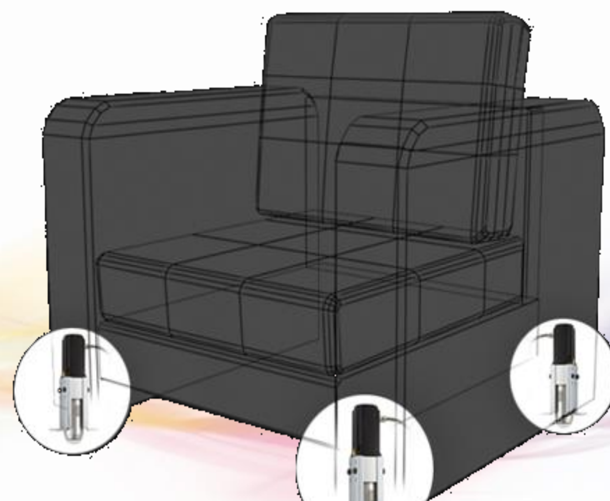
- Framework for producing haptic effects
- Haptic device for HAV
- **Haptic rendering algorithm**
- Haptic cinematography



HAV Rendering

- Objective: introduce haptic rendering for HAV
  - Multiple haptic effects, synchronized with AV content
  - Limited workspace of the haptic device

HapSeat: force-feedback devices



DBox seat: motion platform

HAV Content

Example of video sequence composed of several shots

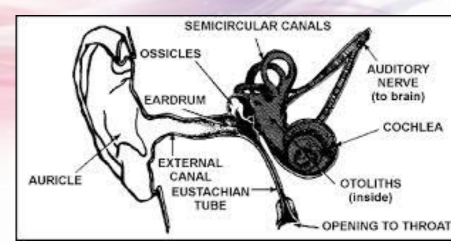
Movement toward the right	No effect	Movement toward the right	No effect	Movement toward the right	No effect

Motion rendering

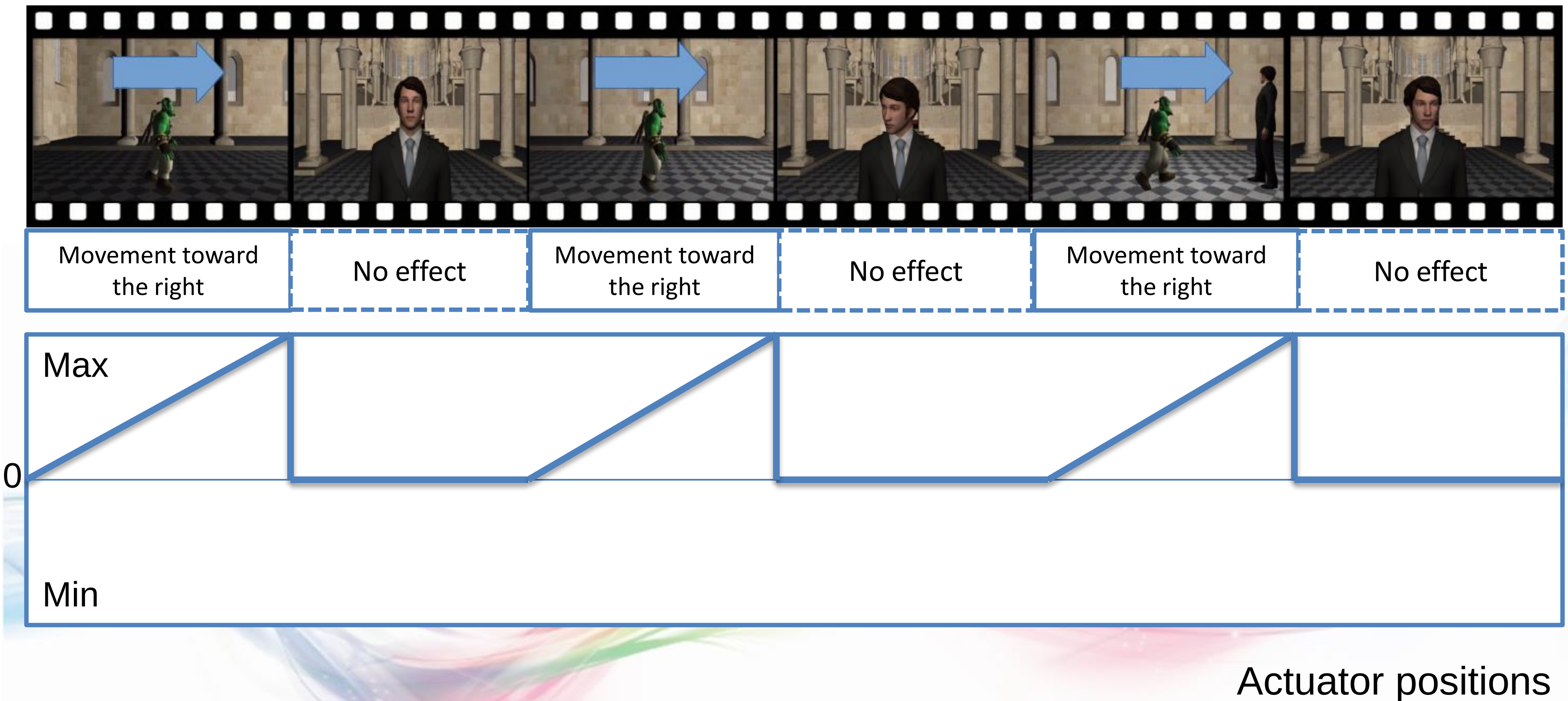
- Control of motion platform
  - Washout filter: moves device under user's perceptual threshold

Movement toward the right	No effect	Movement toward the right	No effect	Movement toward the right	No effect

  - Perceptual threshold defined by the vestibular system *[Nehaoua et al. 2008]*

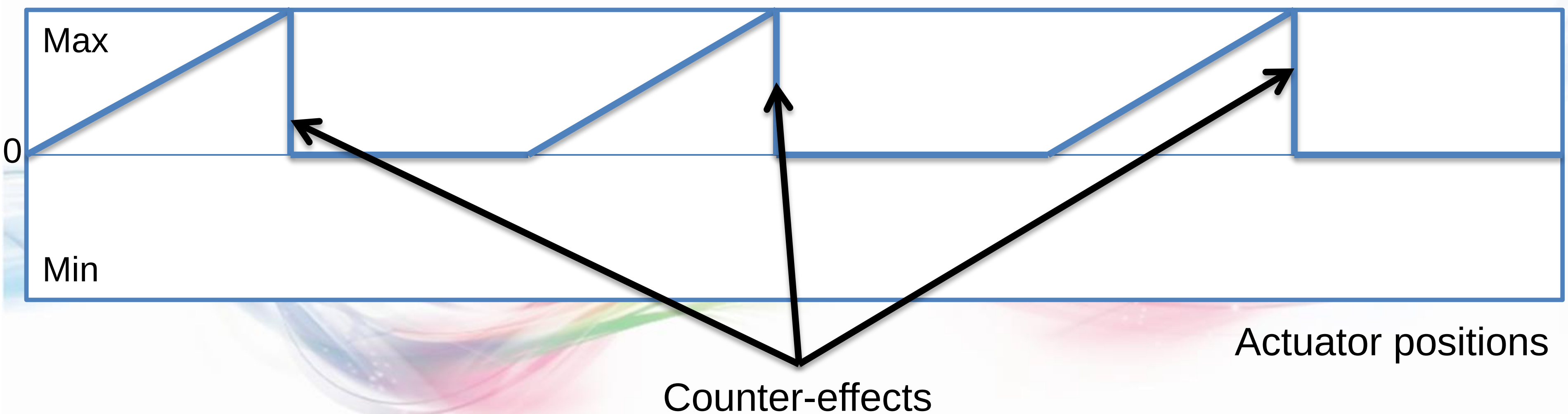


Haptic Rendering



Haptic Rendering

- Transitions between effects must be handled
  - Counter-effects
- Workspace of the actuator is underexploited

