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Scuola Superiore
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CoCo – A Framework for Multicore Visuo-Haptics in Mixed Reality

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REMEDI

TAUM

SEVENTH FRAMEWORK
PROGRAMME

Regione Toscana

REPUBBLICA ITALIANA

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Overview

1. Context and Motivations
2. Features
3. Case Studies
4. Conclusions
5. Future Work

Context and Motivation

Context - VR/MR applications involving sensors, visual and haptic interfaces, vision algorithms, interfacing with robots

Issues – synchronization, efficient resource usage, addressing reference systems in an integrated scenario

Research – research on new schemes for MR applications, reducing the time to demo, and performance tuning

Background

- Robotics
  - ROS is the de-facto standard for robotic applications in research
    - Easy-to use system integration
    - Publisher-subscriber process-oriented
  - Orocos, real-time components
- Mixed and Virtual Reality
  - High-end graphics solutions: Unreal, Unity
  - Research platforms oriented to Data Flow: InTml, FlowVR, X3D InstantReality
  - Visual Tools: vvv

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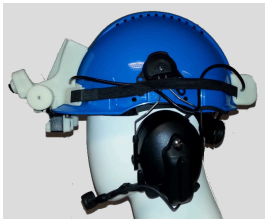
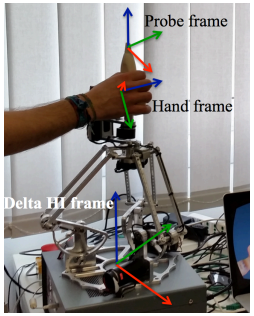
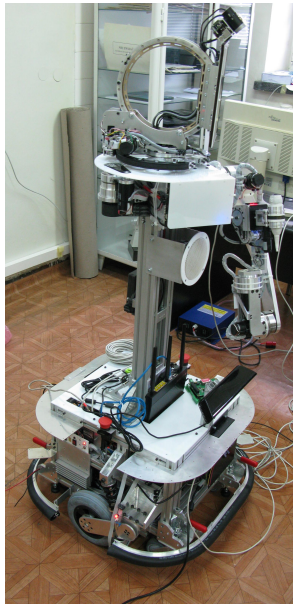
Big Picture

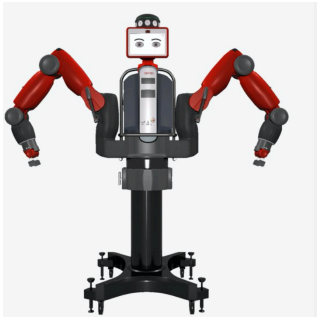




CoCo

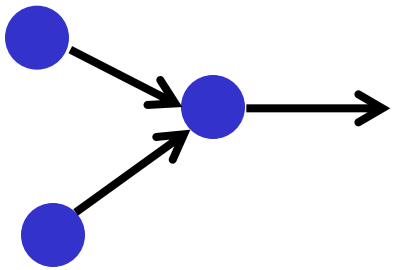


ROS

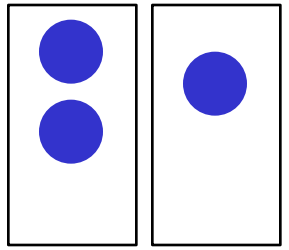


Three orthogonal Graphs

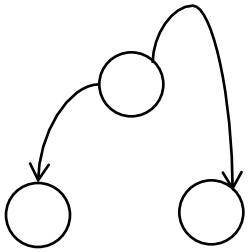
- Computational Graph
  - Component interaction and specification
  - Declarative model with **Data Flow**



- Scheduling Graph
  - Component execution in multithreaded environment
  - Run-time (thread) partitioning using **Activity**



- Transformation Graph
  - Transformation between frames in the MR/VR environment
  - **Declarative** graph with support for any transformation, calibration and fusion



