Toward Real-time Volume-based Haptic Communication with Realistic Sensation

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Outline

- Background, Objectives
- Developed system
- Tetrahedral Adaptive Volumetric Mesh
- Deformation Simulation
- Haptic Communication
- Experimental setup and Results
- Conclusions and Future works

Background and Objective

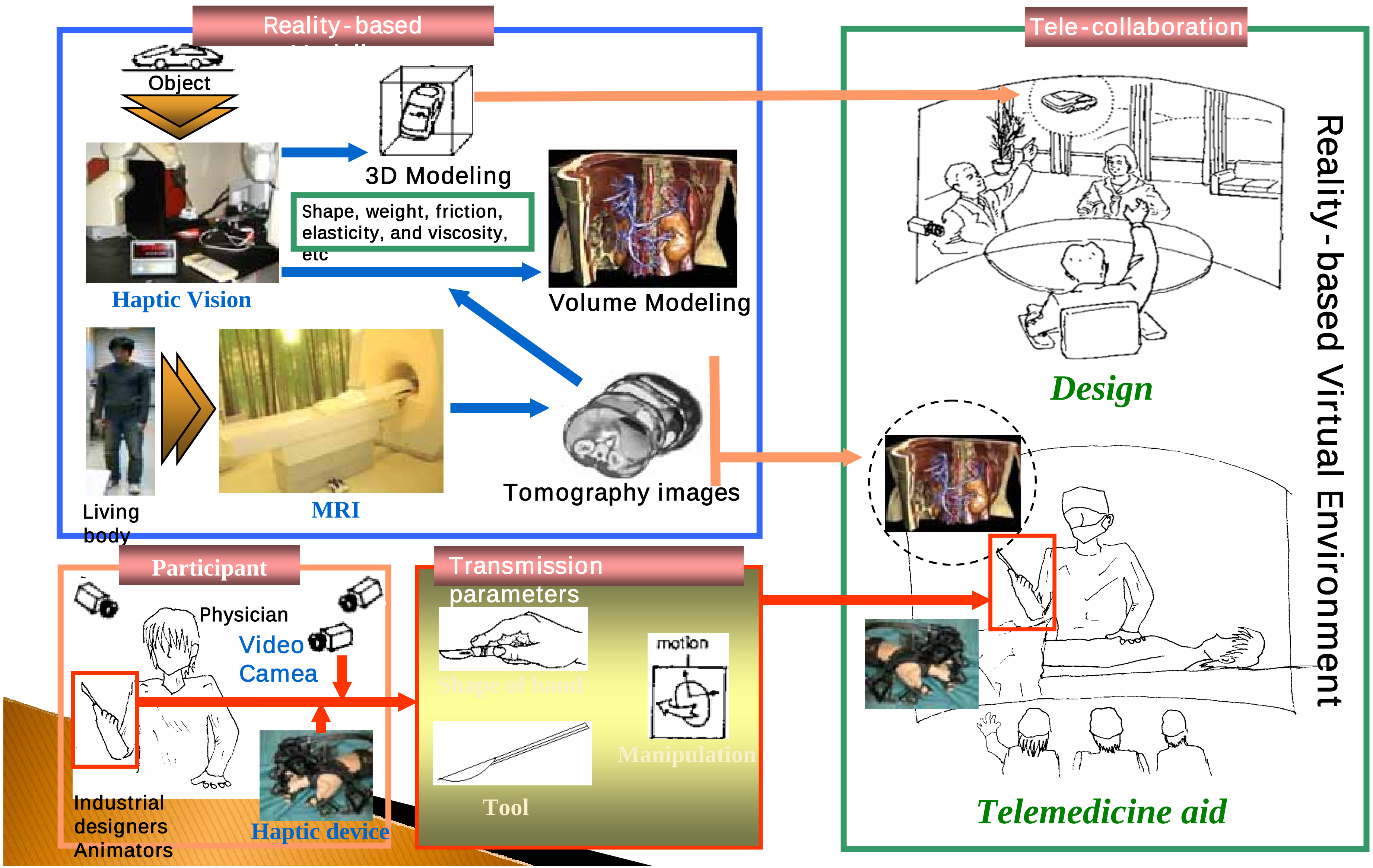
Background and Objective

- Teleconferencing System(ATR, Japan), Tele-Immersion Project(UC Berkeley, U.S.A.)
  - present an object surface as 3D surface graphics

- However, previous works did not achieve realistic sensations for the representational model or achieve real-time performance, and haptics was not well defined.

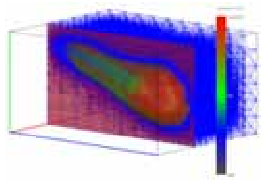
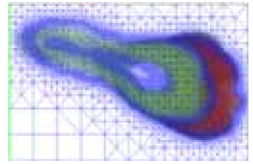
Need for development Volume-based Realistic Communication

Concept of Volume-based Realistic Communication

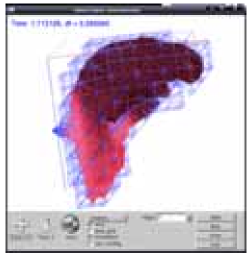


How can we share haptics between distant locations at the same time ?