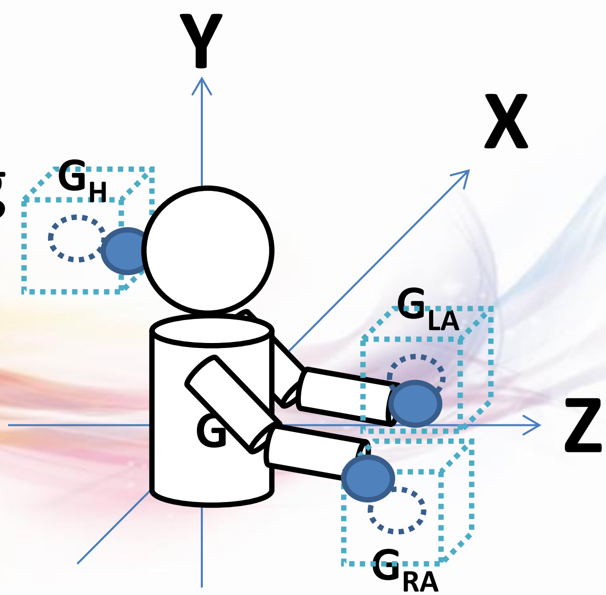


Haptic Rendering

- Transitions between effects must be handled
  - Counter-effects
- Workspace of the actuator is underexploited

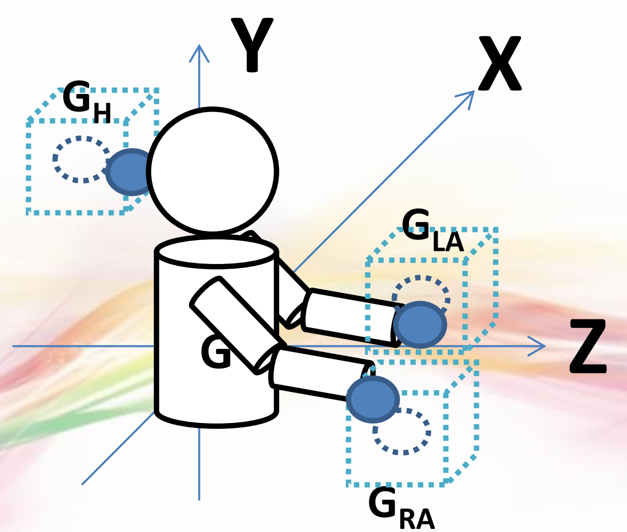
- Washout filter not suitable for haptic rendering
  - Stimulate the kinesthetic system

- Washout filter for haptic rendering
  - User Body Model
  - Perceptive Optimizer
  - Workspace Optimizer



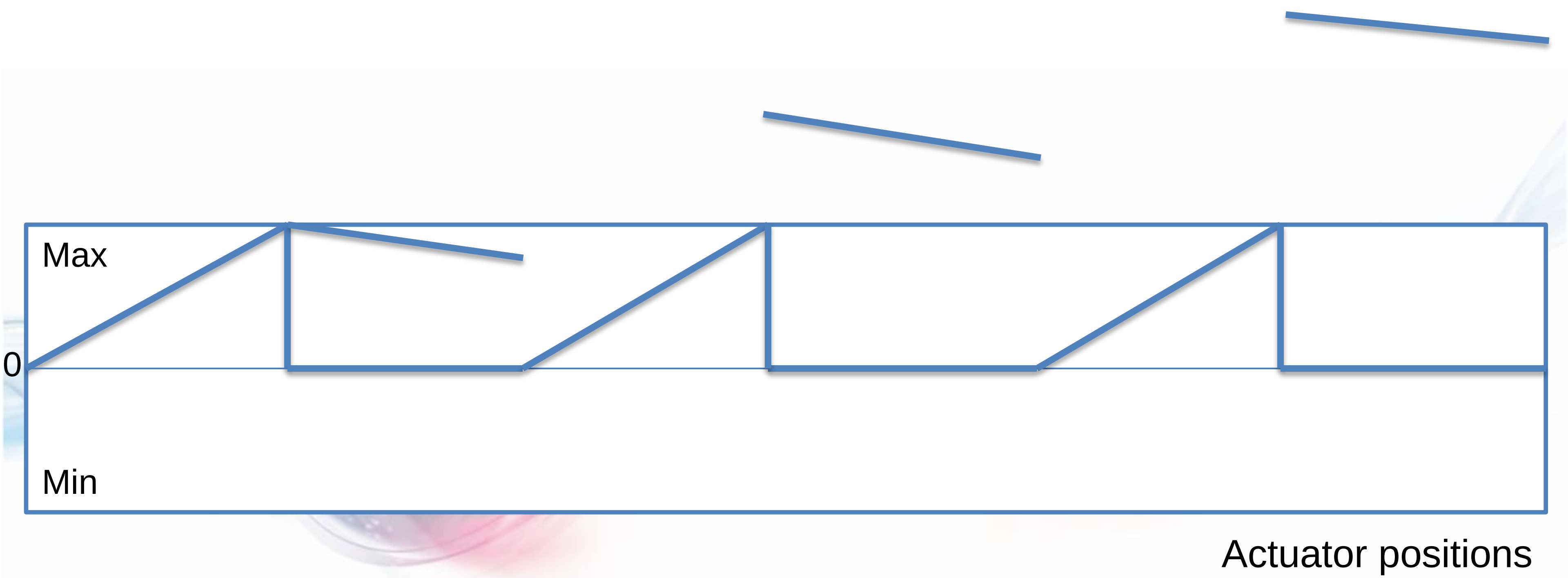
User Body Model

- Composed of segments and joints
  [Schuenke et al. 2010]
- Thresholds for kinesthetic perception
    - Angular speed of joints *[Jones 2000]*
    - Elbow: 1 $deg.s^{-1}$; Neck, Shoulder: 0.5 $deg.s^{-1}$



Perceptive Optimizer

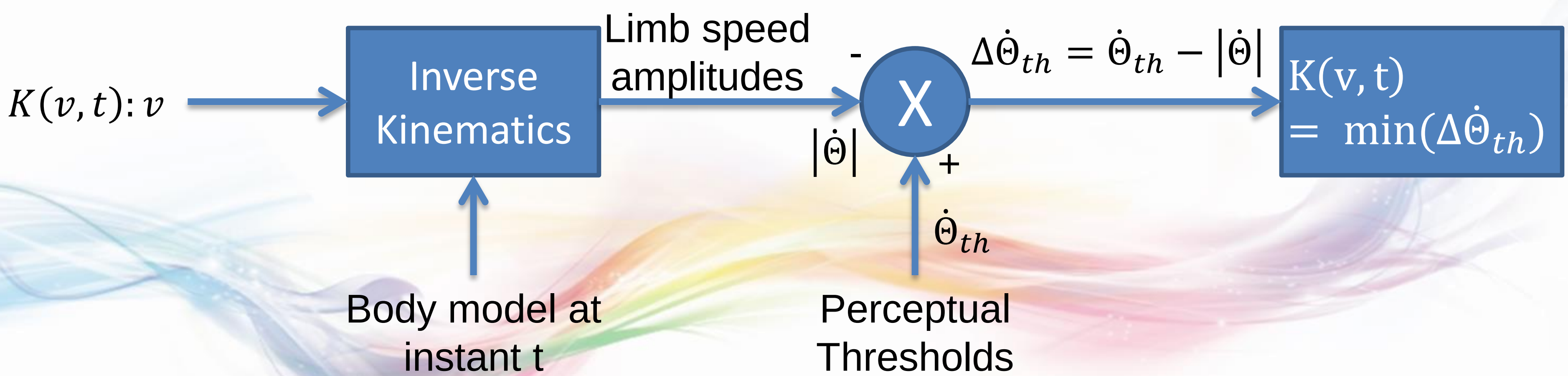
- Inverse Kinematics algorithm + User body model
- Limit speed v of limb to value of thresholds



