Touching distant objects is not a fiction anymore!

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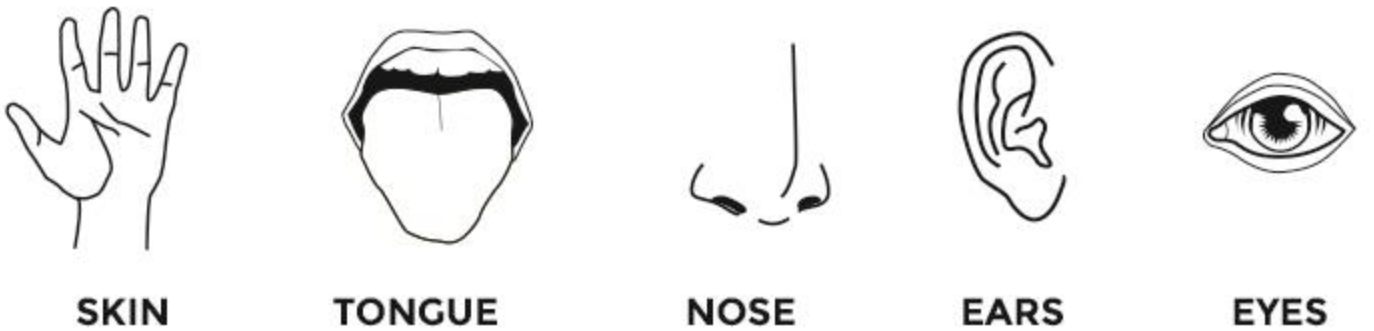
Human Senses



- Capture surroundings
- Stimulate through synthetic objects
- Eyes - animations, ears - music instruments, digital scent and taste

Courtesy: www.waysofperception.com

Touch

Can we synthesize touch? - **Yes**! Ex: mobile vibration

Image courtesy: www.audiworld.com, en.wikipedia.org, www2.pacific.edu, cornell-students.blogspot.com

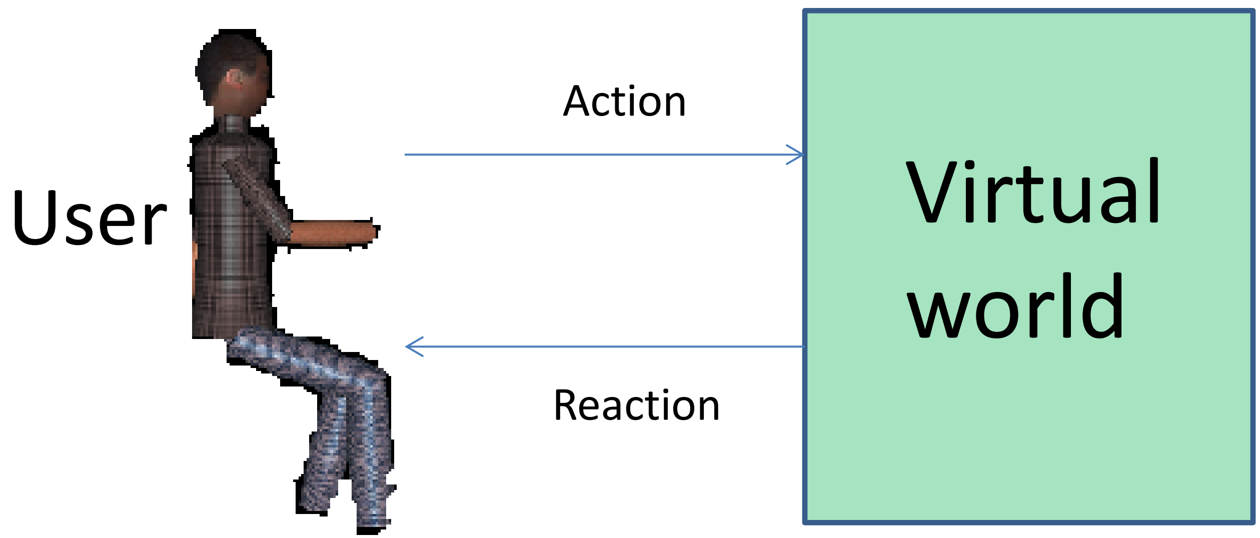
Haptics Technology

Real Touch Virtual Touch

Touch – active sensing mechanism

Contd..

- Virtual world – mesh model



- Action - position and velocity; reaction - force
- Haptic device – input/output interface

Contd..