- 1)represent virtual object as adaptive volume model

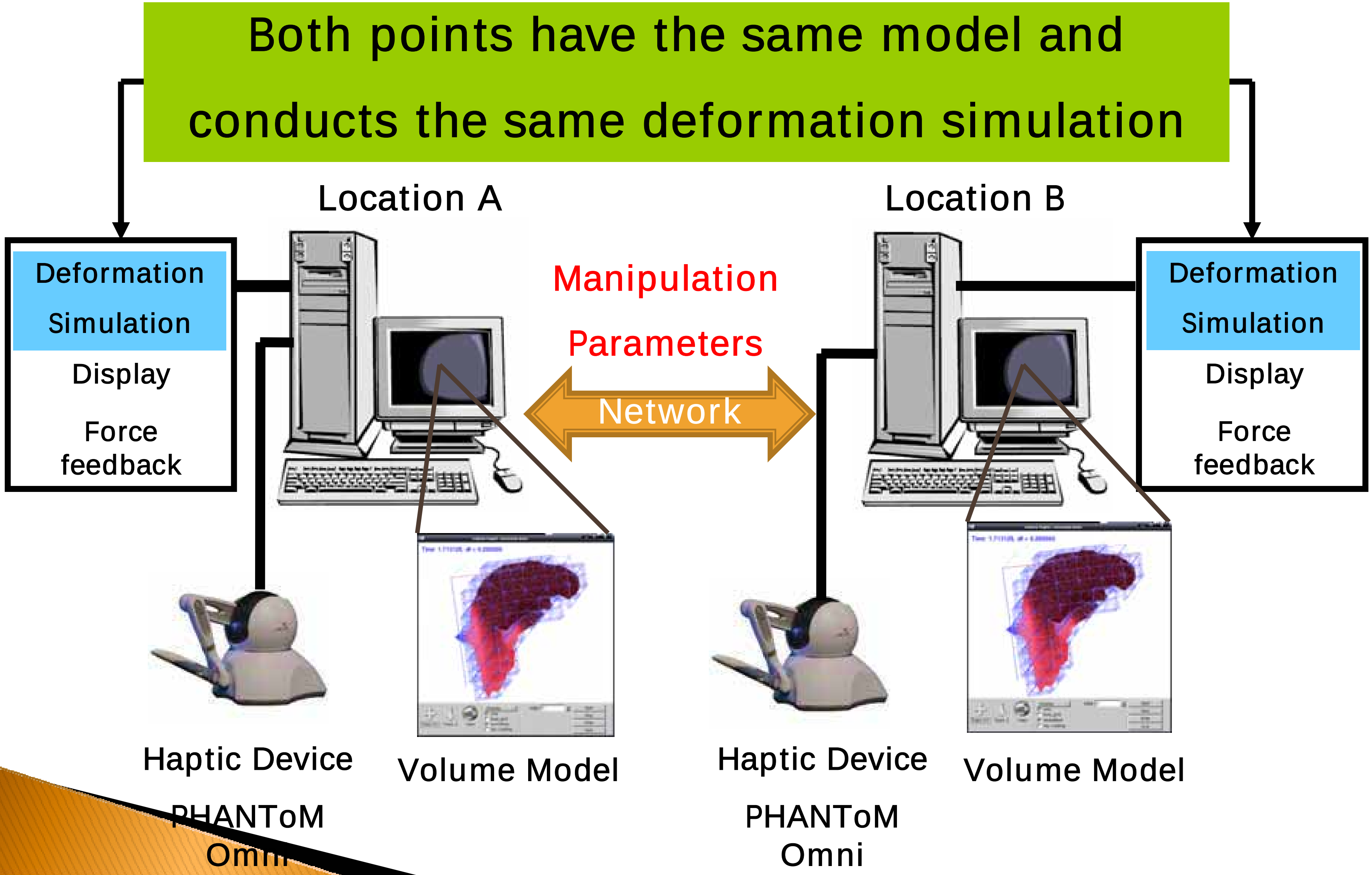
- 2)communicate minimum manipulation parameters
- 3)simulate interaction to soft objects, deformation and reaction force in rapidly and accurately
- 4)display visual and haptic information using volume graphics and haptic device




Real-time (vision 30Hz, haptics 1000Hz)
accuracy & rapidly deformation simulation

Developed System

System Overview



Tetrahedral adaptive volumetric mesh

Simulation Model

- Mass-Spring Model
  - Most General Method, Easy to implement
  - Large numbers of springs and mass points for highly accurate simulations
- Finite Element Model
  - Highly accurate
  - Calculation costs are extremely high

Accuracy ⟷ Calculation Cost

Trade off

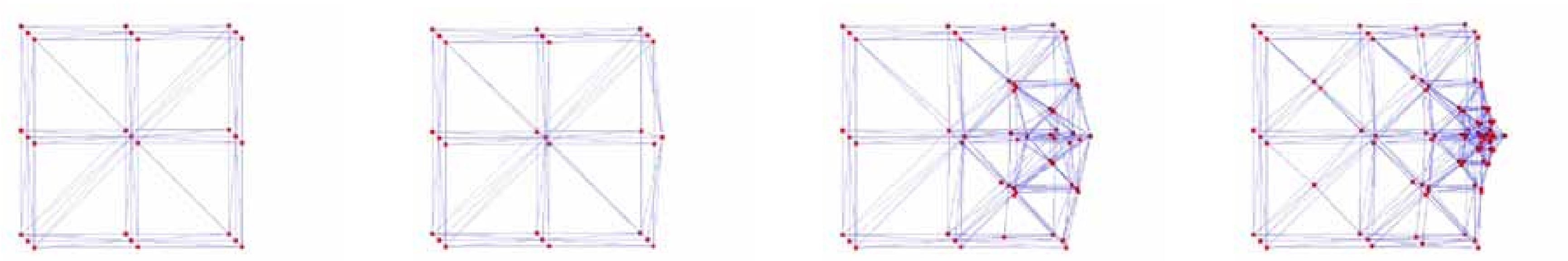
⇒ Multi-resolution model

Online remesh

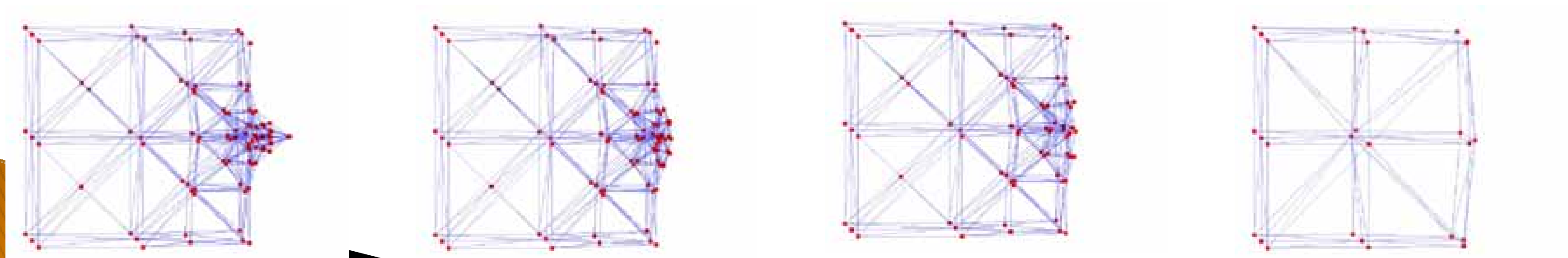
According to online deformation:

Local (contact/deform) modification (insert and delete nodes) while guaranteeing accurate **&** conforming mesh

⇒multi-resolution model with refinement



Initial state



Maximum defomation

Difficulties of online remeshing of volume model

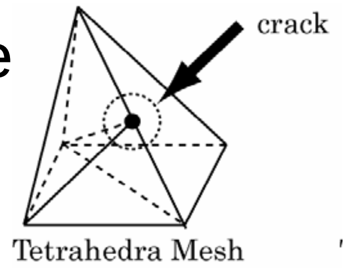
- issue1)Mesh Quality：

  ⇒Loss qualities (aspect ratio, radius-edge ratio) while subdividing initial meshes