Perceptive Optimizer

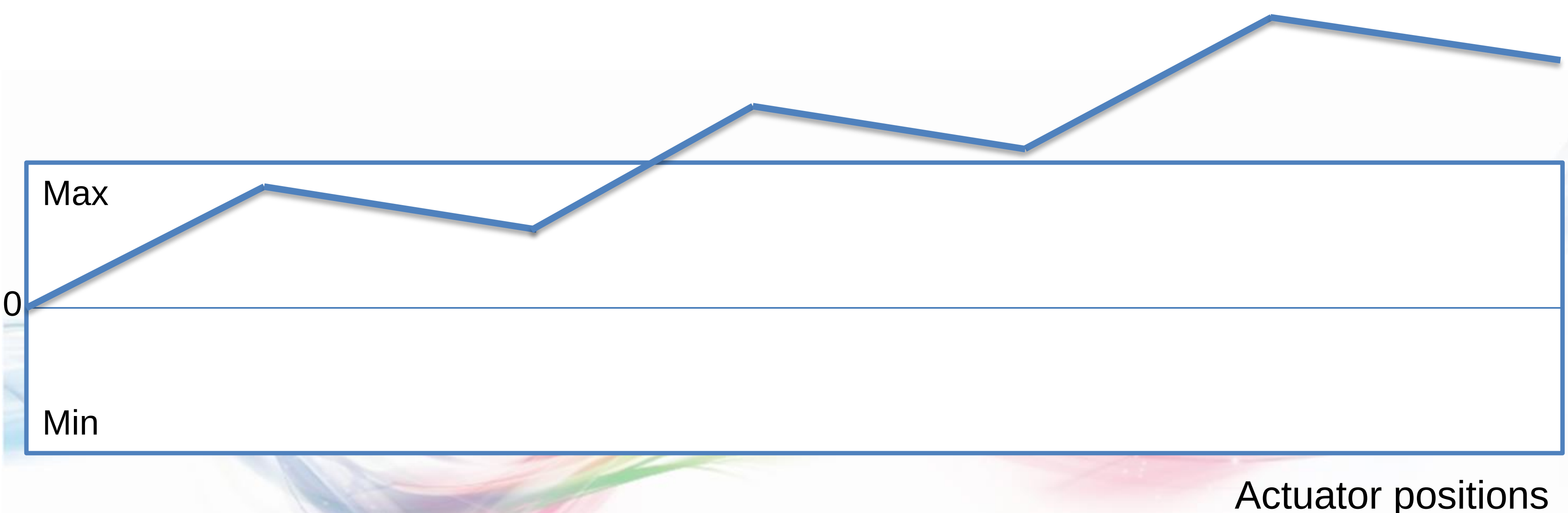
- Inverse Kinematics algorithm + User body model
- Limit speed v of limb to value of thresholds

$$v = \underset{0 \leq K(v,t)}{argmin}(\|P(t-dt) + v\Delta t\|)$$



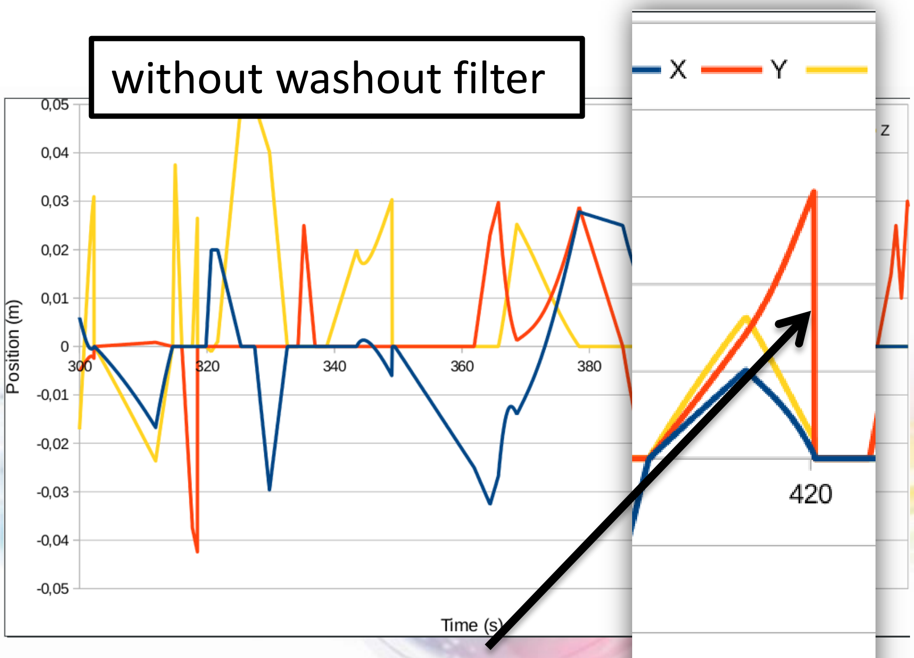
Workspace Optimizer

- Performs an offset to optimize the use of the workspace
- Rescales signal if workspace still not respected

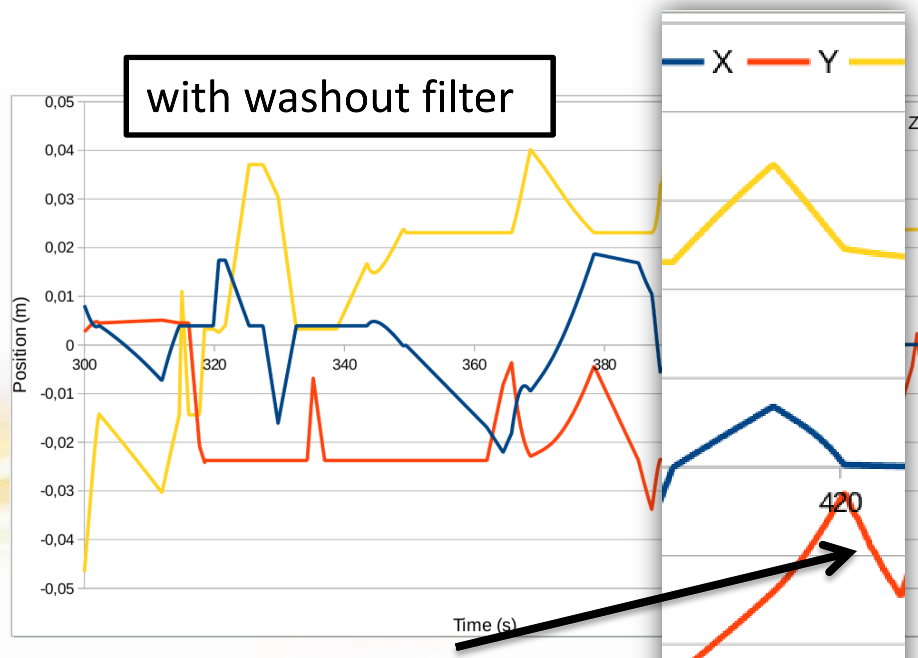


Application to a real movie

- Movie: Sintel [Blender Fundation]
- Duration: 10 minutes
- Design: VFX Artist



Counter-effect



“Imperceptible” counter-effect

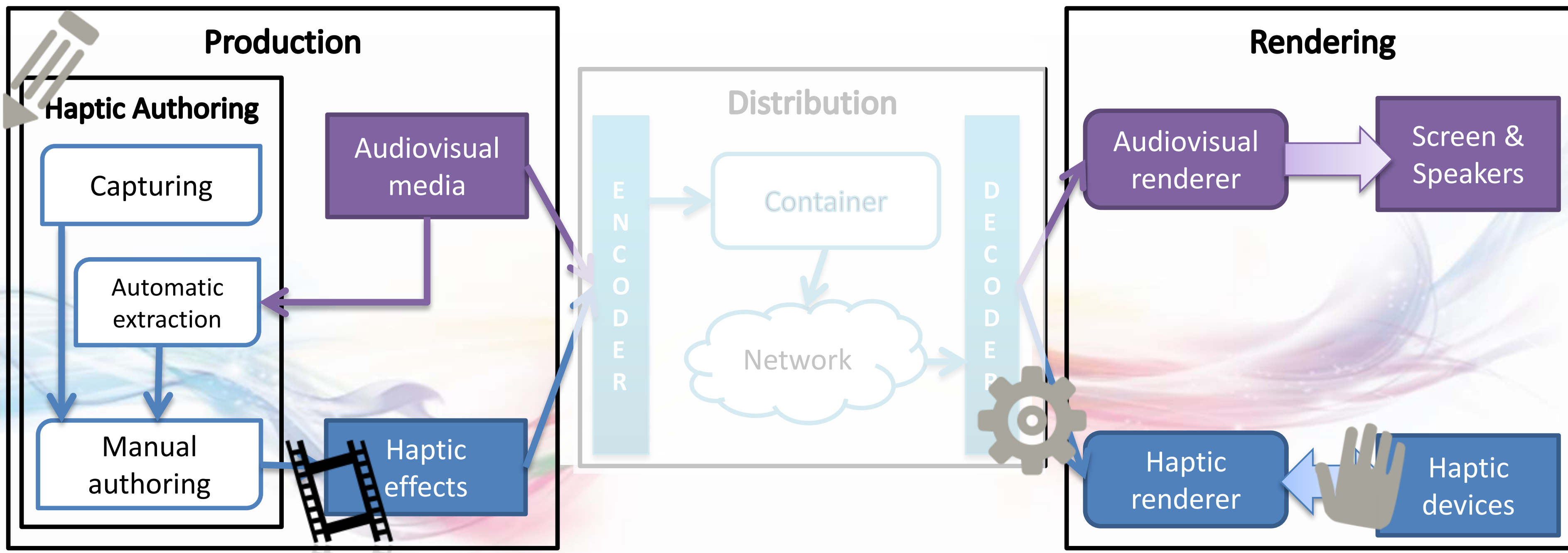
Preliminary Conclusion

- Haptic rendering integrating a washout filter
  - Model of user kinesthetic perception
  - Perceptive optimizer
  - Workspace optimizer
- Application to full video sequence

