



CREB Centre de Recerca en Enginyeria Biomèdica
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Course: Medical Robotics

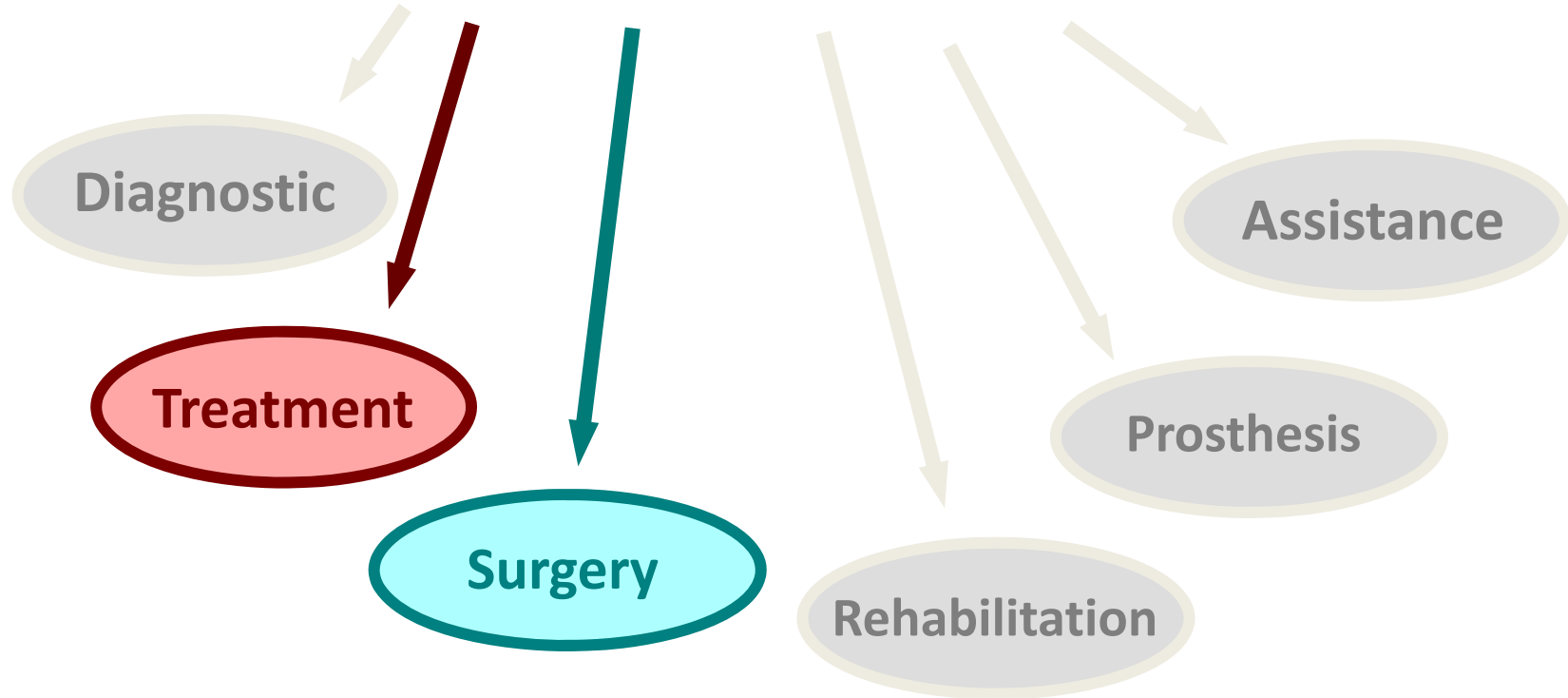
PART II: Surgical Robotics

Alícia Casals

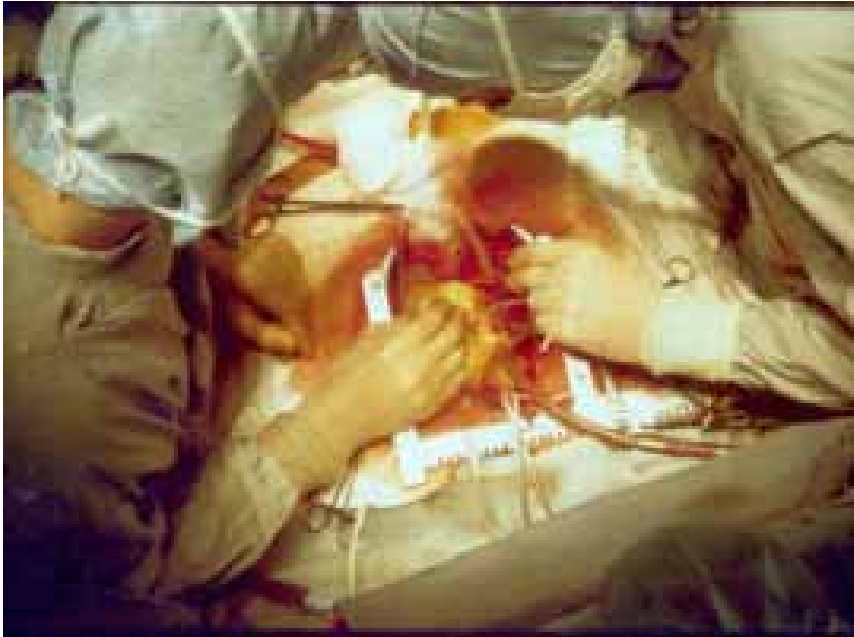
Master in Medical Image and Applications (MAIA)



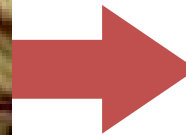
Robotics Application Fields in Medicine



Progress in Surgical Procedures



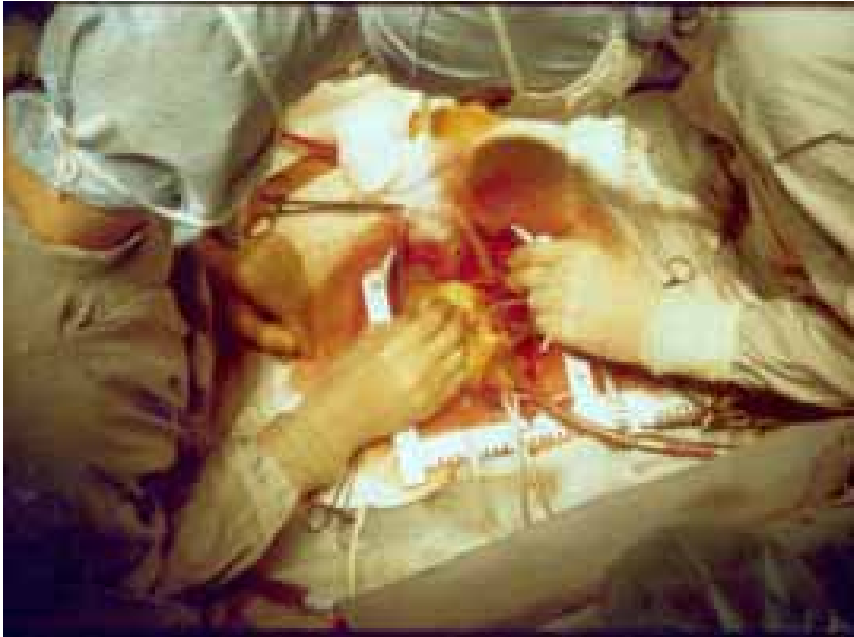
Open surgery



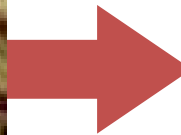
Minimally Invasive Surgery (MIS)



Progress in Surgical Procedures



Open surgery



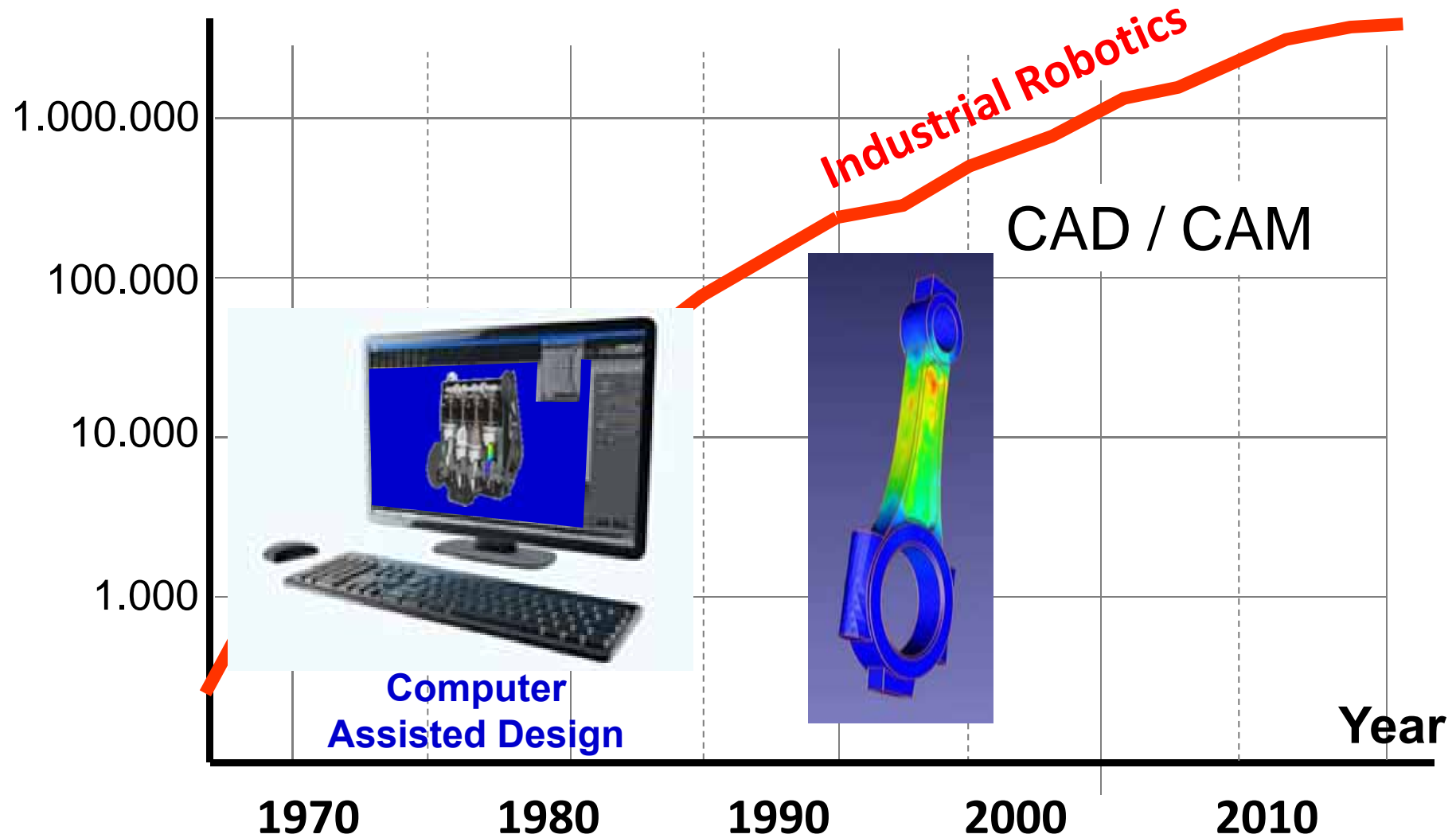
Robotic MIS



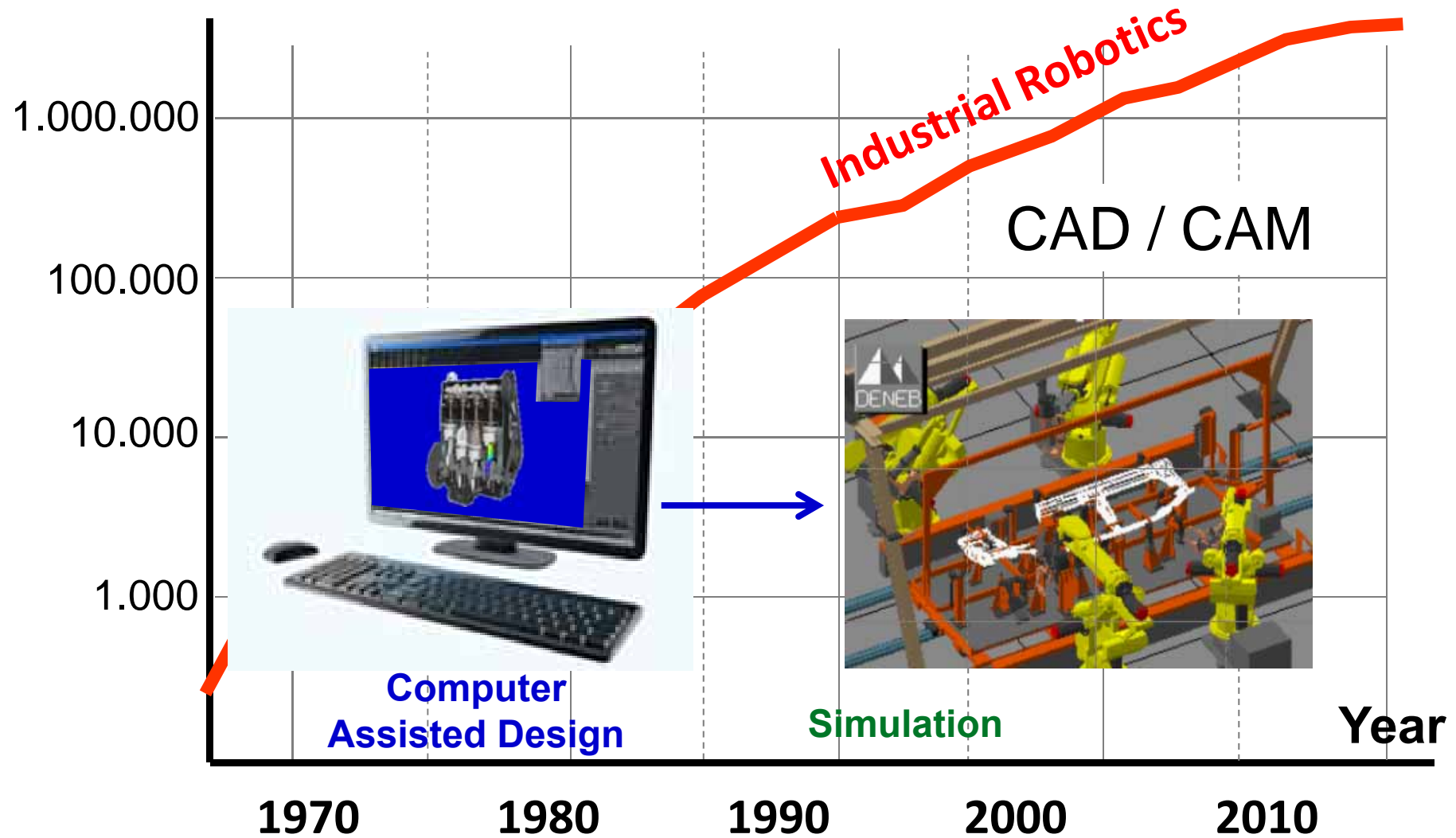
Surgical Environments

- Hard tissues
 - { Stereotaxis techniques applicable
(Skull or pelvis)
 - { Stereotaxis not applicable
(Femur or humerus)
- Soft tissues
 - { Plastic parts
(Kidney or liver)
 - { Elastic parts
(Nerves or tendons)
 - { Static
(Brain or pancreas)
 - { Dynamic
(Heart or lungs)

