Handling Heterogeneity in Collaborative Networked Virtual Surgical Simulators

Seminar of the Ph.D. in Mathematical Engineering

Christian Diaz, Ph.D.

GIDITIC: Grupo I+D+I en Tecnologías de la Información y las Comunicaciones

Inspira Crea Transforma

UNIVERSIDAD EAFIT

Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity affecting collaborative Performance in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

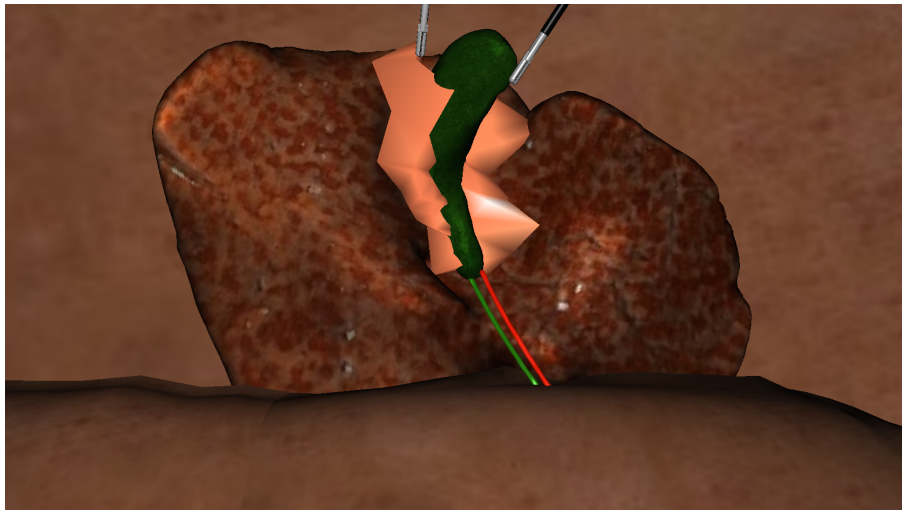
Motivation

Moving from

Traditional training model

"See one,
Do one,
Teach one"

Simulation based model



Risk on the patient, higher surgical cost, no scenario for trial an error

Motivation

Networked Virtual Surgical Simulators

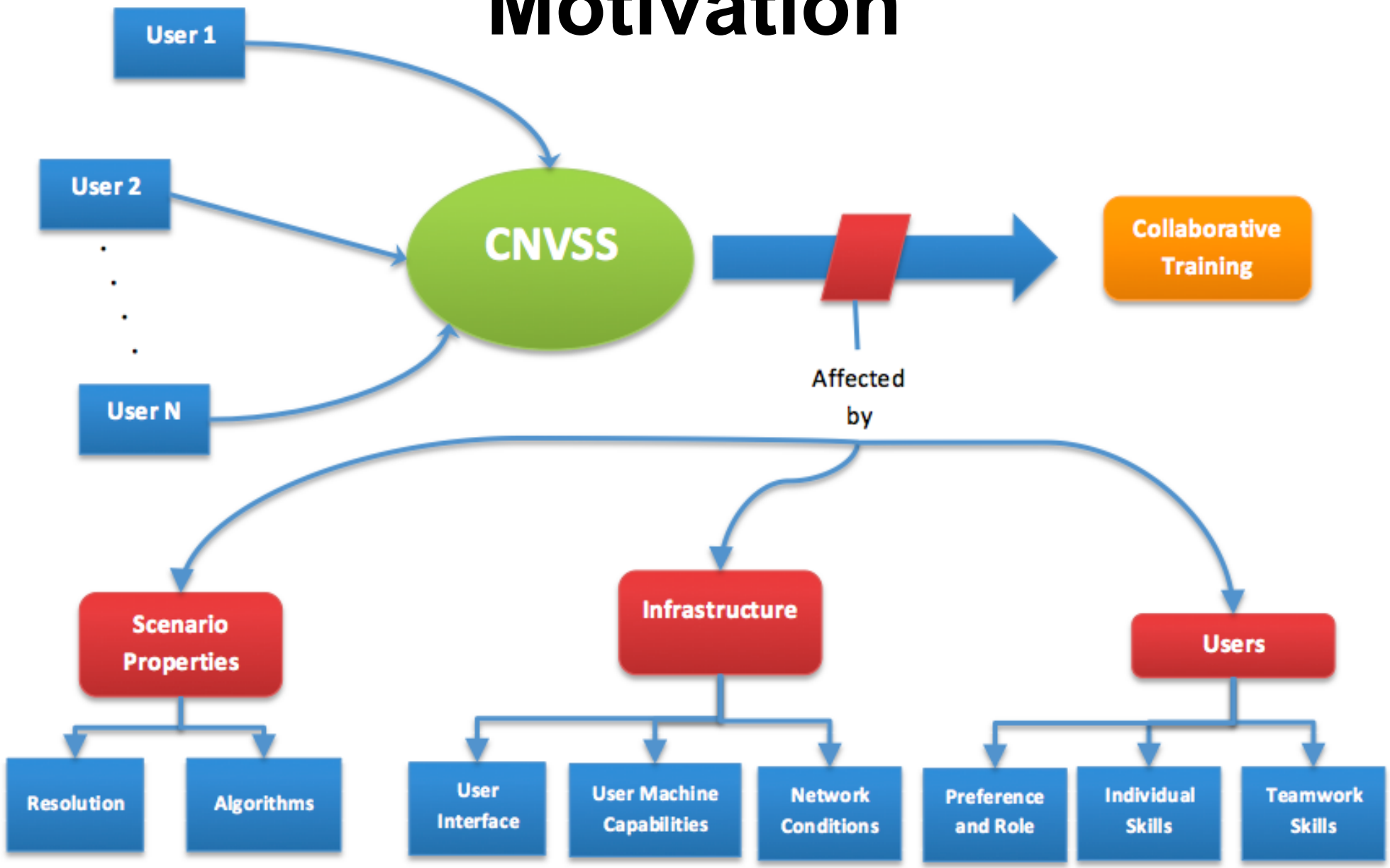
Stand-Alone Virtual Surgical Simulators

Motivation

- Collaborative Networked Virtual Surgical Simulators (CNVSS).

- They are a CVE with special features:
  - Tightly coupled collaboration.
  - High performance requirements.
  - Users focused on a few virtual objects.
  - Enrichment simulation environment.

Motivation


User 1
User 2
User N
CNVSS
Collaborative Training
Affected by
Scenario Properties
Infrastructure
Users
Resolution
Algorithms
User Interface
User Machine Capabilities
Network Conditions
Preference and Role
Individual Skills
Teamwork Skills

Motivation

The main goal:

“Propose a strategy to handle the three groups of heterogeneity factors (user, infrastructure and CNVSS), to attain a good collaborative training performance in a CNVSS”

Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity affecting collaborative Performance in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

Related Works and Main Contributions

Network conditions

Author	Jitter (ms)	Delay (ms)	Percentage of Packet Loss (%)
Park et al. 1999	12.53 – 263.58	10 – 200	N/A
Dev et al. 2002	0 – 25	0 – 150	0.0001 – 100
Alhalabi et al. 2003	N/A	0 – 2000	N/A
Souayed et al. 2004	1 – 15	0 – 50	0.1 – 50
Allison et al. 2004	N/A	0-200	N/A
Hamza-Lup et al. 2005	N/A	0 – 50	N/A
Jay et al. 2007	N/A	0 – 400	N/A

Related Works and Main Contributions

Machine Capabilities

Author	Processor Speed (MHz)	RAM Capacity (MB)	Graphic Card	Network Card Speed (Mbs)
Trefftz et al. 2003	400 – 1500	256 – 1024	Intense3D,16 MB - GeForce2,32 MB	N/A
Hamza-Lup et al. 2005	1500 – 2800	512 – 1024	GeForce 4Ti4200 – GeForce 4Ti4600	100
Jay et al. 2007	2000 – 3200	512 – 1024	N/A	N/A

Related Works and Main Contributions

GiPSiNet
Networked Surgical Simulations

Boulanger et al. 2006
Allard et al. 2007
Gunn 2007
Dev et al. 2008
Qin et al. 2009

Context aware Approaches

Agu et al. 2005
Araujo et al. 2006
Workman et al. 2006
Kuroda et al. 2007

Qin 2010 → Review

Related Works and Main Contributions

2. A novel architecture for a CNVSS based on context-aware concept is described, developed and evaluated to:

- Measure heterogeneity factors.
- Apply inference mechanism.
- Share the state of the simulation.
- Modify properties of the virtual surgical scenario.

Related Works and Main Contributions

Author	Heterogeneity Factors	Inference Method	Improved Variable
Trefftz et al. 2002	User Preferences, Machine Capabilities	Linear Equations	Infrastructure CVE
Quiroz et al. 2004	User Preferences, Machine Capabilities	Heuristics	Infrastructure
Araujo et al. 2006	User Preferences, Machine Capabilities	Rules based on thresholds	Infrastructure
Fujinoku et al. 2006	Network Capabilities	Rules based on thresholds	Infrastructure
Beggas et al. 2013	User Preferences, Machine Capabilities	Fuzzy Logic	Infrastructure

Handling Heterogeneity mechanisms

Related Works and Main Contributions

3. A mechanism for handling heterogeneity factors involved in a CNVSS.

- Infrastructure heterogeneity factors and user preferences as input.
- Surgical scenario properties and compensation mechanism as output.
- Application of artificial intelligence methods.