Features CG – Components, Ports and Operations

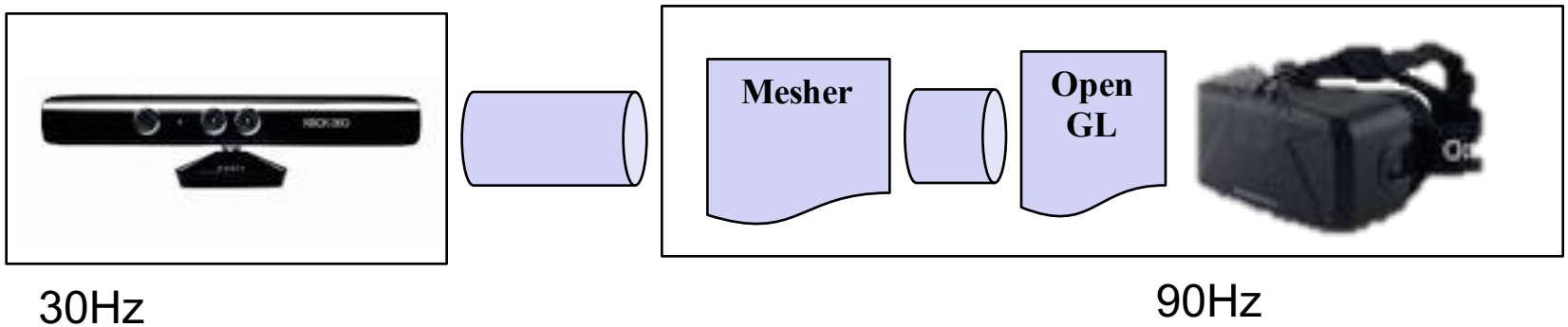
- **Tasks**: building blocks of CoCo
  - Configurable component (onConfig)
  - Externally controlled loop (onUpdate)
  - Interfaced via Input/Output statically typed **Ports**
  - Support **Operations** as asynchronous calls
- **Peers:** children task whose loop depends on the parent

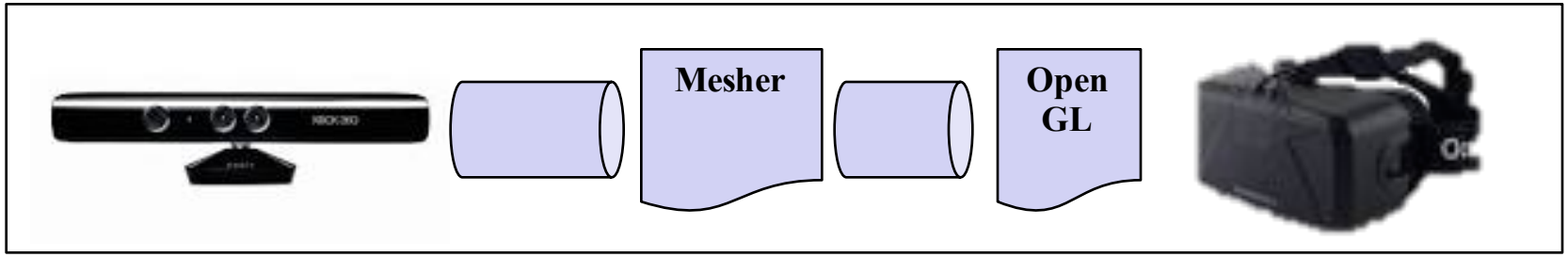
Features CG – Connections

- Different type of connections available between tasks' ports
  - FIFO: **Linear** buffer / **Circular** buffer
  - **Locked** / **Unsync** / Lock-free
- Instantiated at run-time
- Independent from the Task or Port type

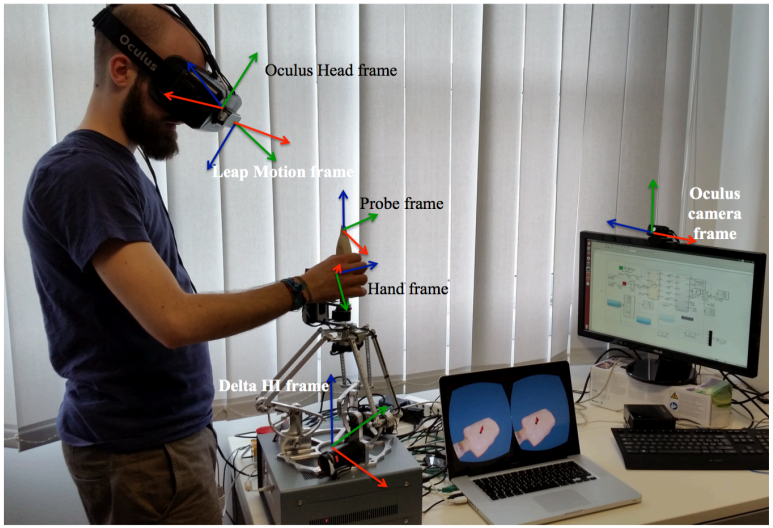
Features SG – Execution and Scheduling

- Tasks attributes and connections decided at start-time through **XML file** or dynamic via API
- Tasks execution can be **periodic** or **triggered** on data reception on specific port
- Each task can run on a **different thread** or can be grouped and executed **sequential** in the same thread