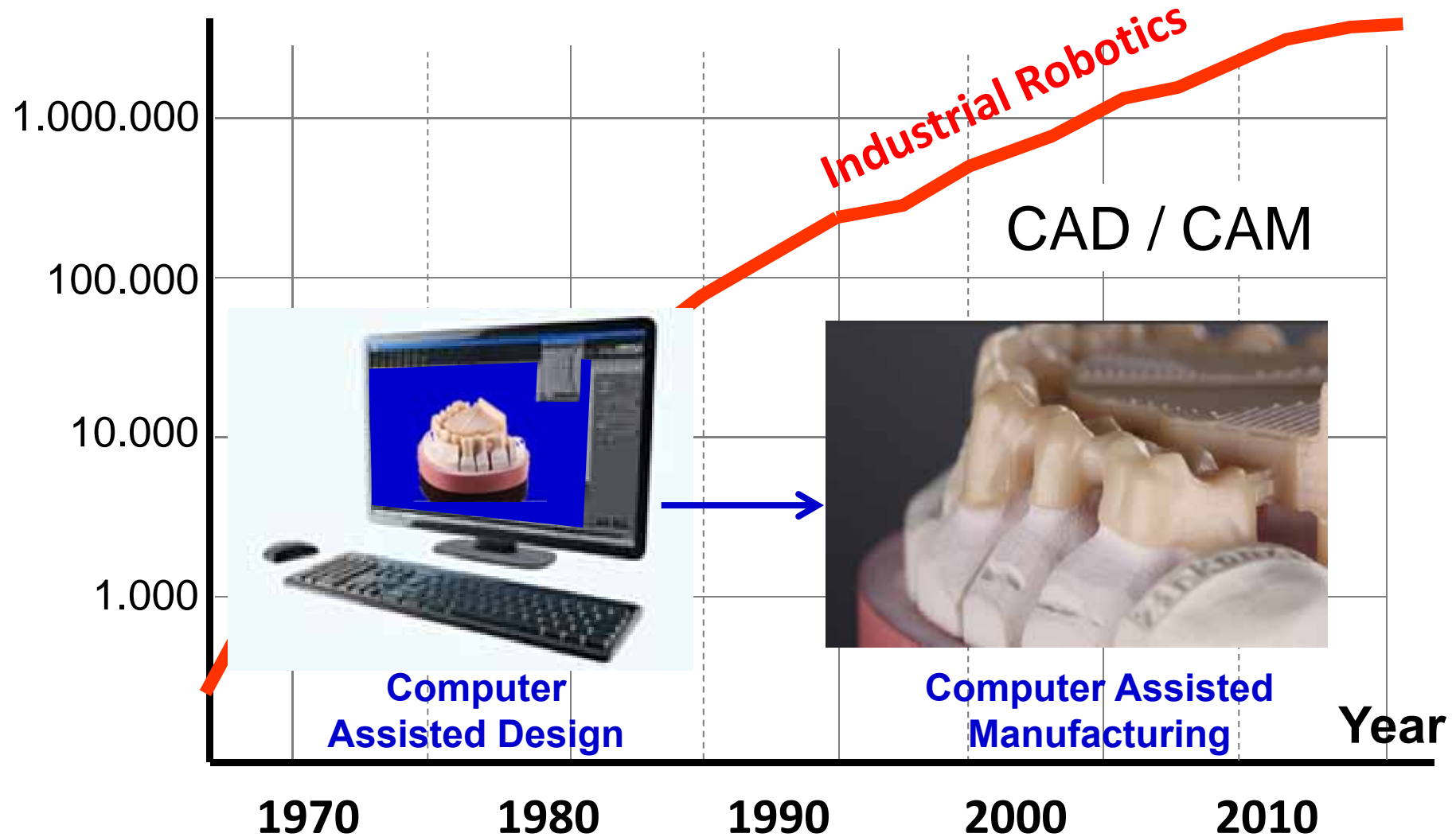
Industrial versus Surgical Robots



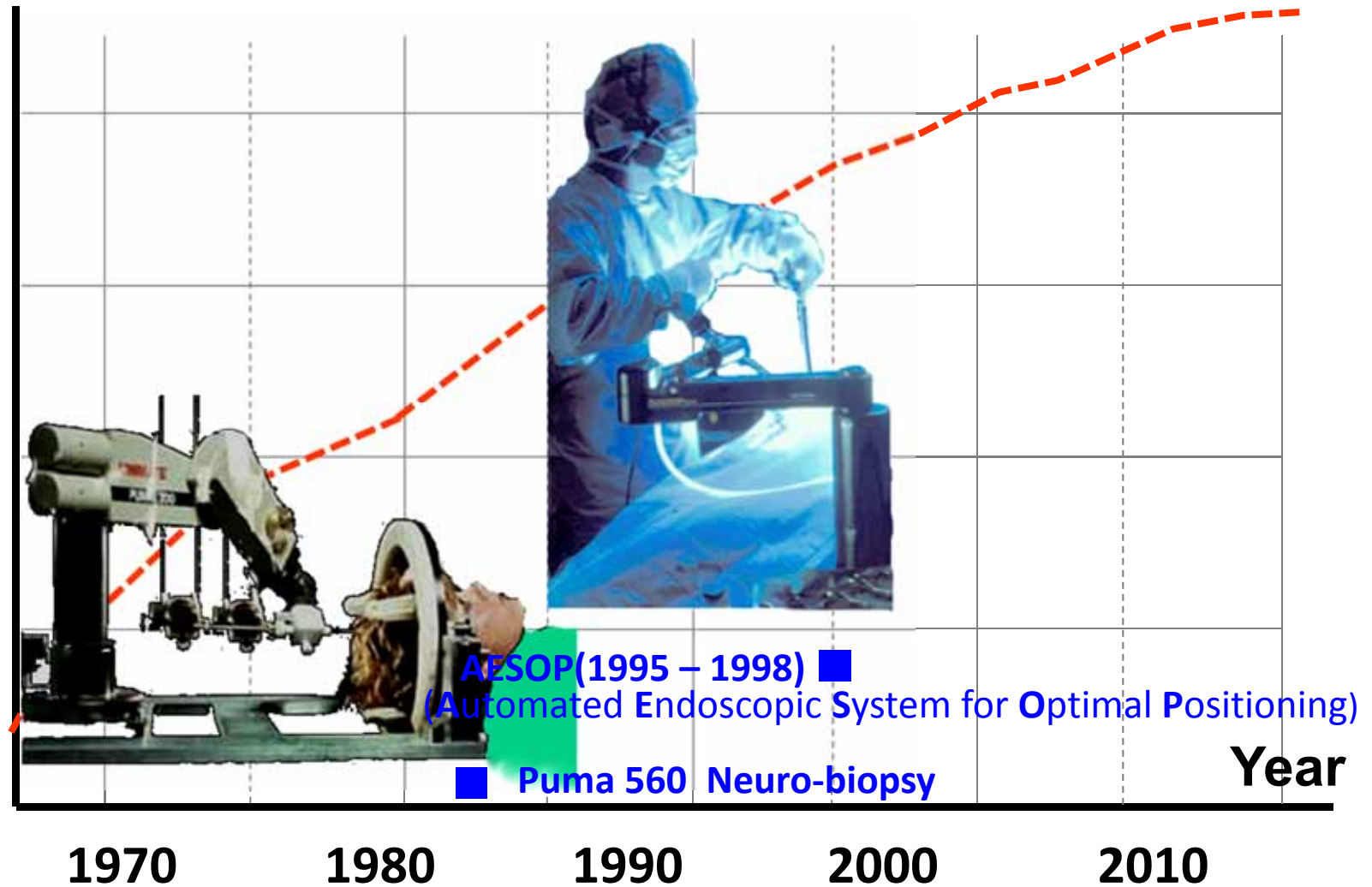
Industrial versus Surgical Robots



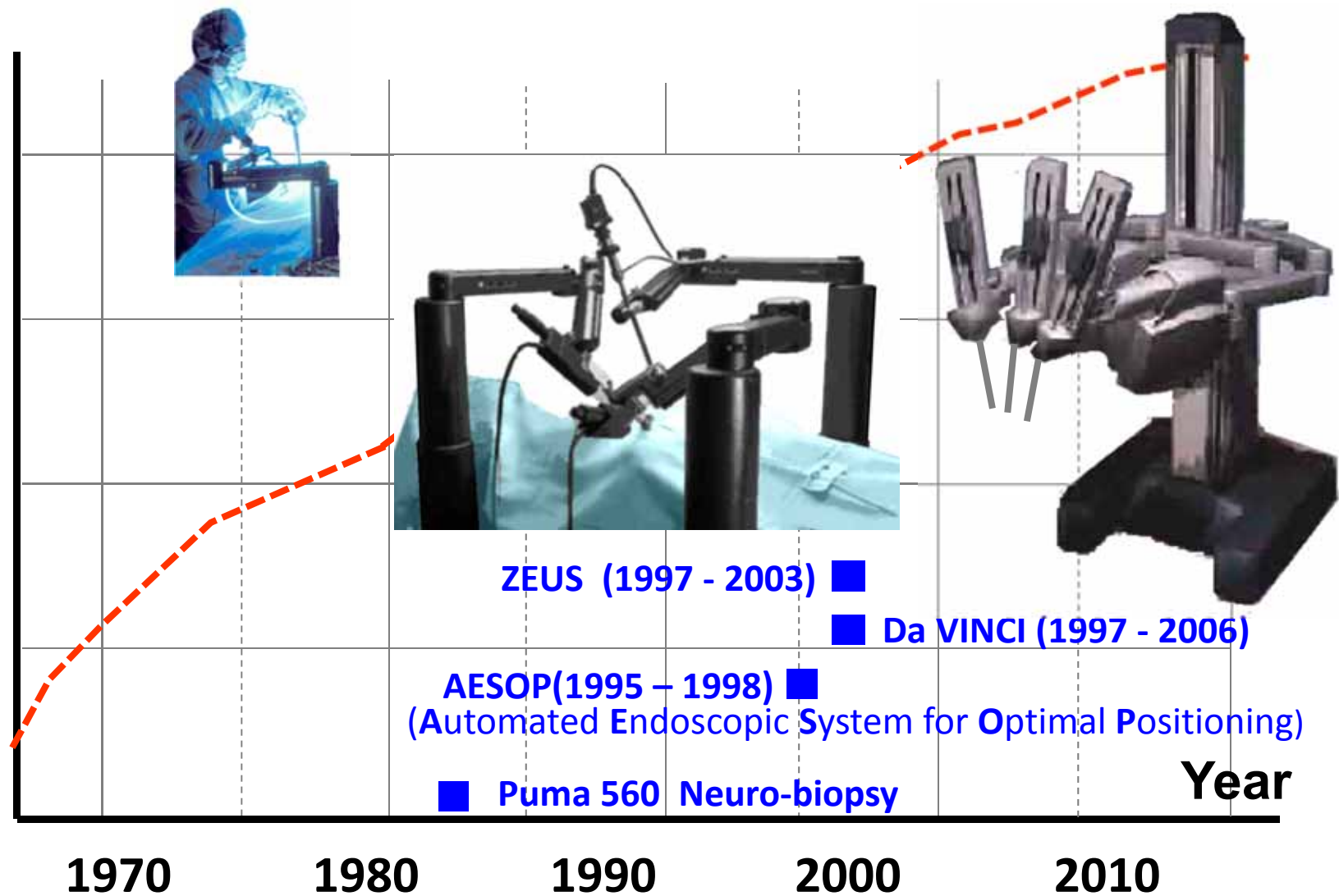
Industrial versus Surgical Robots



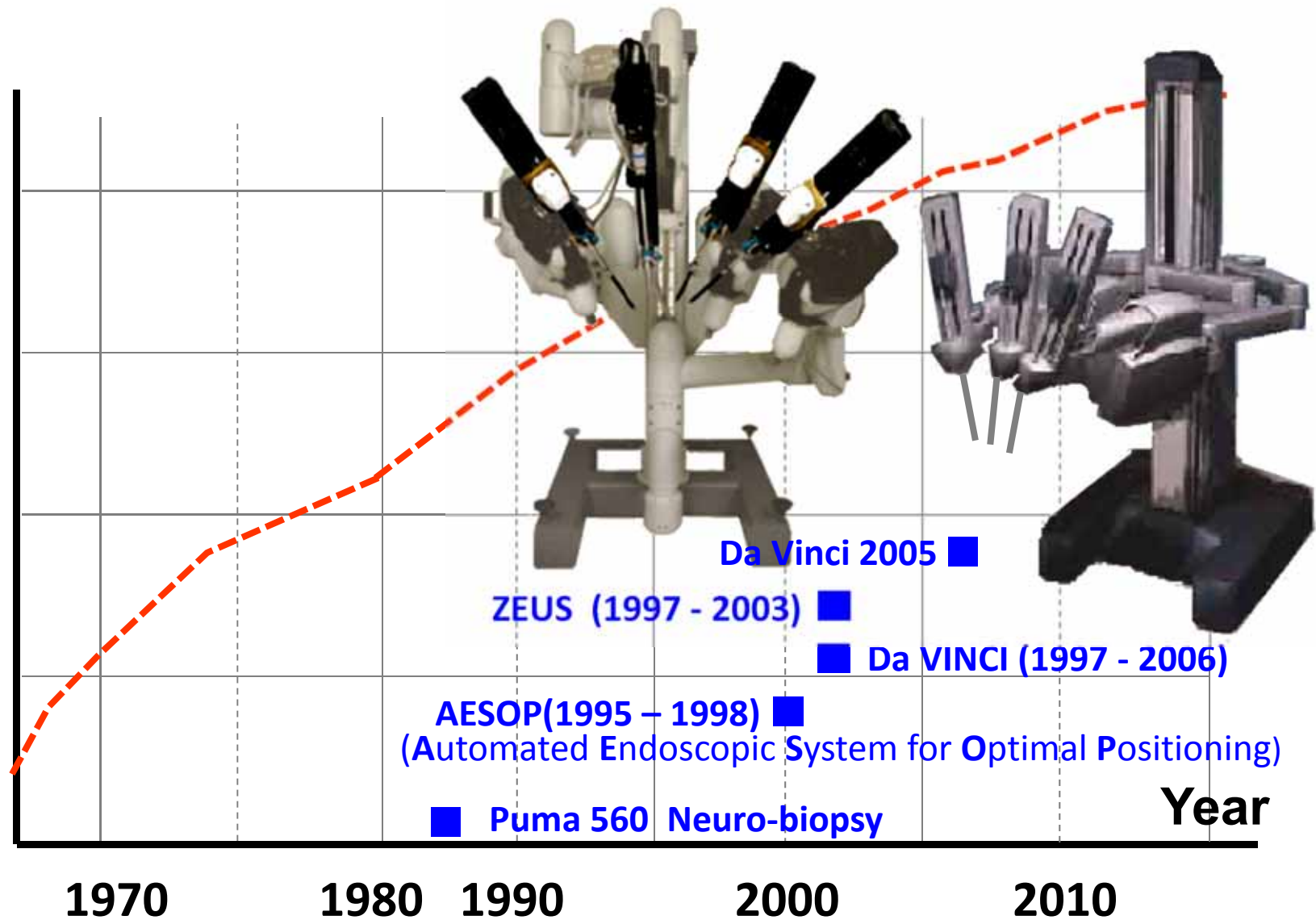
Industrial versus Surgical Robots



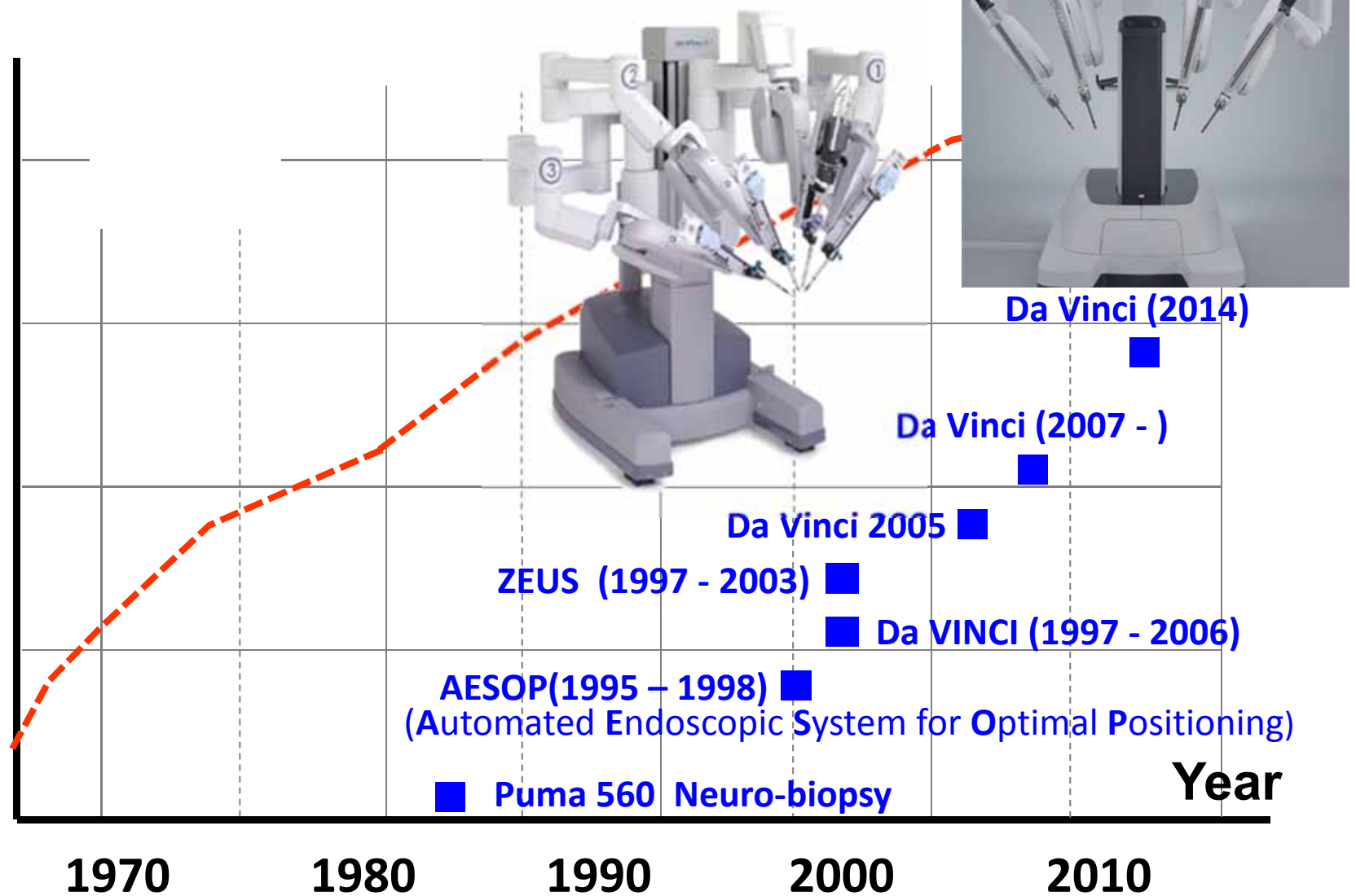
Industrial versus Surgical Robots



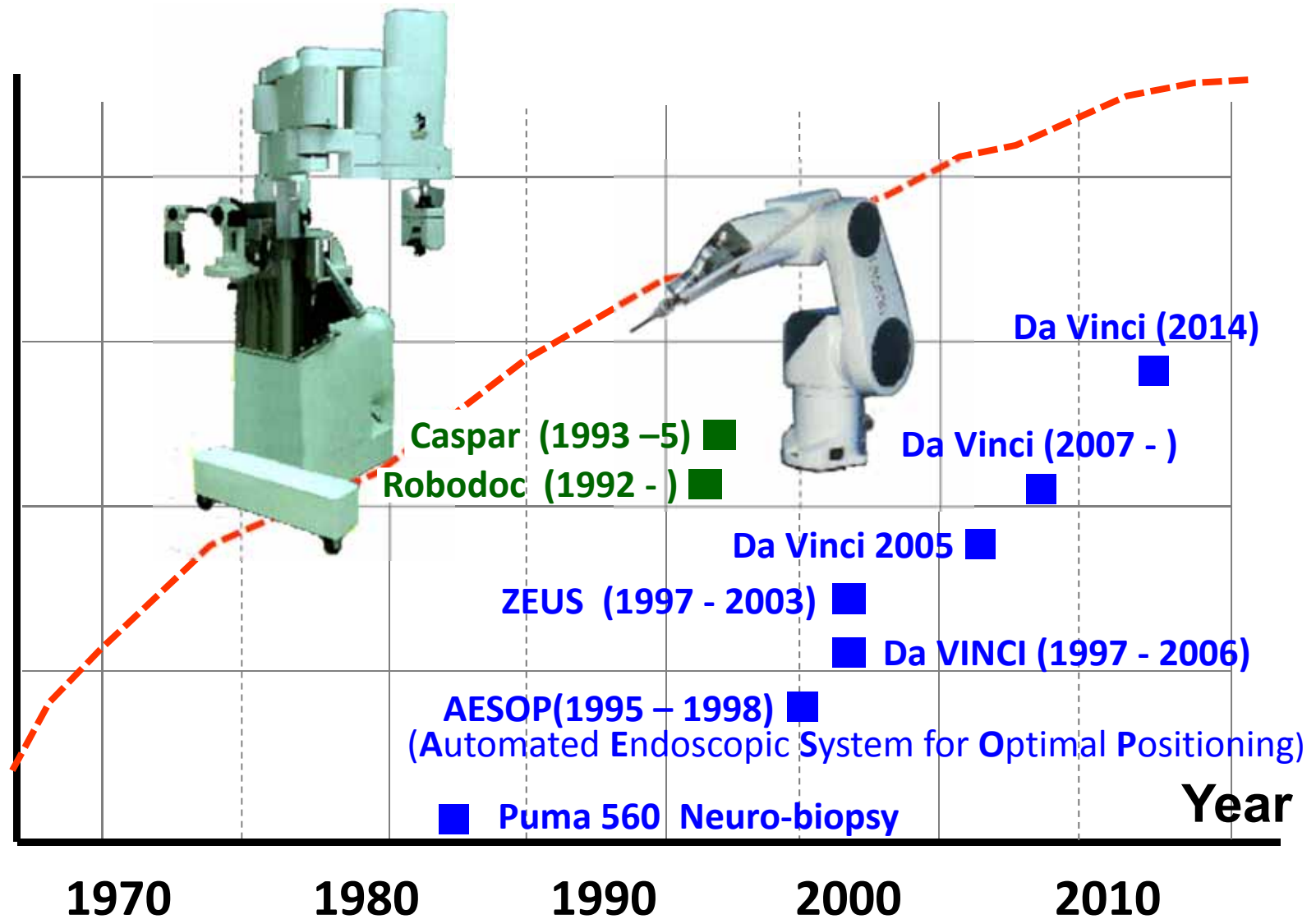
Industrial versus Surgical Robots



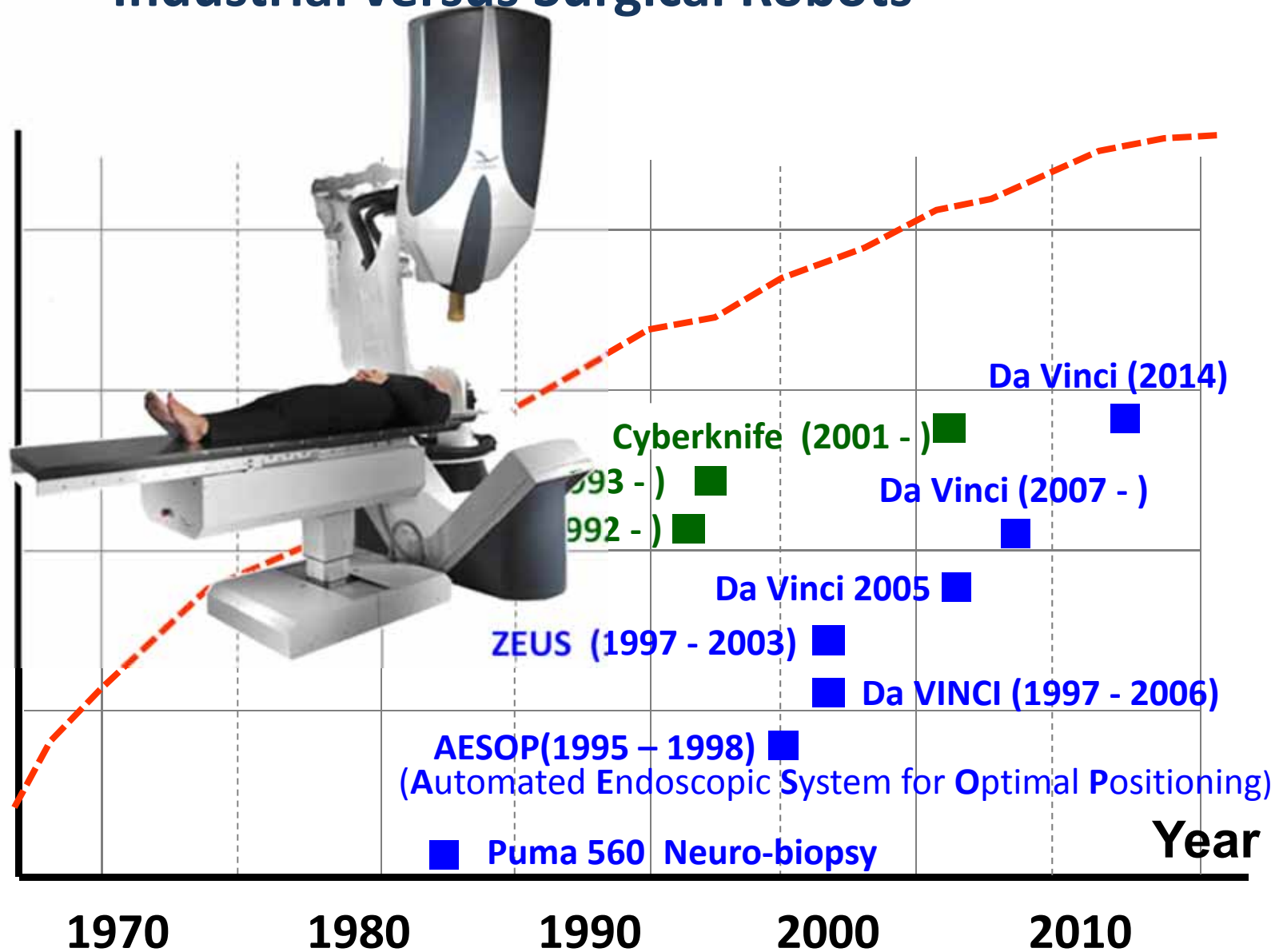
Industrial versus Surgical Robots



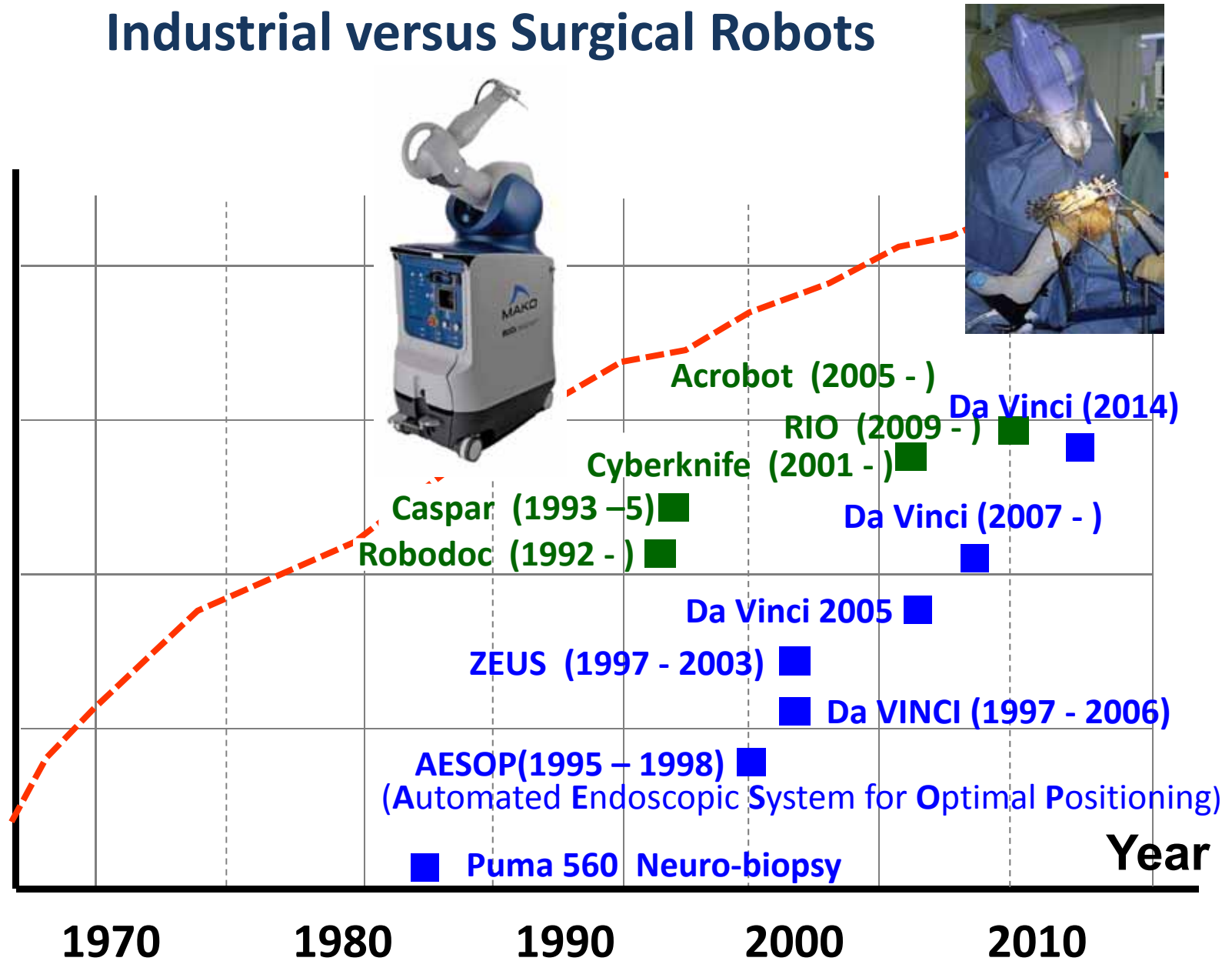