Outline

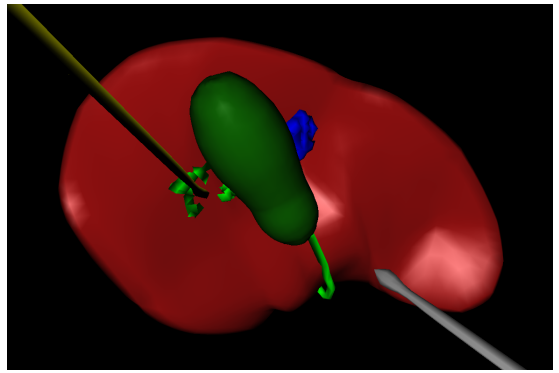
1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity factors affecting collaborative performance significantly in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

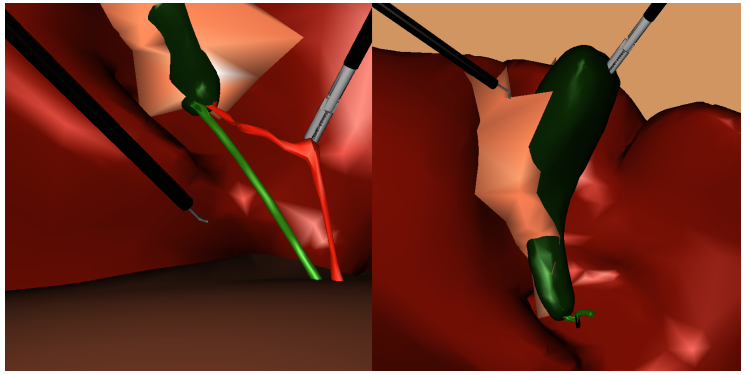
Our Approach

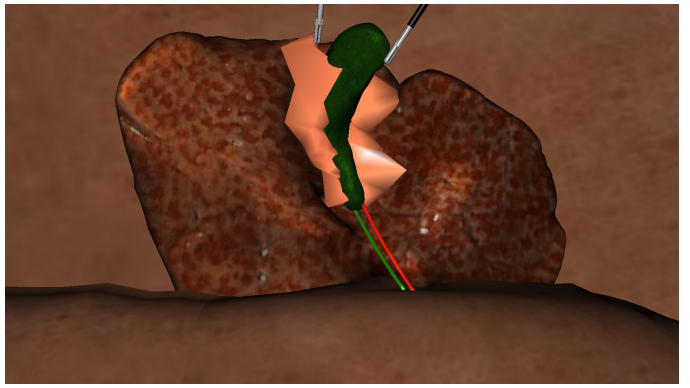
Factors affecting collaboration → Context-Aware Architecture → Inference Mechanism

SOFA
Simulation Open Framework Architecture

12 components modified and 7 new created



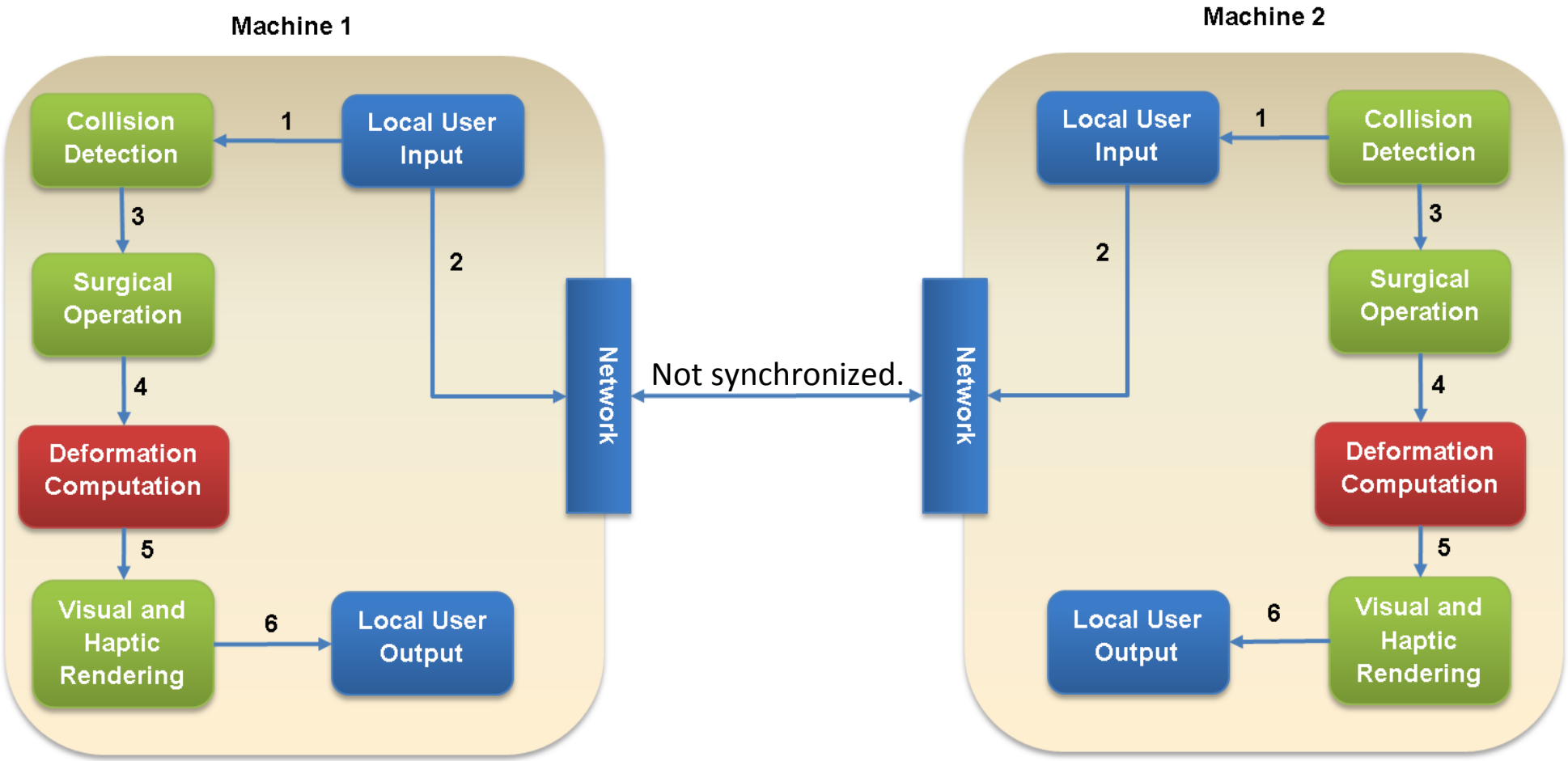




Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity factors affecting collaborative performance significantly in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

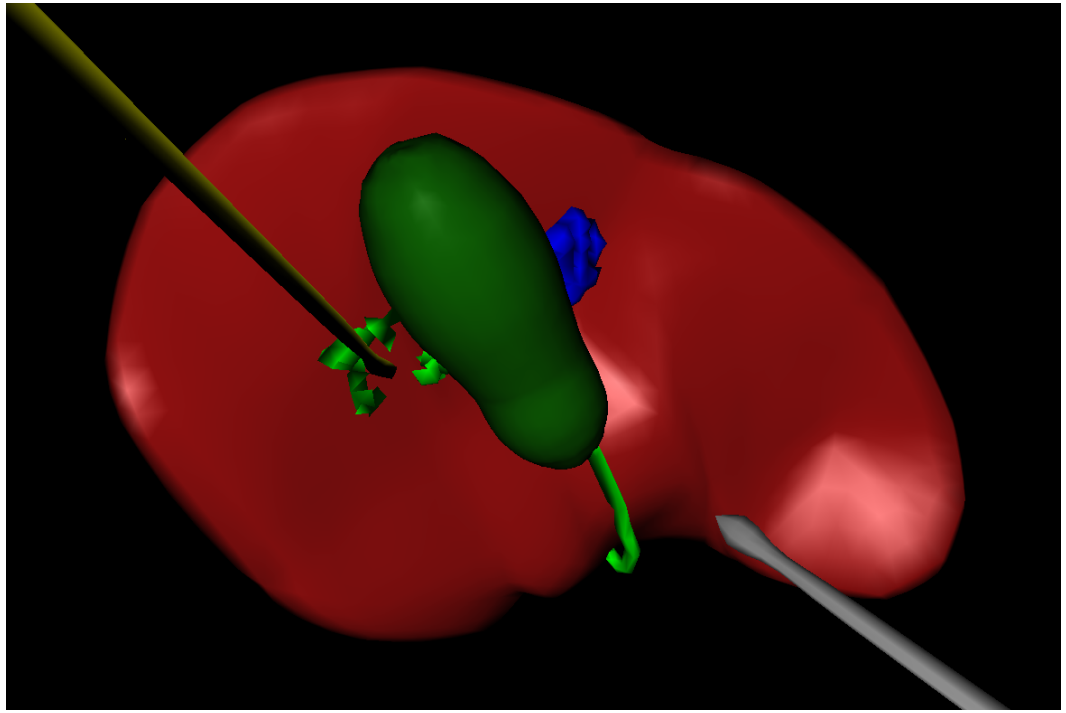
Heterogeneity Factors Affecting Collaboration