- issue2)Conform mesh：

  ⇒need much time to maintain mesh structure

  ⇒difficult in real time

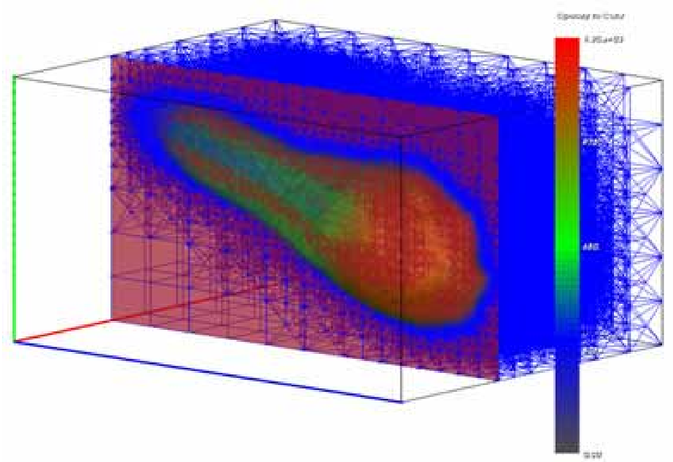


- issue3) irreversible refinement process：

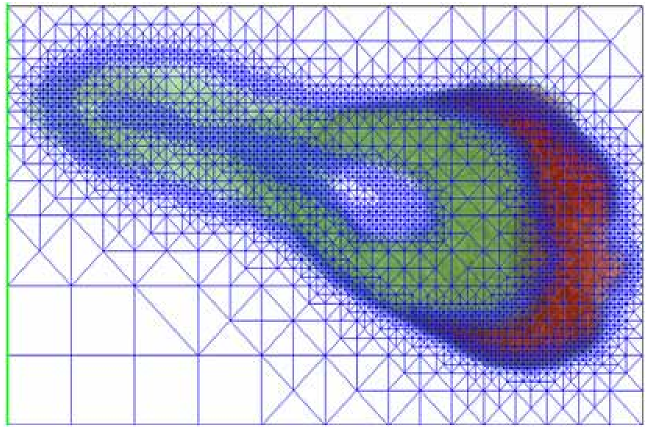
  ⇒can not reconstruct original mesh after sometimes subdivision

Tetrahedral Adaptive Volumetric Mesh

- An algorithm recursively bisects tetrahedral elements
- High-quality multi resolution mesh



Tetrahedral adaptive mesh

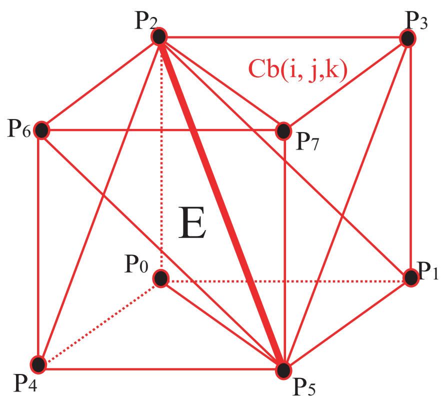


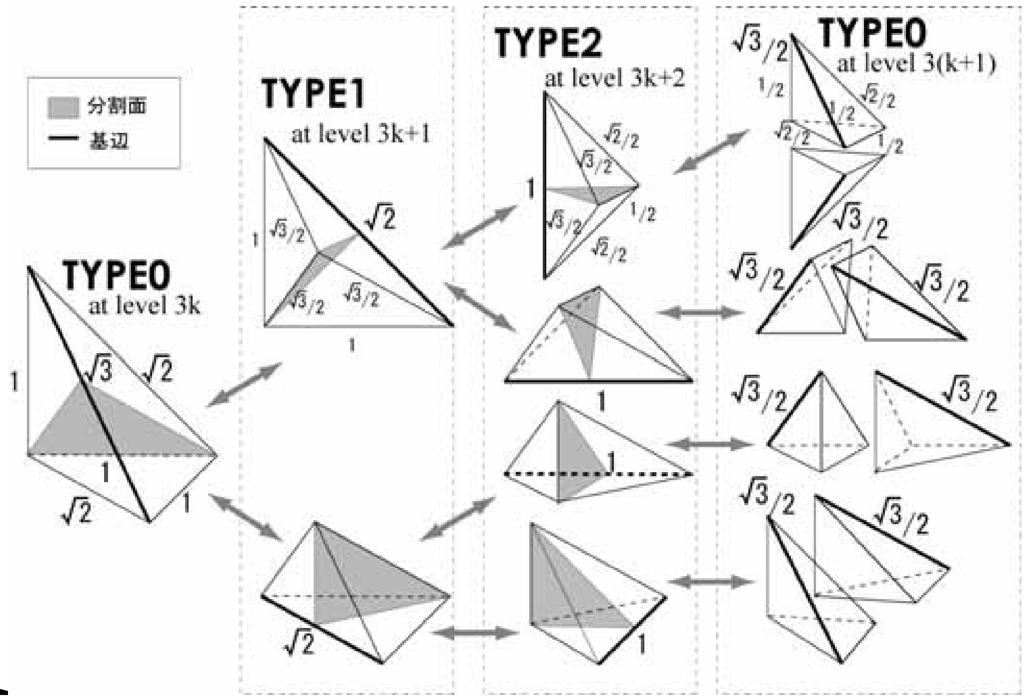
Cross-sectional view

H. T. Tanaka et al., "Accuracy-based sampling and reconstruction with adaptive grid for parallel hierarchical tetrahedrization", *Proc. of the 2003 Eurographics/IEEE TVCG Workshop on Volume graphics*, 2003.

Recursive tetrahedra subdivision

- Calculation costs are low
- Subdivision process in O(log n)
- Recursive binary subdivision
  - ⇒Three type of a tetrahedron





Mesh quality of recursive binary subdivision: "Well-Shaped " criterion

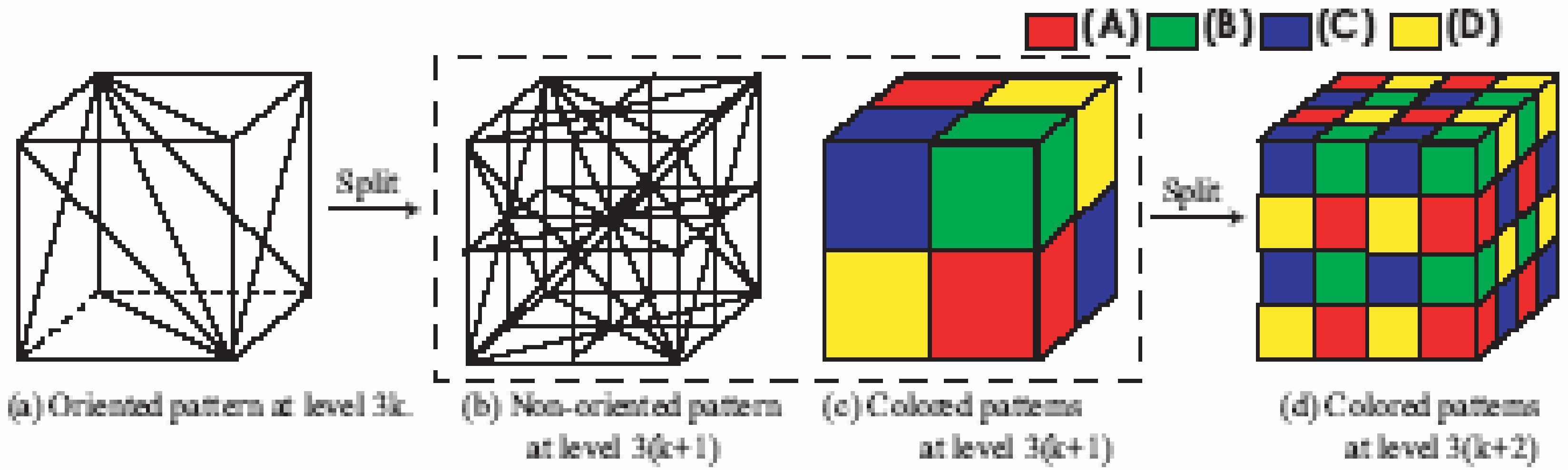
Mesh quality of recursive binary subdivision

ratio	regular	$TYPE0$	$TYPE1$	$TYPE2$
Aspect	1.0	0.72	0.64	0.70
Radius-Edge	0.61	0.87	0.87	1.11

∗Radius-Edge ratio by Delaunay subdivision: 2 or $\sqrt{2}$

Better "Well-Shaped" than Delaunay subdivision

Mesh quality of neighbor tetrahedra



Isotropy is said to hold for the entire tetrahedron set within the neighboring region of eight cubes, for each cube at any splitting level.