- Three classes
  - Machine haptics: mechanical design of haptic devices
  - Computer haptics: rendering objects, communication
  - Human haptics: human perception

Haptic Devices

- Single point of contact
  - Novint Falcon

3 DoF I/O
Max force: 8 N

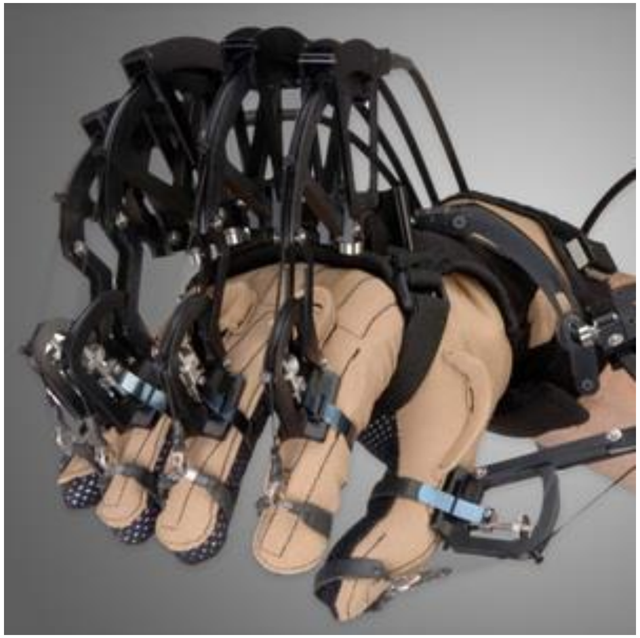
  - Phantom Omni

6 DoF I, 3 DoF O
Max force: 3 N

Image courtesy: www.giantbomb.com, www.dentsable.com

Contd..