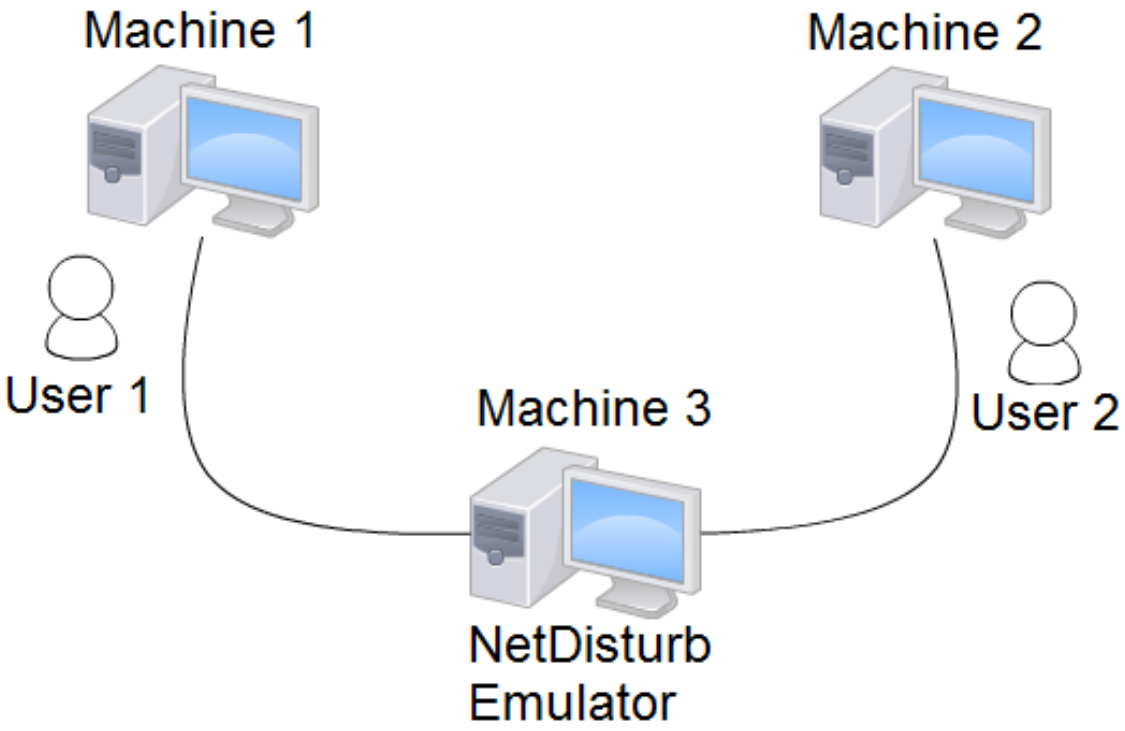
Peer-to-Peer architecture implemented

Heterogeneity Factors Affecting Collaboration

Peer-to-Peer experiment Setup



Surgical Scenario



System Configuration

Heterogeneity Factors Affecting Collaboration

Factor	Lower Level	Higher Level
Delay (ms)	0	300
Packet Loss (%)	0	70
Jitter (ms)	0	50
Bandwidth (Mbps)	100	1000
Processor Speed (GHz)	2.6	3.4
RAM Memory (Gb)	1	2
Network Card Speed (Mbs)	100	1000

Peer-to-Peer experiment Setup.

2^{7-4} Fractional

Factorial DOE

Response variables

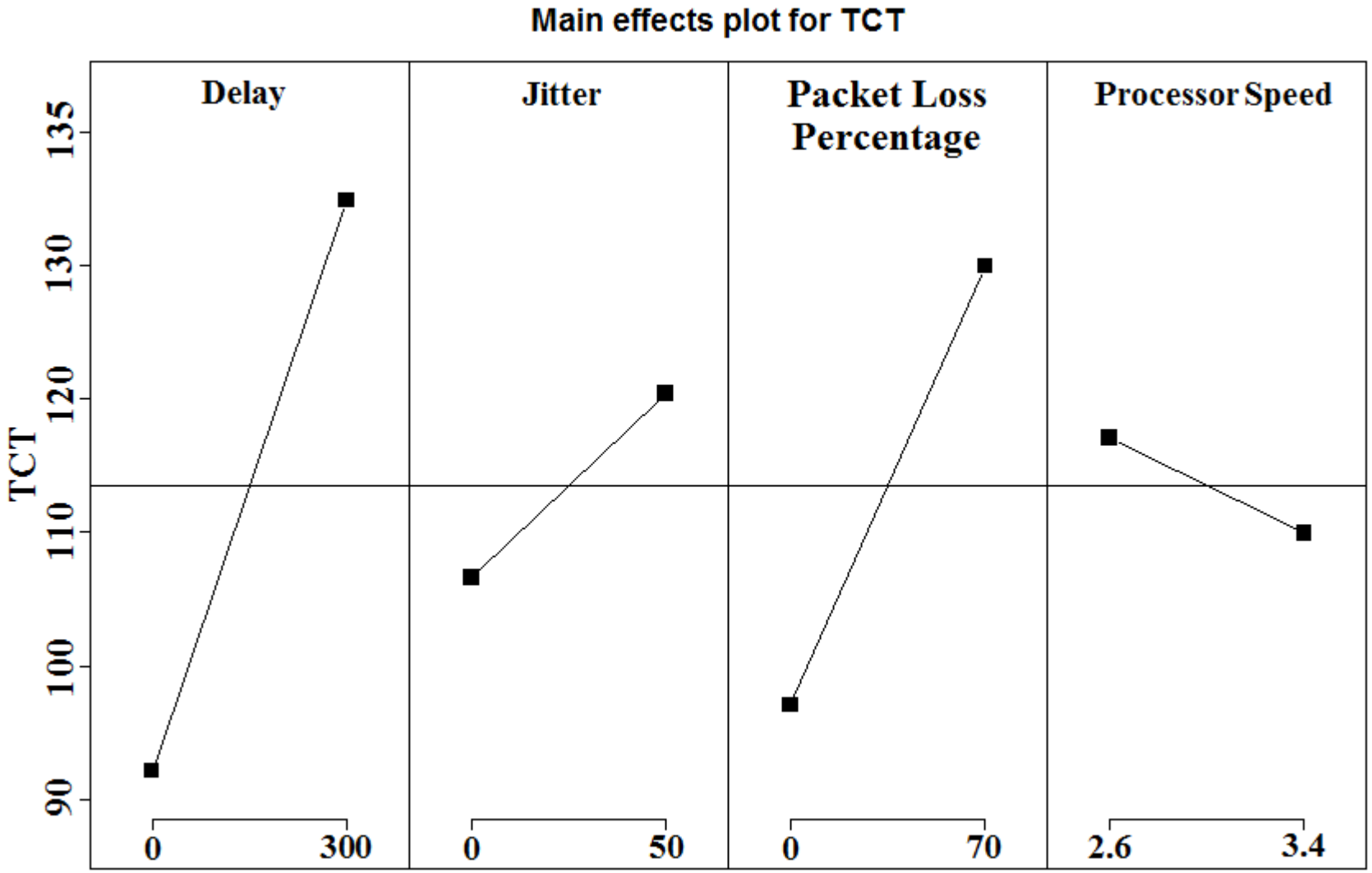
Frames per second (FPS)

Task Completion Time in seconds

(TCT)

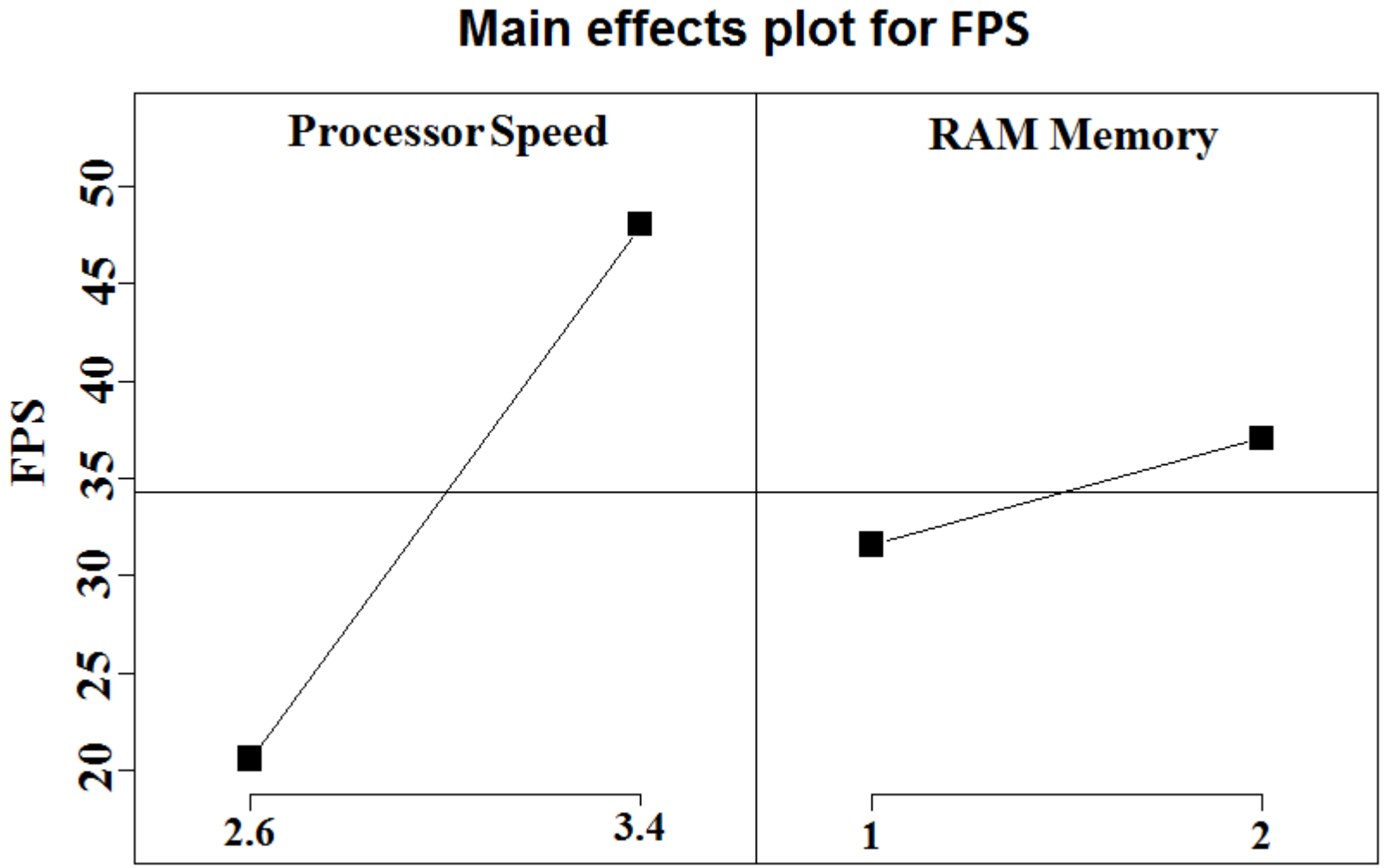
Heterogeneity Factors Affecting Collaboration