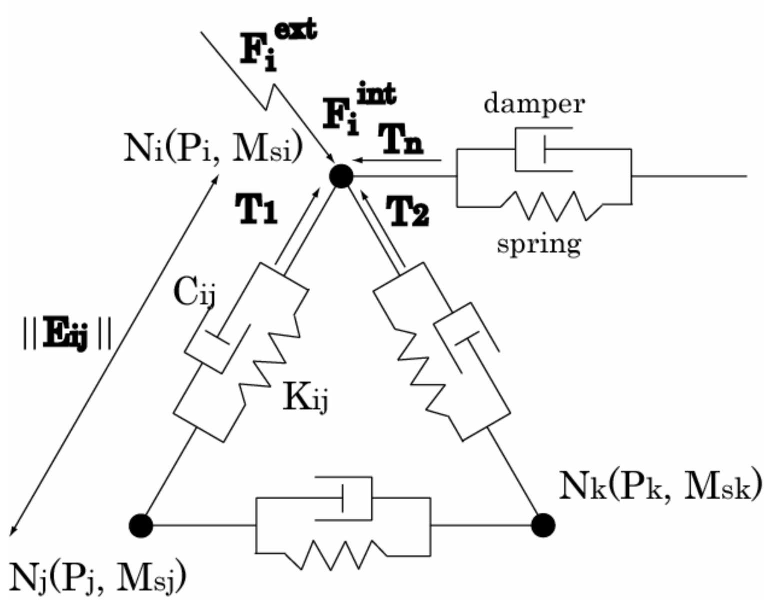
Deformation simulation

Deformation Simulation

Coordinates P_i and a mass point having mass M_i are assigned to each node N_i

$$\mathbf{F_i} = M_i \mathbf{a_i} = M_i \ddot{\mathbf{P}}_\mathbf{i}$$

Using the mass and the resultant force F_i acting on each mass point, the acceleration a_i, velocity v_i, and position P_i of the mass point after a movement can be calculated by solving the differential equation



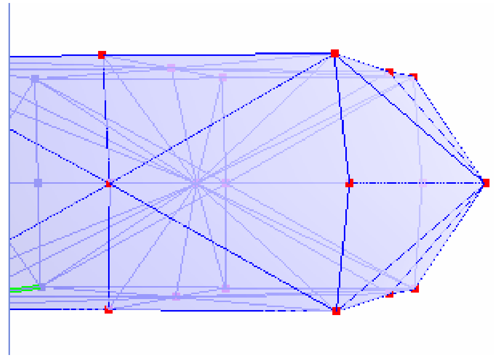
Online remesh for tetrahedral adaptive volume mesh

- In the assessment of binary splitting or merging, we use the modulus of elasticity of the edges as the associated mass point moves, to evaluate the magnitude of deformation
- The modulus of elasticity **σ**

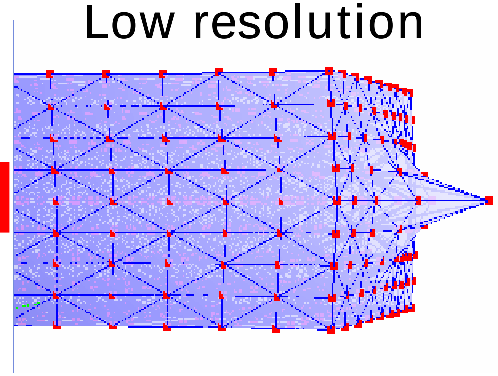
$$\sigma = \frac{|L_c - L_{init}|}{L_{init}}$$

L_{init}: Initial length of an edge
L_c: Current length of that edge

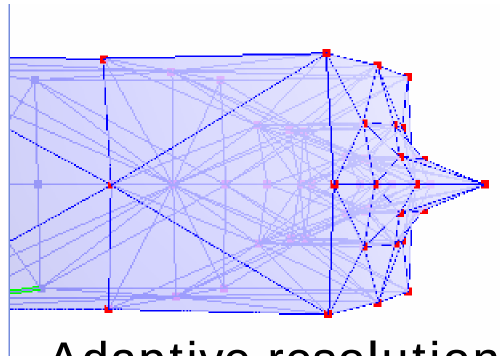
Computational time



Low resolution



High resolution



Adaptive resolution

Haptic Communication

Haptic Communication Software

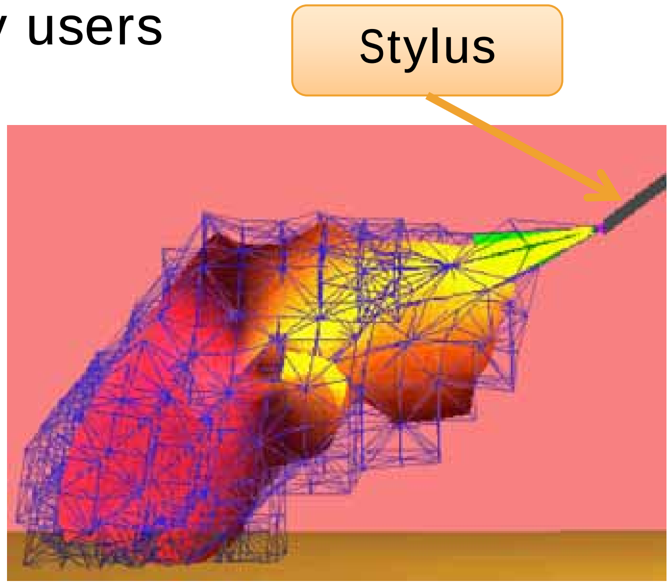
Haptic Communication Toolkit 3D Incorporated

- is a developer's kit for communication control and also a network library that is developed for communication between two or more haptic devices
- can only transmit to 256[byte] to achieve the haptic rate(more than 1000[Hz])
- use TCP/IP as communication protocol

Send/Receive Packets

- 3D position of a tip of the stylus in virtual space (8[byte]×3=24[byte])
- Tetrahedron ID held by users (8[byte])
- 3D pose of the stylus (8[byte]×3=24[byte])
- Node ID manipulated by users (8[byte])
- 3D position of node manipulated by users (8[byte]×3=24[byte])