- Multiple point of contact
  - Cybergrasp



Max force: 12 N per finger

Image courtesy: www.cyberglovesystems.com

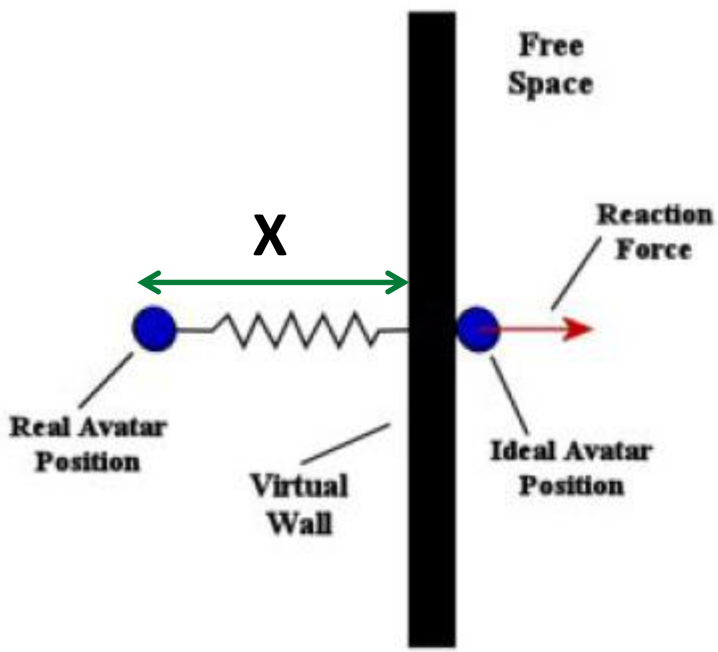
Contd…

- Kinesthetic devices: Force
  - Ex: Novint Falcon, Phantom Omni, Cybergrasp

- Tactile devices: Texture, heat
  - Ex: Cybergrasp

Reaction Force

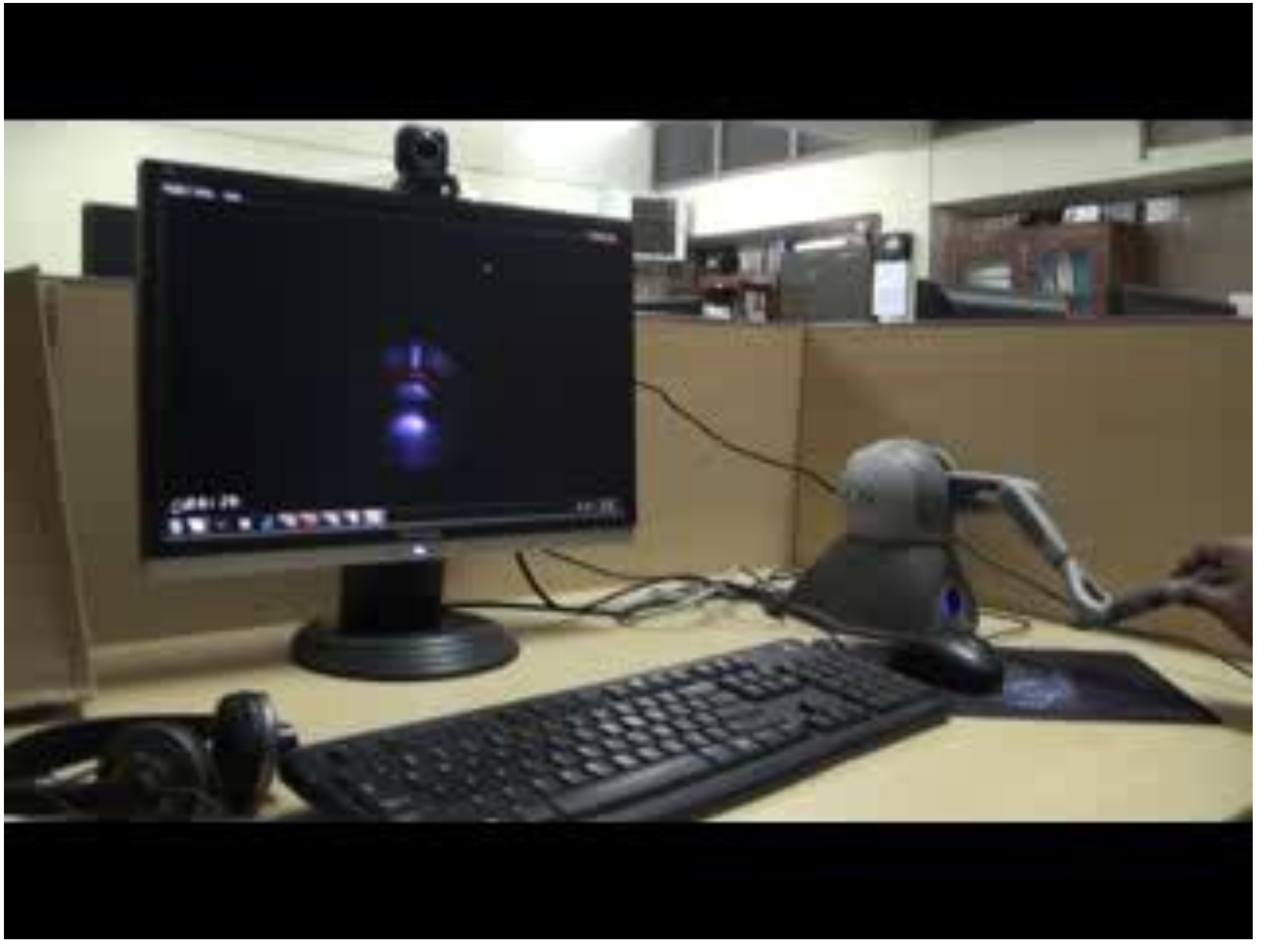
- Haptic interaction Point (HIP) or Avatar
- Reaction Force F: Hooke's law + Newton's 3rd law



$F = -m\mathbf{X}$, m - stiffness

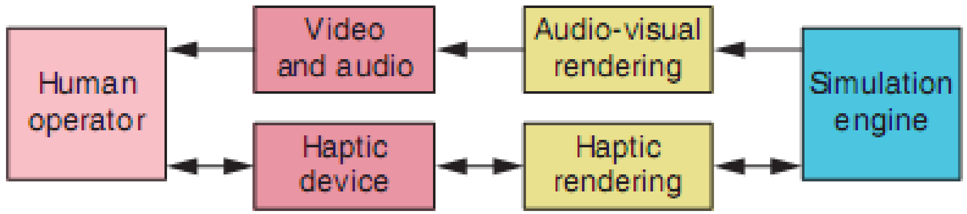
Courtesy: K Salisbury et. al

Haptic Interaction



Courtesy: Chai3D

Components of haptic system



- Software
  - Simulation engine (collision detection - response)
  - Rendering algorithms (response -> human perceivable form)
- Hardware interfaces
  - Haptic device, speaker, monitor.

Courtesy: K Salisbury et al.

Contd..

- Perception of haptic objects
  - Weight, texture, shape, size etc.
- Manipulation of haptic objects
- Higher degree of immersion
- Accurate control of task
- Applications: virtual reality gaming, touch-enabled digital museum, medical training, prosthetic organ, medical diagnostics.

Telehaptics

Telehaptics

- Remote haptic interaction
- User and object physically separated
- Perceive/manipulate remote objects
- Faithful replication of human actions
- Faithful delivery of interaction forces

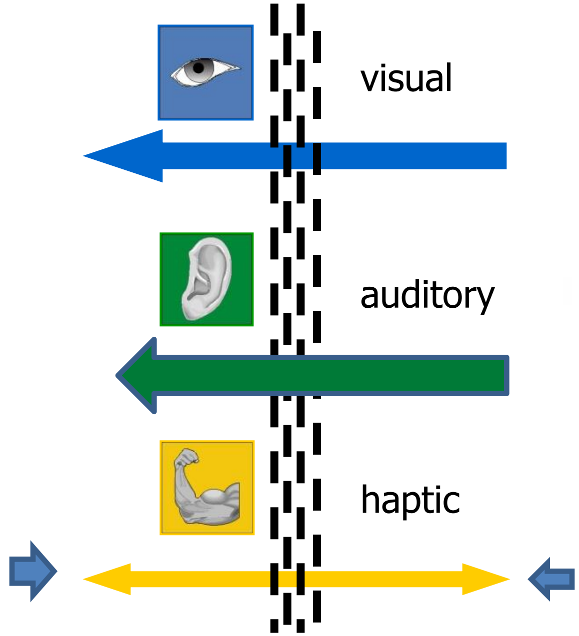
Standalone to Telehaptics

- Remote object
- Communication network
- Actions to remote end
- Reactions from remote end
- Audio-visual feedback from remote end
- Robotic device for physical interaction