Peer-to-Peer experiment Results

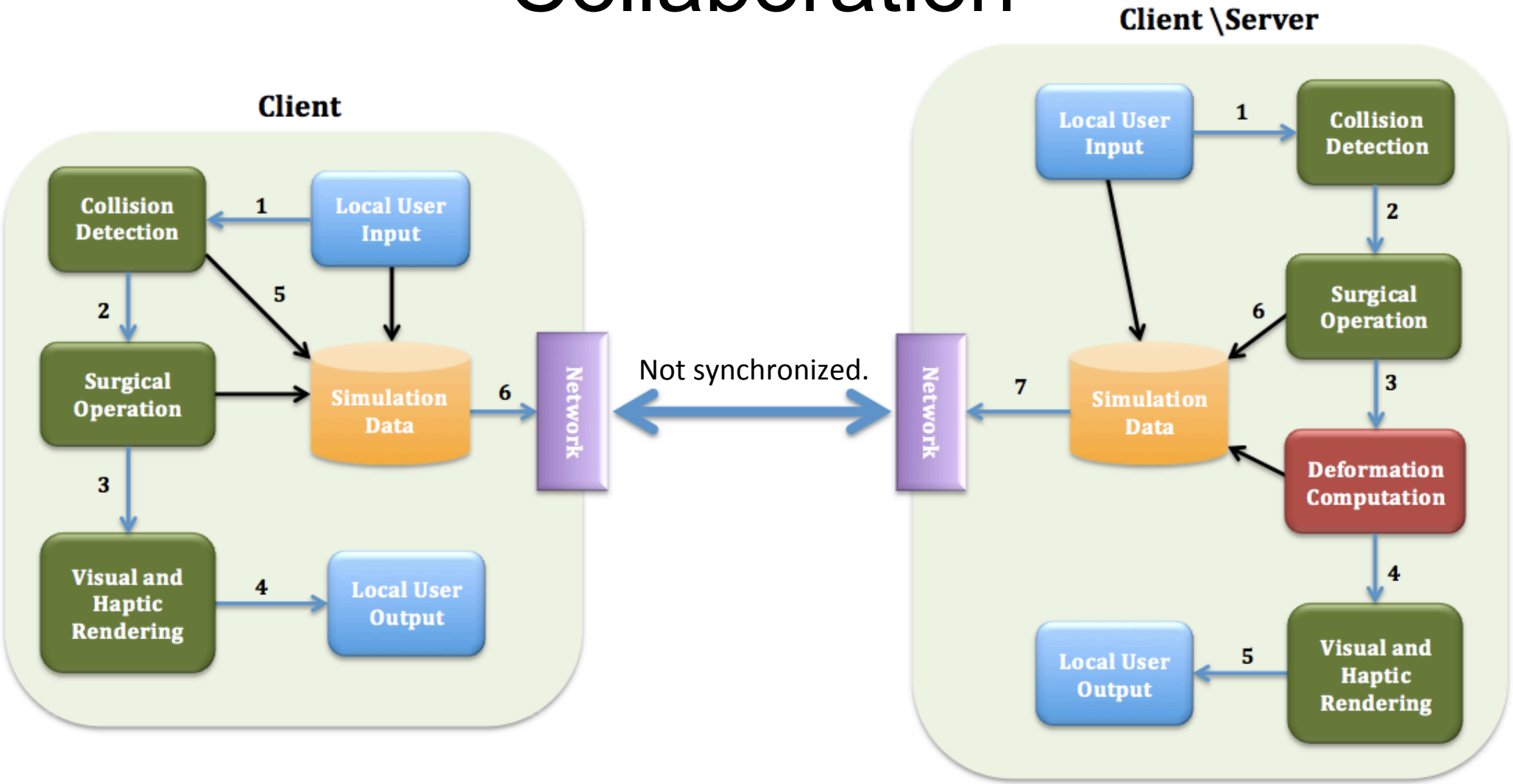


Heterogeneity Factors Affecting Collaboration

Peer-to-Peer experiment Results



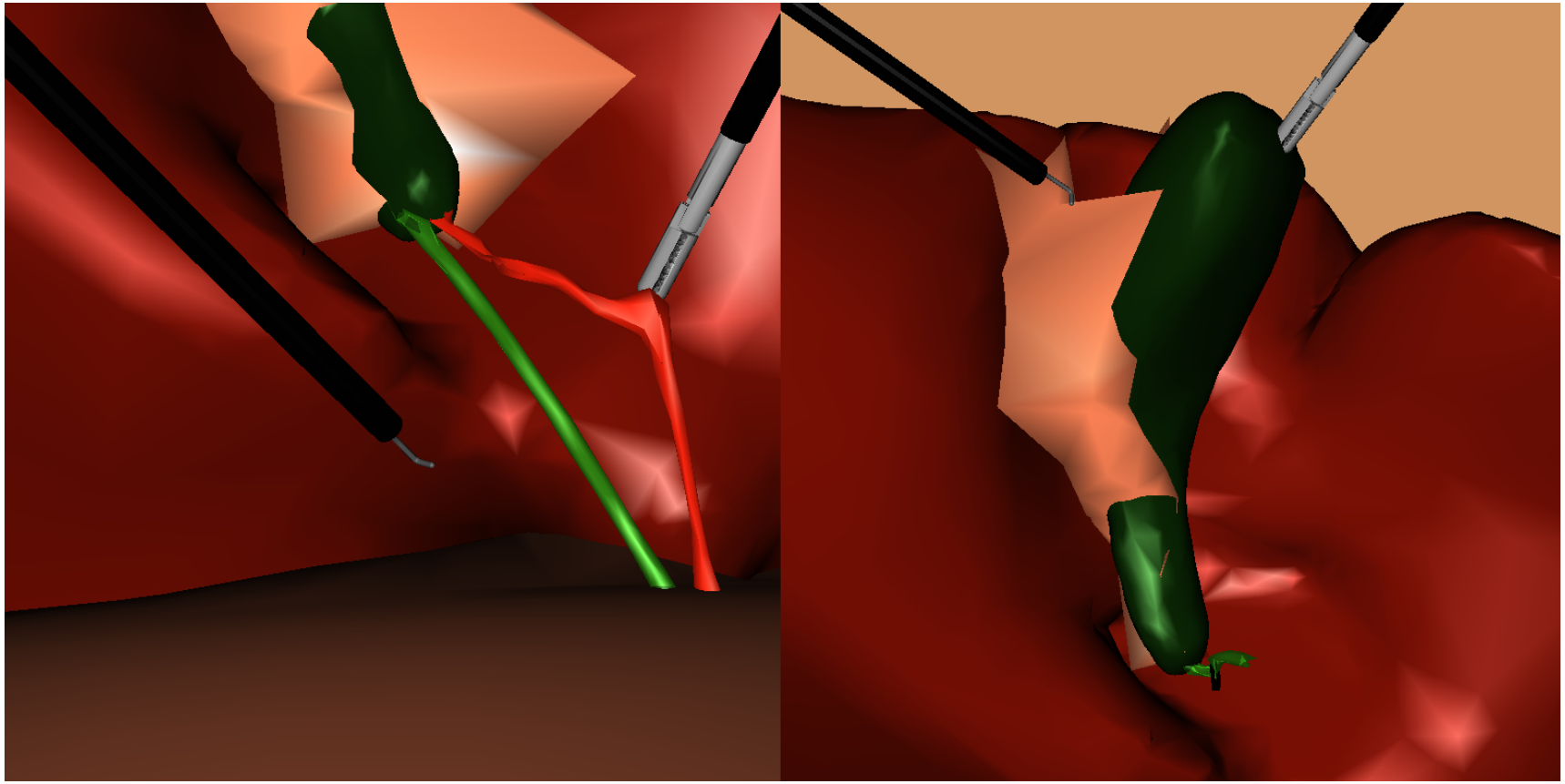
Heterogeneity Factors Affecting Collaboration



Hybrid Client-Server architecture implemented

Heterogeneity Factors Affecting Collaboration

Hybrid Client-Server experiment Setup



Surgical Scenario

Same System Configuration

Heterogeneity Factors Affecting Collaboration

Hybrid Client-Server experiment Setup

Factor	Lower Level	Higher Level
Delay (ms)	0	300
Packet Loss (%)	0	50
Jitter (ms)	0	50
Bandwidth Available Percentage (%)	70	100
Server and Client Benchmark (ms)	59.47	34.53