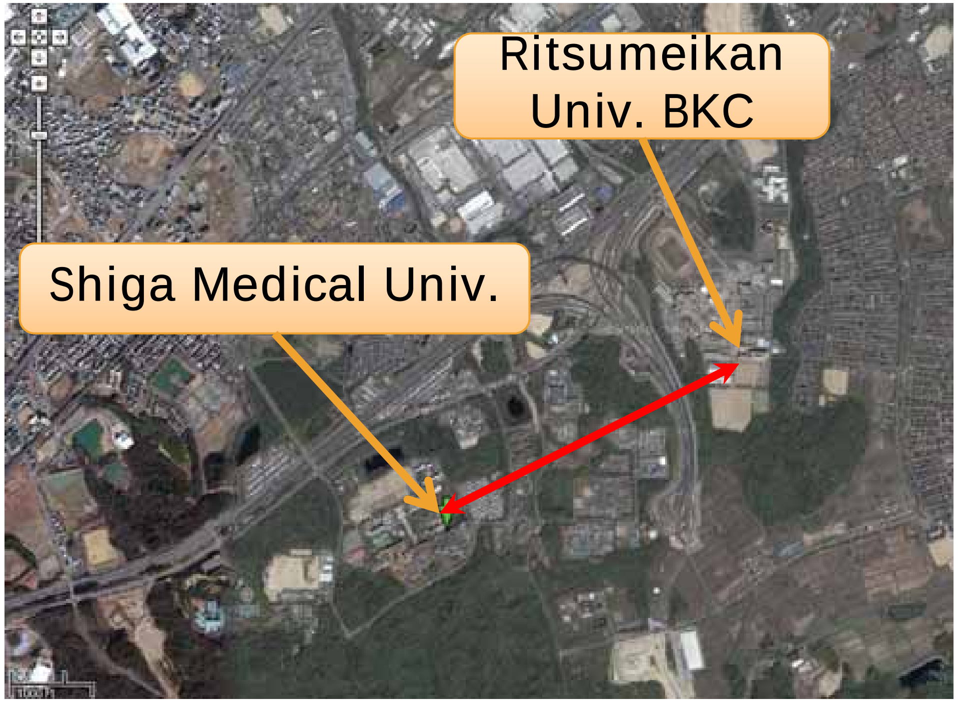
88[byte]<256[byte]



Experimental setup and results

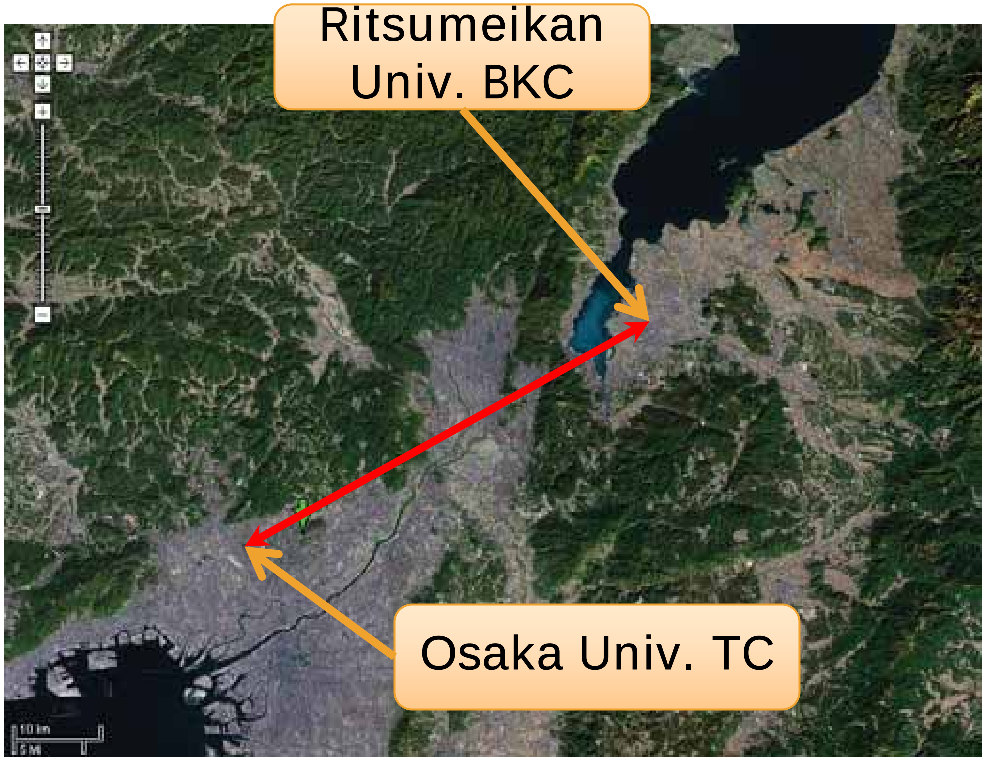
Experimental Condition 1

- The distance between server(Ritsumeikan Univ. Biwako Kusatsu Campus(BKC)) and client(Shiga Medical Univ.) on a straight line is about 2 kilometers