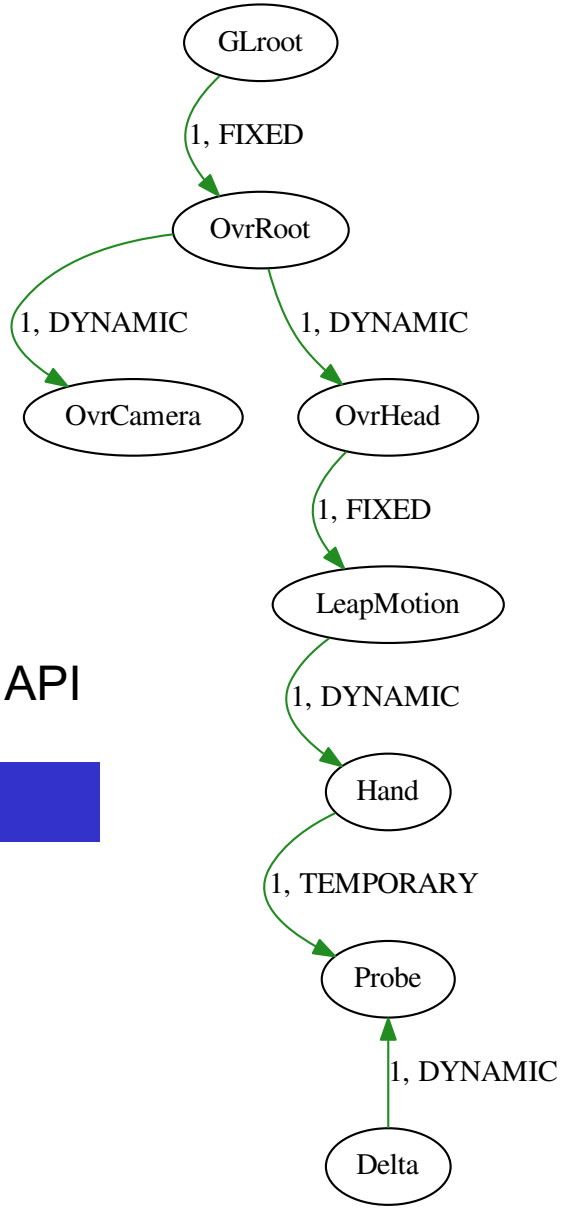


Features TG - Transformation



Scenario with HMD, Haptics and Tracking

Declaration of References and Transformations



Runtime API

- Query Transformation between any References
- Populate DYNAMIC Transformations
- Support Calibrations

Integration with CoCo components

Publishing pending

Transformations & Calibrations

- Query Transformation between any References
- Populate DYNAMIC Transformations
- Support Calibrations