2^{6-3} Fractional

Factorial DOE

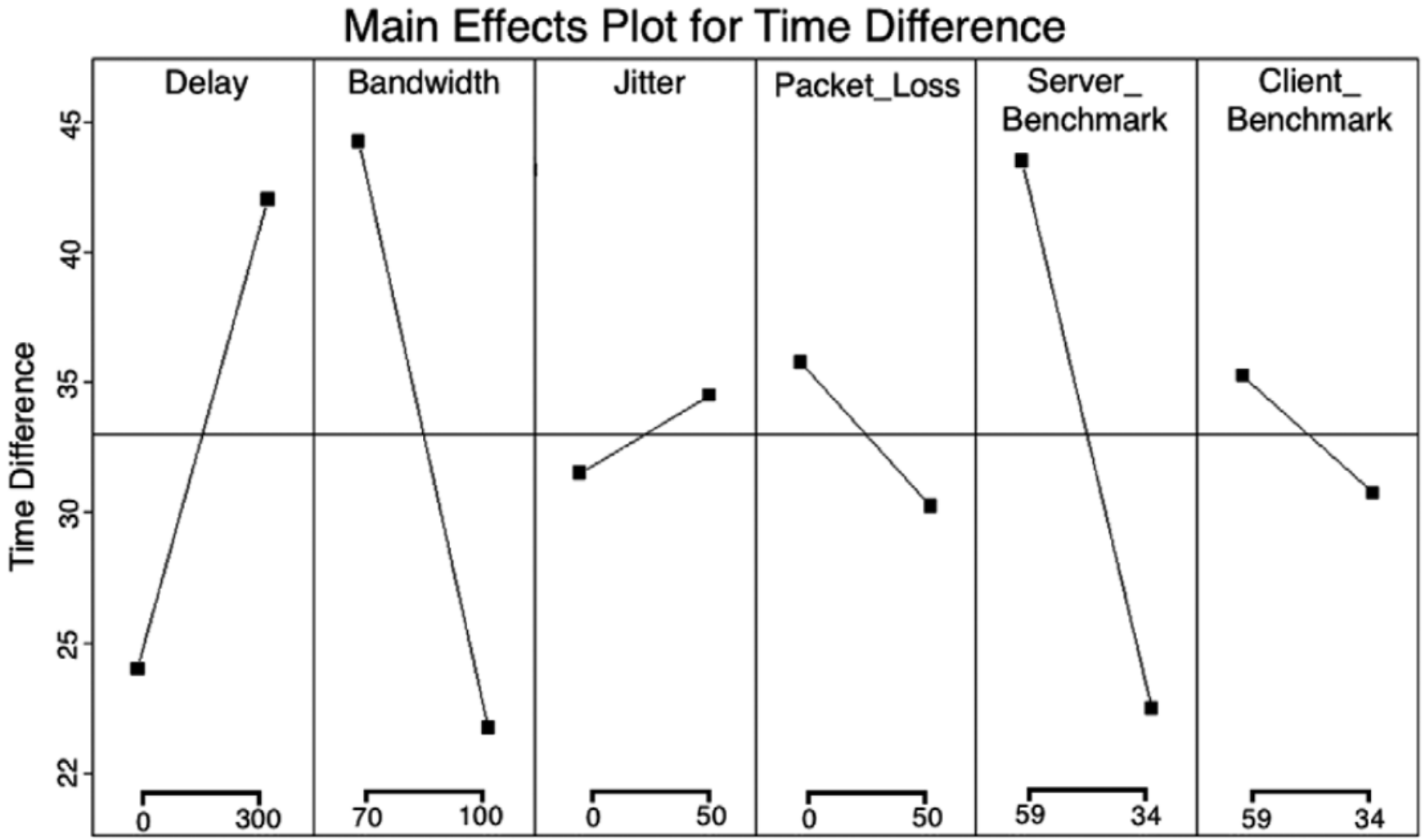
Response variables

Inconsistency (cm)

Time Difference (sec)