Telehaptics

A

User with
Human-System Inferface



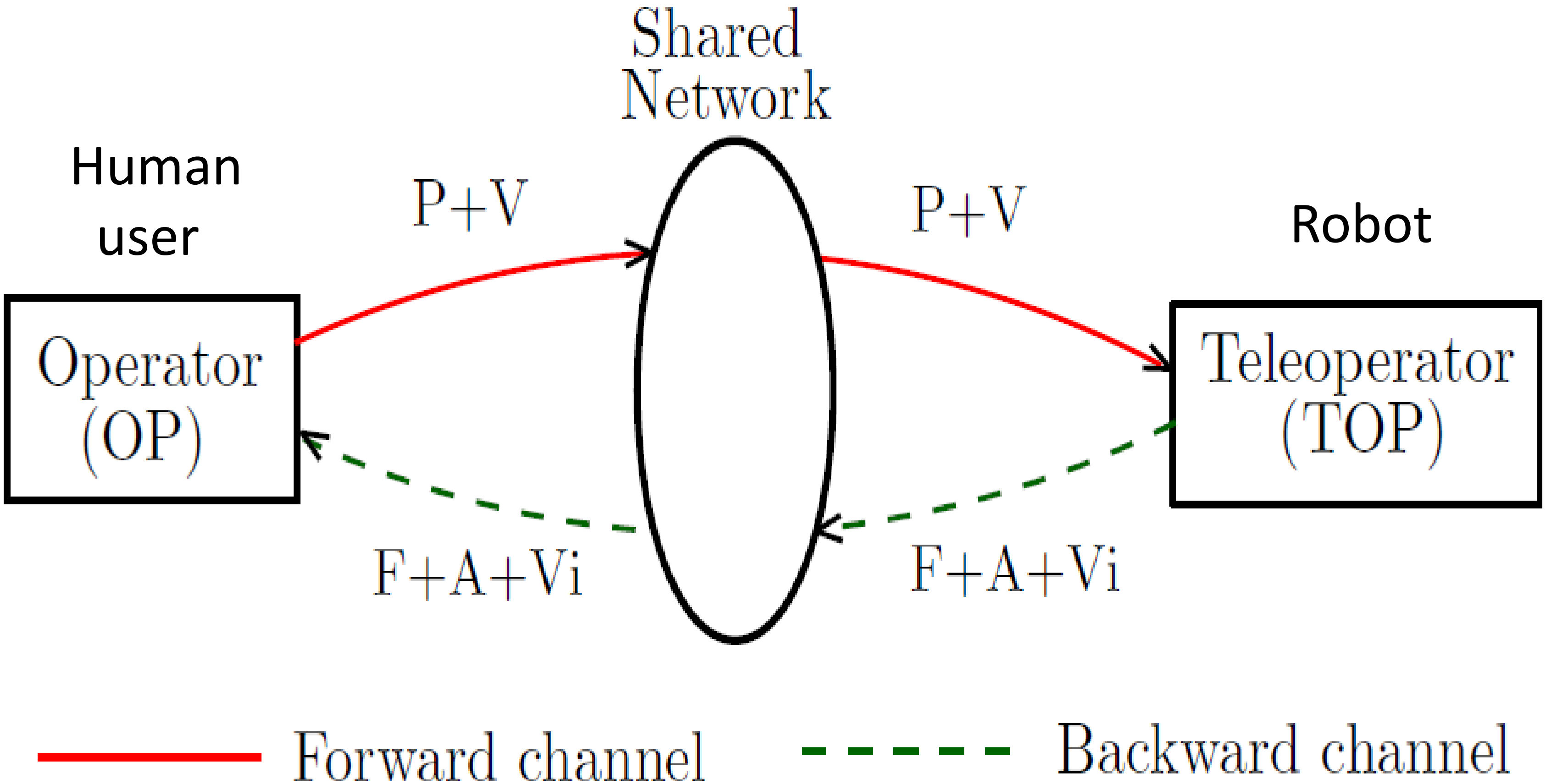
Communication of Multiple modalities

B

Robot in
remote environment

Courtesy: Dr. Julius Kammerl, TUM, Munich

Contd..