Naming
Reference frame: R
Transformation edge:
$T(R,1,R2) = {}^{1}T_{2}$

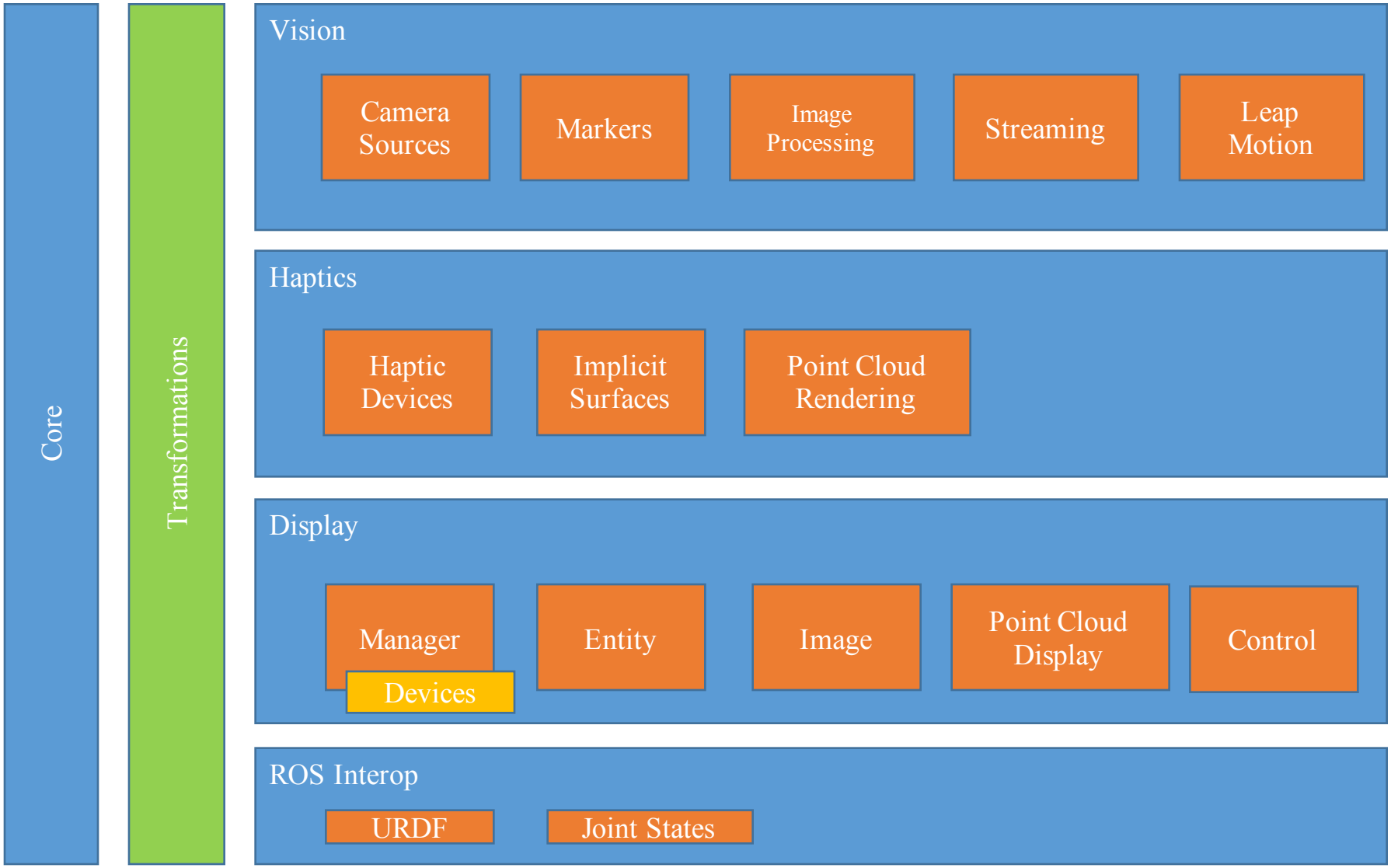
Integration with CoCo components:

- Sensor components publish transformations between two reference frames
- Graphical components are attached to a given reference frame

Calibration means to compute the transformation between two reference frames based on temporary transformation

- Temporary transformations are accumulated and then averaged in SE3
- The resulting calibration is stored in the Graph
- The temporary edge is removed

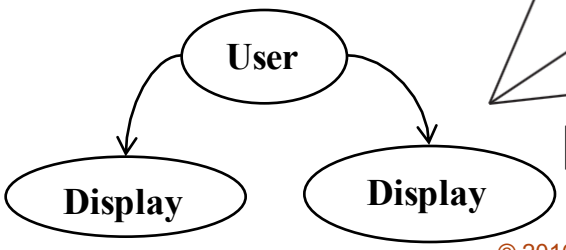
Components for Mixed Reality (CoCoMR)

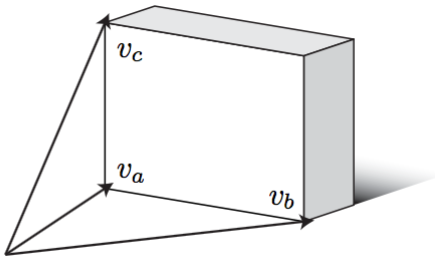


CoCo is a C++ library for Linux, OSX, (Windows)