Industrial versus Surgical Robots



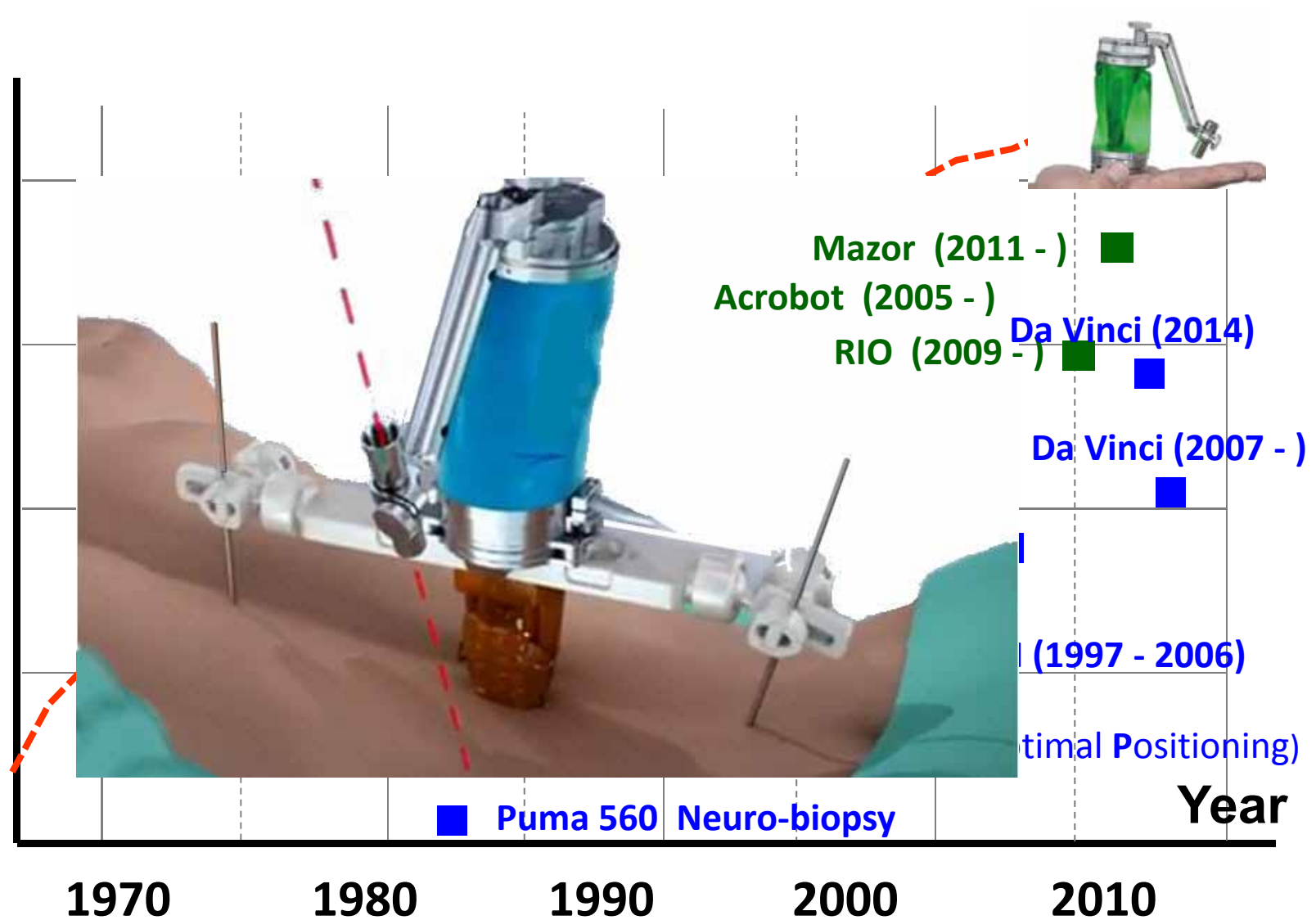
Industrial versus Surgical Robots



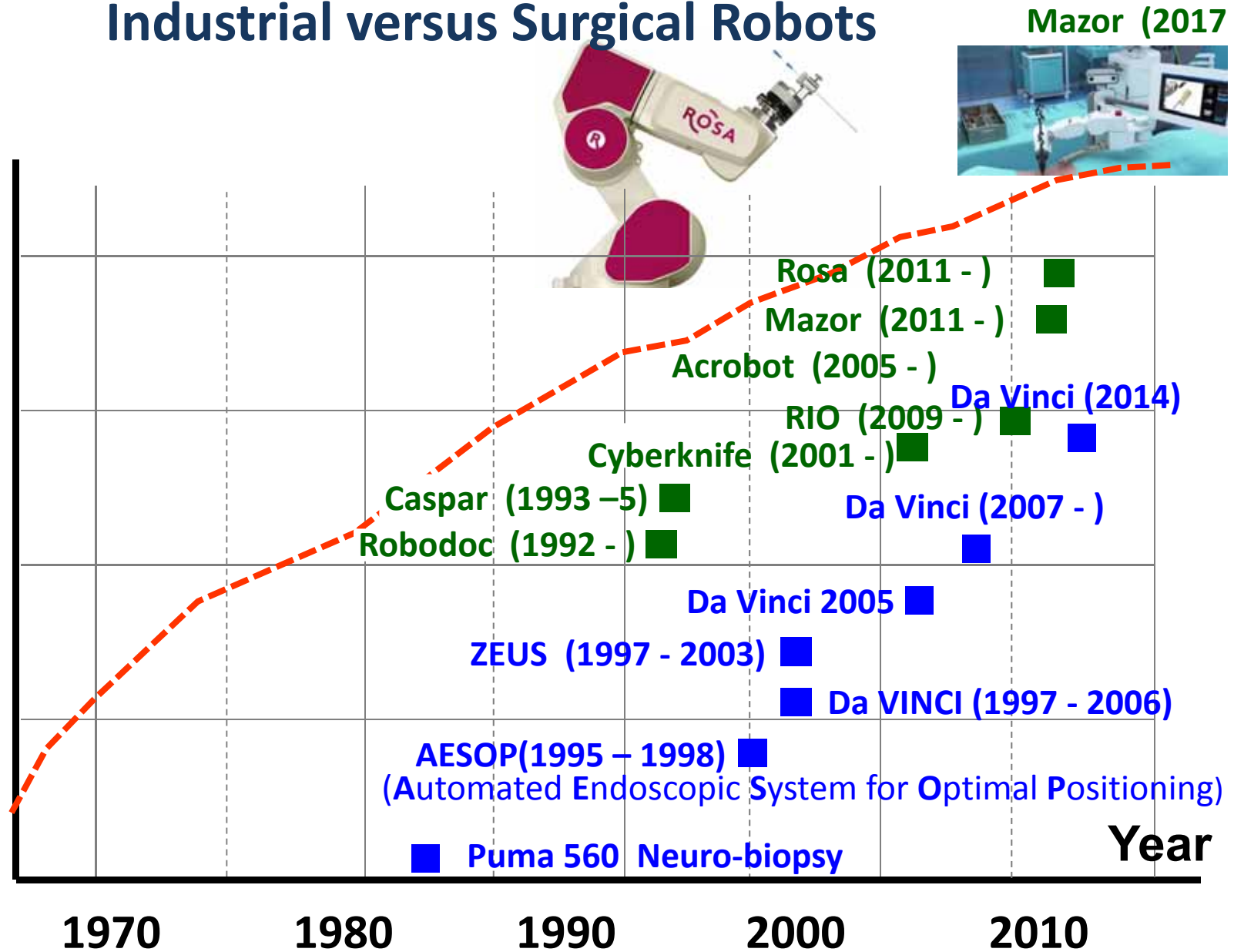
Industrial versus Surgical Robots



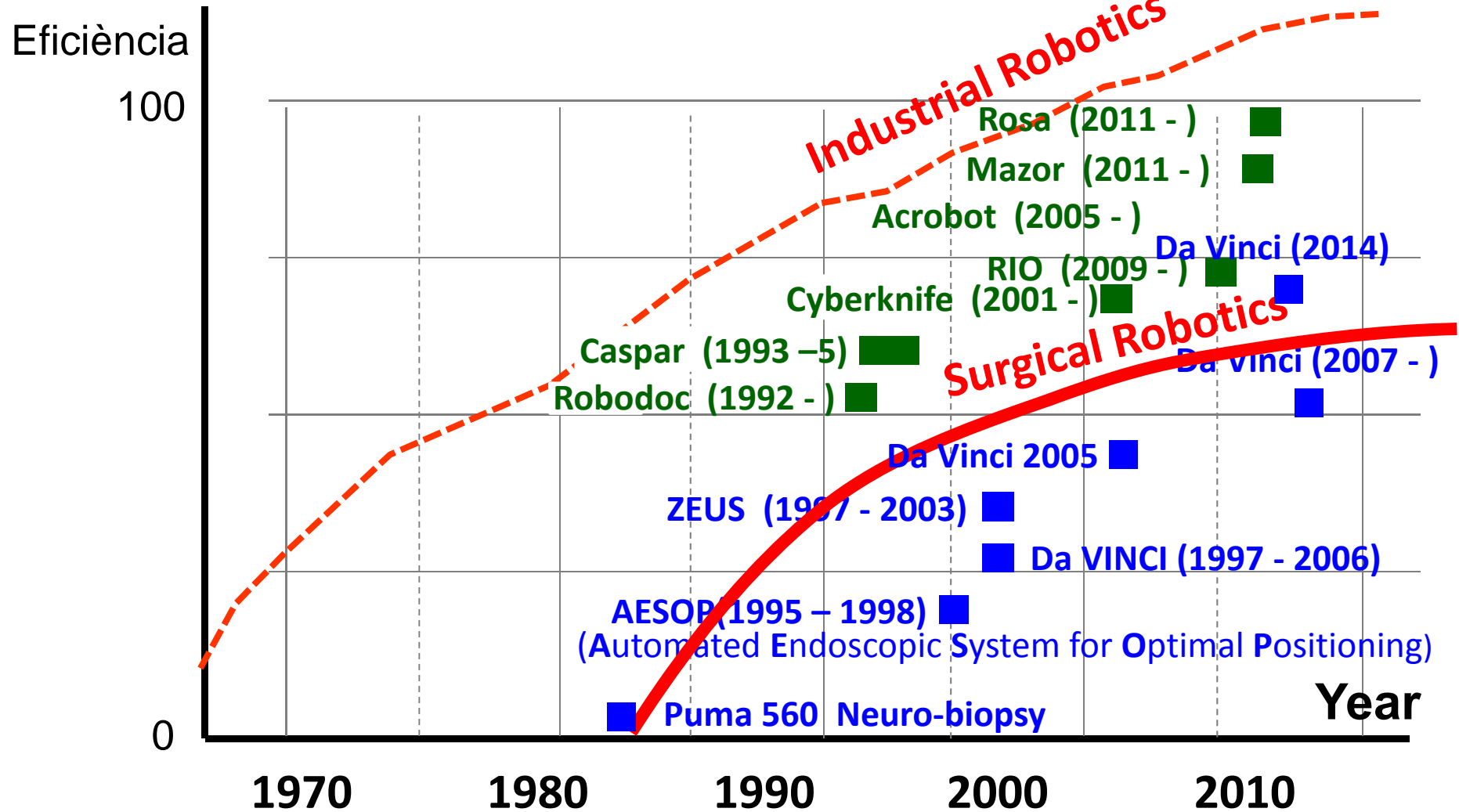
Industrial versus Surgical Robots

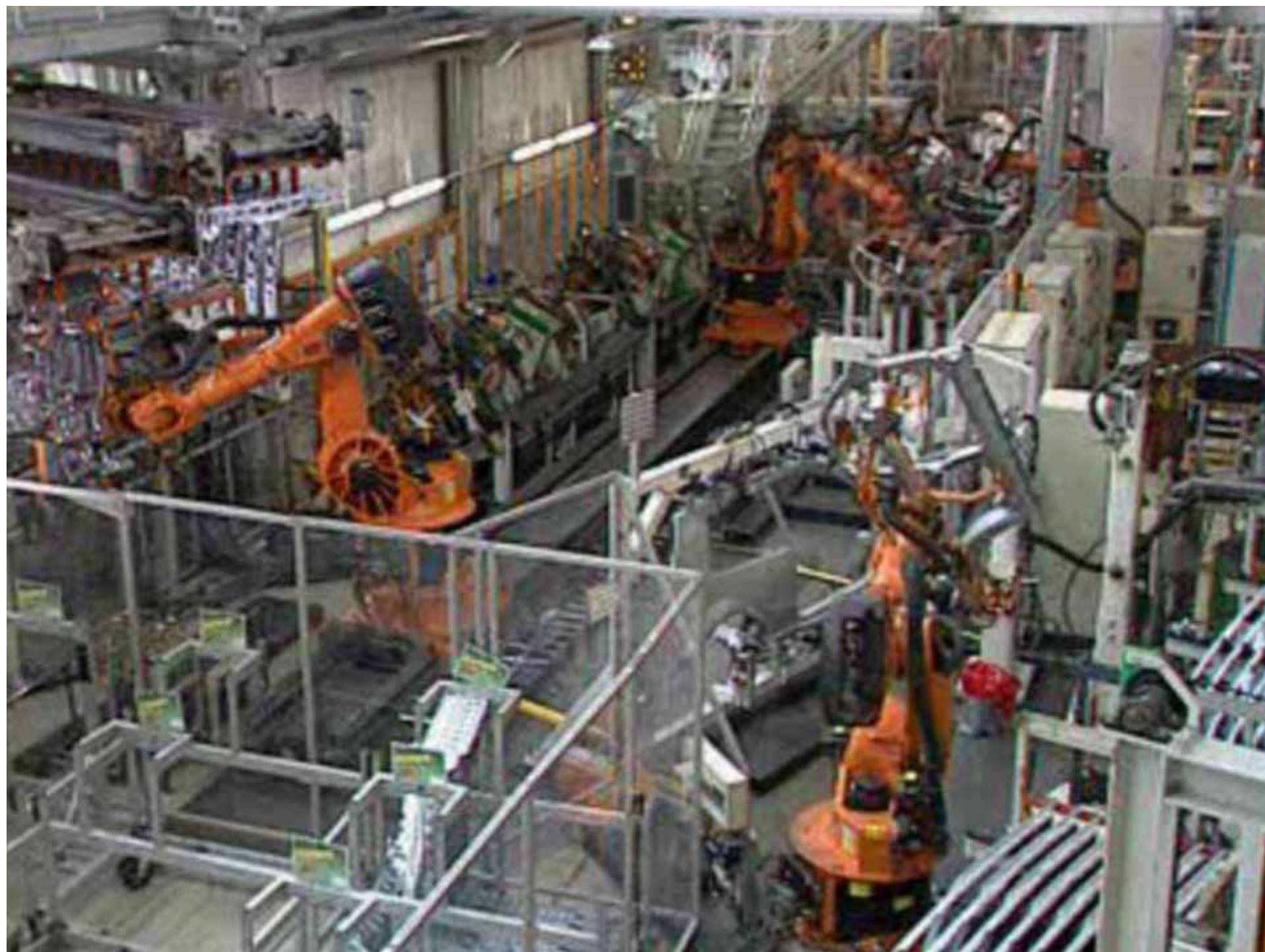


Industrial versus Surgical Robots



Industrial versus Surgical Robots

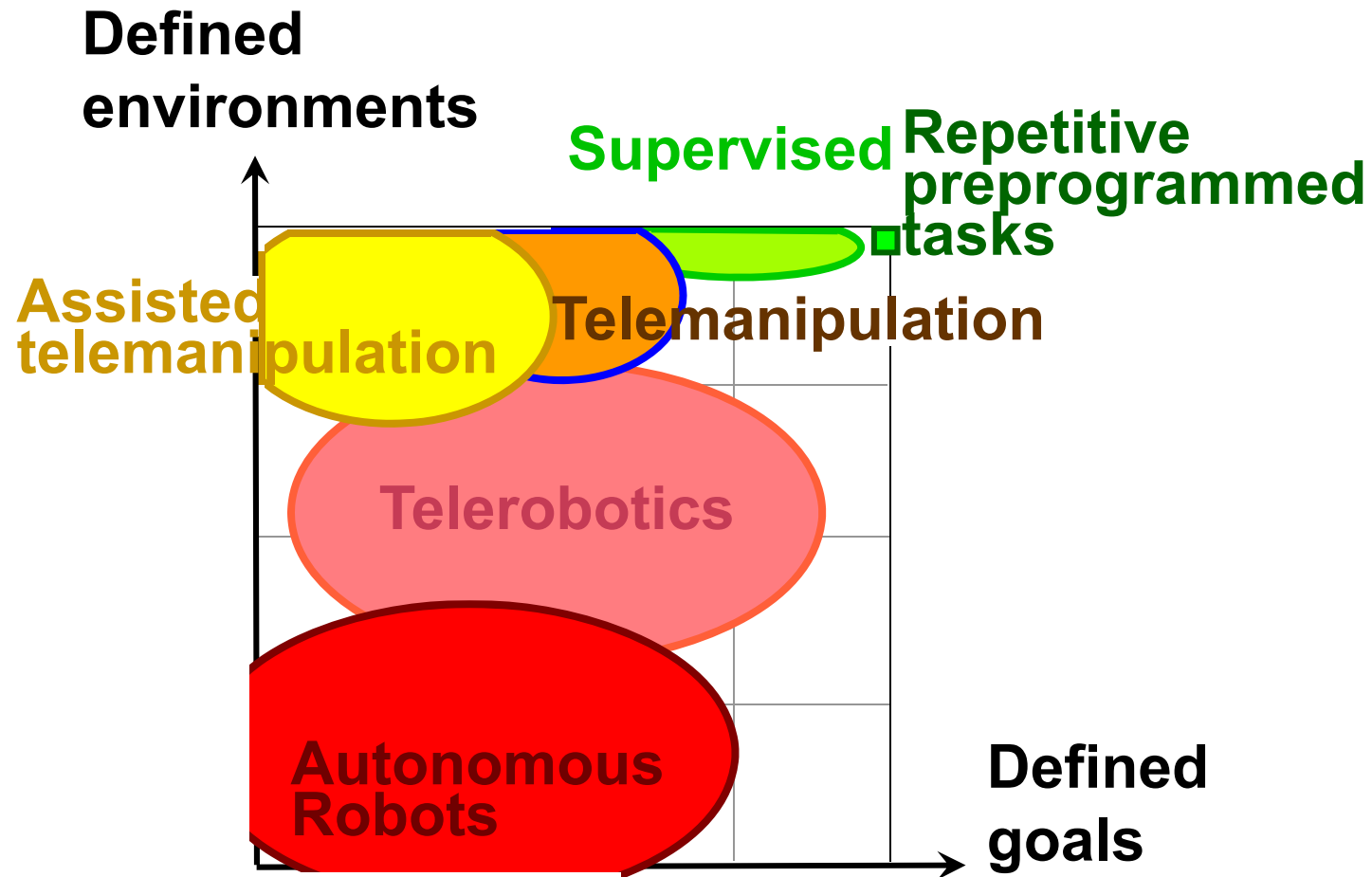




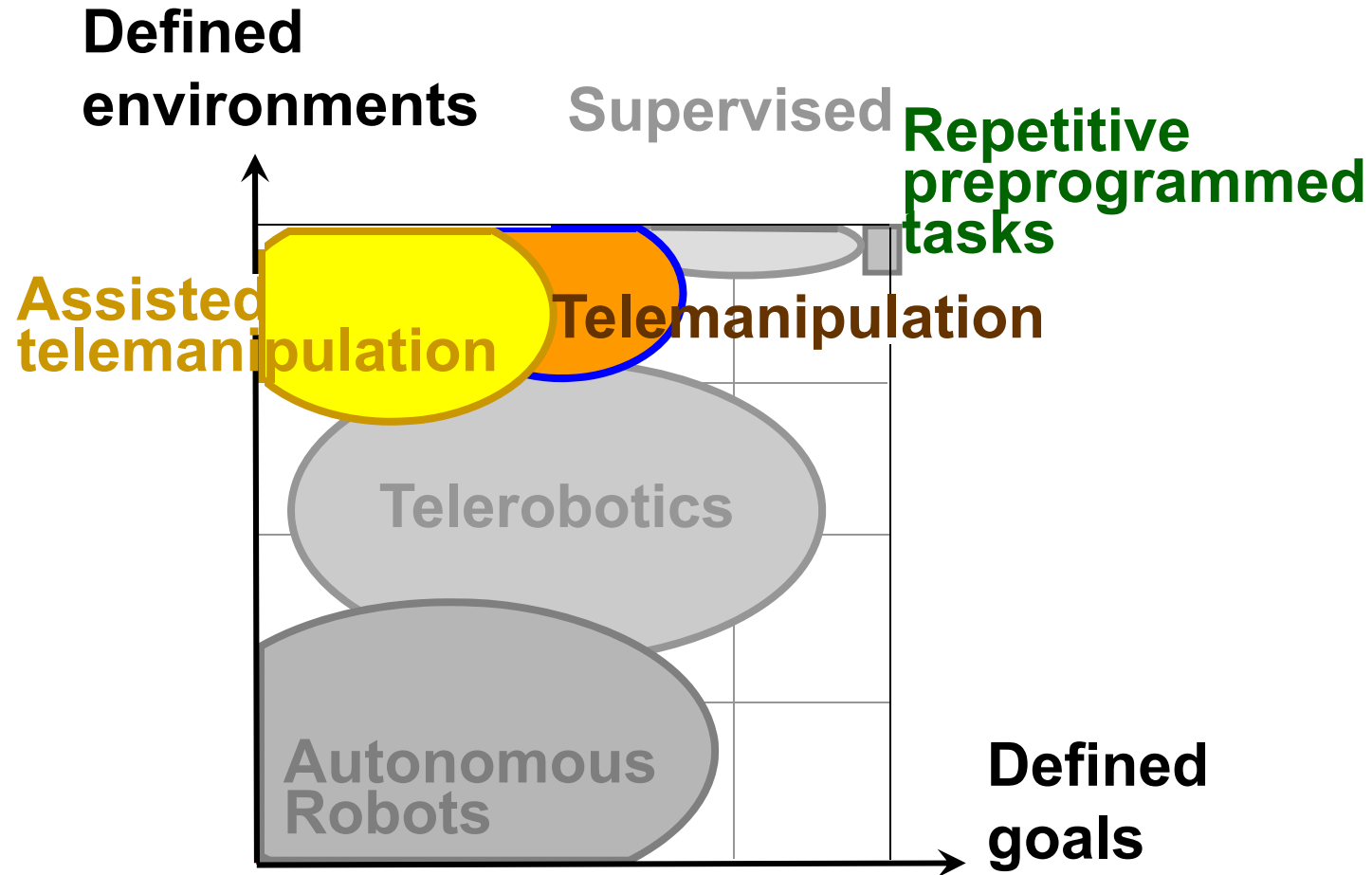
Human - Robot Cooperation

Type	Robot contribution	The role of cooperation
Microsurgery		
Neurosurgery		
Transcutaneous		