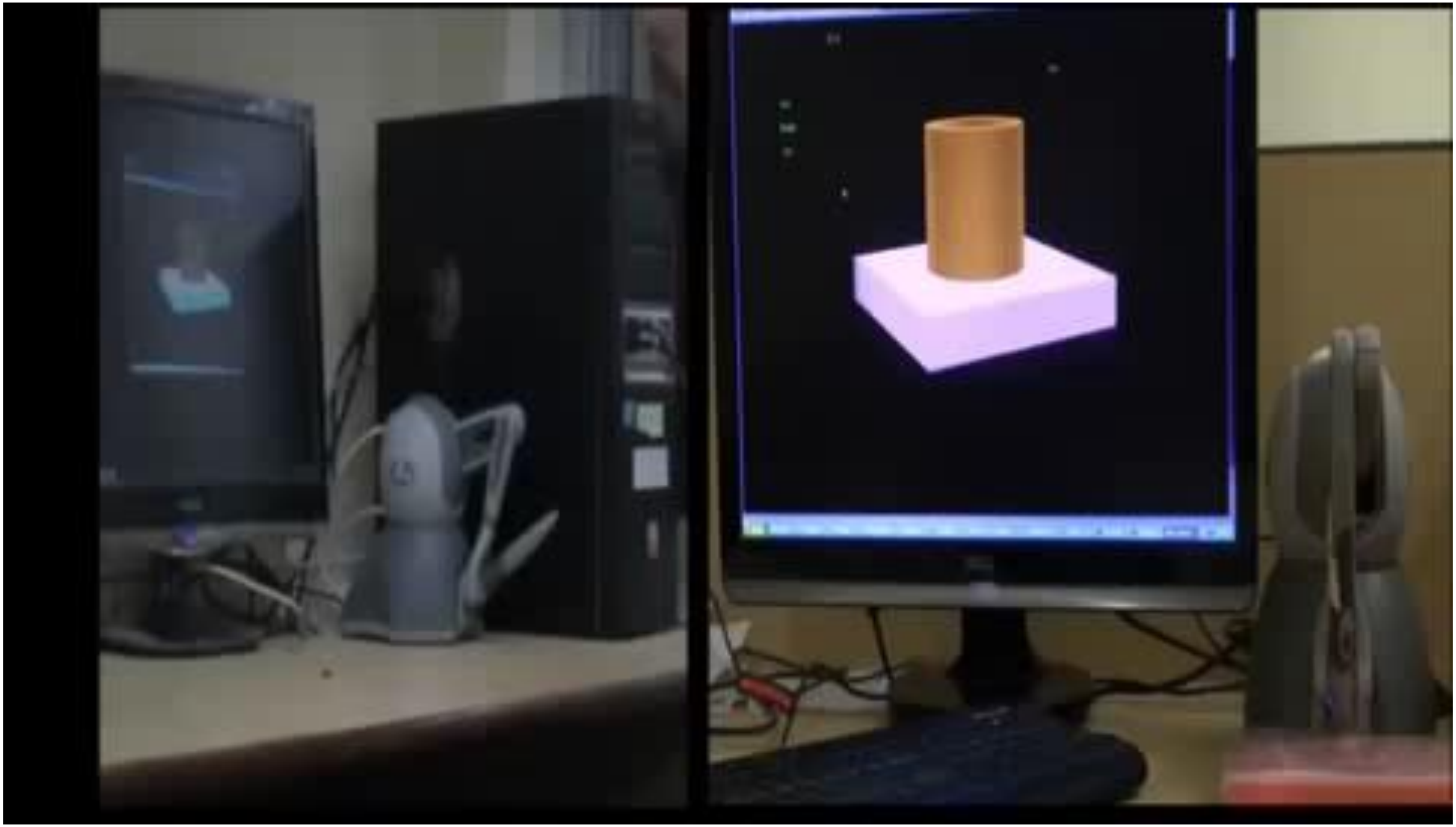
P: position, V: velocity, F: force, A: audio, Vi: video

Courtesy: V. Gokhale et al., 2016

Applications

- Surgical training
- Tele-manipulation
  - Space, hazardous environments
- Tele-medicine
  - Telesurgery, tele-touch therapy
- Haptic-enabled teleconferencing
- Collaborative tasks
- Networked games

Telehaptics Video Demo



Telehaptic Environment

- Media
  - Heterogeneous
- Data flow
  - Bi-directional
  - Asymmetric traffic
- Haptic global control loop
  - Update rate: 1 kHz
- UDP
- Human (OP) involved

Quality of Service (QoS)