- User Study
  - Washout filter enhances QoE

Contribution #4

- Framework for producing haptic effects
- Haptic device for HAV
- Haptic rendering algorithm
- Haptic cinematography



How to associate haptic effects to movies?

- Mainly used with action movies
  - Physical events : explosions, car chases, gun shots, etc.
  - Ex: movies proposed by D-Box

- Rarely used for enhance drama, comedy, romantic movies

How to associate haptic effects to movies?

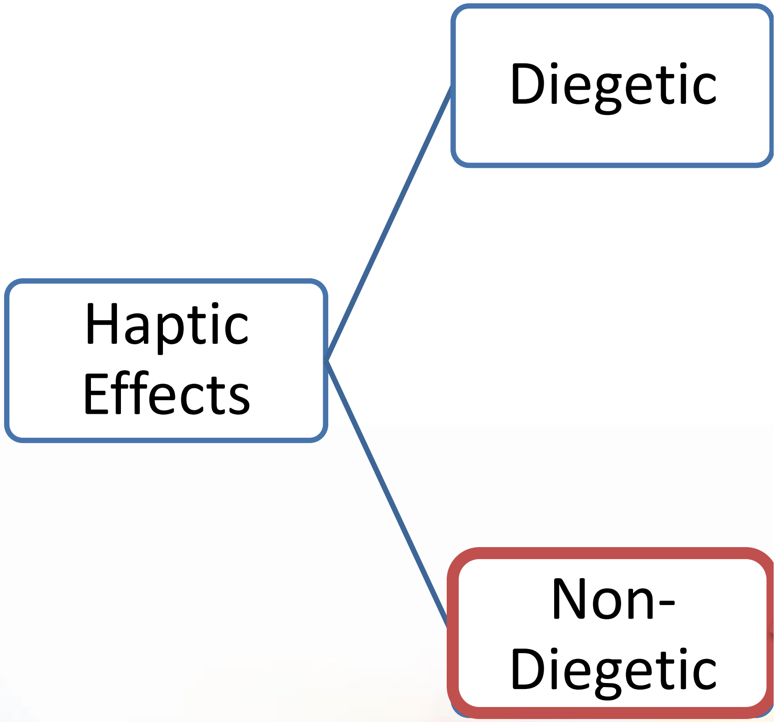
- Mainly used with action movies
  - Physical events : explosions, car chases, gun shots, etc.
  - Ex: movies proposed by D-Box

- Drama, comedy, romantic movies?
- Move beyond enhancement of only physical events

  →**non-diegetic effects**

Explicit Ills, 2008. Mark Webber

Taxonomy of Haptic Effects



[Danieau et al. 2013b]

Cinematographic Camera Effects

- Camera Effects
  - Cinematic
  - Semantic

- Typical effects
  - Crane shot
  - Dutch Angle
  - Arcing
  - Traveling
  - Tilting
  - Zoom-in
  - Vertigo

[Mascelli. 1998]
[Thompson and Bowen. 2009]

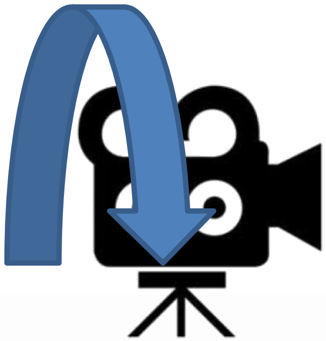
Crane Shot

Dutch Angle

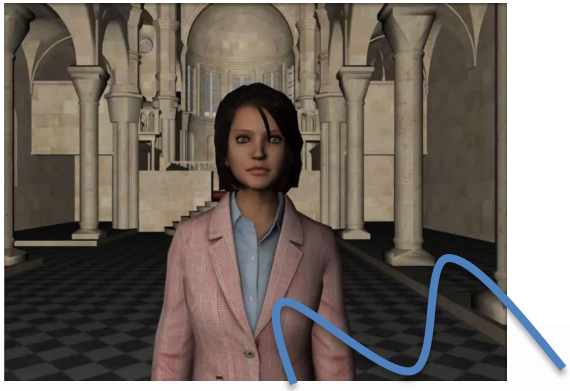
Haptic Effects based on Camera Effects

- 2 control models

Cinematic



Semantic



- Proof-of-Concept
  - 7 Video Sequences
  - HapSeat
    - Cinematic model
    - Semantic model

Control Model #1: Cinematic

- Follows camera movement

Cinematic model with Arcing, Tilting and Zoom-in sequences

Control Model #1: Cinematic

- Follows camera movement
- Extension of Geometrical Model

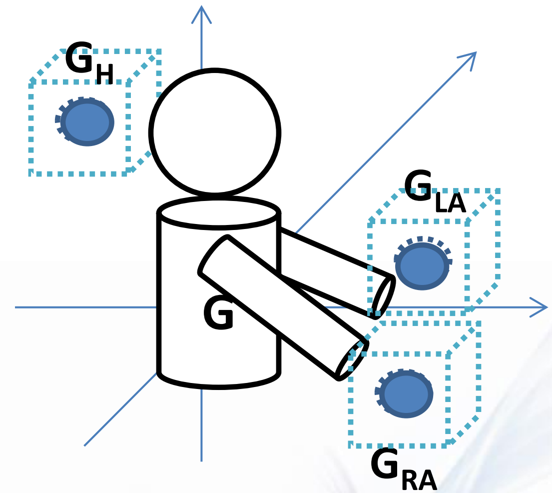
$$\overrightarrow{G_A G'_A} = f\left(\vec{T}, \vec{R}\right)$$

$$f\left(\vec{T}, \vec{R}, \vec{Z}\right) = \frac{\|\vec{T}\|T + \|\vec{R}\|R \boxed{+ \|\vec{Z}\|Z}}{\|\vec{T}\| + \|\vec{R}\| \boxed{+ \|\vec{Z}\|}}$$

$$\vec{T} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} a(t)$$

$$\vec{R} = \left(R_x\left(m_x w_x(t)\right) R_y\left(m_y w_y(t)\right) R_z\left(m_z w_z(t)\right) - I_3\right)\overrightarrow{GP_A}$$

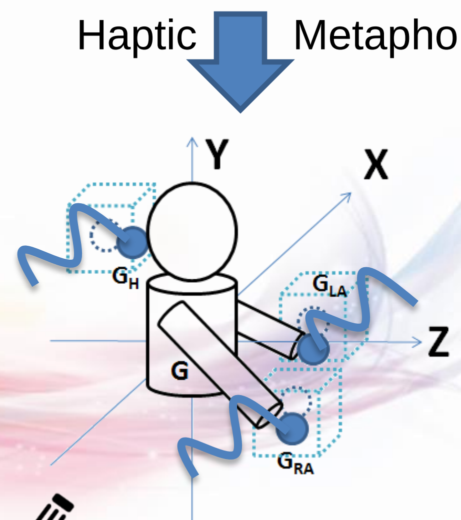
$$\boxed{\vec{Z} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & k_z \end{bmatrix} z(t)}$$



P_A = position of the body part (head, hand)
s_x, s_y, s_z, m_x, m_y, m_z , k_z = scaling factors
I_3 = Identity matrix
R_x, R_y, R_z = rotation matrices