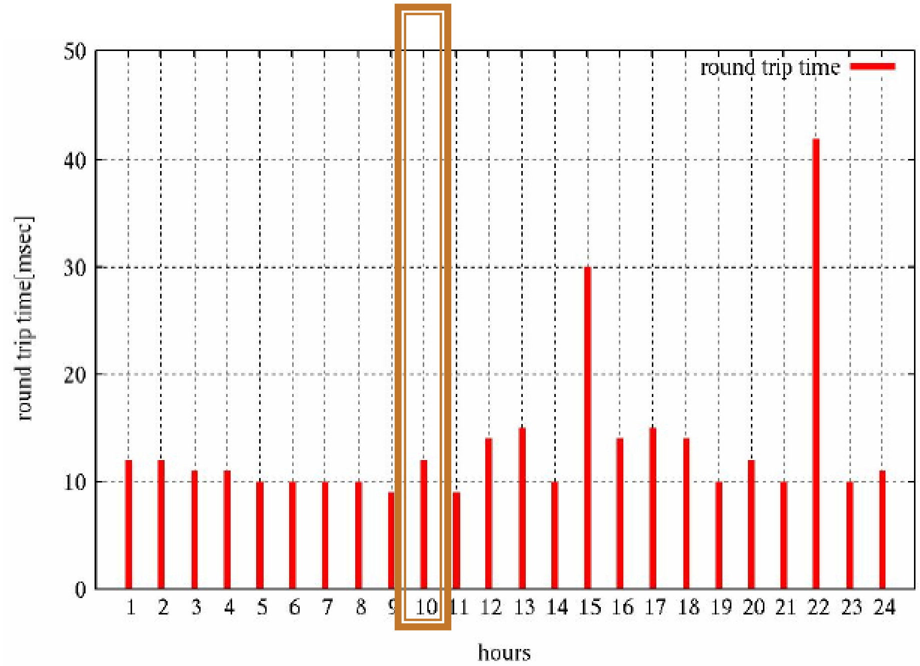


Experimental Condition 2

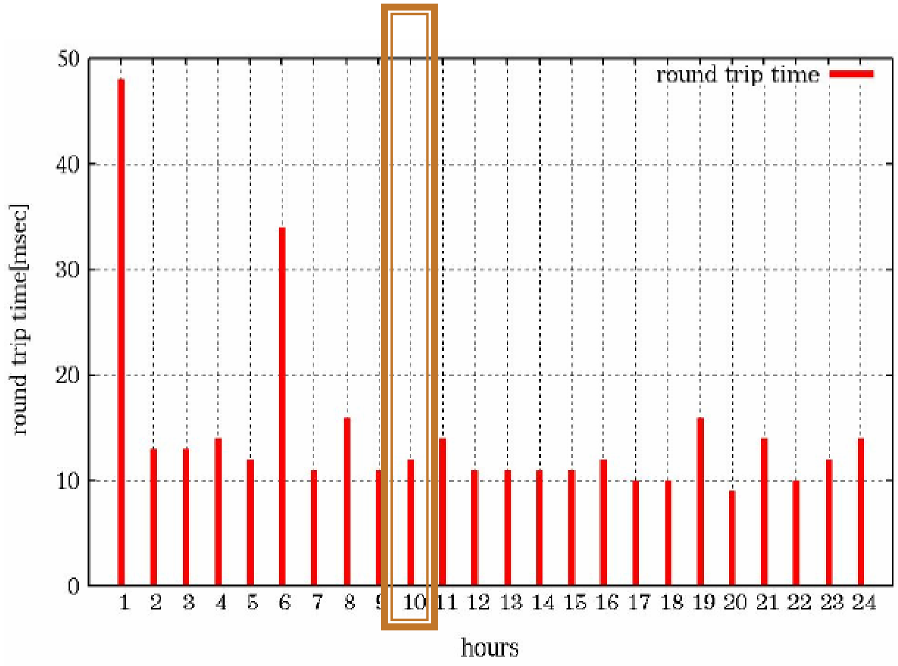
- The distance between server(Ritsumeikan Univ. BKC) and client(Osaka Univ. Toyonaka Campus(TC) on a straight line is about 52 kilometers



Network Traffic



Ritsumeikan Univ. BKC
-Shiga Medical Univ.

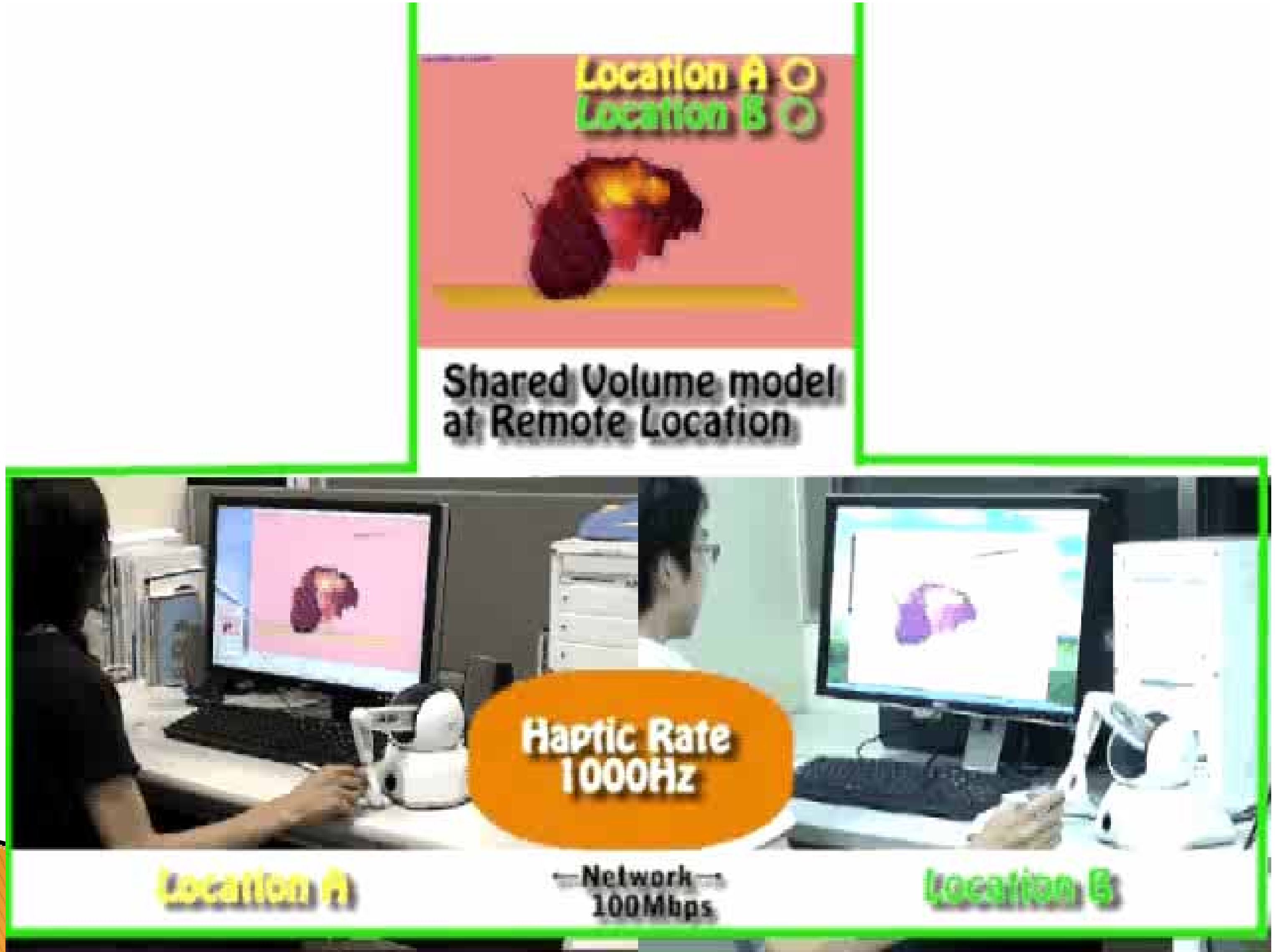


Ritsumeikan Univ. BKC
-Osaka Univ. TC

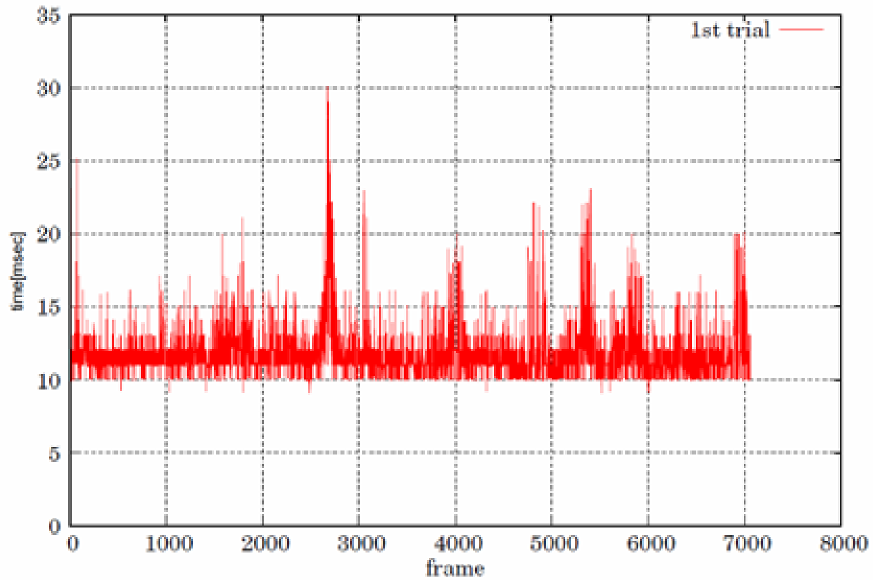
Experimental Conditions

- The round trip time between server and client
- The number of frames from 10,000 to 25,000 (only correct frames)
- Average times, maximum times and minimum times
- Repeat five times
- The round trip time between server and client in the case of the tele-communication at three remote locations