- Promise by underlying resources

Media	Delay (ms)	Jitter (ms)
Haptic	30	10
Audio	150	30
Video	400	30

- Haptic – most sensitive media
- Violation causes perceptual degradation

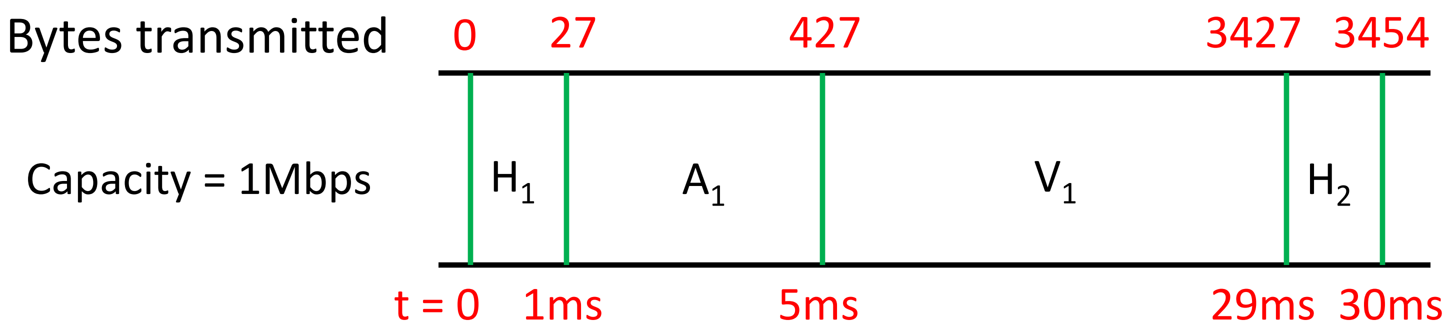
Effects of Haptic QoS Violation

- Haptic delay > 60 ms
  - Perceptual degradation of object
    - Example: hard object perceived as soft
  - Instability in control loop
- Haptic jitter > 10 ms
  - Object of variable mass