Percutaneous		
Intracavity		
Orthopedics		

Cooperation levels



Cooperation levels



Teleoperation

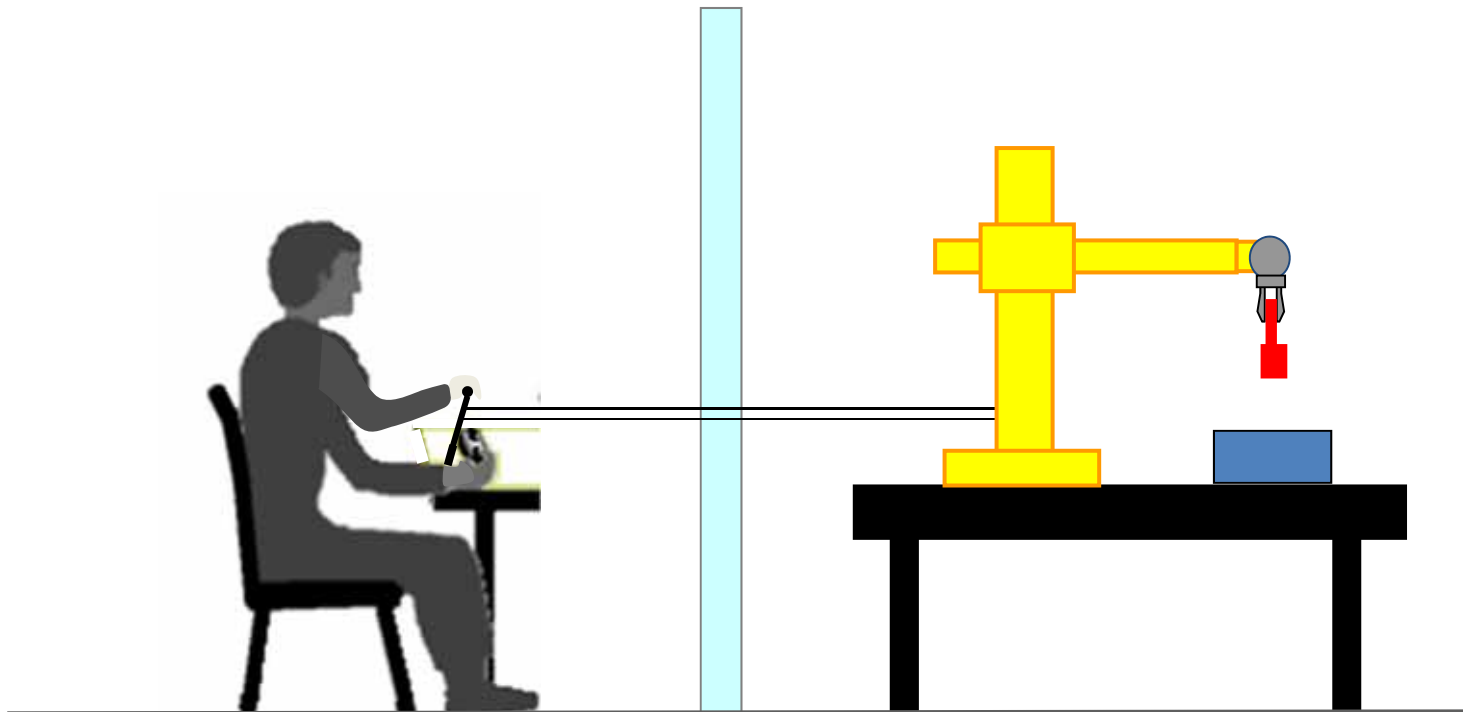
Mechanical transmission

Mechanical servotransmission

Assisted teleoperation (computer support)

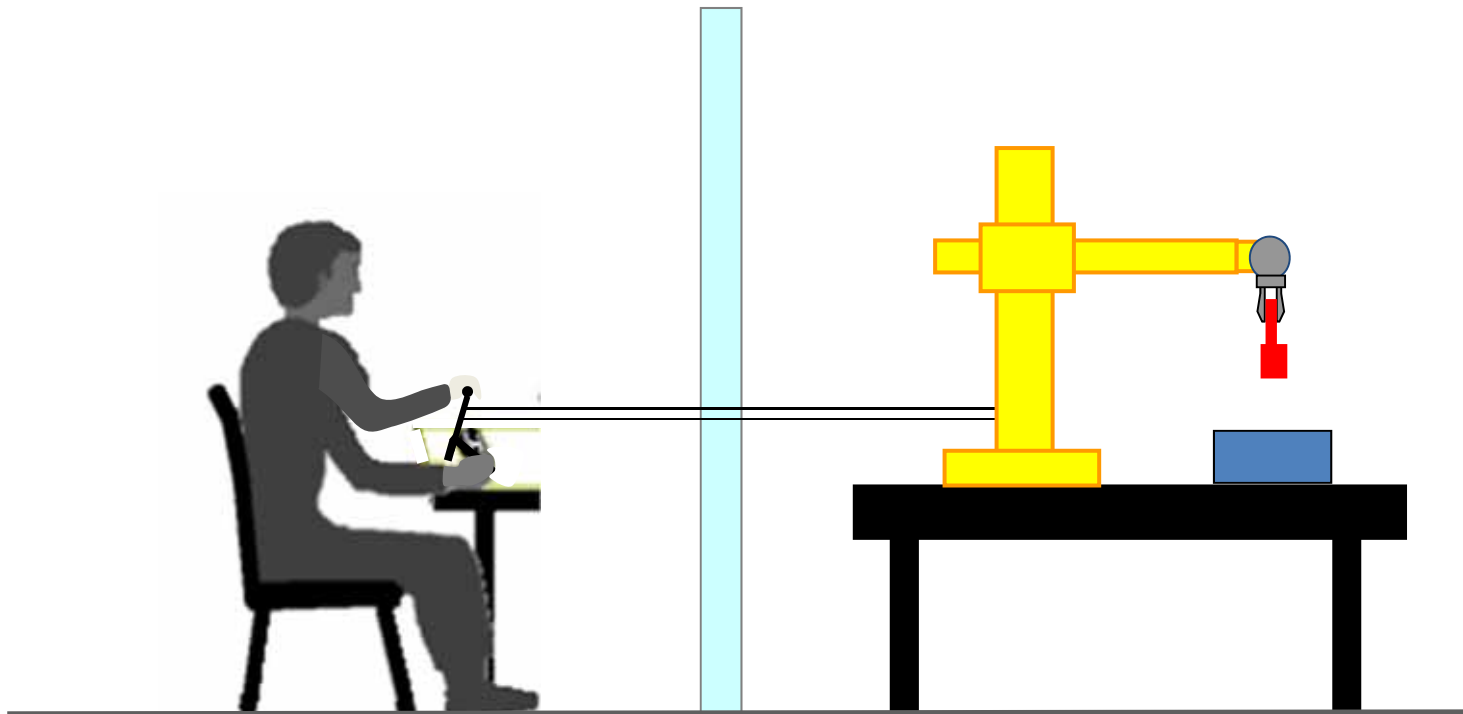
Teleoperation

Mechanical transmission



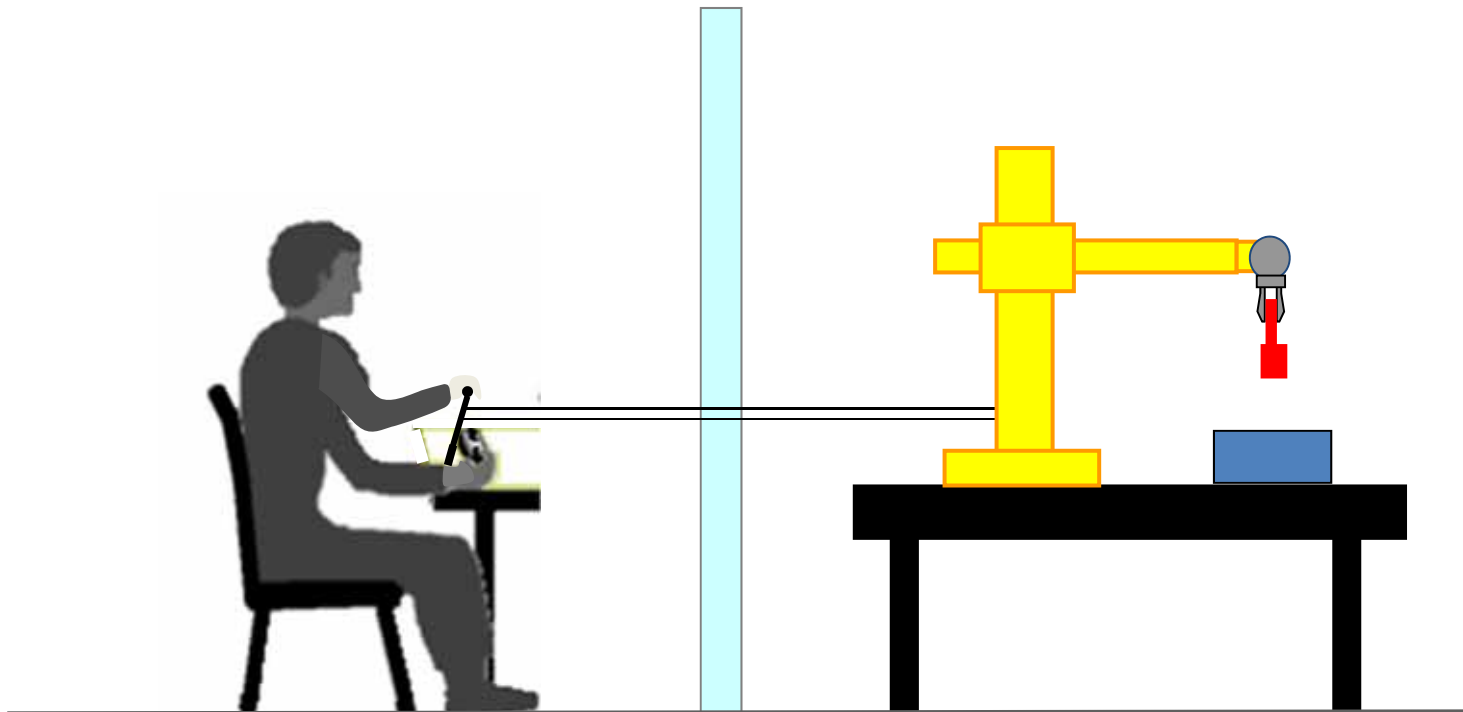
Teleoperation

Mechanical transmission



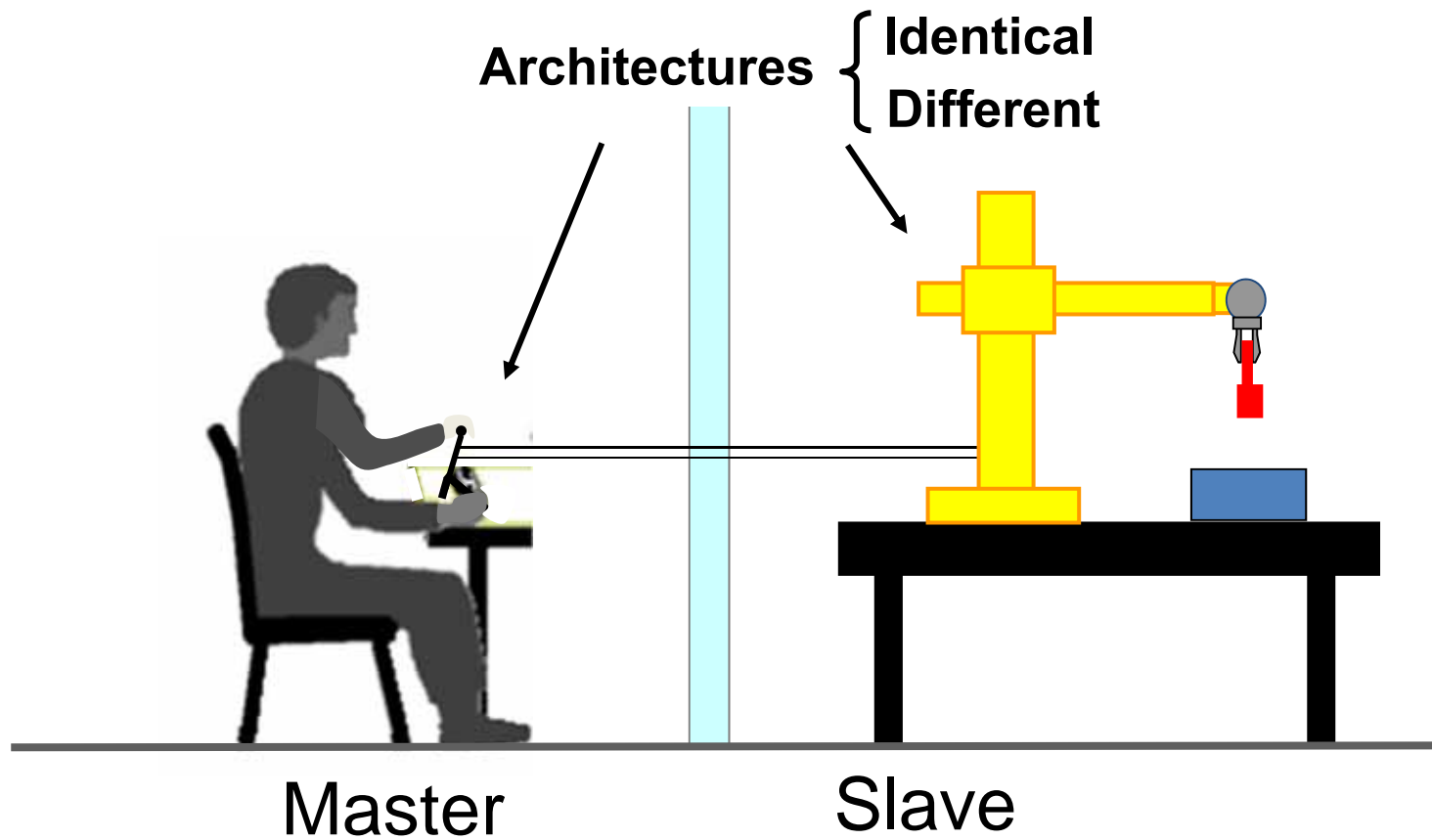
Teleoperation

Mechanical transmission



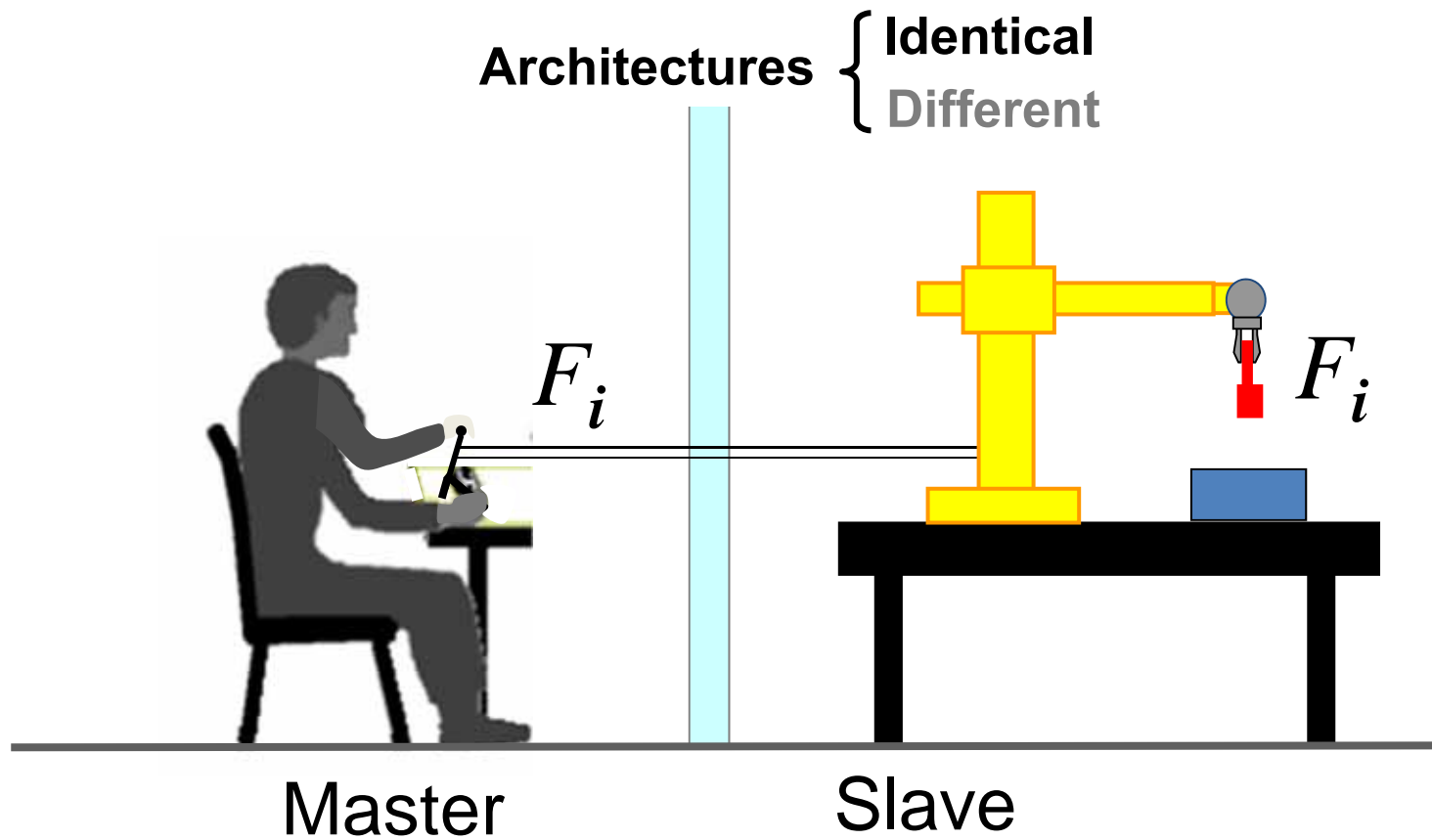
Teleoperation

Mechanical transmission (1940 ...)