Control Model #2: Semantic

- Based on the semantic of the Camera Effect
  - Crane Shot → Flying away
  - Dutch Angle → Instability
  - Arcing → Intensification
  - Traveling → Crab Walk
  - Tilting → Inferiority
  - Zoom-in → Walk forward
  - Vertigo → Vertigo



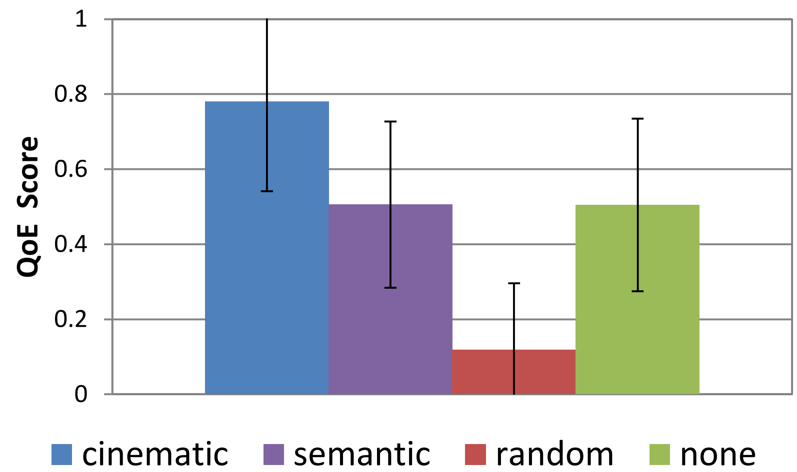
- Designed with our authoring tool

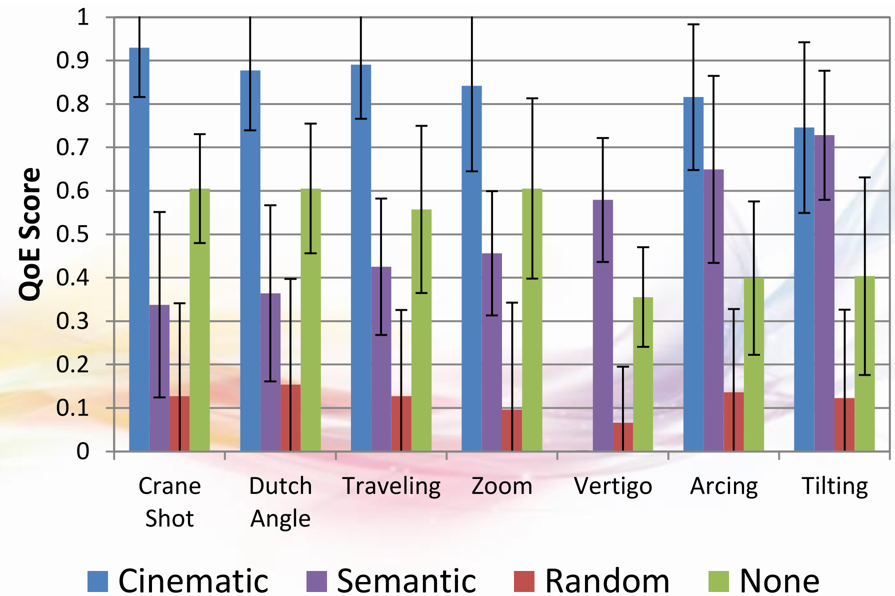
User Study

- Objective: study of the influence of the haptic effects based on camera motions on the QoE
- Hypothesis
  - New haptic effects increases QoE
- Variables
  - 7 video sequences
  - 4 haptic conditions
    - Cinematic, Semantic, Random and None
- Measure
  - Pairwise comparison (78 couples)
  - Score computed for each model
- 38 Participants
  - Age: 36.3 (SD 10.4)

User Study: Results

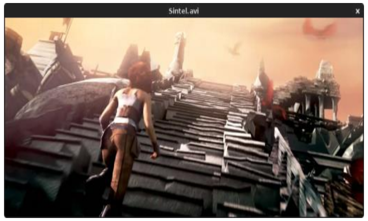
- Statistical analysis
  - Friedman anova
  - Wilcoxon tests
- Haptic effects enhance QoE
  - Cinematic > Semantic ≈ None > Random
  - Semantic > None
    - Vertigo
    - Arcing
    - Tilting
- Discussion
  - Metaphors well understood
  - Dynamics of haptic feedback should be similar to dynamics AV content





Application to real movies

Big Buck Bunny



Sintel

Tears of Steel

Preliminary Conclusion

- Haptic Cinematography
  - Taxonomy of haptic effects
  - Haptic effects based on camera motions
- User study
  - Cinematic model enhances QoE
  - Semantic model works on particular cases
- Application to real movies

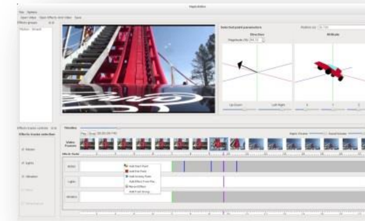
Big Buck Bunny

Sintel

Tears of Steel

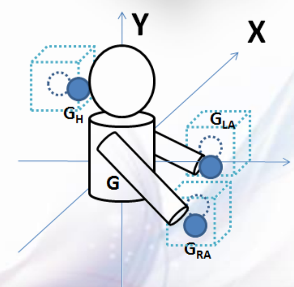
Conclusion

- Study of haptic feedback for AV content



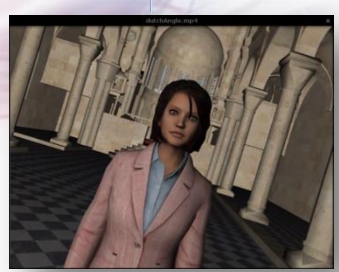
Framework for creating haptic effects
  - Capture, automatic, manual and preview

Haptic device for enriching the AV experience
  - 6DoF sensation of motion based on force-feedbacks



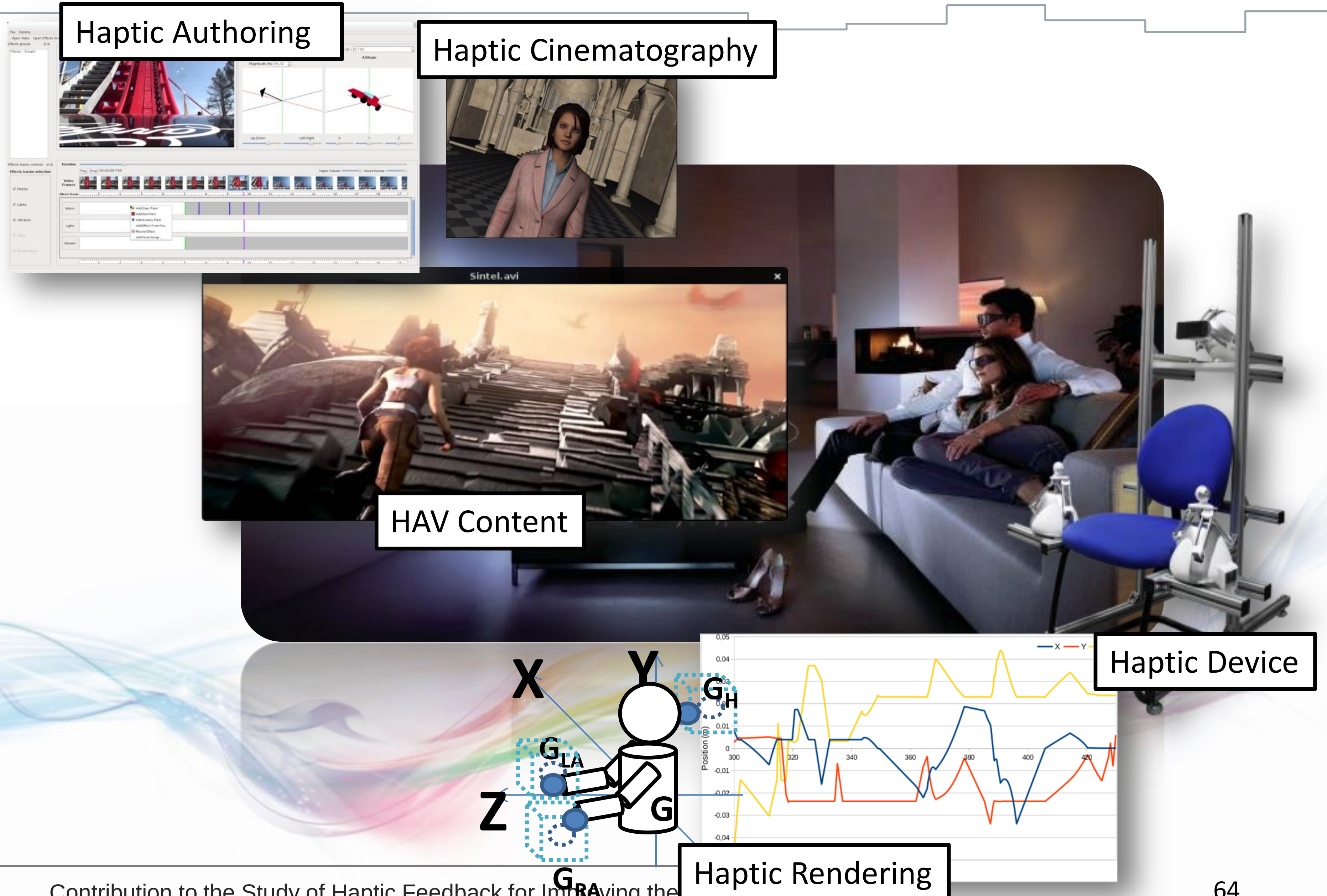
Haptic Rendering for HAV
  - Washout filter for kinesthetic perception