Dealing with Display

- Classic Approach: Scene Graphs
  - Hierarchy of objects augmented with cameras
- Data Flow Approach
  - Geometrical nodes produce output that flow into renders
- CoCo Approach
  - Geometrical nodes are children of the renderer (peers)
  - Participate to flow at global scale
  - Attached to any Reference Frame
    - This allow rendering from multiple point of views
  - Constrained to scheduling of OpenGL (single thread)
- Displays Targets
  - Oculus SDK (Linux, < 0.5)
  - **Generic Stereo display surface with Oblique Projection integrated in Transformation Graph**
  - Render to Texture

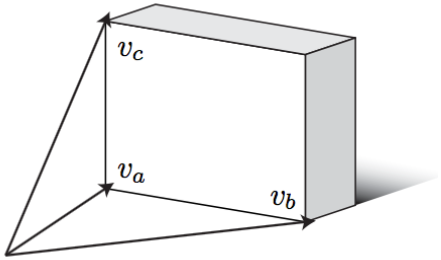


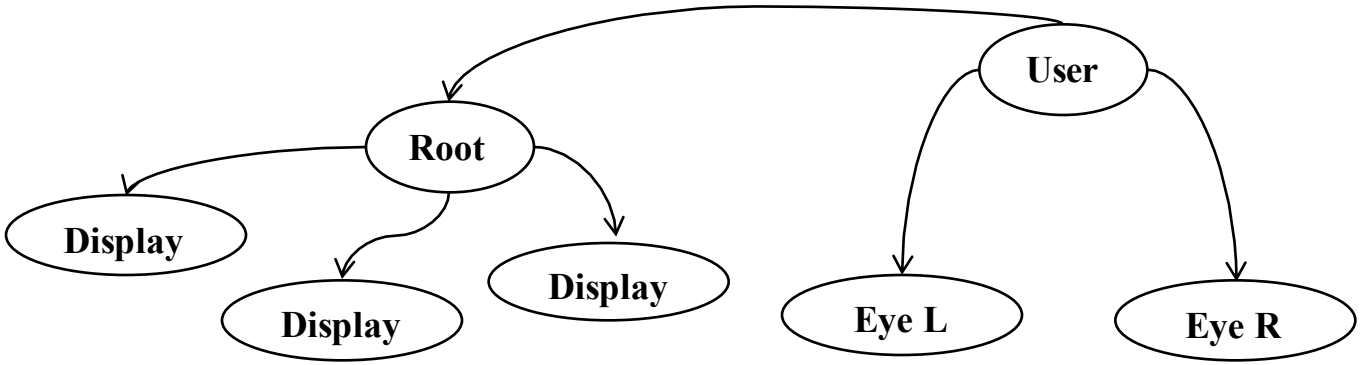


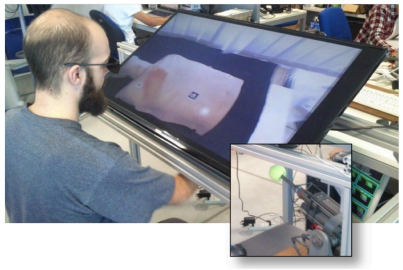
[Lenglyel 2011]

Dealing with Display

- Displays Targets
  - Oculus SDK (Linux, < 0.5)
  - Rendering to Texture
  - Generic Display surface with Oblique Projection [Lenglyel11] connected to **Transformation Graph**
  - **Needed for Head Tracking**







Haptic Rendering (HR)

Definition

HR deals typically with impedance models in which the position of the user's proxy collides with the virtual environment computing a resulting force at 1kHz

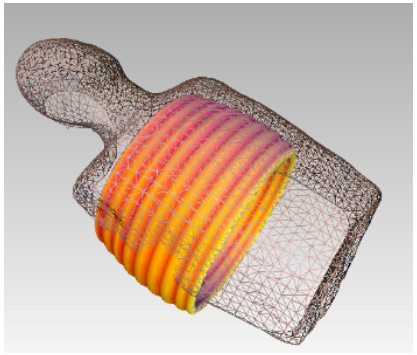
CoCo

- Connection with the Haptic Interface (UDP/USB to Haptic device)
- Geometry management
  - Triangular Mesh
  - Point Cloud
- Force computing component
  - Implicit surface Rendering
  - *3DoF Finger Proxy from CHAI*