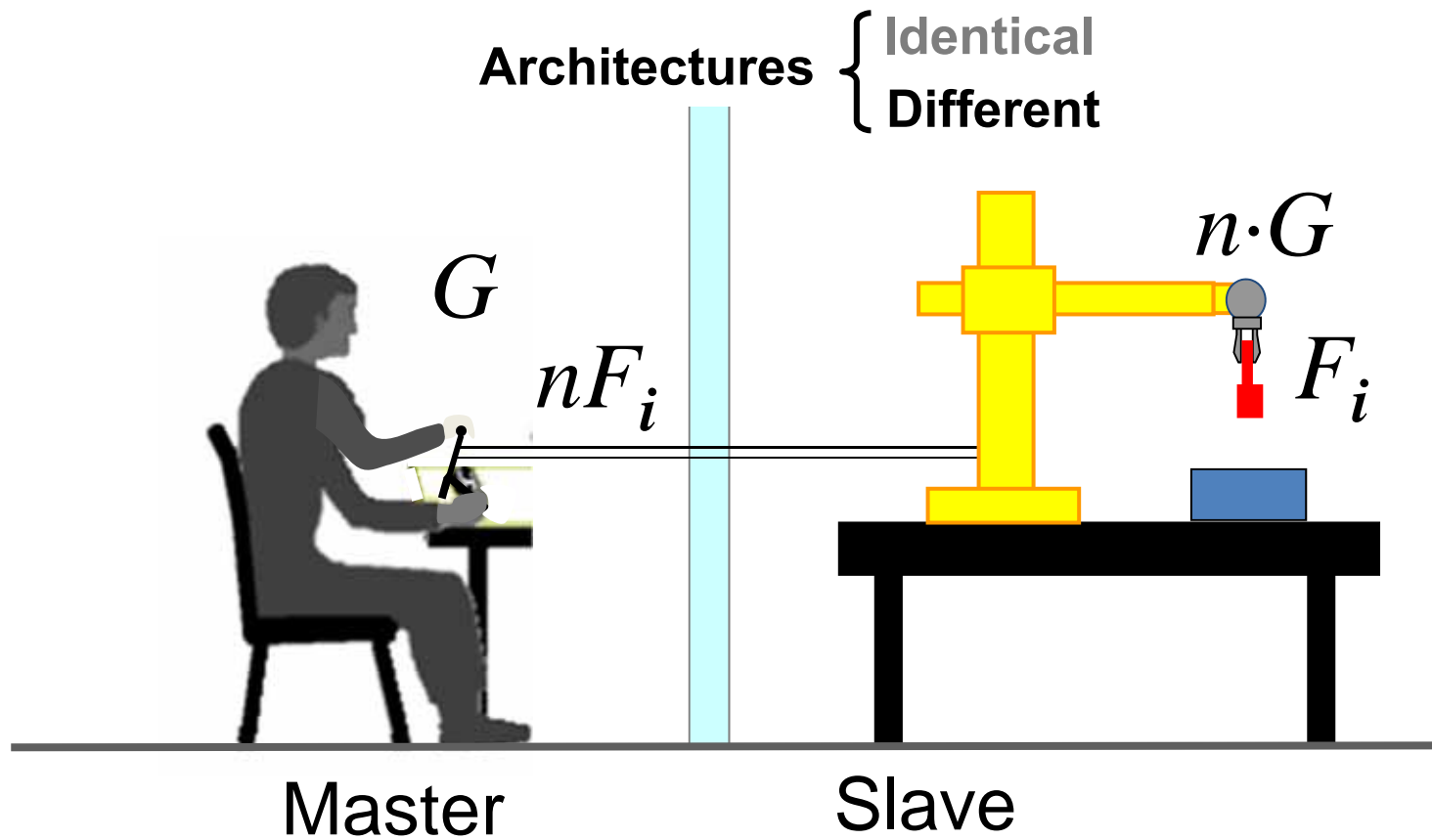
Teleoperation

Mechanical transmission (1940 ...)



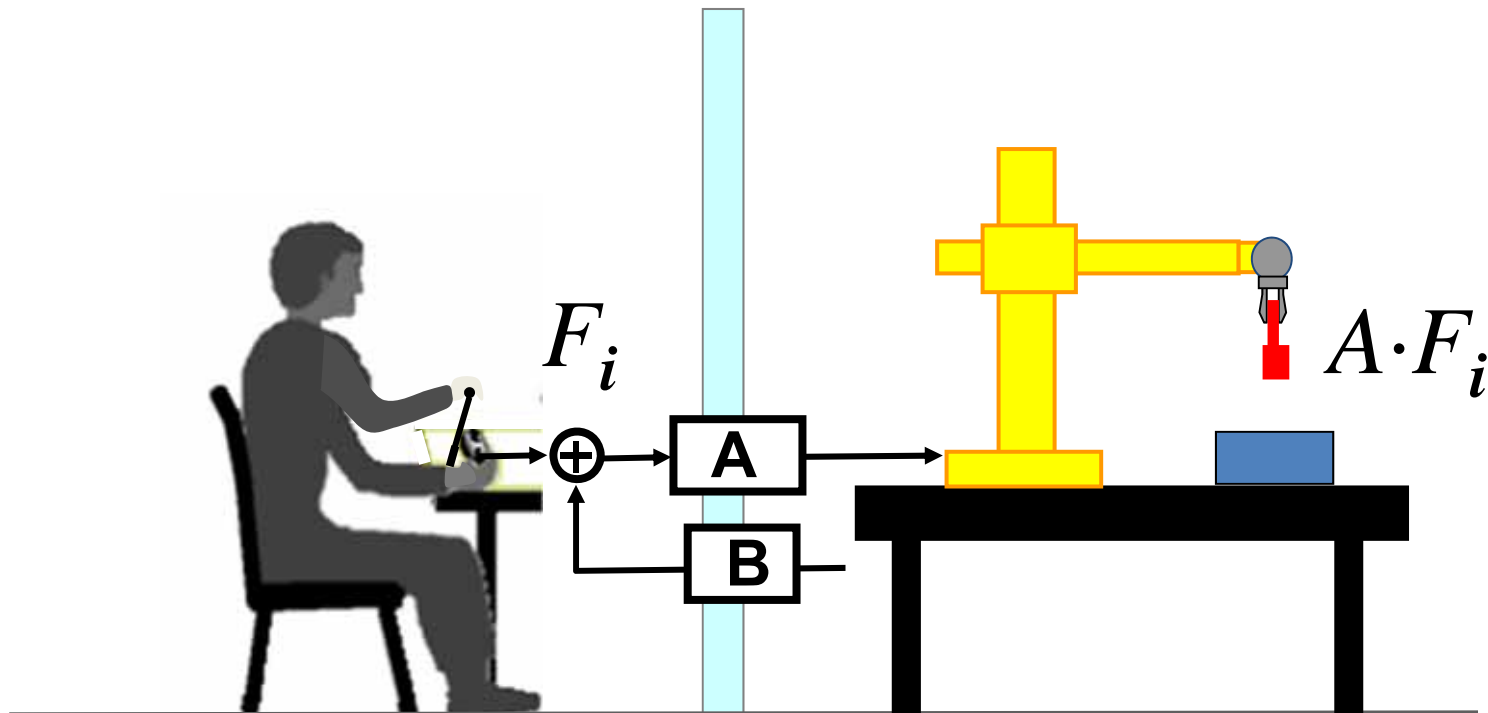
Teleoperation

Mechanical transmission (1940 ...)



Teleoperation

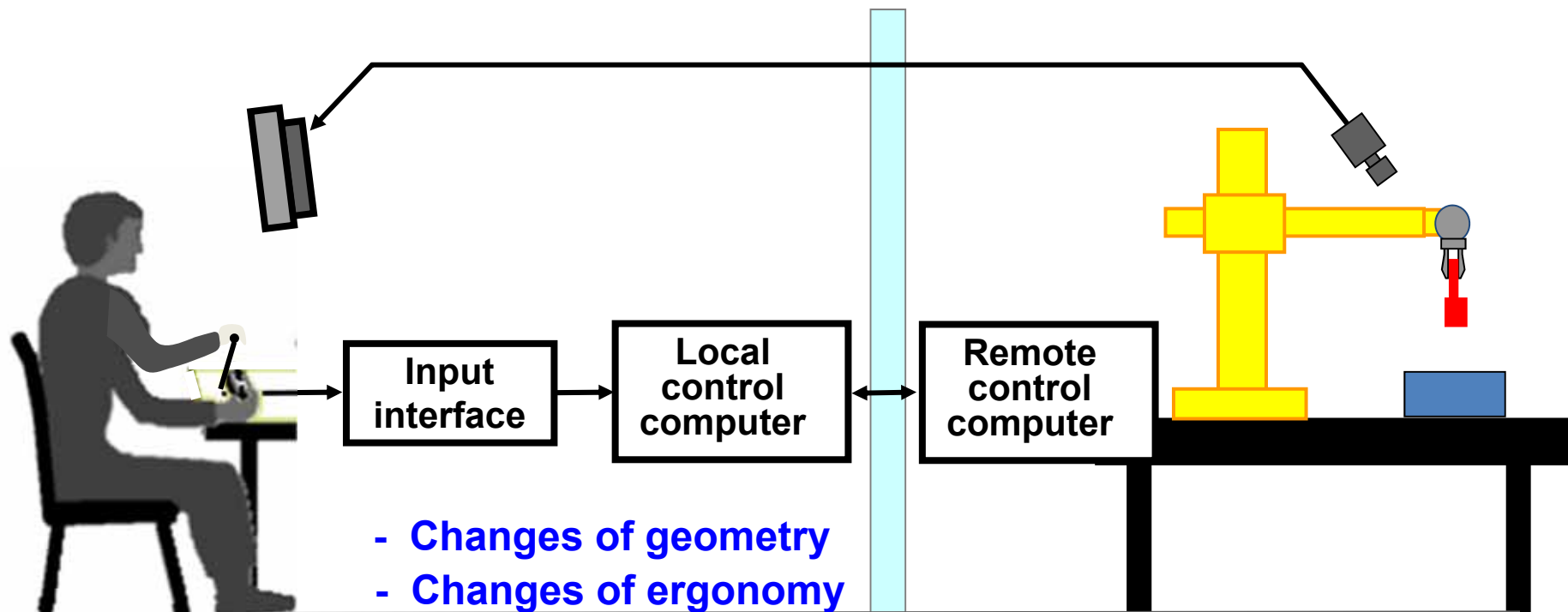
Mechanical servotransmission



- A independent of n
- Unlimited M-S Distance

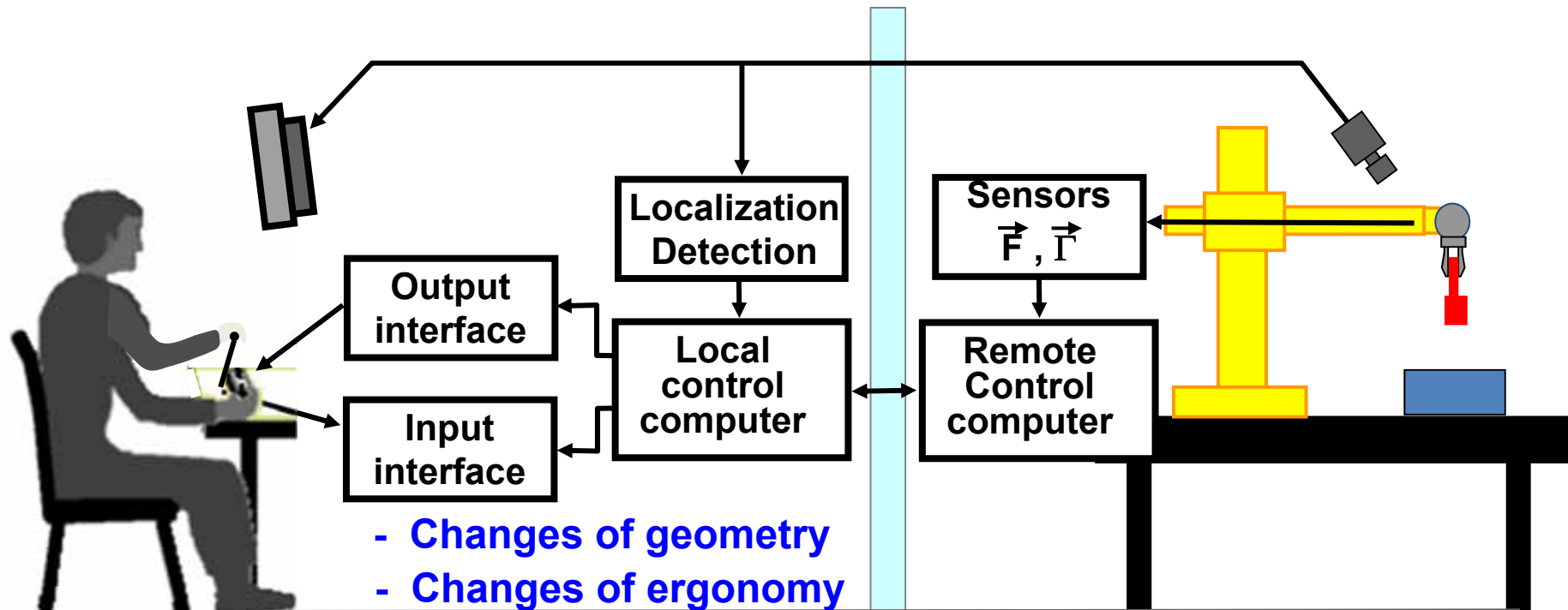
Teleoperation

Assisted teleoperation



Teleoperation

Assisted teleoperation



- Changes of geometry
- Changes of ergonomy
- Sensor feedback
- Tracking (movement compensation)
- Virtual reality

Assisted teleoperation

Remote: $\begin{cases} \textit{Far away} \\ \textit{Close} \end{cases}$



Assisted teleoperation

Teleoperation modes



Remote

- *Far away*

- *Close*

Comanipulation

(Master = Slave)

Assisted teleoperation

Position control

Force control

Hybrid control

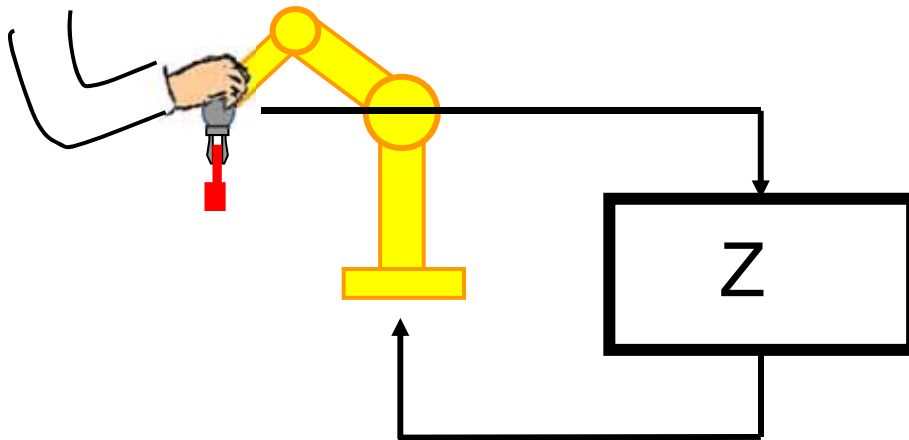
Impedance / Admittance control

Assisted teleoperation

Position control

Force control

Compliant control



$Z = 0$ Blocked

$Z = \infty$ Compliant

$Z = f(x, y, z)$ Supervised

I: $F \rightarrow V$

Human - Robot Cooperation

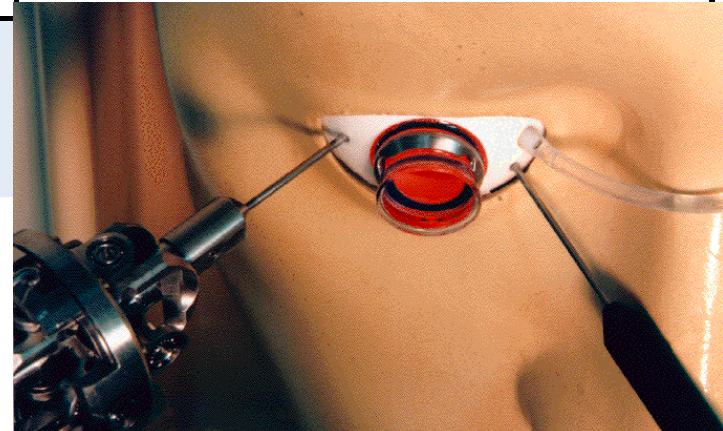
Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	



Scaling

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	

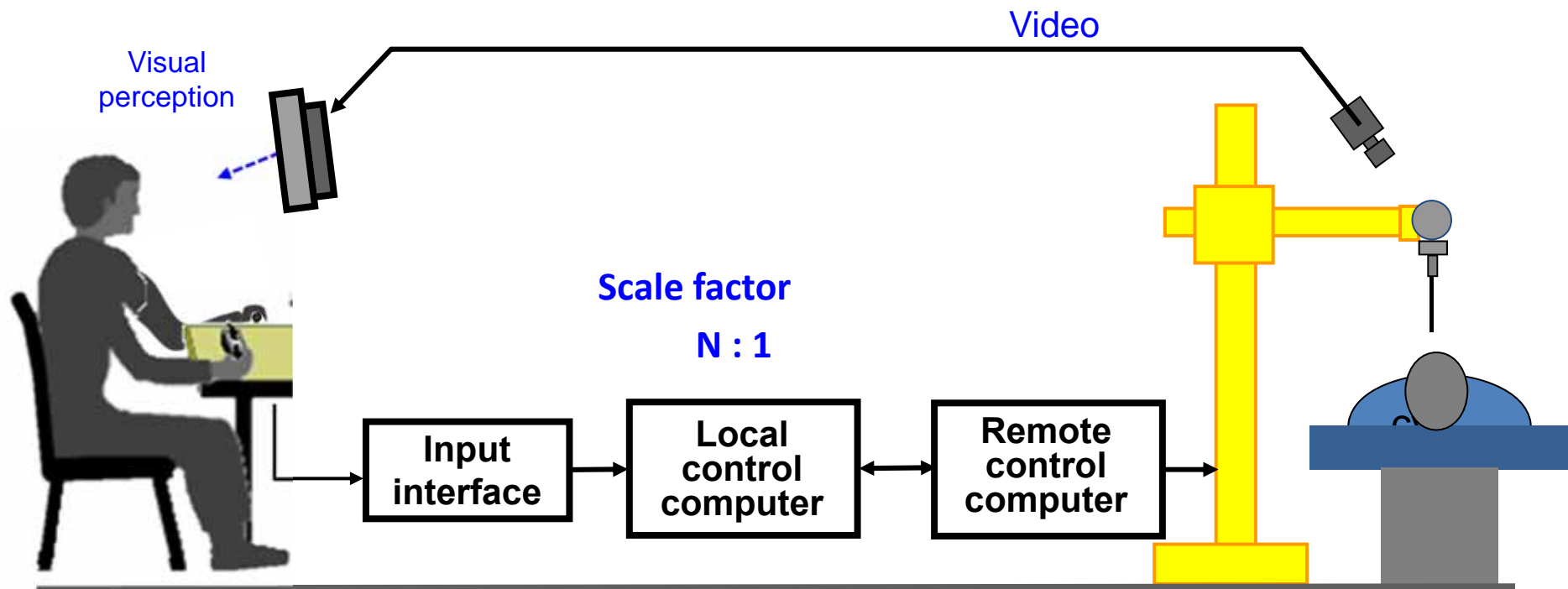


Scaling



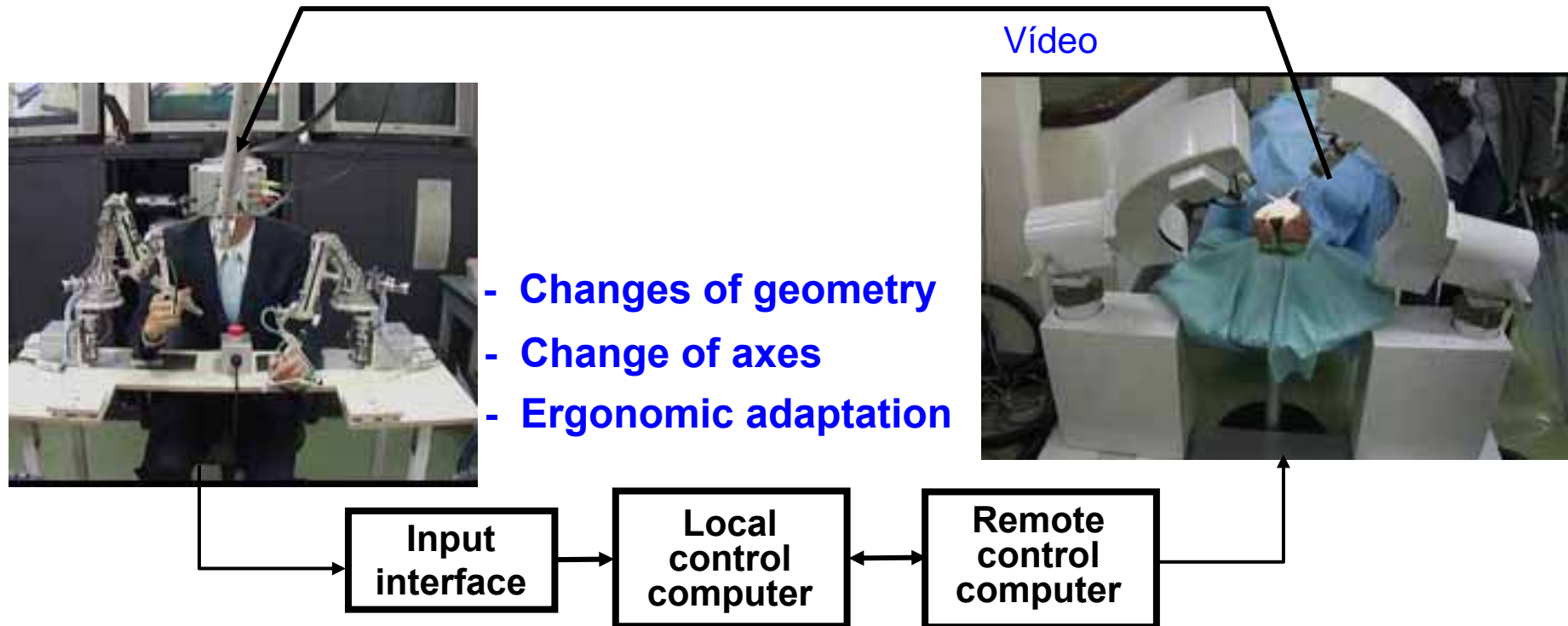
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	