Haptic Cinematography
  - Haptic effects based on cinematographic camera motions



- User studies
  - First guidelines for designing haptic effects

Conclusion


Haptic Authoring
Haptic Cinematography
Sintel.avi
HAV Content
Haptic Device
X
Y
Z
G
Haptic Rendering

Short-term perspectives

- H-Studio
  - Comparison editing methods: usability studies
  - Automatic extraction of motion effects
- HapSeat
  - Improve sensation of motion: more points of stimulation
  - Improve comfort: different rendering for head and hands
- Washout filter
  - Enhance workspace optimizer: limit rescaling
  - Improve user model: user’s attention
- Haptic Cinematography
  - Exploring the taxonomy of haptic effects
  - Combination of diegetic and non-diegetic effects

Long-term perspectives

- Production
  - Create numerous haptic sensations (pressure, temperature, etc.)
  - Edit complex haptic effects (explosion = vibrations + temperature + motion)
- Rendering
  - Hardware: render multiple sensations (vibrations + temperature + motions + etc.), full-body experience
  - Software: adapt haptic effects to any end-devices
- Distribution
  - Contribution to standard (ex: MPEG-V)
- User Experience
  - Objective evaluation of the user experience (biosignals)
  - Model of the user HAV experience

Publications

- Journals
  1. F. Danieau, A. Lécuyer, P. Guillotel, J. Fleureau, N. Mollet, and M. Christie. "Enhancing audiovisual experience with haptic feedback: a survey on HAV". *IEEE Transactions on Haptics*, vol. 6, no 2, pages 193-205, 2013.
  2. F. Danieau, A. Lécuyer, P. Guillotel, J. Fleureau, N. Mollet, and M. Christie. "Toward Haptic Cinematography: Enhancing Movie Experience with Haptic Effects based on Cinematographic Camera Motions". *IEEE Multimedia*, In Press.
  3. F. Danieau, A. Lécuyer, P. Guillotel, J. Fleureau, N. Mollet, and M. Christie. "Haptic Rendering for Audiovisual Contents based on a Washout Filter". *IEEE Transactions on Haptics* (submitted).
- Conferences
  1. F. Danieau, J. Fleureau, A. Cabec, P. Kerbiriou, P. Guillotel, N. Mollet, M. Christie, and A. Lécuyer. "A framework for enhancing video viewing experience with haptic effects of motion". In *IEEE Haptics Symposium*, pages 541–546, 2012.
  2. F. Danieau, J. Fleureau, P. Guillotel, N. Mollet, M. Christie, and A. Lécuyer. "HapSeat: Producing Motion Sensation with Multiple Force-feedback Devices Embedded in a Seat". In *ACM VRST*, pages 69–76, 2012.

Publications

- Patents
  1. J. Fleureau, F. Danieau, P. Guillotel, and A. Lécuyer. " Methods to command a haptic renderer from real motion data ". WO2013041152.
  2. F. Danieau, F. Fleureau, P. Guillotel, N. Mollet, A. Lécuyer and M. Christie. "Haptic Chair for motion simulation". WO2013153137
  3. F. Danieau, F. Fleureau, P. Guillotel, N. Mollet and A. Lécuyer. " Method to render global 6DoF motion effects with local force-feedback". WO2013153086
- Demo / Posters
  1. F. Danieau, J. Bernon, J. Fleureau, P. Guillotel, N. Mollet, M. Christie and A. Lécuyer. "H-Studio: An Authoring Tool for Adding Haptic and Motion Effects to Audiovisual Content." demonstrated at *ACM UIST*, St Andrews, UK, October 2013.
  2. F. Danieau, J. Fleureau, P. Guillotel, N. Mollet, M. Christie and A. Lécuyer. "HapSeat: a novel approach to simulate motion in audiovisual experiences." demonstrated at *ACM SIGGRAPH Emerging Technologies*, Anaheim, CA, USA, July 2013.
  3. F. Danieau, J. Fleureau, P. Guillotel, N. Mollet, M. Christie and A. Lécuyer. "HapSeat: A Novel Approach to Simulate Motion in a Consumer Environment." demonstrated at *ACM CHI Interactivity*, Paris, France, May 2013.

Thank you! Questions?

Contribution to the Study of Haptic Feedback for Improving the Audiovisual Experience

<u>Publications</u>

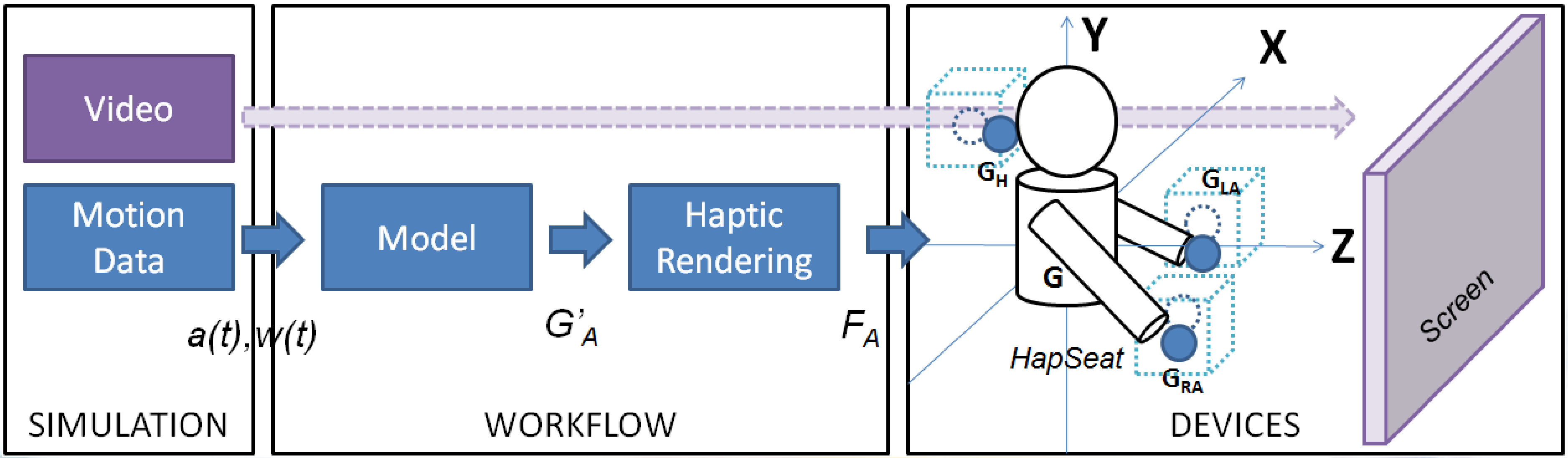
- Journals: IEEE ToH (x2), IEEE Multimedia.
- Conferences: IEEE Haptics Symposium, ACM VRST.
- Patents (x3)
- Demos: ACM SIGGRAPH ET, ACM CHI, ACM UIST.