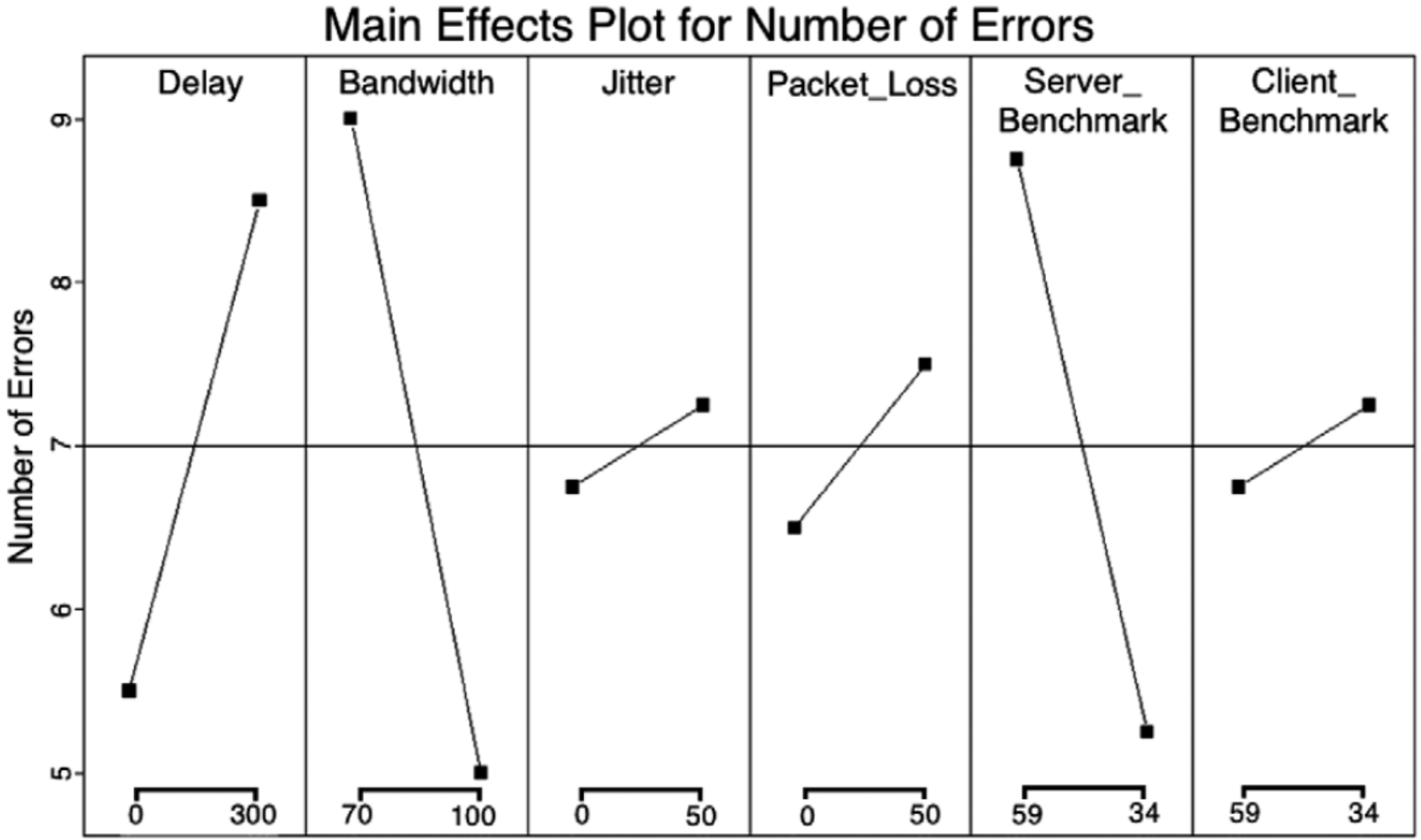
Number of errors

Heterogeneity Factors Affecting Collaboration



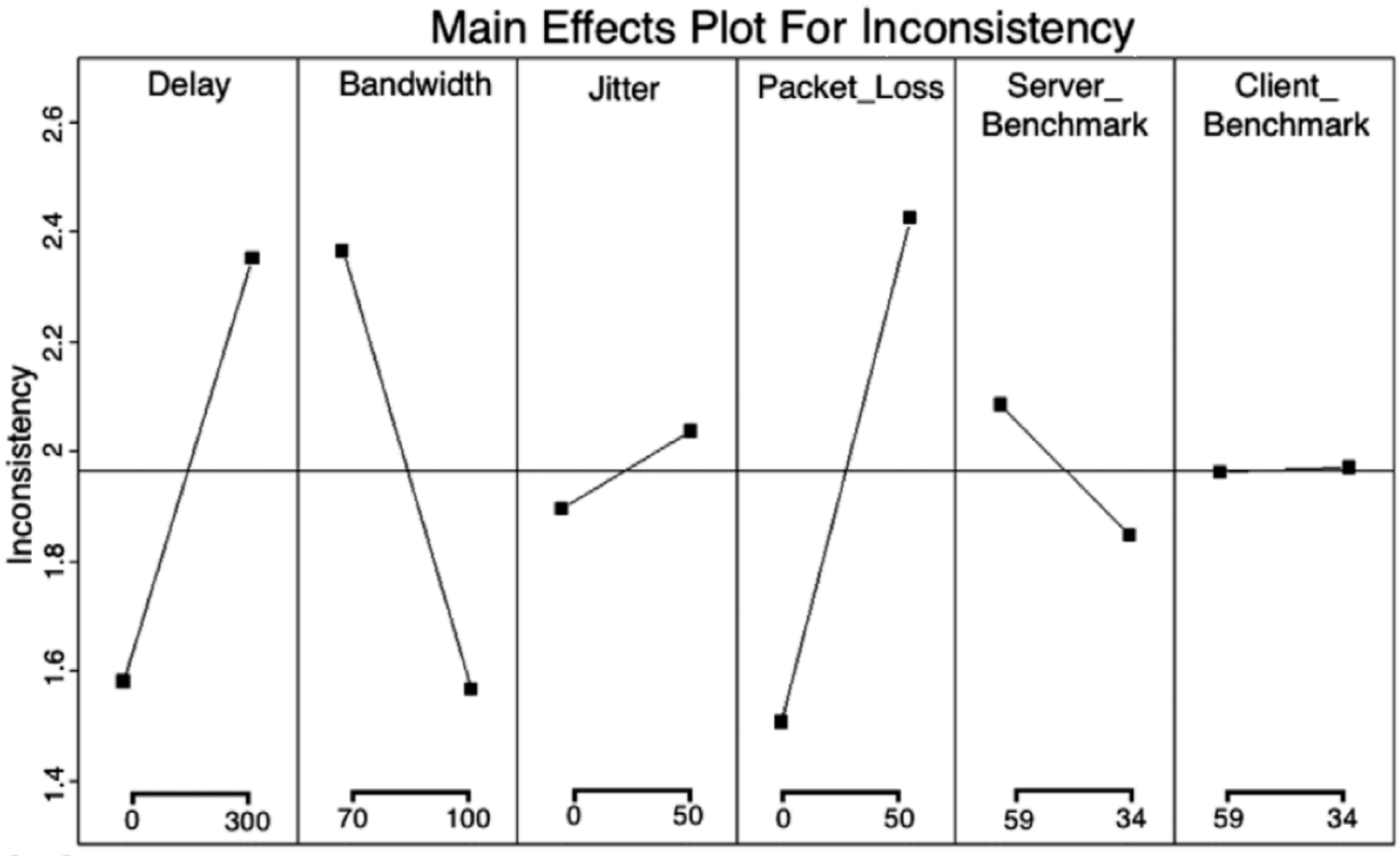
Hybrid Client-Server experiment Results

Heterogeneity Factors Affecting Collaboration



Hybrid Client-Server experiment Results

Heterogeneity Factors Affecting Collaboration

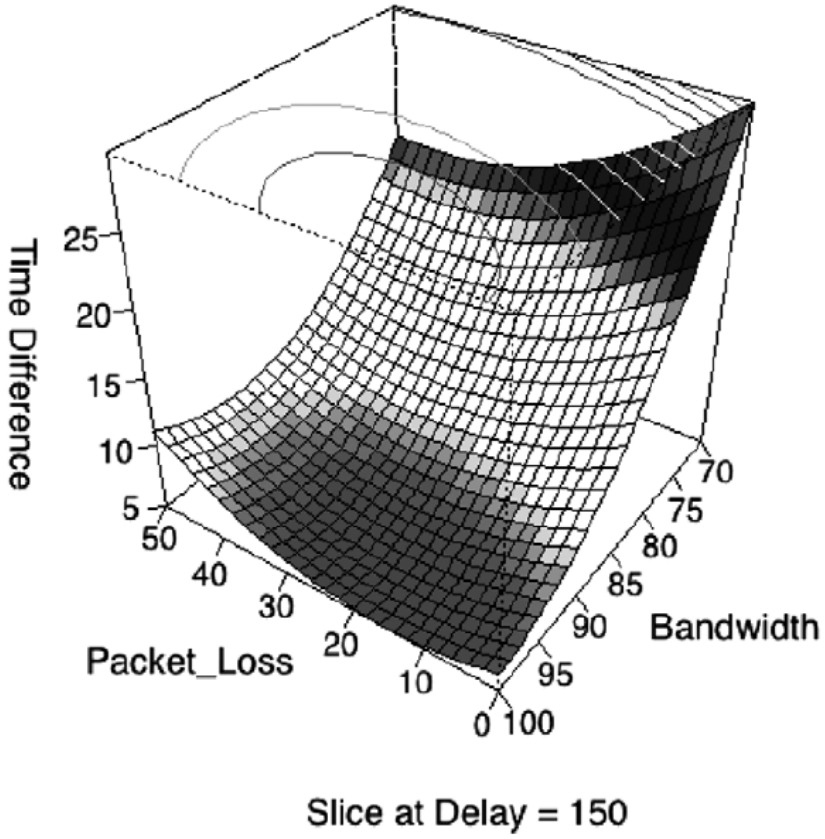


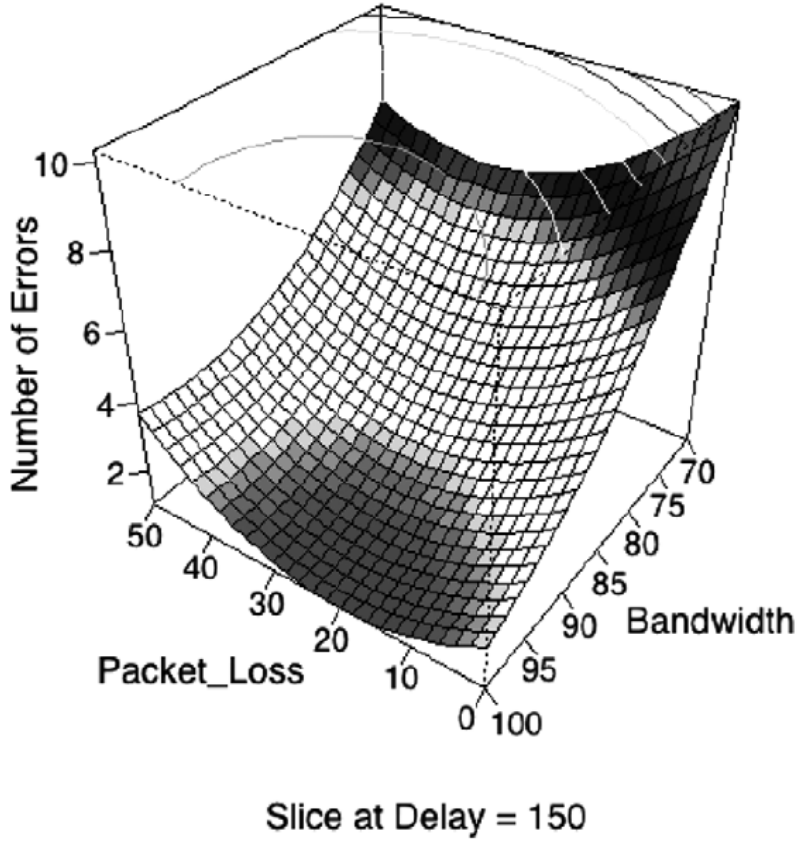
Hybrid Client-Server experiment Results

Heterogeneity Factors Affecting Collaboration

Surface Response DOE

- Bandwidth
- Packet Loss
- Delay





Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity factors affecting collaborative performance significantly in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

Context-Aware Architecture for a CNVSS

Important components for the CA-Architecture:

- Context management.
- Context-aware adaptation.
- Context based-inference machine.

Context-Aware Architecture for a CNVSS

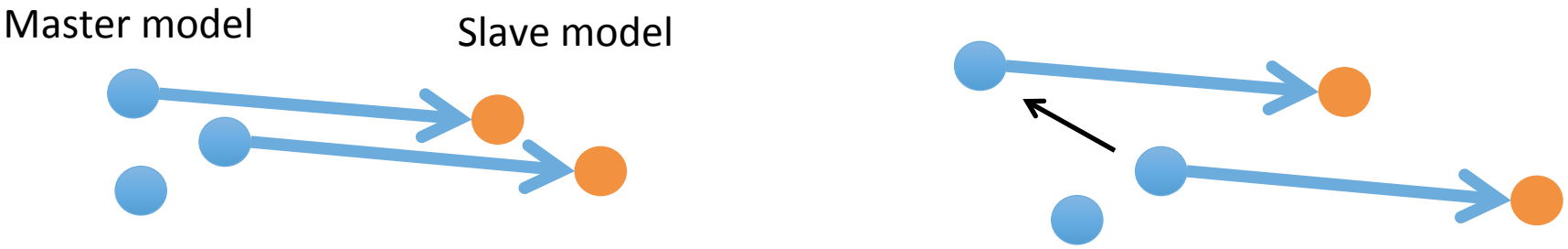
CNVSS context

Entity	Heterogeneity Factors
User	Preferences
	Role
	User skills
	Team skills
Infrastructure	Machine Capabilities
	Bandwidth Available
	Delay
	Jitter
	Packet Loss
CNVSS	Collision detection model resolution and algorithm
	Deformation computation model resolution and algorithm
	Visual and Haptic model resolution and algorithm

Context-Aware Architecture for a CNVSS

Mapping process applied by SOFA:

- Mapping between collision model and deformation model.
- Mapping between deformation model and collision model.
- Mapping between deformation model and visual model.



Context-Aware Architecture for a CNVSS

Previous computation:

- Barycenter for each tetrahedron.
- Closest tetrahedron of the master model to each point of the slave model.