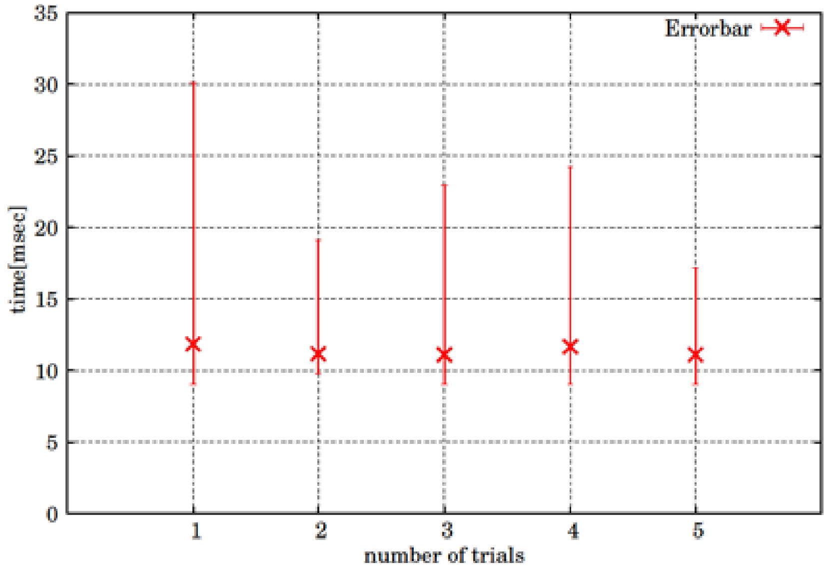
Scene of Haptic Communication



Experimental Results



Round trip times on the 1st trial

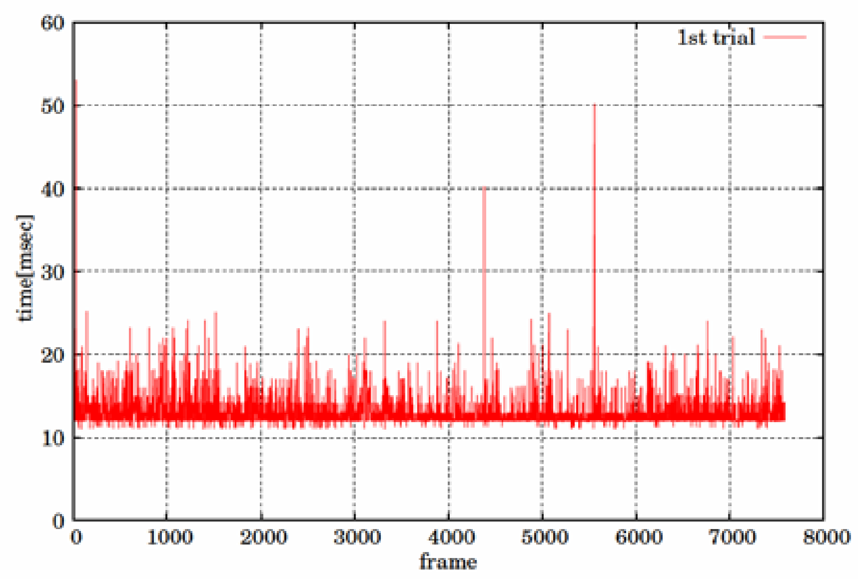


Average times, Maximum times, and Minimum times

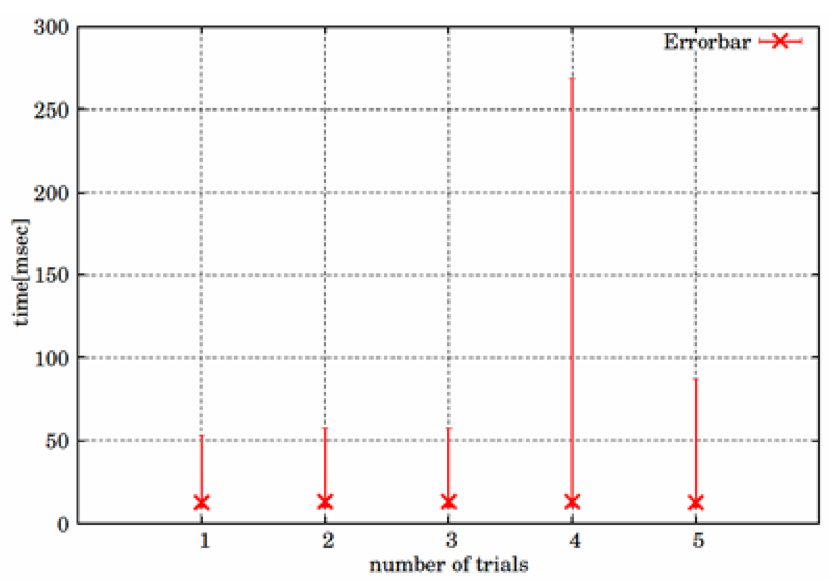
Experimental results between Ritsumeikan Univ. BKC and Shiga Medical Univ.

	1st	2nd	3rd	4th	5th
Maximums	30.1	19.1	23.0	24.1	17.2
Minimums	9.0	9.8	9.0	9.0	9.0
Averages	11.9	11.2	11.1	11.7	11.1