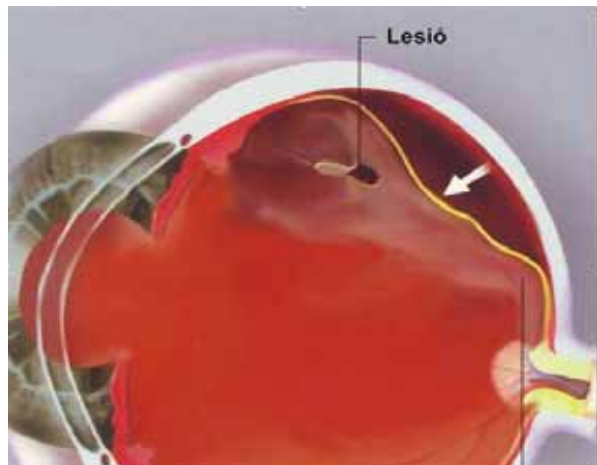
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	

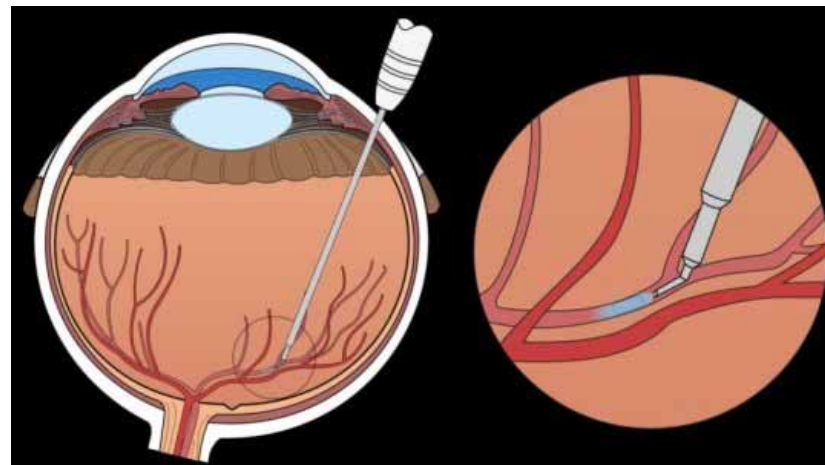


Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	



RETINA DETACHMENT



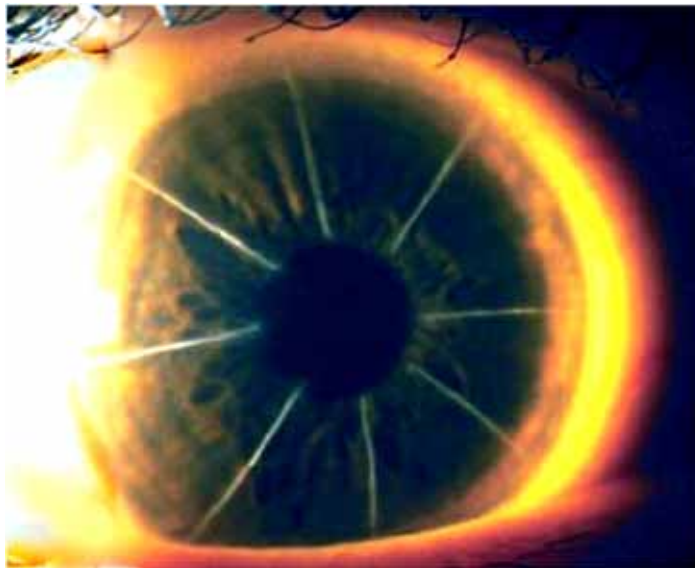
Vein cannulation (Eureyecase)

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation

$$\frac{1}{y_1} + \frac{1}{y_2} = \frac{1}{f}$$

CAD - CAM

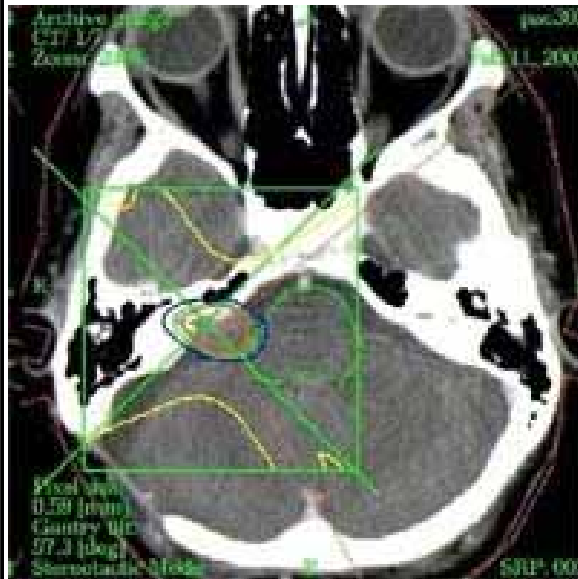


Steady hand



Human - Robot Cooperation


Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	

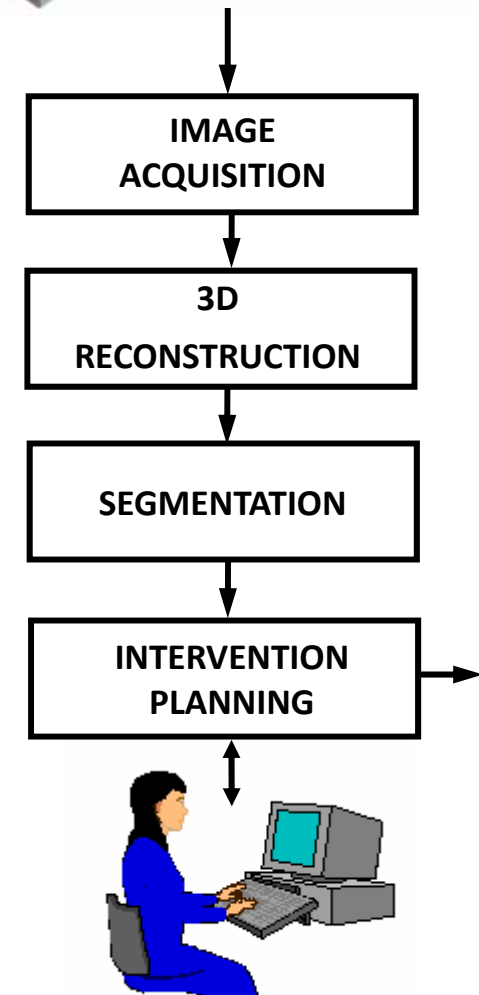


Implant of depth electrodes
(Parkinson)

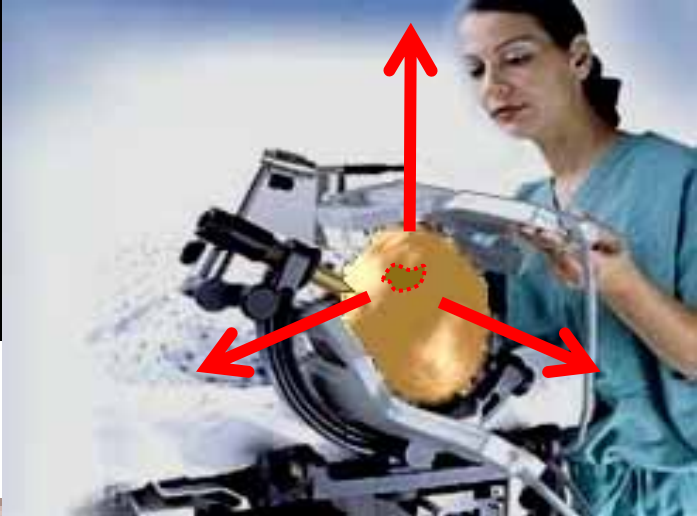
Image guided

Human - Robot Cooperation

Type	Robot contribution
Microsurgery	3D surface generation, task precision, 6DoF teleoperation
Neurosurgery	3D trajectories, increase precision and minimizing damage
	



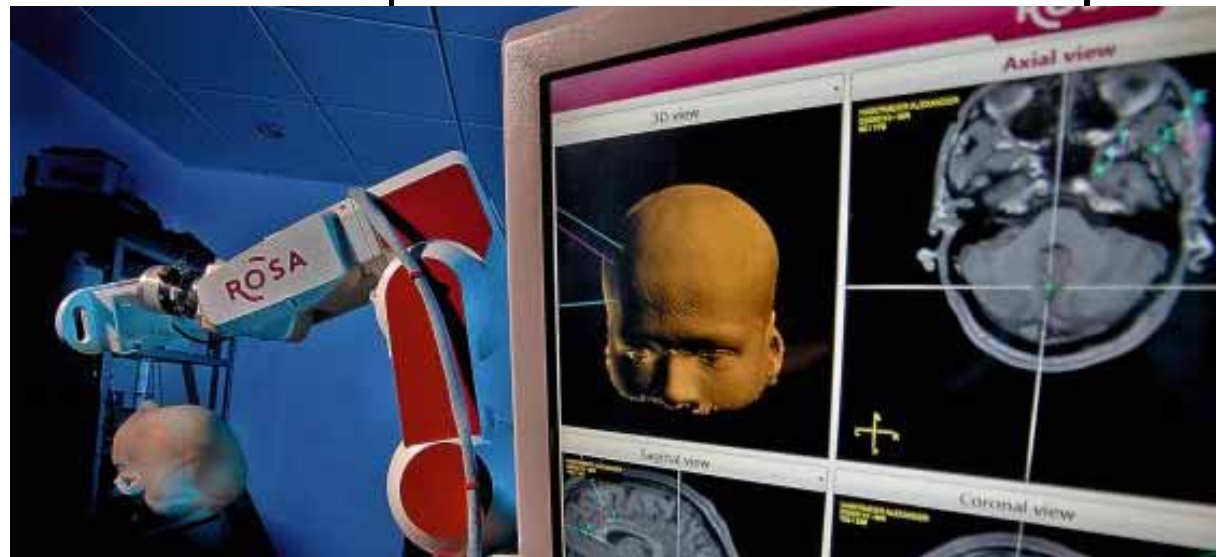
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	



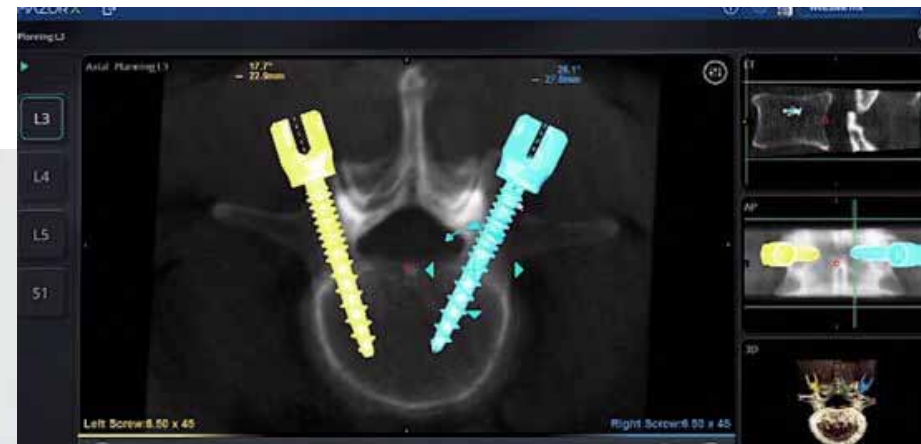
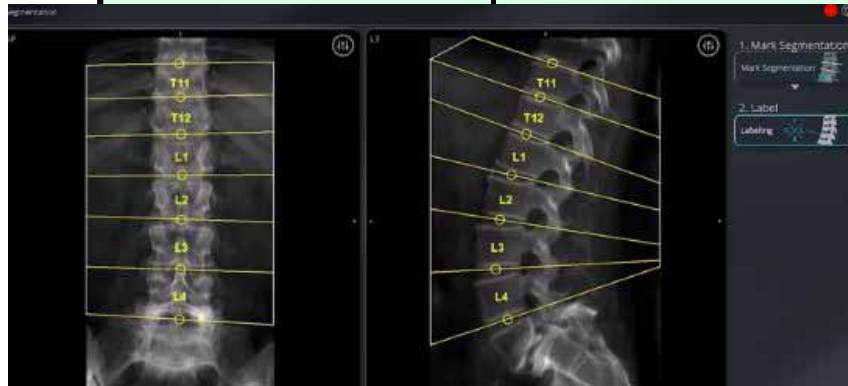
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
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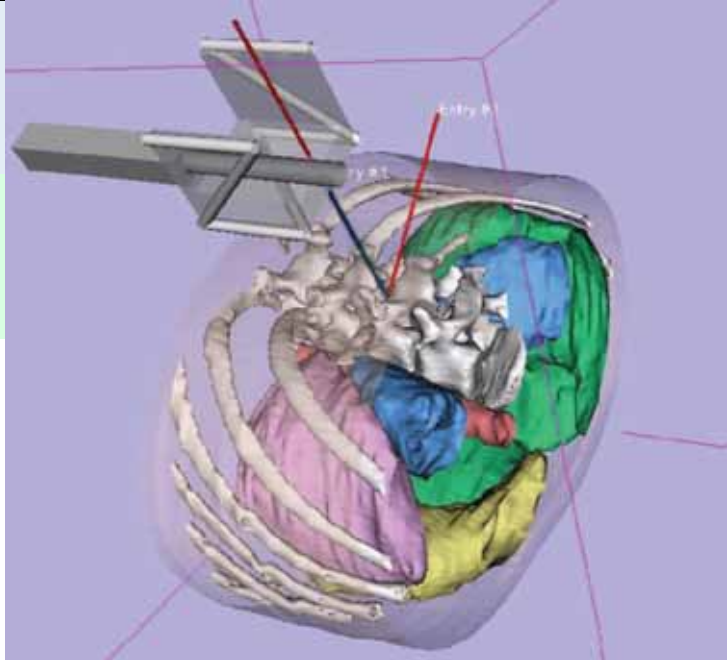


Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	



Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	

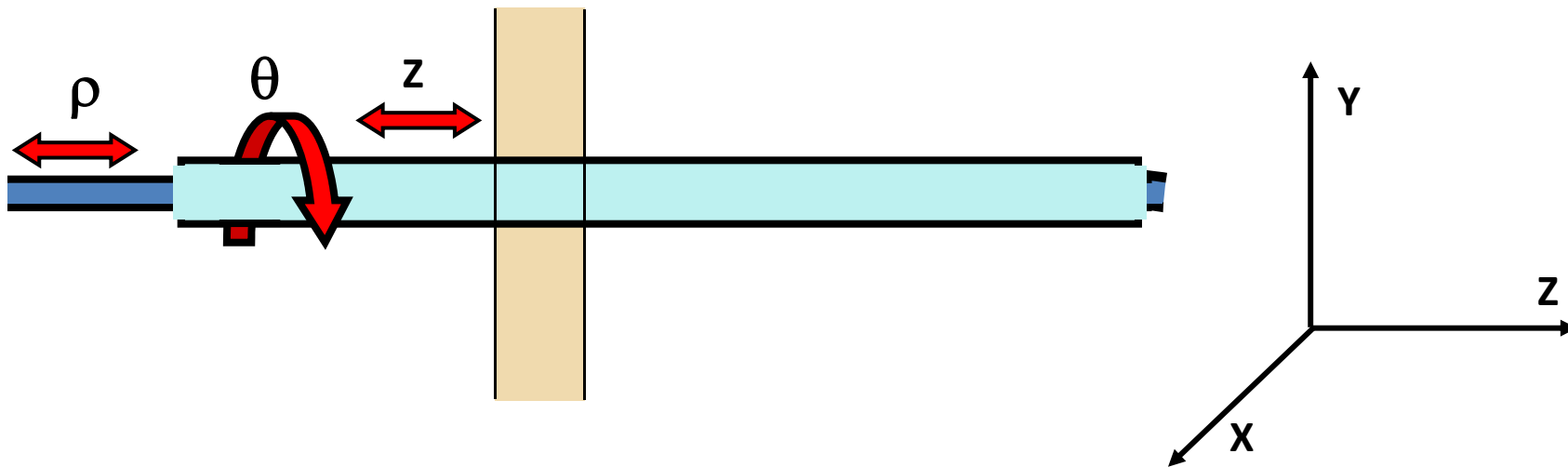


Special flexible mechanisms

Needle insertion

Active probes

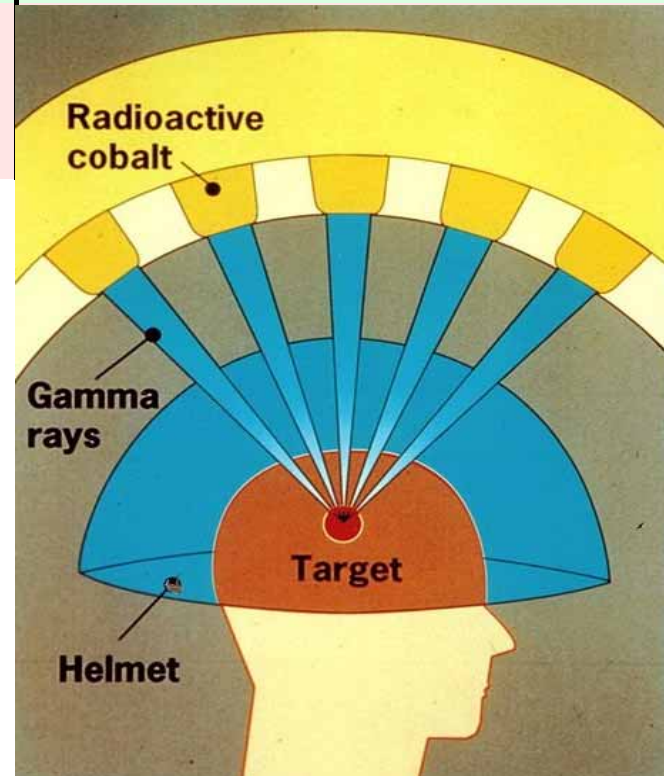
Prebended coaxial tubes



Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	Real time validation and corrections
Transcutaneous	Precise positioning	

Gamma Knife

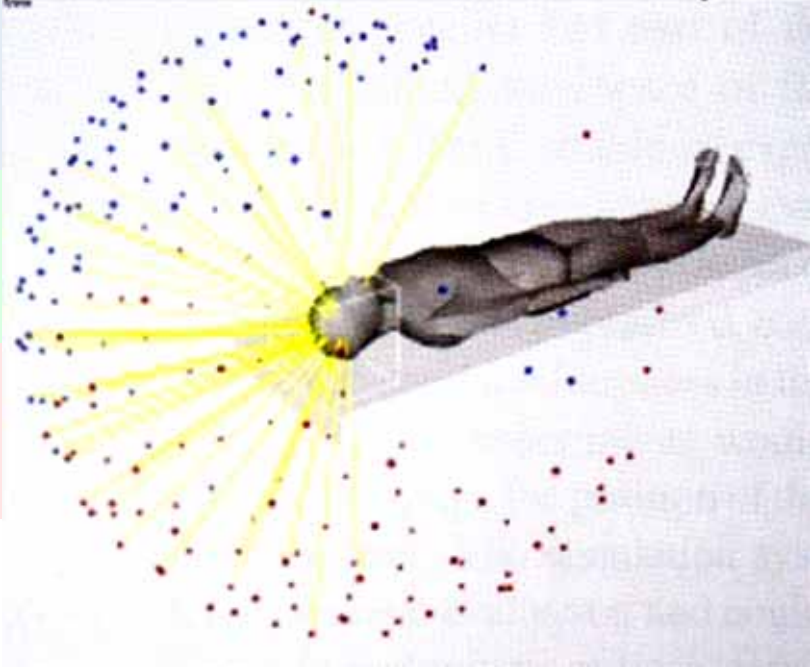


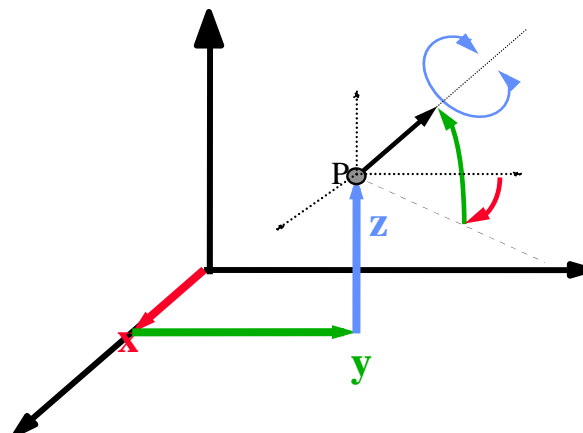
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	Real time guidance, validation or corrections
Transcutaneous	Precise positioning	



Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	



TRANSCUTANEOUS

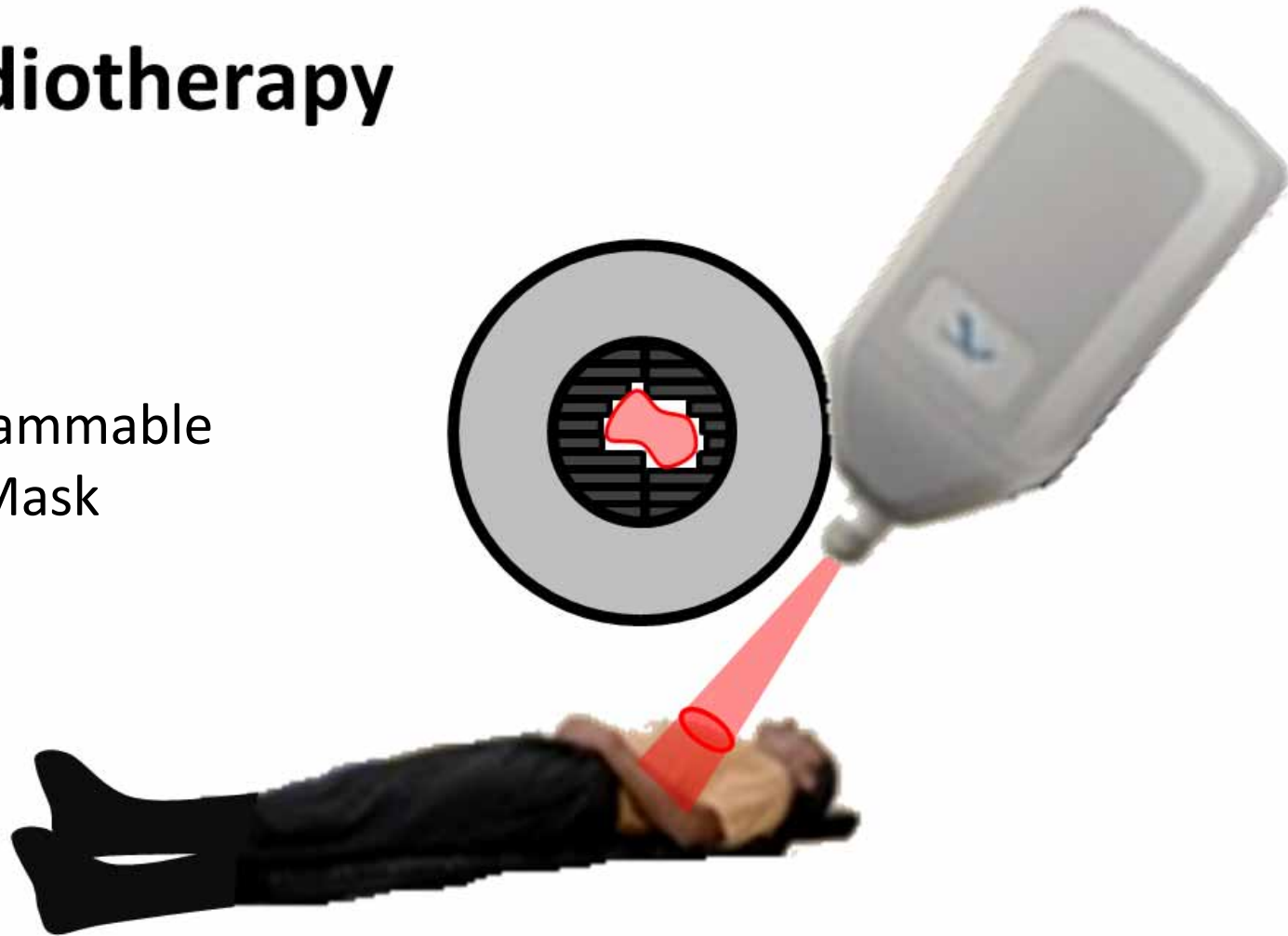
Radiotherapy




TRANSCUTANEOUS

Radiotherapy

Programmable
Mask

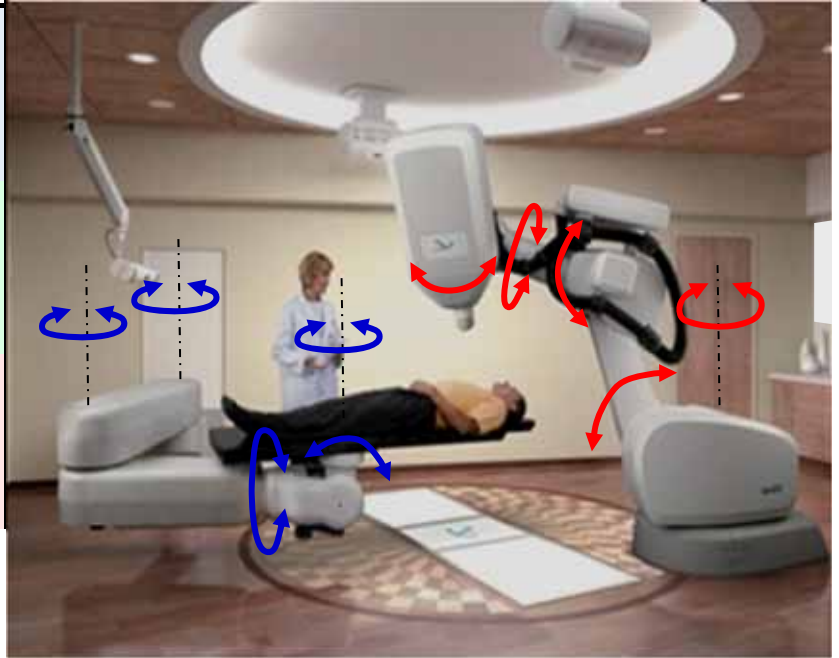


Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	

Intraoperative

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	

Radiosurgery: XR, γ

Combining Robot and Bed Degrees of Freedom

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	Real time guidance, validation or corrections
Transcutaneous	Precise positioning	Adjustments and surveillance

- Previous systems: Based on a beam of the tumor size

Beam size: from 4cm to 15 cm



- Robot performances: Allow focalization in the precise tumor area (adapt to its shape)

- Beam size: ~3 mm

- Scanning over the tumor area



Human - Robot Cooperation


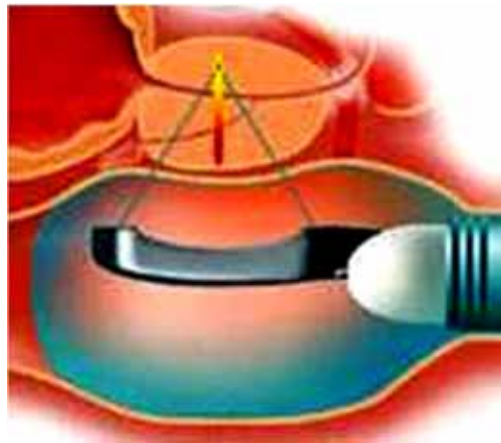
Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	



Image acquisition

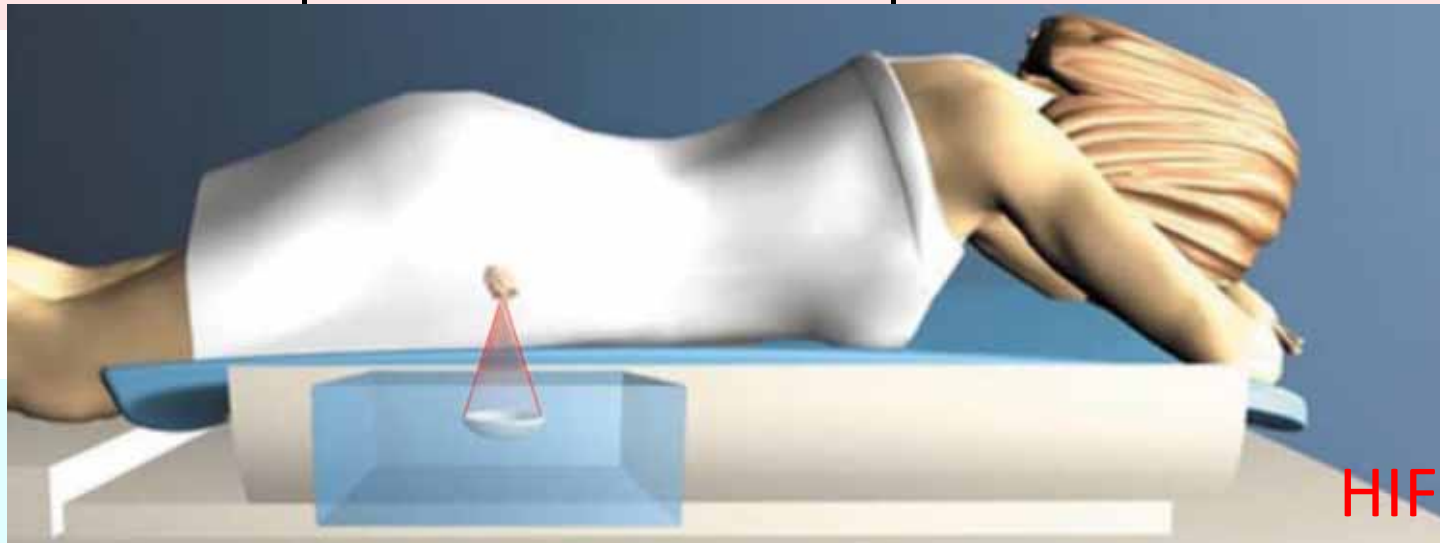


Treatment without moving: no positioning problem

US (HIFU)
High Frequency Ultrasound

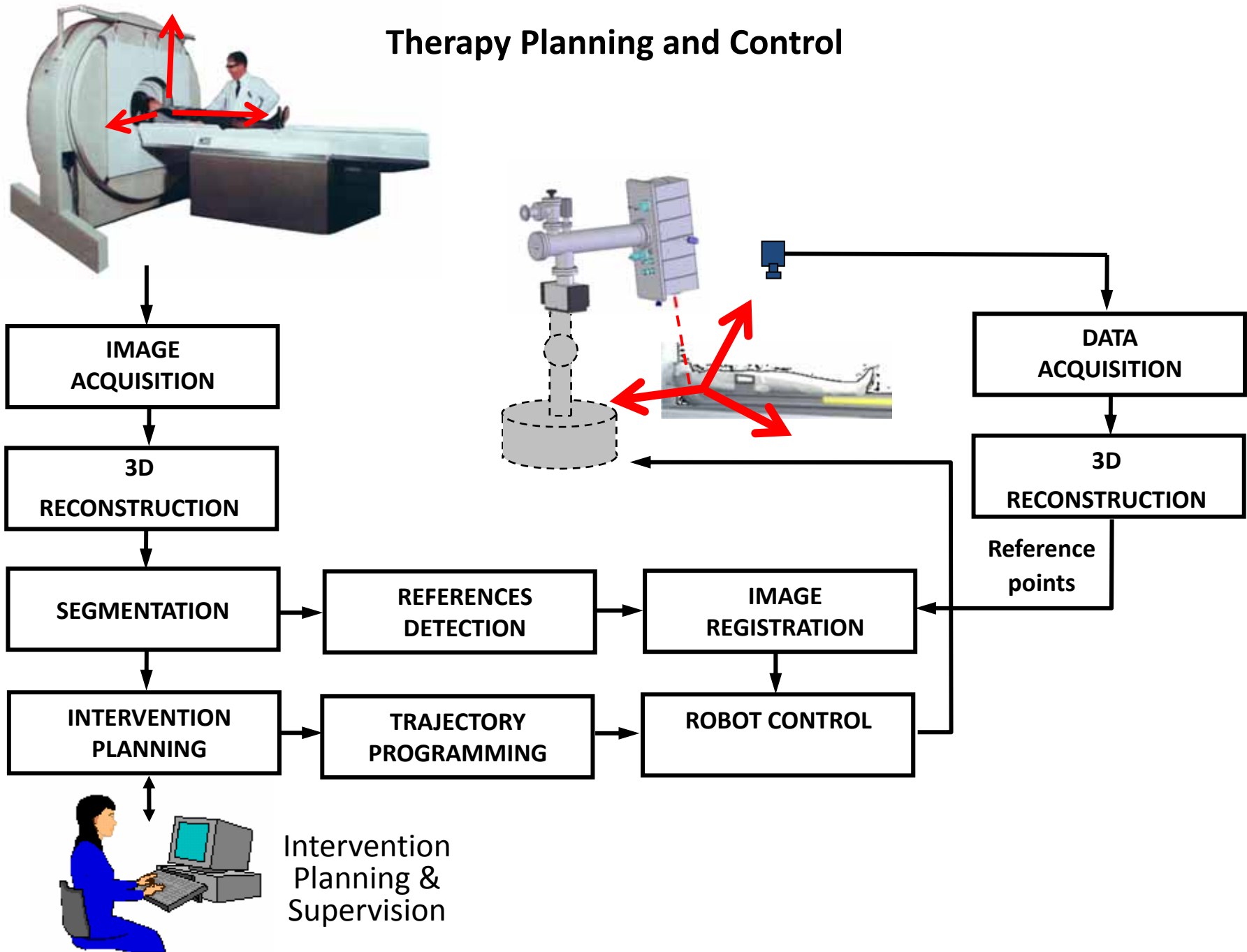
Surgical robotics: Possibilities and challenges

Type	Robot contribution	The challenges
Microsurgery	Precision, 6 Degrees of freedom, 3D surface reconstruction	More intelligent robot implication
Neurosurgery	3D trajectories, Better precision, Minimizing risks/ damage	From simple incisions to new robotized catheters
Transcutaneous	Precise positioning Precise trajectories	



HIFU

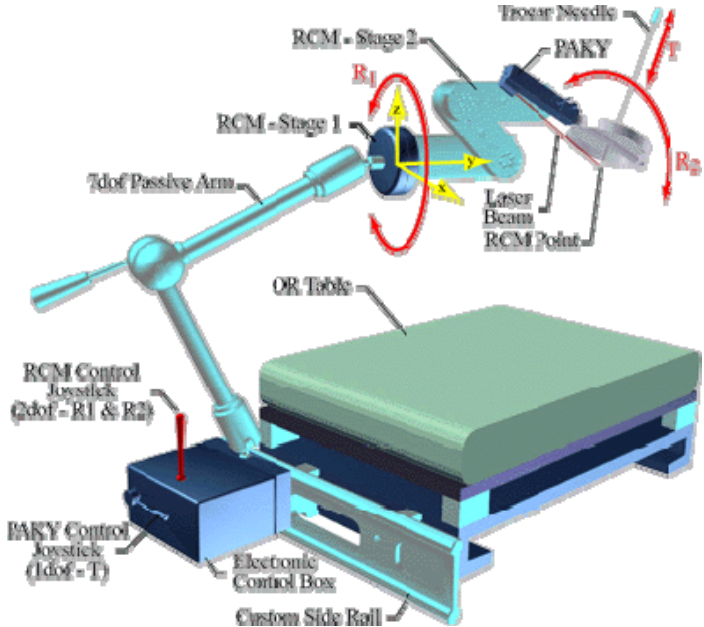
Therapy Planning and Control



Human - Robot Cooperation


Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	Real time validation and corrections
Transcutaneous	Precise positioning	Adjustments and surveillance

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	


Holding an instrument

Human - Robot Cooperation

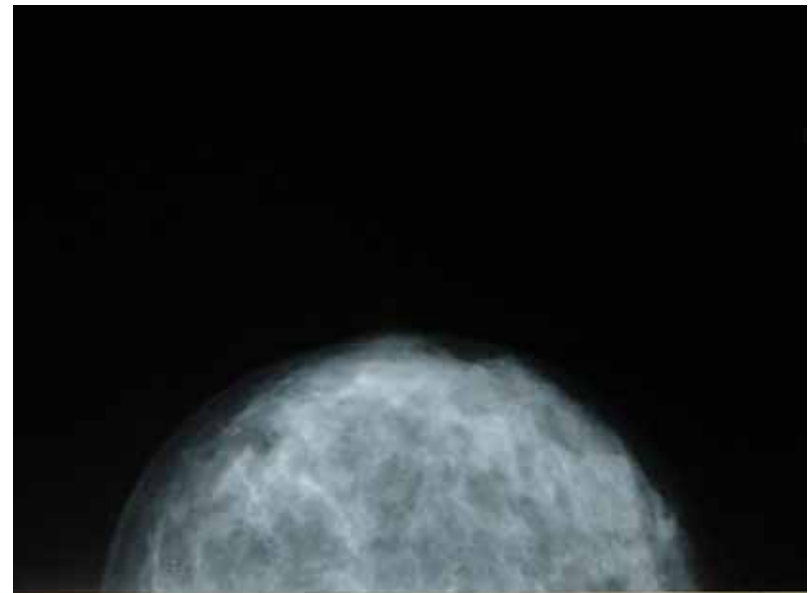
Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	

Stereotaxis: Fix positioning

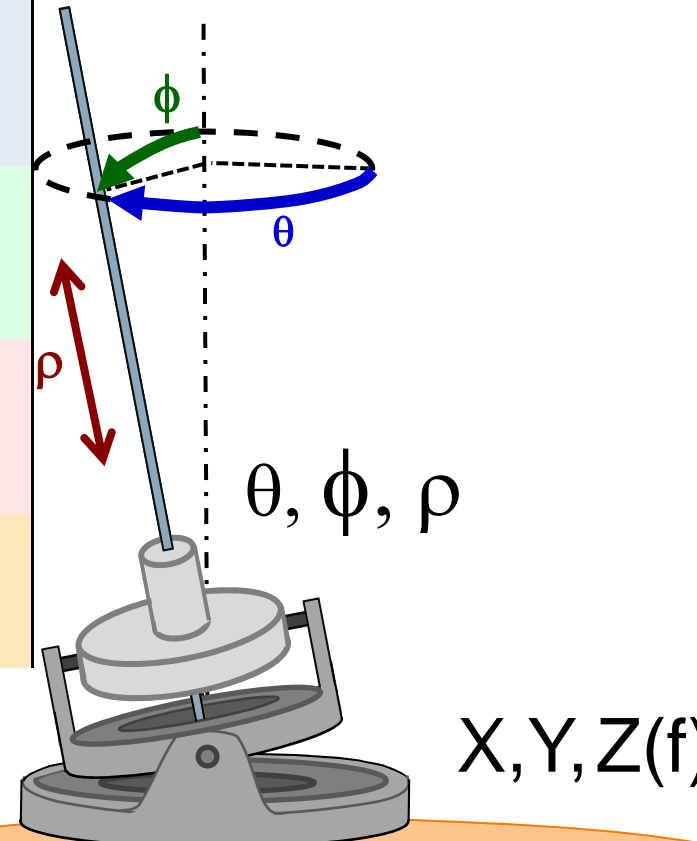
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	

Simultaneous image
acquisition and robot
actuation: Image guided
surgery

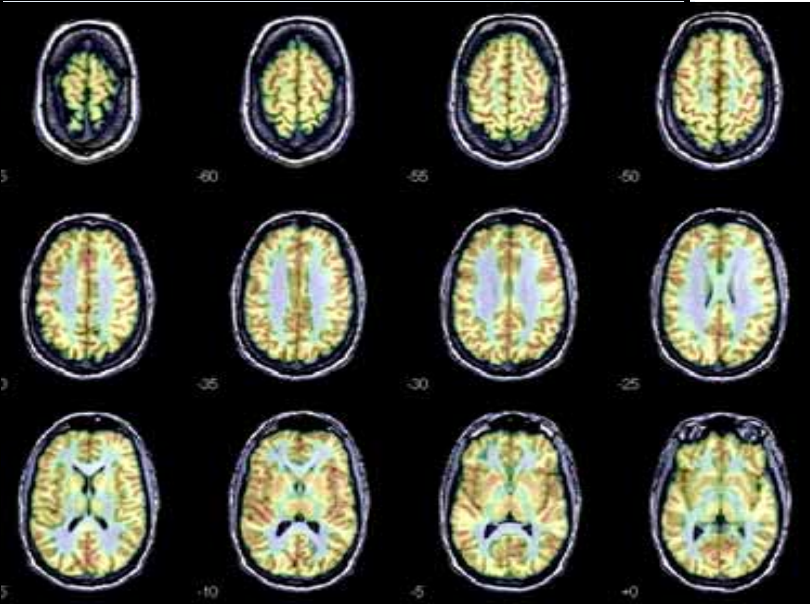


Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	 <p>The diagram illustrates a robotic arm with multiple degrees of freedom. It shows a base with a coordinate system $X, Y, Z(f)$. The arm has joints labeled with Greek letters: θ (rotation around the vertical axis), ϕ (rotation around the arm's longitudinal axis), and ρ (extension/retraction of the arm). The arm is shown in a position where it is angled towards the right and slightly forward.</p>
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	