Bandwidth Modification Mechanism

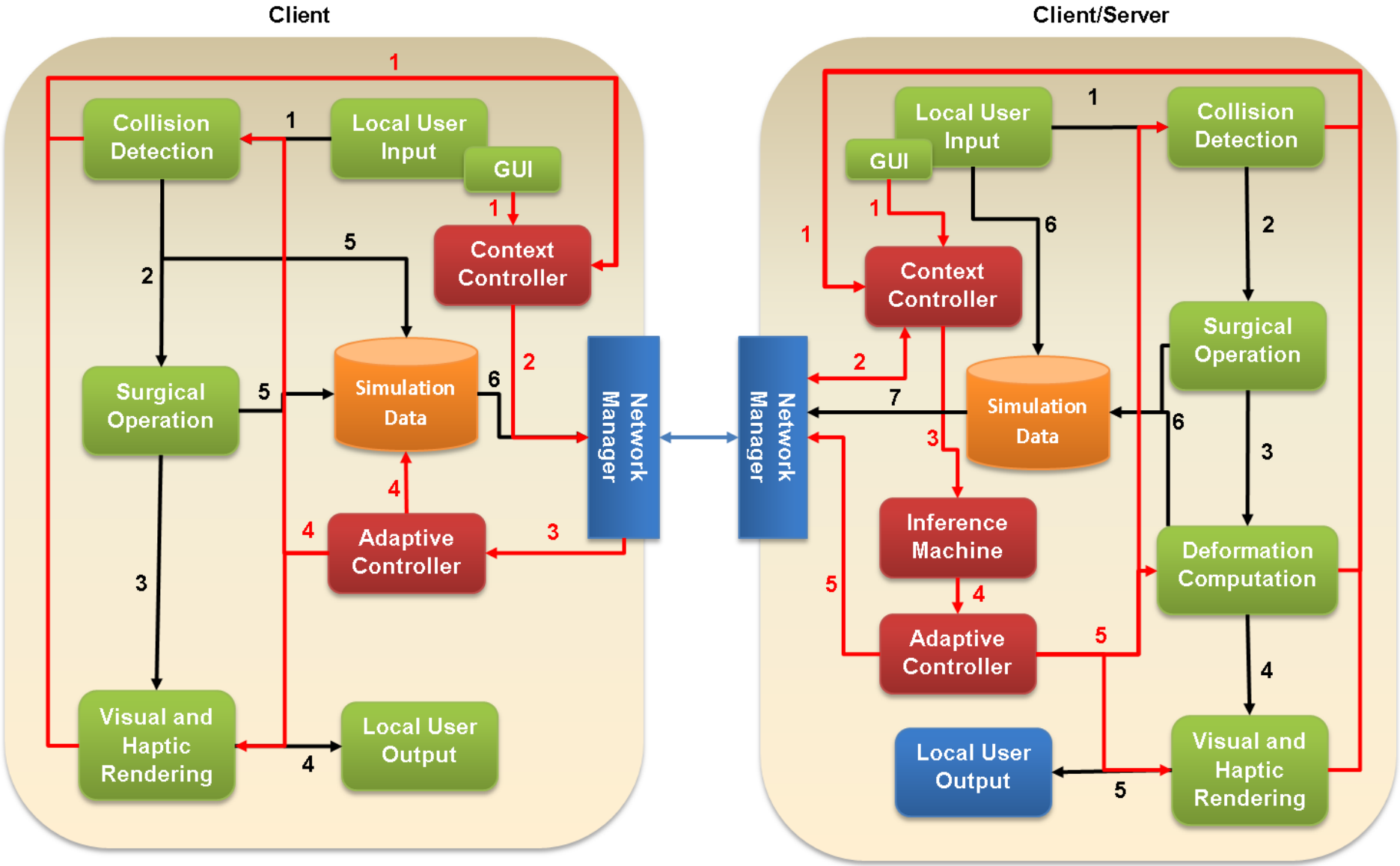
Context-Aware Architecture for a CNVSS

Cases:

1. Change in deformation model.
2. Change in collision model.

Machine Capabilities Modification Mechanism

Context-Aware Architecture for a CNVSS



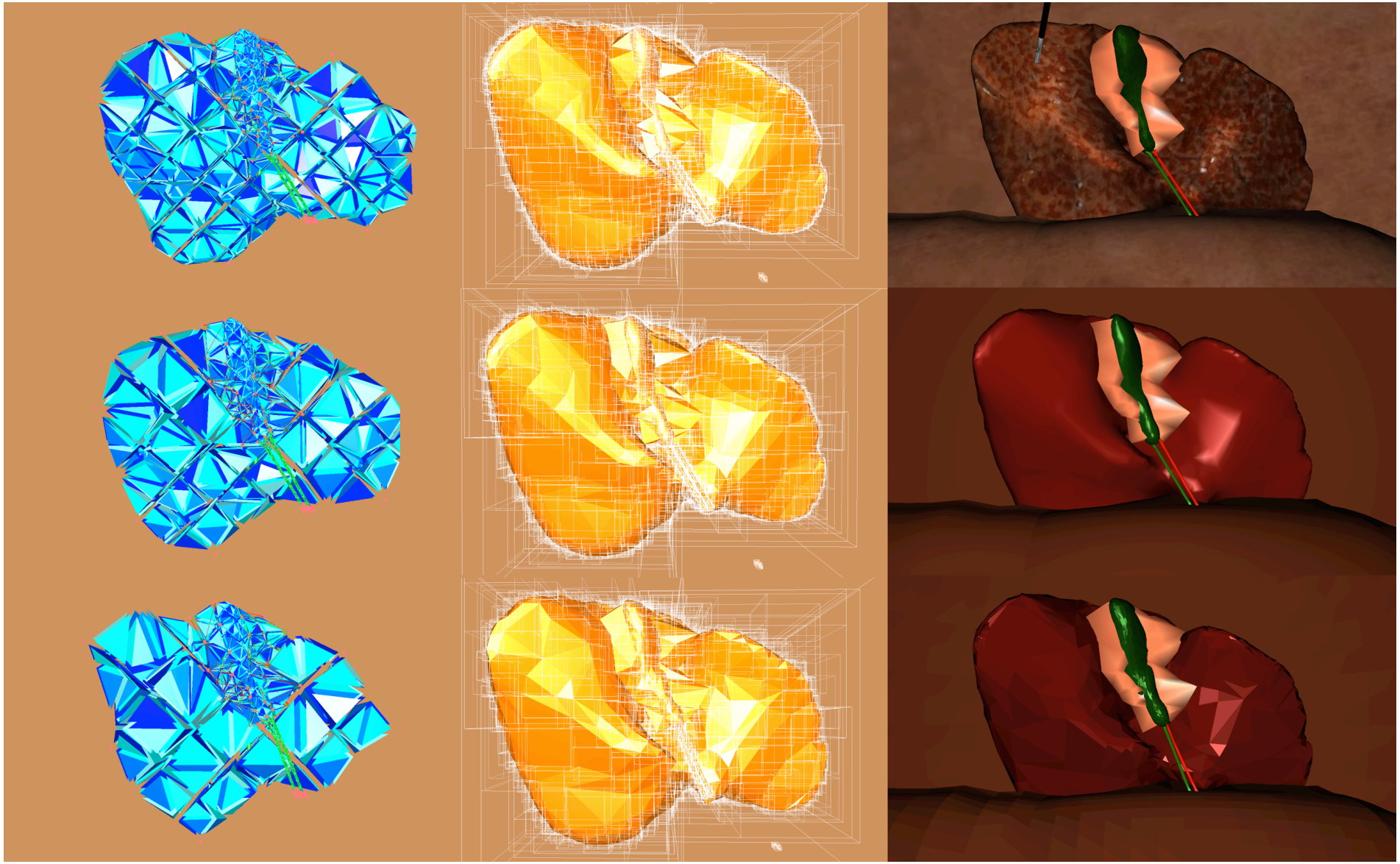
Red lines:

Context-aware flow

Black lines:

Hybrid Client-Server Architecture Flow.

Context-Aware Architecture for a CNVSS



Context-Aware Architecture for a CNVSS

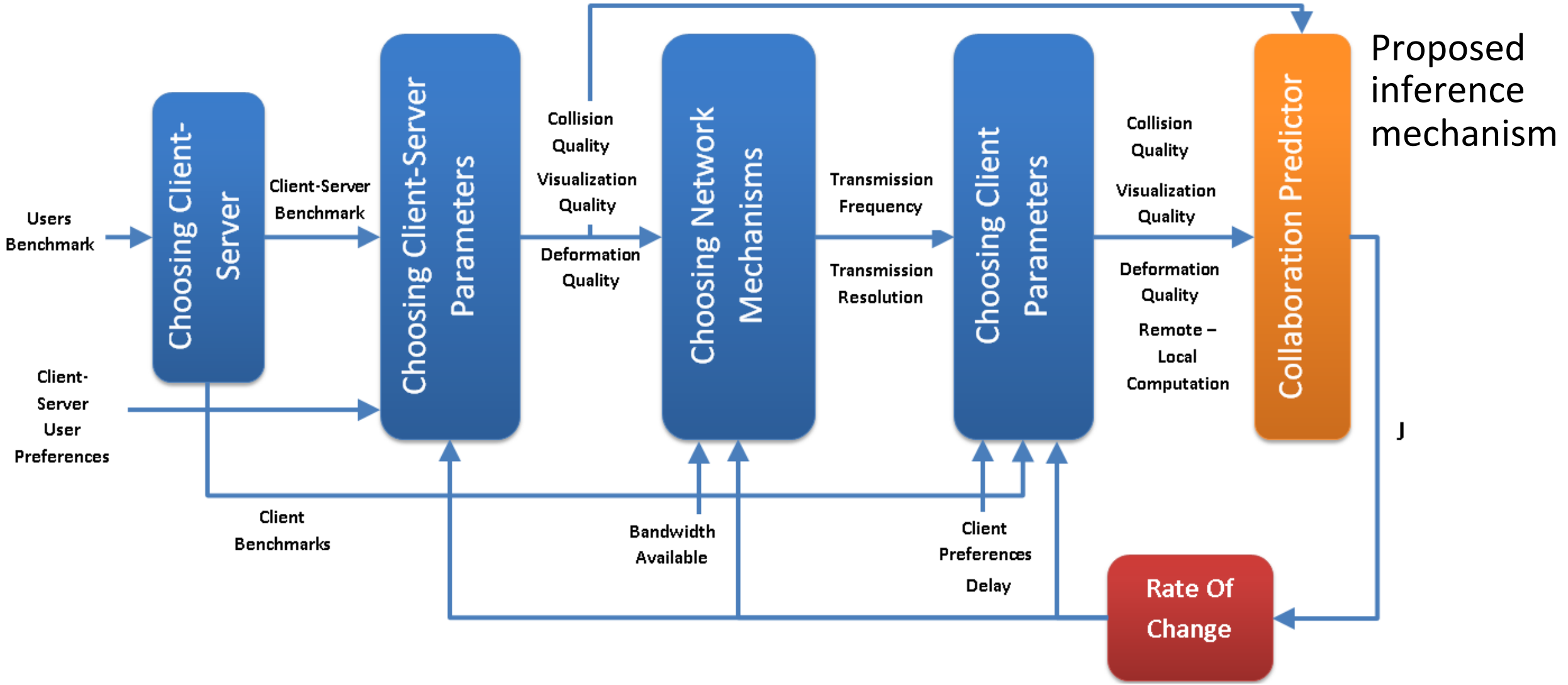
			Simulation Complexity		
			Low	Medium	High
Context Aware	Client	FPS	60.1	59.7	60.2
		Memory (KB)	107.692	108.564	109.092
	Server	FPS	22.2	26.9	33.5
		Memory (KB)	129.416	132.016	134.532
Non Context Aware	Client	FPS	60.3	59.7	60.2
		Memory (KB)	81.875	98.374	102.235
	Server	FPS	19.2	25.1	31.4
		Memory (KB)	101.036	117.148	12.528