Implicit Rendering

- 3DOF proxy computed over an implicit surface f(xyz) = 0
- Proxy with friction
- Implicit surface from CSG composition of basic surfaces
- Implicit surface obtained from point cloud or mesh sampling
  - RGB-D source from Kinect
  - KD-Tree as background structure

```
tr 0.5 0.35 0.015
tx -0.6 -0.3 -0.06 -30 0 0 1
+ tr -0.03 0.0 0.0 torusx 0.182 0.009
+ tr -0.01 0.0 0.0 torusx 0.184 0.01
```



...ni A. & Avizzano C.A. (2015). Co-Located ...SG exploration. In *Proceedings of IEEE EMBC*

Outline

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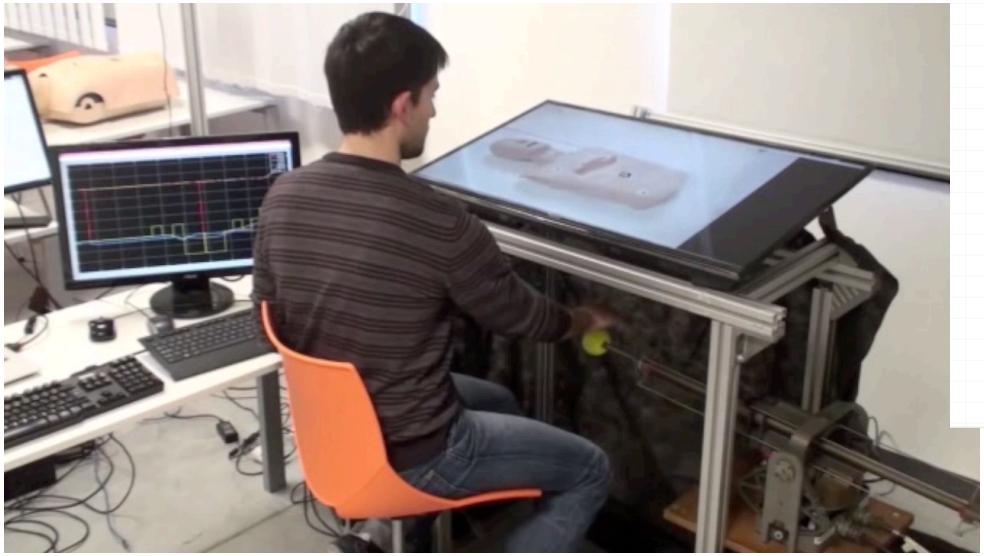
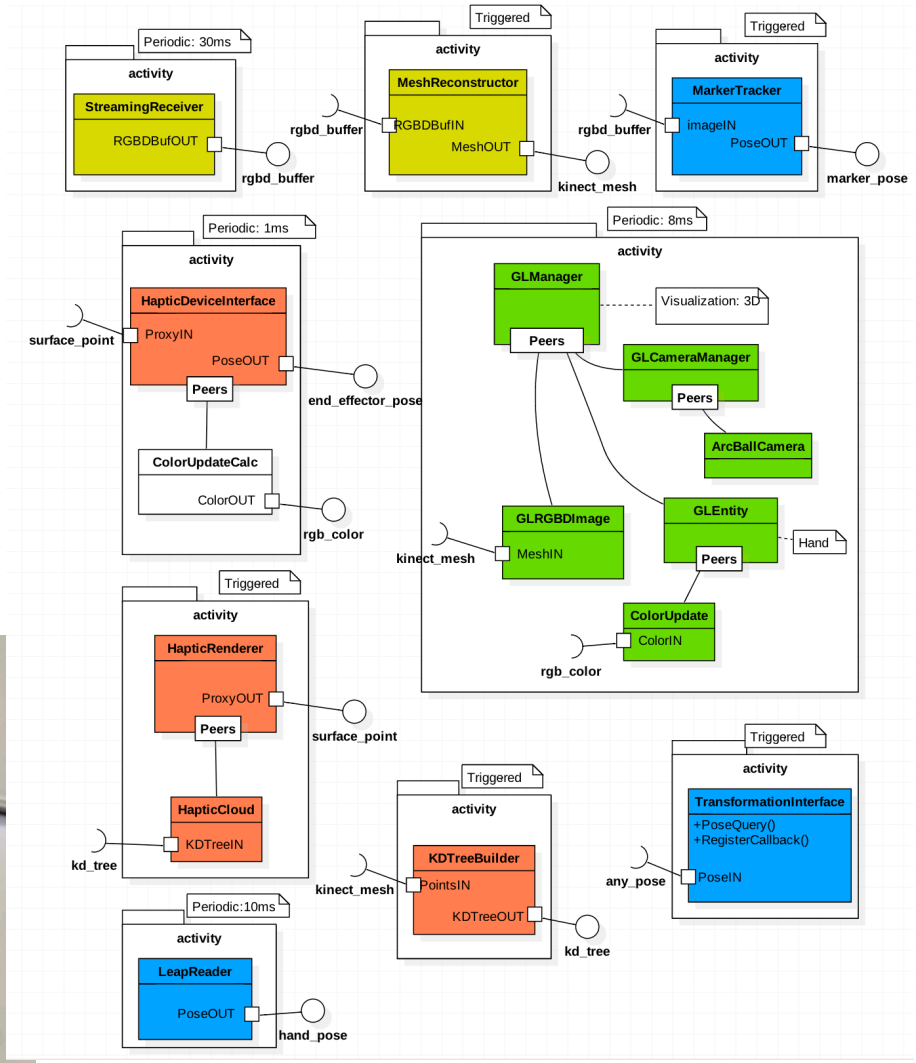
Remote Palpation