Telehaptic Challenges and Proposed Solutions

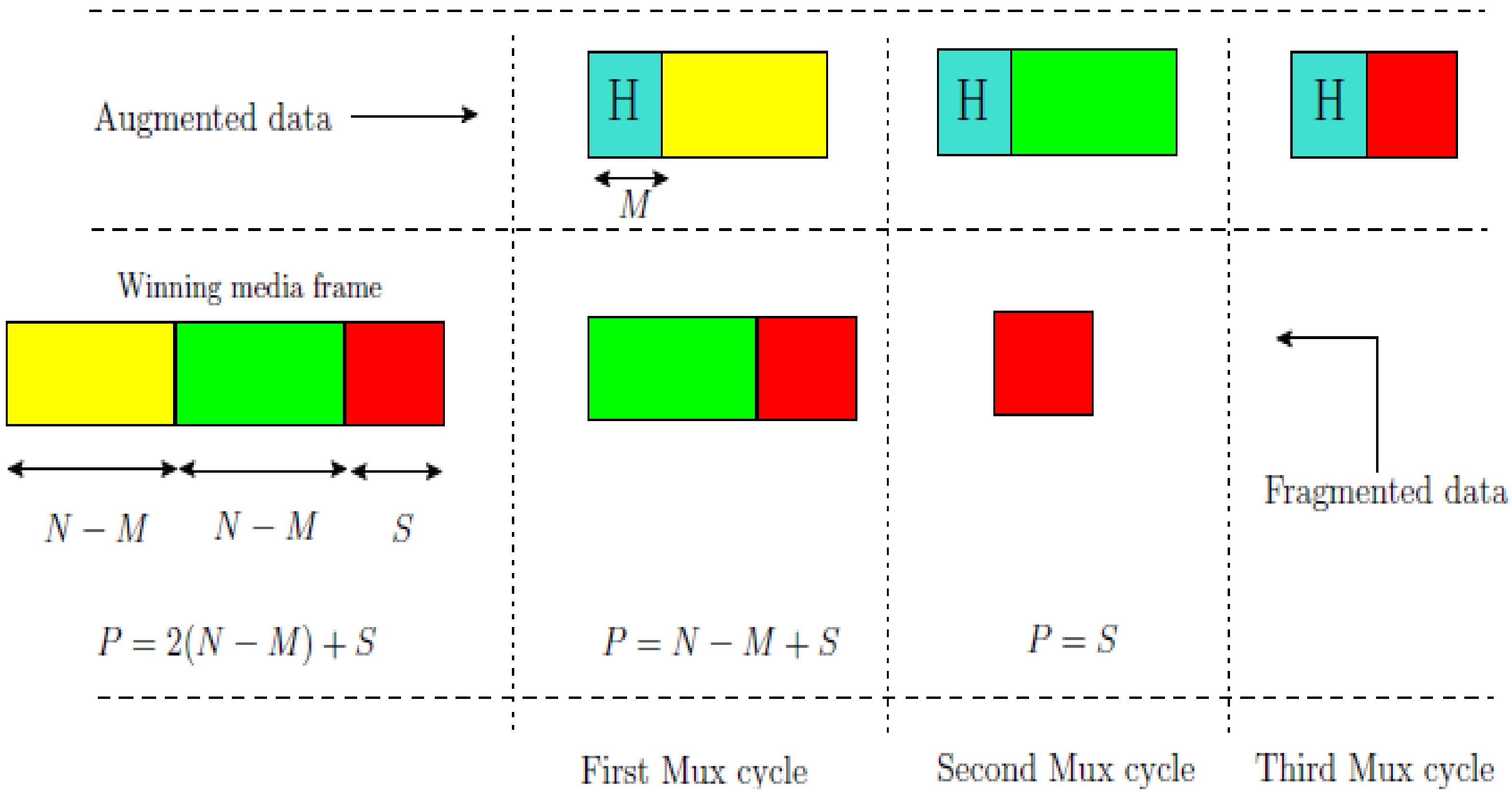
Transmission scheduling

- Round-robin (Cizmeci et al., 2014)



- Larges audio/video frames - fragmentation
- QoS-wise priority
- Packetization
  - Separate packets for each fragment: high overhead
  - Merge different media types - augmentation
  - 1 packet per milli-second

Backward Channel Scheduling



Backward channel traffic – 1.1 Mbps!

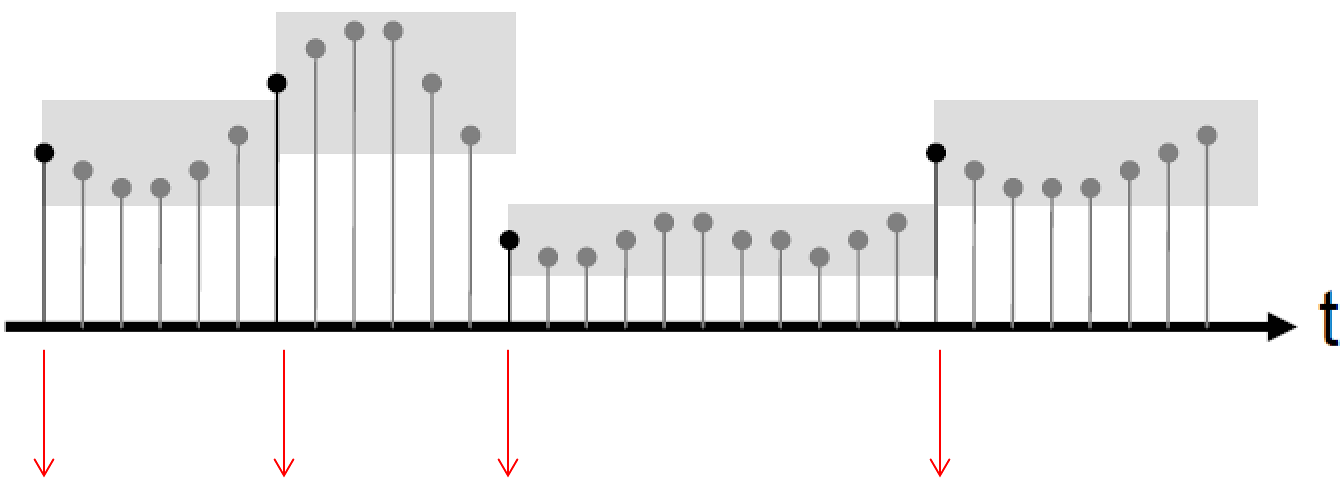
V. Gokhale et al., 2015

Haptic compression

- Reduce telehaptic source rate
- DPCM, DCT - induce delay
- *Being human* - tolerance to certain level of distortion
- Adaptive sampling
  - Subsampling based on perceptual significance
  - Choose ***N*** samples/sec out of 1000
  - Example: Weber's law, level crossings
  - Backward channel
  - Lossy, yet perceptually similar

Contd..

- Weber's law of perception
  - Small relative force changes are unnoticeable
  - $$\left| \frac{X(t) - X_{n-1}}{X_{n-1}} \right| \geq \delta$$ (Hinterseer et al., 2008)



90% reduction!

Transmit

Contd..

- Visual-haptic multiplexing (Cizmeci et al., 2014)
- Adaptive sampling
- Multiplexing video and haptic data
- Buffered scheduling
- Zero haptic jitter
- Network-oblivious