Experiment for evaluating memory and performance

Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity factors affecting collaborative performance significantly in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

Inference Mechanism for Handling Heterogeneity



Proposed inference mechanism

Inference Mechanism for Handling Heterogeneity

Collaboration Predictor and Rate of Change

Parameters	Best case	Average Case	Worst Case
Delay (ms)	0	300	600
Bandwidth available (%)	100	90	80
Server Benchmark (ms)	33	33	66
Client Benchmark (ms)	33	66	66

Number of Data

$J \approx 0$ Best case

$J \approx 2$ Worst case

$$J = \frac{TCT_p}{TCT_{max}} + \frac{NE_p}{NE_{max}}$$

$$TCT_p = TCT_{max}$$

$$NE_p = NE_{max}$$

Inference Mechanism for Handling Heterogeneity

Case	Bandwidth Available	Delay	Client-Server Bench.	Client Bench.	Preferences
1	90	250	28	28	Low, Low-High, High
2	80	500	28	28	Low, Low-High, High
3	90	250	8	8	Low, Low-High, High
4	80	500	8	8	Low, Low-High, High
5	90	250	28	8	Low, Low-High, High
6	80	500	28	8	Low, Low-High, High
7	100	0	38	38	Low, Low-High, High

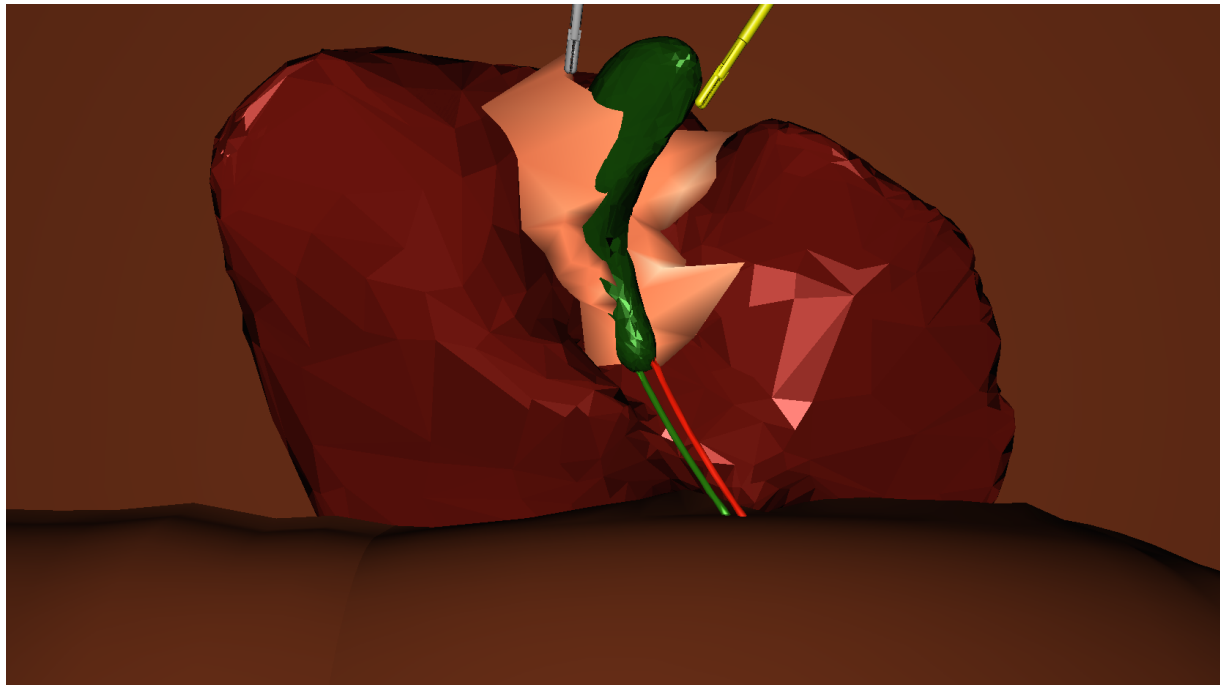
Experimental Setup

Control Group

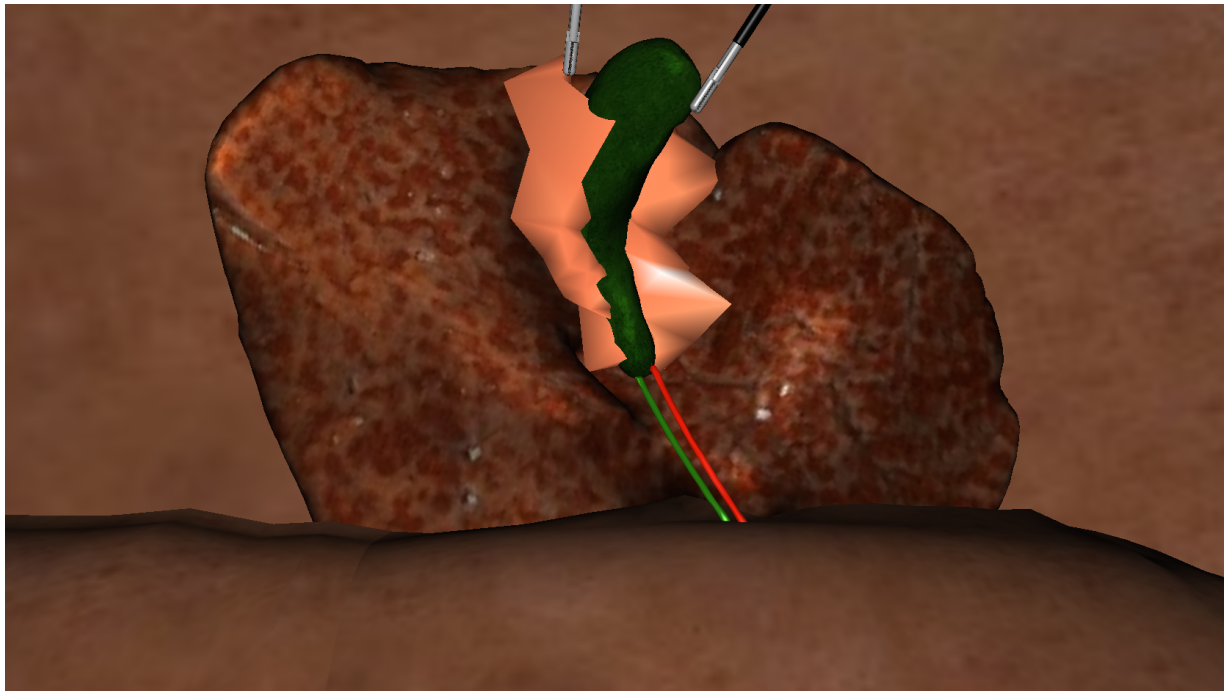
Interventional Group

Inference Mechanism for Handling Heterogeneity

CNVSS handling heterogeneous conditions



Client-Server Machine



Client Machine

Outline

1. Motivation.
2. Related Works and Main contributions.
3. Our Approach.
   - Heterogeneity affecting collaborative Performance in CNVSS.
   - Description and implementation of a Context Aware Architecture for CNVSS.
   - Inference Mechanism for Handling Heterogeneity factors in CNVSS.
4. Conclusions and future research.

Conclusions

1. Some infrastructure factors have a more profound impact on collaboration than others.

2. On each architecture the factors that affect the collaboration the most are:
   - For peer-to-peer: Processor speed, RAM memory, jitter, delay and percentage packet loss.
   - For hybrid client-server: bandwidth, server benchmark, delay.

Conclusions

3. The context-aware architecture proved to handle heterogeneity in a proper manner without affecting system performance.

4. The inference mechanism proved to be very successful determining the most appropriate adaptations.

5. The level of collaboration is improved by using the context-aware CNVSS, even under adverse infrastructure conditions.

Future Research

1. Understanding how poor collaboration among users, in a CNVSS, affects the acquisition of skills and dexterities.

2. Extend case studies for implementation and evaluation in the CNVSS: e.g., other surgical roles, additional surgical scenarios, more than two users, etc.

3. Increase the granularity of the simulation qualities in order to fine tune the system.

Thanks
Questions

Thank You

- Helmuth Trefftz, Ph.D., Advisor.
- Diego Acosta, Ph.D., Design of Experiments.
- Lucia Quintero, Ph.D., Artificial intelligence.
- Sakti Srivastava, M.A., Surgical training.