Feedback from SIGGRAPH and CHI demos

technicolor

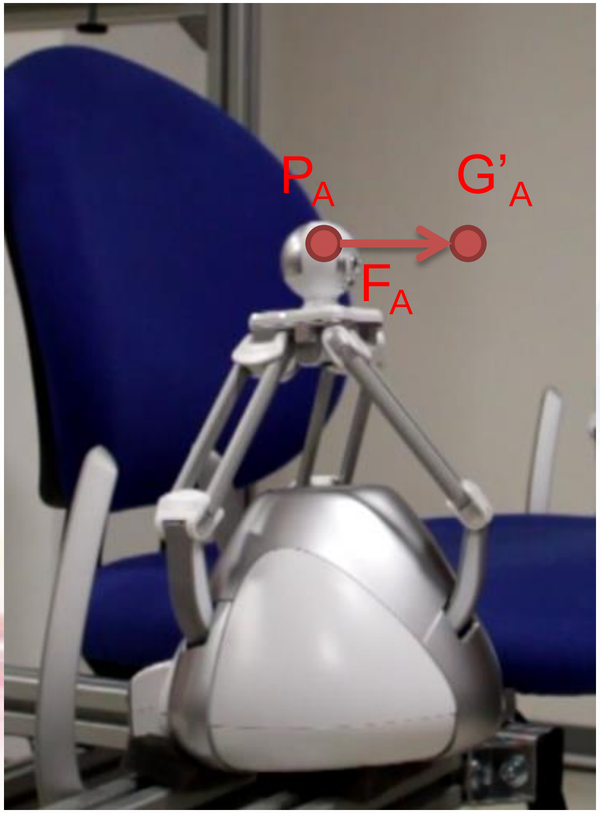
informatics mathematics
Inria

HapSeat: workflow



HapSeat: Haptic Rendering

- Output of Model = Positions
- Novint Falcons are impedance devices
  - Output = force
- Pseudo-Position control using spring-damper model

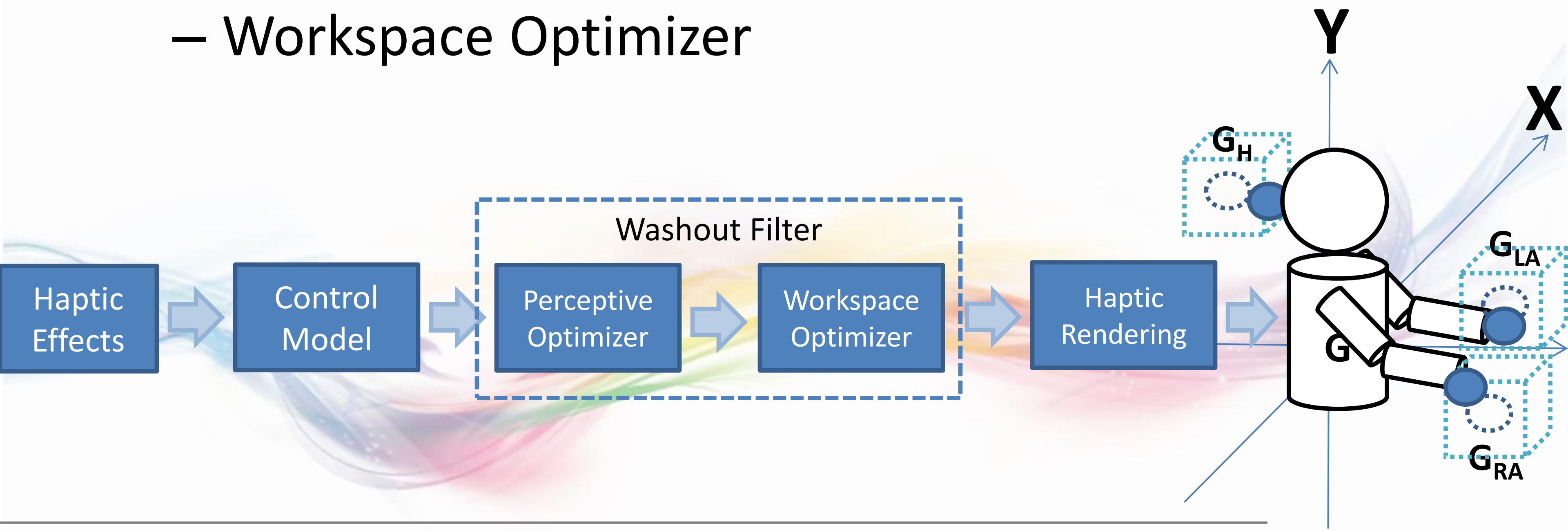


$$F_A = k(G'_A - P_A)dV_A$$

G'_A = target position
P_A = current position
k = spring constant
d = damping constant

Washout filter for Haptic Rendering

- Washout filter added to the workflow
  – Optimize positions computed by control model
- 3 main components
  – User Body Model
  – Perceptive Optimizer
  – Workspace Optimizer



User Study: Questionnaire

- Background
  - Presence: feeling to be physically situated in a virtual environment [Witmer1998]
  - Usability: how a system is to use [ISO 9241-11]
- Questions associated to factors
  - 7 questions evaluated on 5-point scale

- Presence
  - Control
  - Sensory
  - Realism
  - Distraction

- Usability
  - Efficiency
  - Effectiveness
  - Satisfaction

- HAV QoE
  - Sensory
  - Realism
  - Satisfaction
  - Comfort

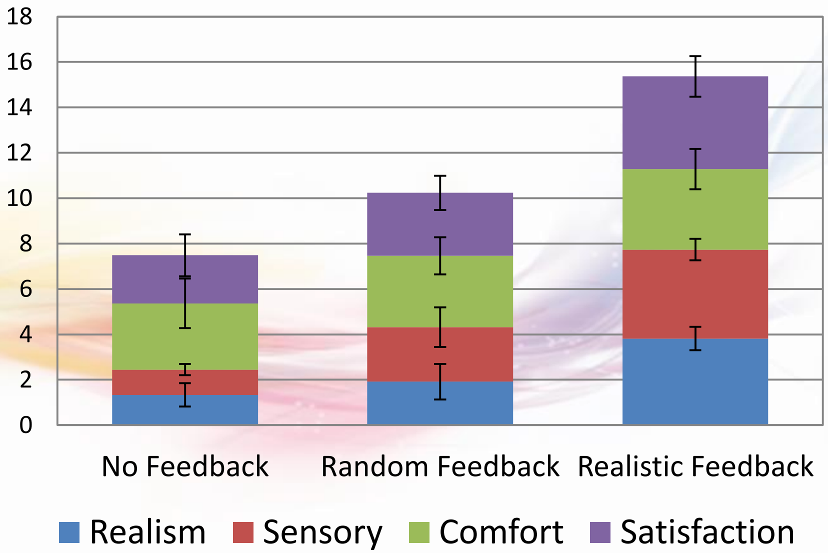
User Study: Questionnaire

- 7 questions evaluated on 5-point scale

Factor	Question
Realism	• How much did this experience seem consistent with your real-world experiences? • How strong was your feeling of self-motion?
Sensory	• How much did the haptic feedback contribute to the immersion? • Were the haptic and visual feedback synchronized together?
Comfort	• Was the system comfortable? • How distracting was the control mechanism?
Satisfaction	• How much did you enjoy using the system?