- Remote palpation with a Robot/Haptic device
- Augmented Desktop display
- Hand-Haptic co-location
- RGB-D streaming

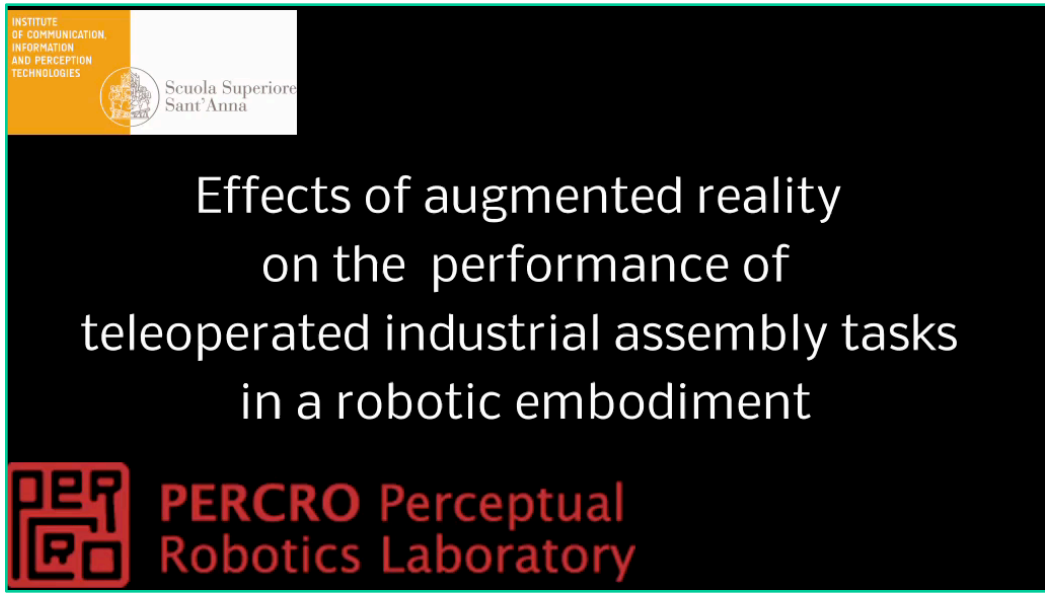


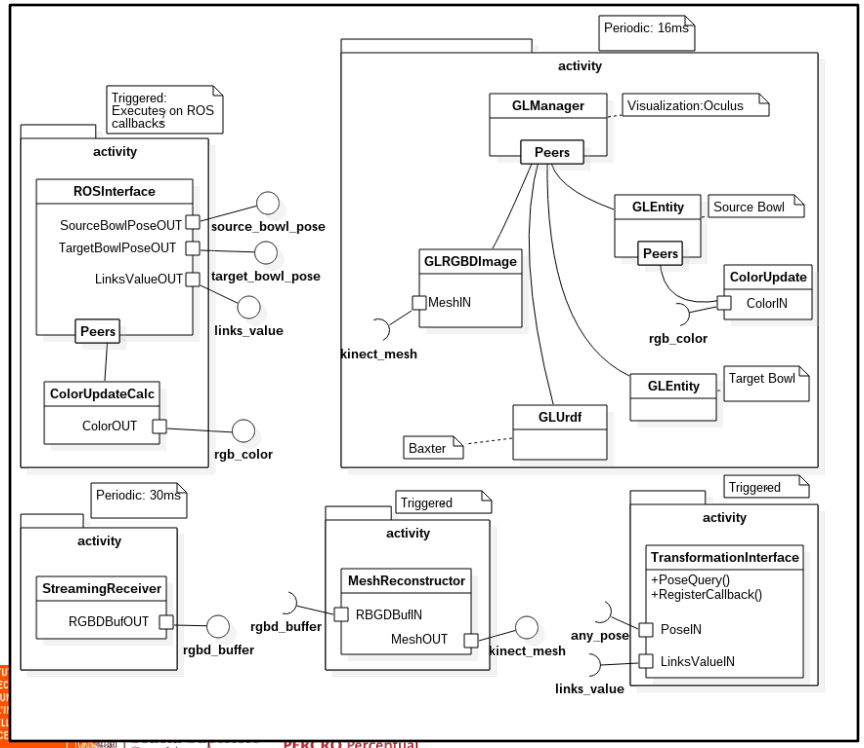


Filippeschi A., Brizzi F., Ruffaldi E., Jacinto J.M. & Avizzano C.A. (2015). Encountered-type haptic interface for virtual interaction with real objects based on implicit surface haptic rendering for remote palpation. In *IEEE IROS Proceedings*

AR for Teleoperation

- Study of AR for Robot Teleoperation
- Baxter robot with ROS
- Display with Oculus DK2
- Human motion using inertial device and haptic interface





Augmentations

- Robot body with URDF overlay
- Target object
- Distance to object

Peppoloni L., Brizzi F., **Ruffaldi E.** & Avizzano C.A. (2015). Augmented Reality-aided Tele-presence System for Robot Manipulation in Industrial Manufacturing. VRST

Submitted to IEEE THMS

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Scenario Comparison

Remote Palpation

- 3D Screen Display
- Hand tracking
- RGB-D streaming
- Implicit surface from RGB-D

Robot Teleoperation