Experimental Results



Round trip times on the 1st trial

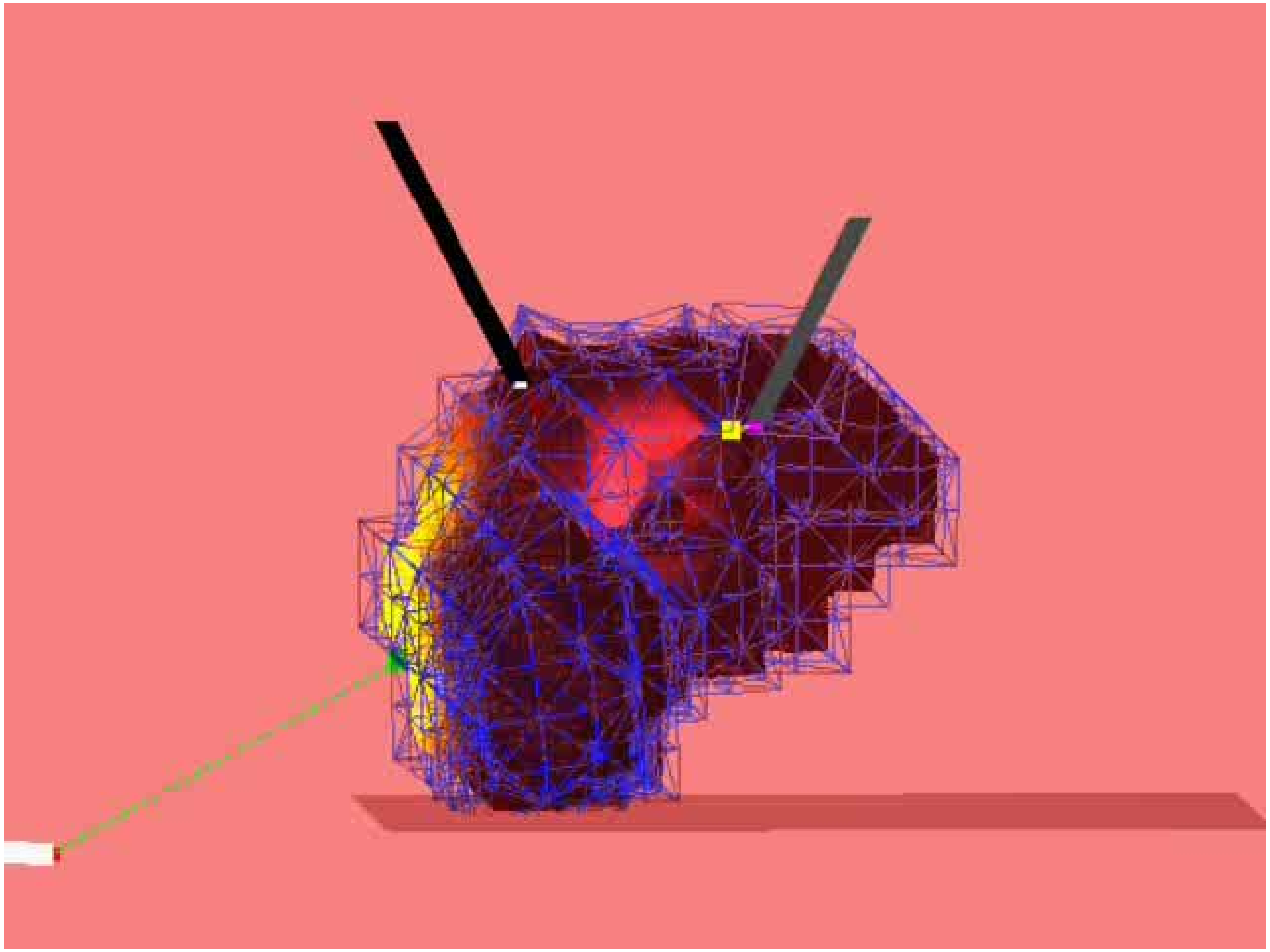


Average times, Maximum times, and Minimum times

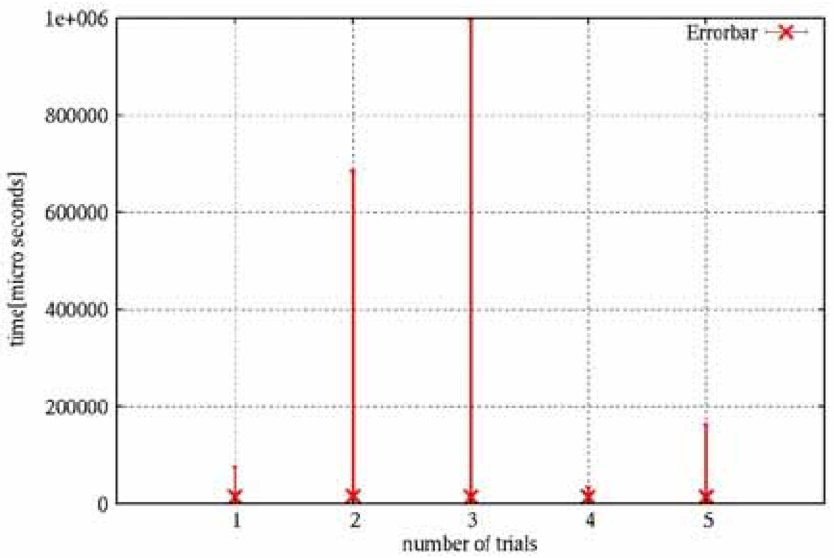
Experimental results between Ritsumeikan Univ. BKC and Osaka Univ. TC

	1st	2nd	3rd	4th	5th
Maximums	53.1	57.2	57.2	268.7	87.1
Minimums	10.9	10.9	10.9	11.0	10.9
Averages	13.1	13.2	13.2	13.6	13.1

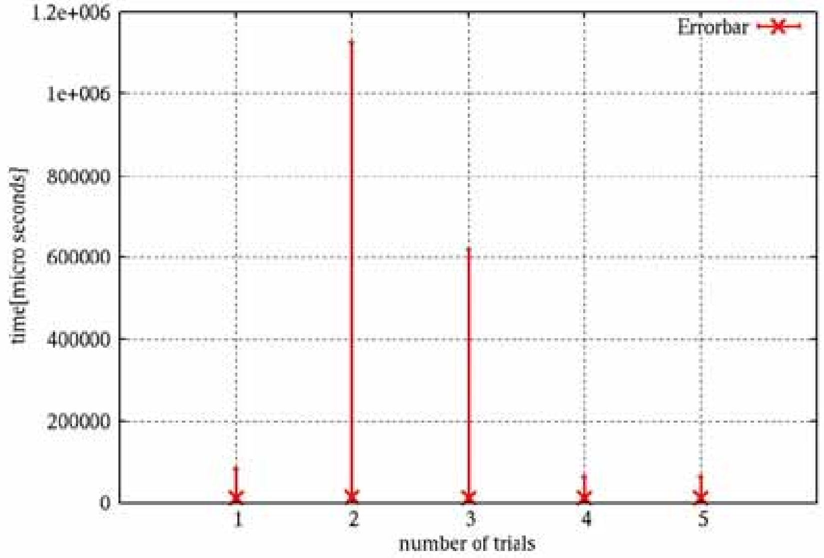
Movie of three remote locations



Experimental Results



Average times, maximum times and minimum times (OU-TC Location A)



Average times, maximum times and minimum times (OU-TC Location B)

Round trip times of all trials (OU-TC Location A))[msec]

	1st	2nd	3rd	4th	5th
Maximums	77.5	684.8	998.5	36.1	164.4
Minimums	11.9	11.2	11.0	11.0	11.9
Averages	13.4	16.2	14.7	14.0	14.4

Round trip times of all trials (OU-TC Location B))[msec]

	1st	2nd	3rd	4th	5th
Maximums	83.3	1,127.0	618.5	65.0	65.2
Minimums	11.0	11.0	11.0	10.9	10.9
Averages	12.8	14.7	13.6	13.2	13.5

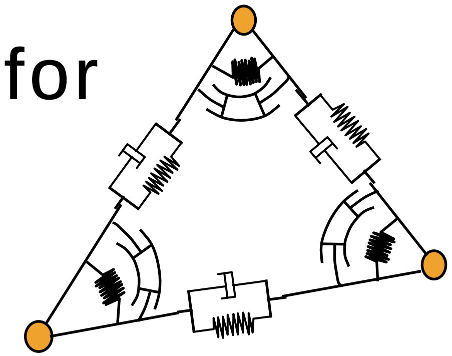
Conclusions and Future works

Conclusions

- We described a volume-based haptic communication system that shares an adaptive volume model at remote locations.
- We investigated the efficiency of our system via experiments on a simulation of a soft object with high haptic rendering rates at remote locations on a WAN
- The experimental results show that the delay due to network traffic is negligible.

Future works

- Extend the capability of our system by using multi core CPUs, by synchronizing visualization between server and client, and by developing an interpolation algorithm for force feedback
- Development mass-spring model comparable continuum model
- Application to a surgical simulator for training and an amusement



Acknowlegement

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Thank you for your attention!