User Study

- Objective: Study of the captured motion effect
- Hypotheses
  - Motion effect increases QoE
  - Motion effect is realistic
- Experimental Plan
  - 15 participants. Age: 27.8 (SD 9.7)
  - 4 videos and 3 haptic feedback
    - None, Random, Realistic
  - Protocol: QoE Questionnaire
    - Realism, Sensory, Comfort, Satisfaction
- Results
  - QoE Real > QoE Random > QoE None
  - Realism, Sensory and Satisfaction improved by haptic feedback
  - Comfort is stable

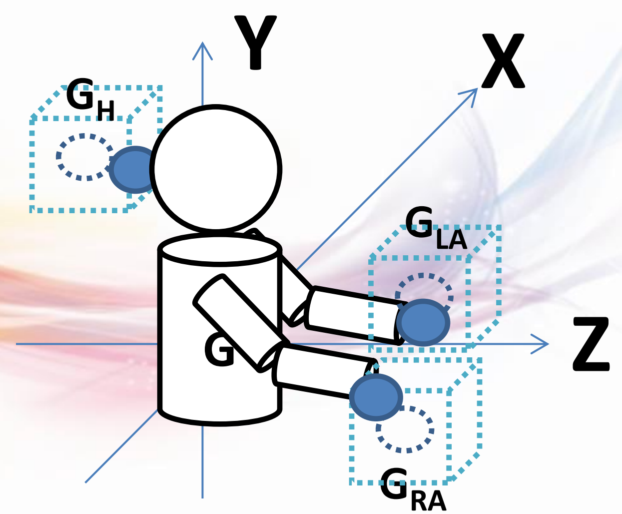


Washout Filter for Haptic Rendering

- Thresholds for kinesthetic perception
  - Angular speed of joints *[Jones 2000]*
  - 3 profiles

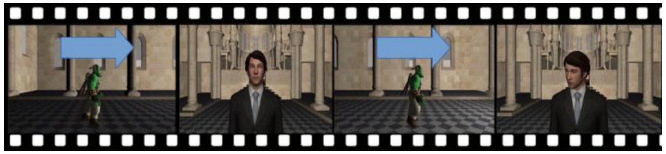
T1 *[Jones 2000]*	**Threshold ($deg.s^{-1}$)**
Neck, Shoulder, Elbow	0.5; 0.5; 1
T2	**Threshold ($deg.s^{-1}$)**
Neck; Shoulder; Elbow	1.5; 1.5; 2.5
T3	**Threshold ($deg.s^{-1}$)**
Neck; Shoulder; Elbow	3; 3; 4

- User body model
  - Used to model user's perception
  - Composed by segments and joints *[Schuenke et al. 2010]*



User Study

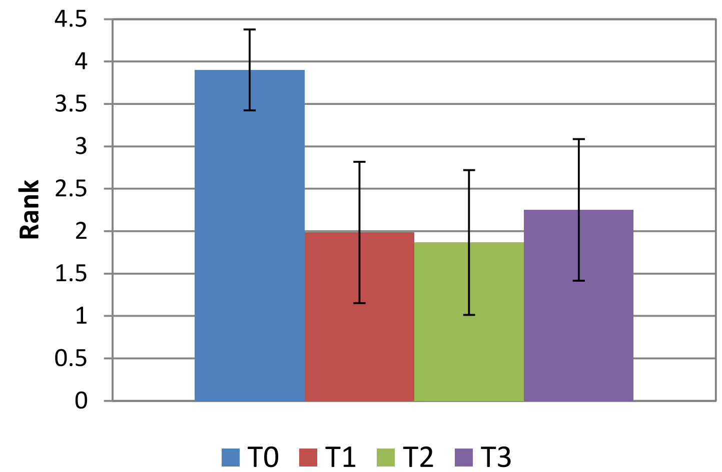
- Objective: study of the influence of the washout filter on the QoE
- Hypotheses
  - Counter-effects must be not perceived
  - Washout filter enhances QoE
- Variables
  - 3 videos: 3, 4 and 5 haptic effects
  - 4 haptic feedback:
    - T0 (no Washout Filter),
    - T1, T2 and T3 (Washout Filter with different thresholds)
- 20 Participants
  - Age 39.7 (SD 9.2)



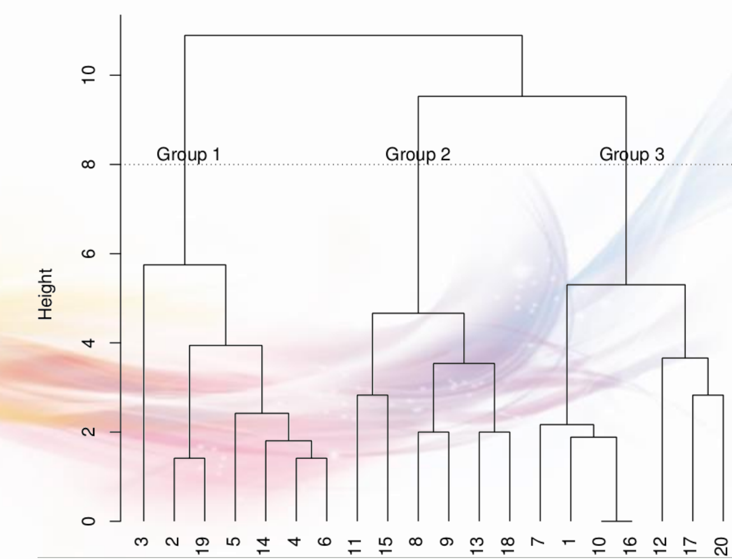
T1 *[Jones 2000]*	**Threshold (deg.s^{-1})**
Neck; Shoulder; Elbow	0.5; 0.5; 1
T2	**Threshold (deg.s^{-1})**
Neck; Shoulder; Elbow	1.5; 1.5; 2.5
T3	**Threshold (deg.s^{-1})**
Neck; Shoulder; Elbow	3; 3; 4

User Study: Results

- Washout filter improves QoE
  - T0 > T1, T2 and T3 (low rank is the best)
  - No difference observed between thresholds



- 3 groups observed during experiment
  - Found with hierarchical cluster analysis



User Study: Results

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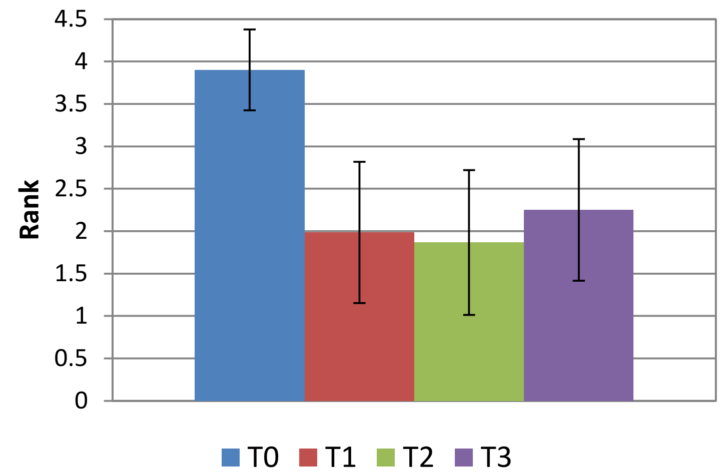
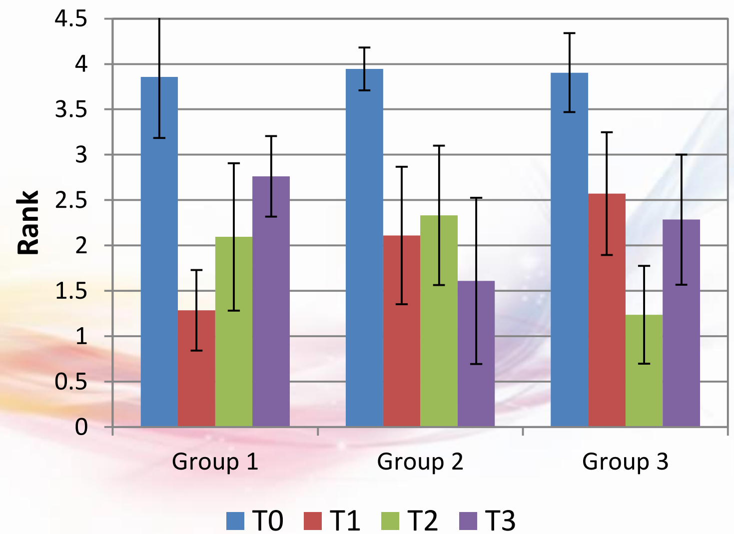


- 3 groups observed during experiment
  - Found with hierarchical cluster analysis
  - Group 1 : T1 < T2 < T3
  - Group 2 : no preference
  - Group 3 : T2 < T1 and T3



Guidelines for designing Haptic Effects

- Synchronization
  - Ex: random feedback, counter-effects
- Dynamics
  - Ex: semantic model
- AV defines context
  - Ex: semantic model
- Haptic / Audiovisuals combinations
  - Taxonomy

- **Need for user studies to identifiy more rules**
- **Need to organize these rules**