- Oculus
- Robot interoperability
- AR Display
- Robot-User Co-Location

Virtual USG

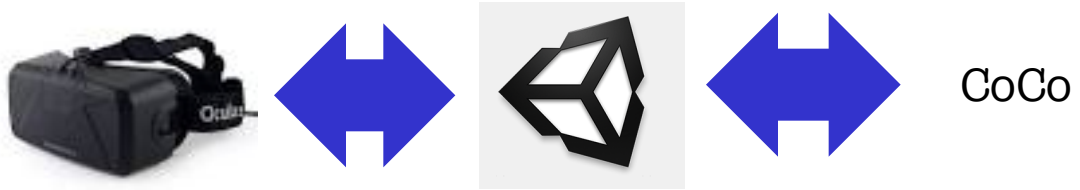
- Oculus
- 3DOF Haptic Device
- Haptic-HMD Co-Location
- Implicit surface modeling

Diagnostic Tools

- Web-based tools for accessing the graphs
  - Transformation viewer
  - Component connections
  - Profiling of data exchange

Conclusions and Future Work

- GPU data types and tasks
- Processing patterns: pipeline and farm
  - Useful when dealing with computer vision
- Automatic Scheduling Graph
  - Semantic and profiling guided allocation of components in the Scheduling Graph
- Interface with Unity for high-end graphics



Thanks for your attention!

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Done with CoCo: poster *"Third point of view Augmented Reality for robot intentions visualization"*

References

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- 3DUI15 - Peppoloni L., *Brizzi F.*, Avizzano C.A. & Ruffaldi E. (2015). Immersive ROS-integrated framework for robot teleoperation. In *Proceedings of IEEE 3DUI* (pp. 177--178).