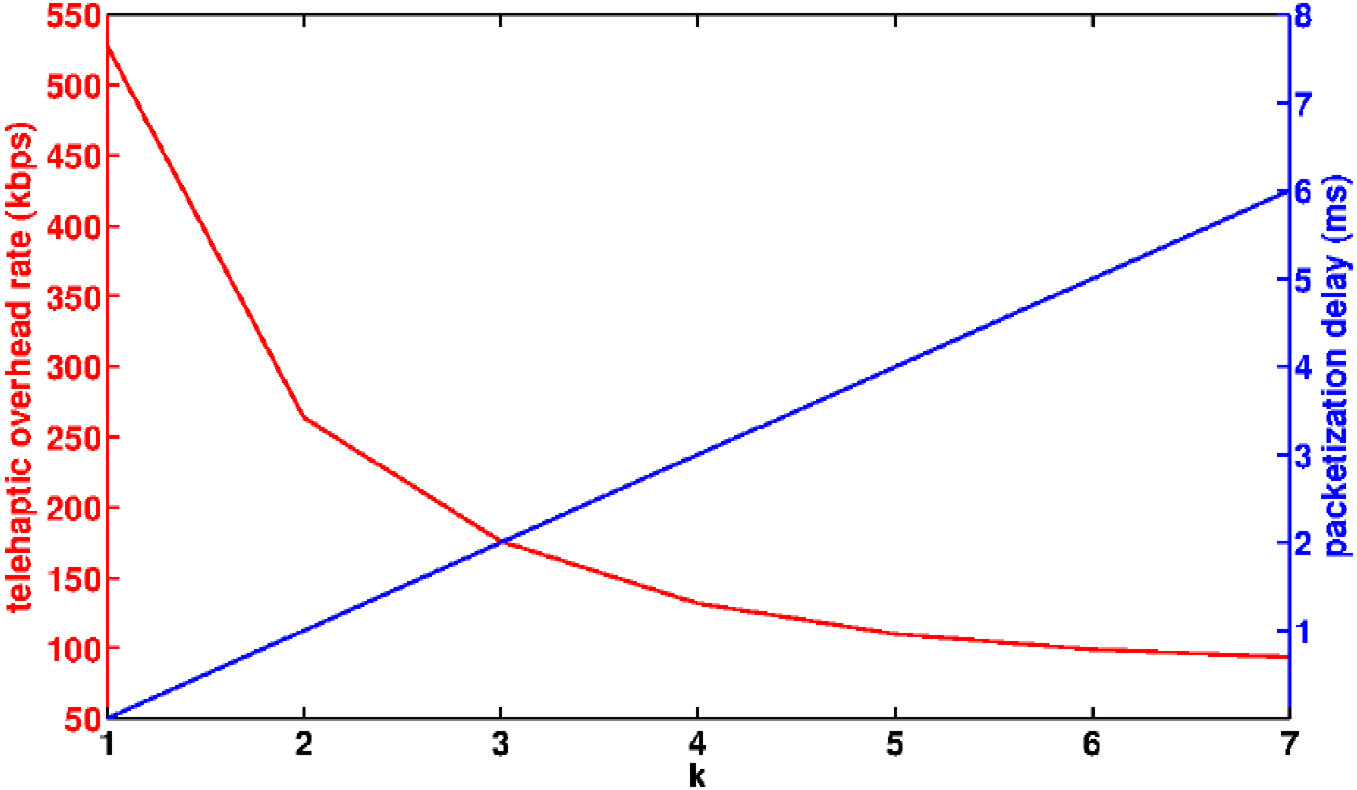
Lossless Compression

- Forward channel
- Robotic device has no deadband
- Payload: 192 kbps, **header: 528 kbps (74%)**
- Curtail header
- Bunch multiple haptic samples
  - Ex: bunching 2 samples halves header rate

Contd..

- Packetization interval (Fujimoto et al., 2005)
  - Bunched 8 samples per packet (call it ***k***)
  - Huge overhead reduction
  - Suboptimal
  - No rationale for no. of bunched samples
  - Network-oblivious

Contd..



V. Gokhale et al., 2016

Contd..

- Dynamic packetization (V. Gokhale et al., 2016)
  - Estimate network condition
  - End-to-end delay based, not RTT
  - Dynamic selection of ***k***
  - ***k*** <= 4
  - Follows additive-increase-multiplicative-decrease
  - Jitter upper bound << 10 ms
  - Coarse quantization of source rate
  - Over-friendly to TCP

Thank You

References

- K. Salisbury, F. Barbagli, F. Conti, ‘Haptic Rendering: Introductory Concepts’.
- V. Gokhale, J. Nair, S. Chaudhuri, ‘Traffic Adaptive Telehaptic Communication over Shared Networks’, submitted to ACMTOMM.
- V. Gokhale, S. Chaudhuri, O. Dabeer, ‘HoIP: A Point-to-Point Haptic Data Communication Protocol and Its Evaluation’, IEEE National Conference on Communications 2015.
- P. Hinterseer, S. Hirche, S. Chaudhuri, E. Steinbach, M. Buss, ‘Perception-based Data Reduction and Transmission of Haptic Data in Telepresence and Teleaction Systems’, IEEE Transactions on Signal Processing, 2008.
- M. Fujimoto, Y. Ishibashi, ‘Packetization interval of haptic media in networked virtual environments’, ACM SIGCOMM, 2005
- B. Cizmeci, R. Chaudhari, X. Xu, N. Alt, E. Steinbach, ‘A Visual-Haptic Multiplexing Scheme for Teleoperation Over Constant-Bitrate Communication Links’, Proceedings of Eurohaptics, 2014