Guidance of multiple degrees of freedom


Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	



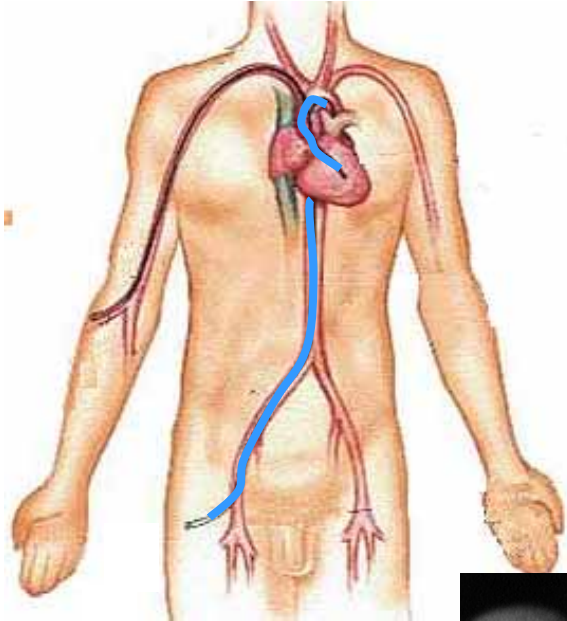

CAD / CAM

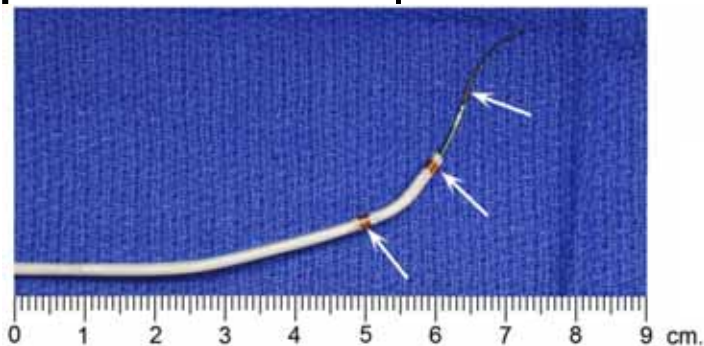
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	

Positioning
Registration

Human - Robot Cooperation

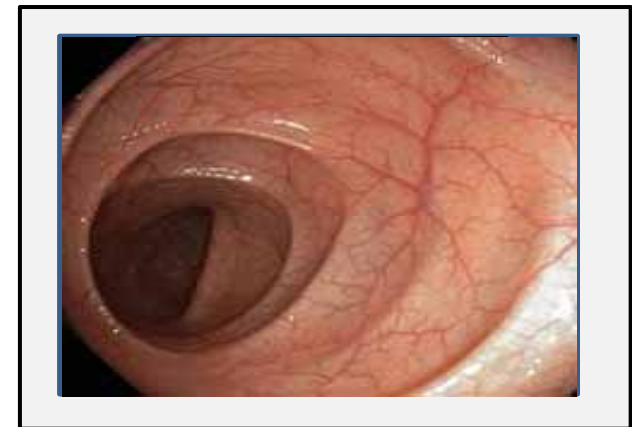
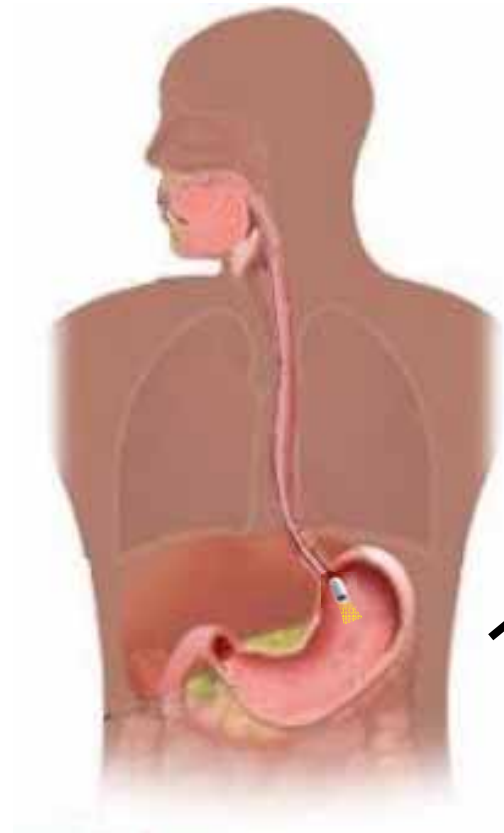
Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	 <p>Image guided intervention</p> 
Neurosurgery	3D trajectories, increase precision and minimizing damage	
Transcutaneous	Precise positioning	
Percutaneous	Precise advancing and avoidance	



Sensorized
instruments

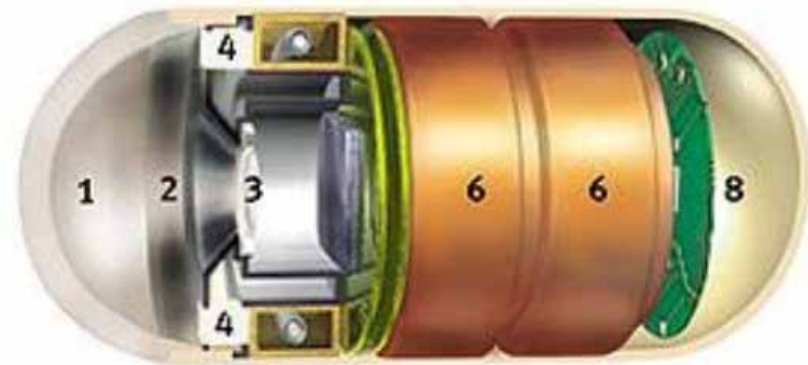
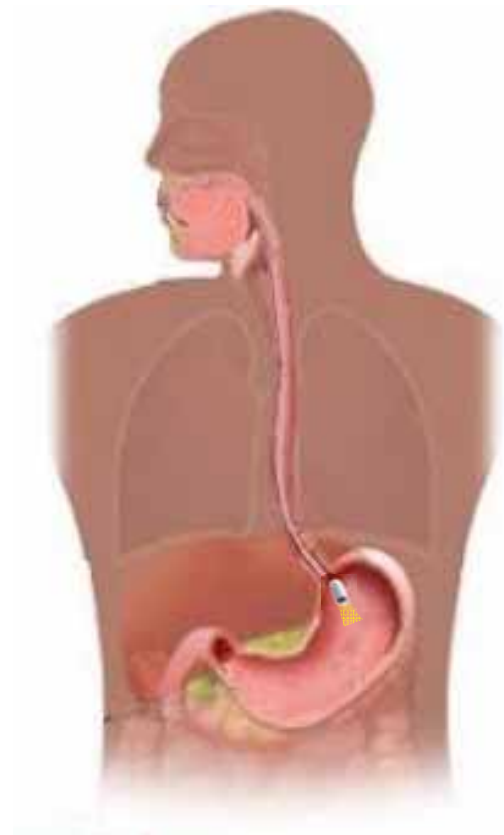
Endoscopy

Smart Pill



Endoscopy

Smart Pill

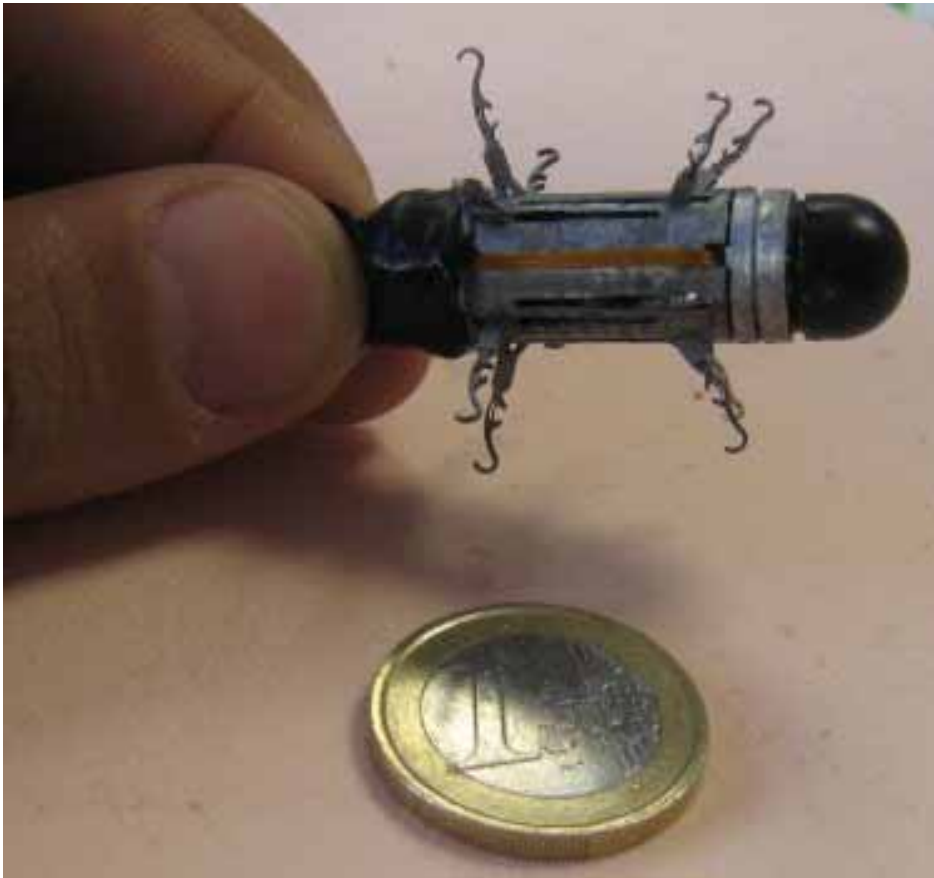


1 - Protector de l'òptica
2 - Òptica
3 - Lent
4 - Leds

5 - Processador
6 - Bateria
7 - Transmissor
8 - Antena

Endoscopy


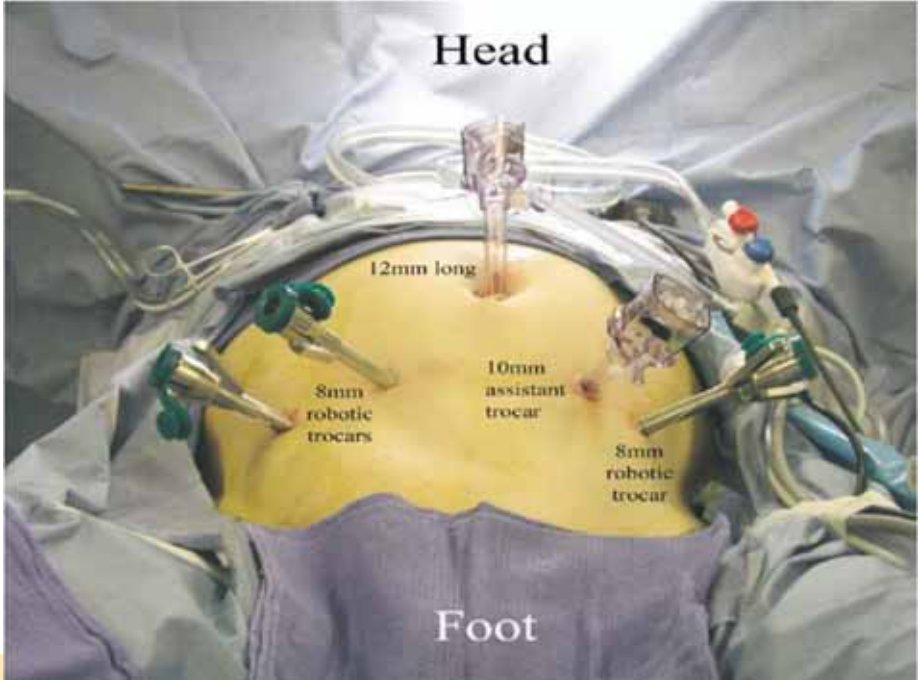
Smart Pill

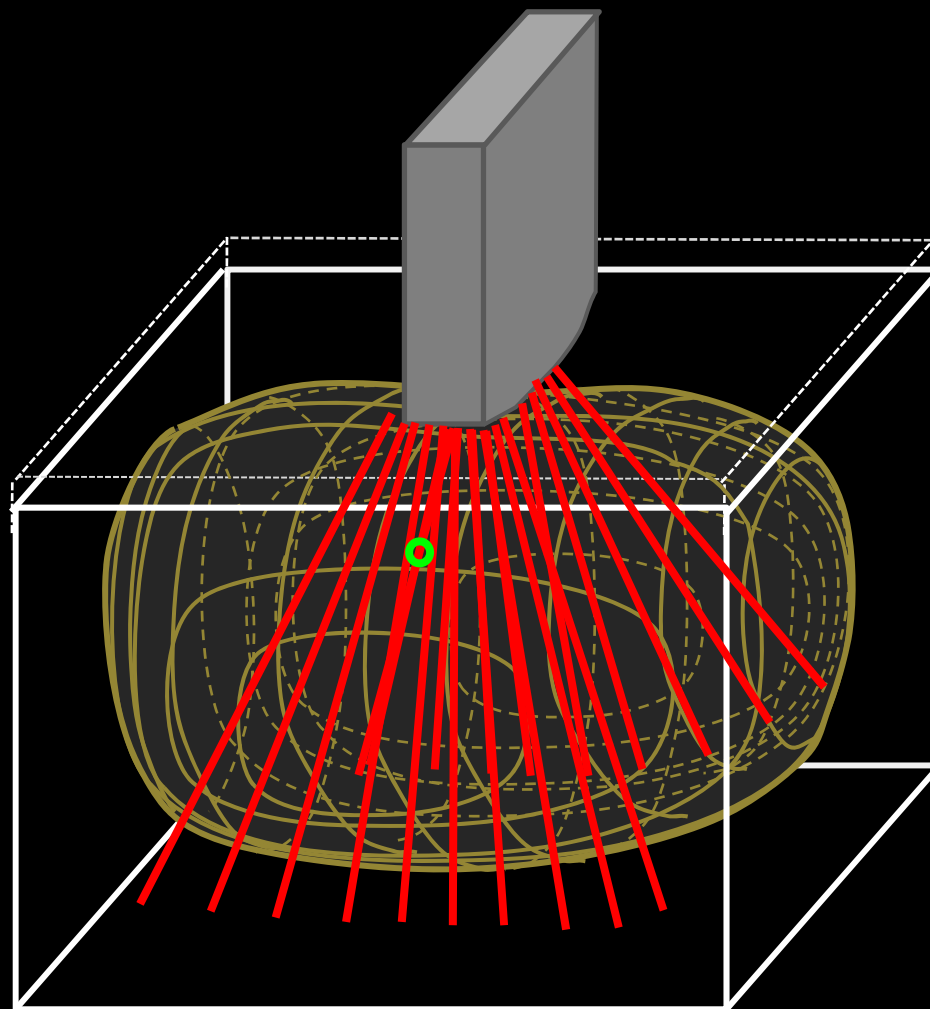
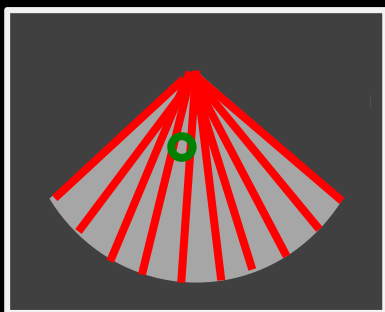


Human - Robot Cooperation

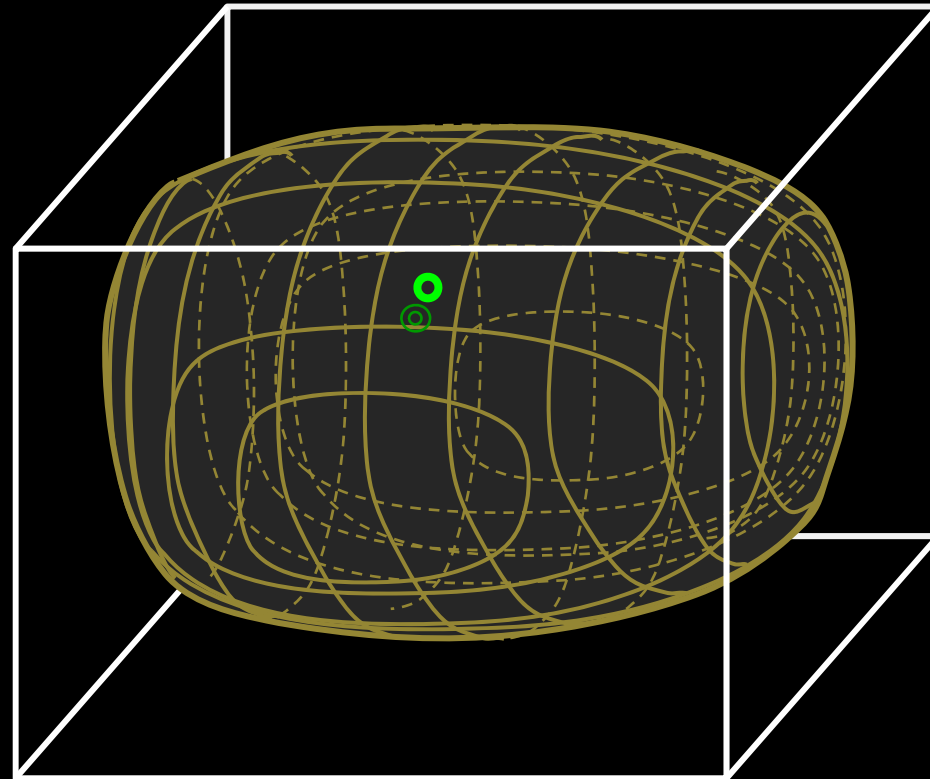
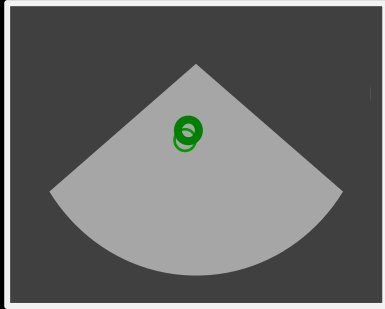
Type	Robot contribution	Cooperation needs
Microsurgery	3D surface generation, task precision, 6DoF teleoperation	Real time supervision and anatomic adaptation
Neurosurgery	3D trajectories, increase precision and minimizing damage	Real time validation and corrections
Transcutaneous	Precise positioning	Adjustments and surveillance
Percutaneous	Precise advancing and avoidance	Real time restrictions identification and safety

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
		
		<p>Ability: Non programmable</p>

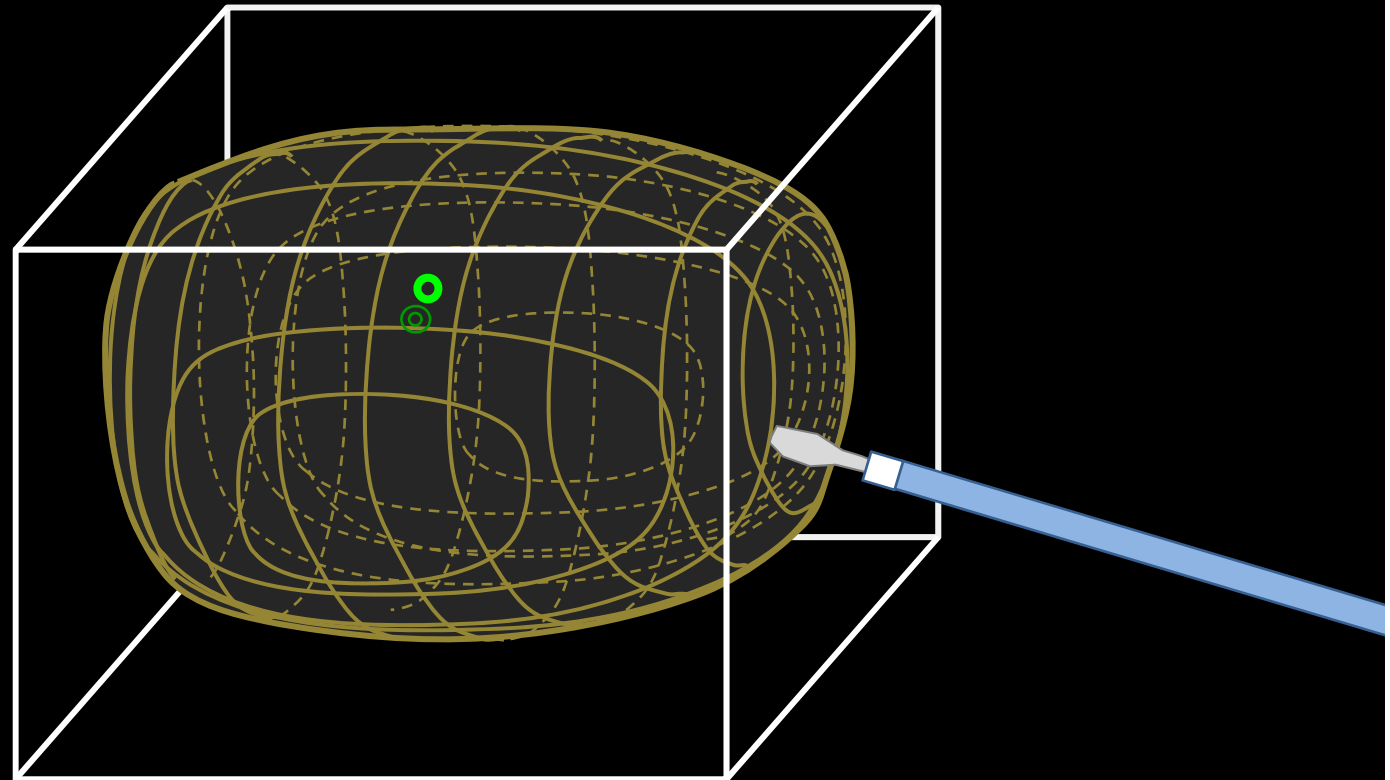
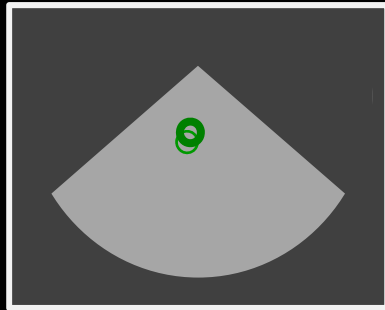


Displacement of the target
due to sensor contact



$$P_{XYZ}\{R_{D1}\} \rightarrow P'_{XYZ}\{R\}$$

New displacement of the target
due to instrument actuation



$$P_{XYZ}\{R_{D1}\} \rightarrow P'_{XYZ}\{R\} \rightarrow P''_{XYZ}\{R_{D2}\}$$

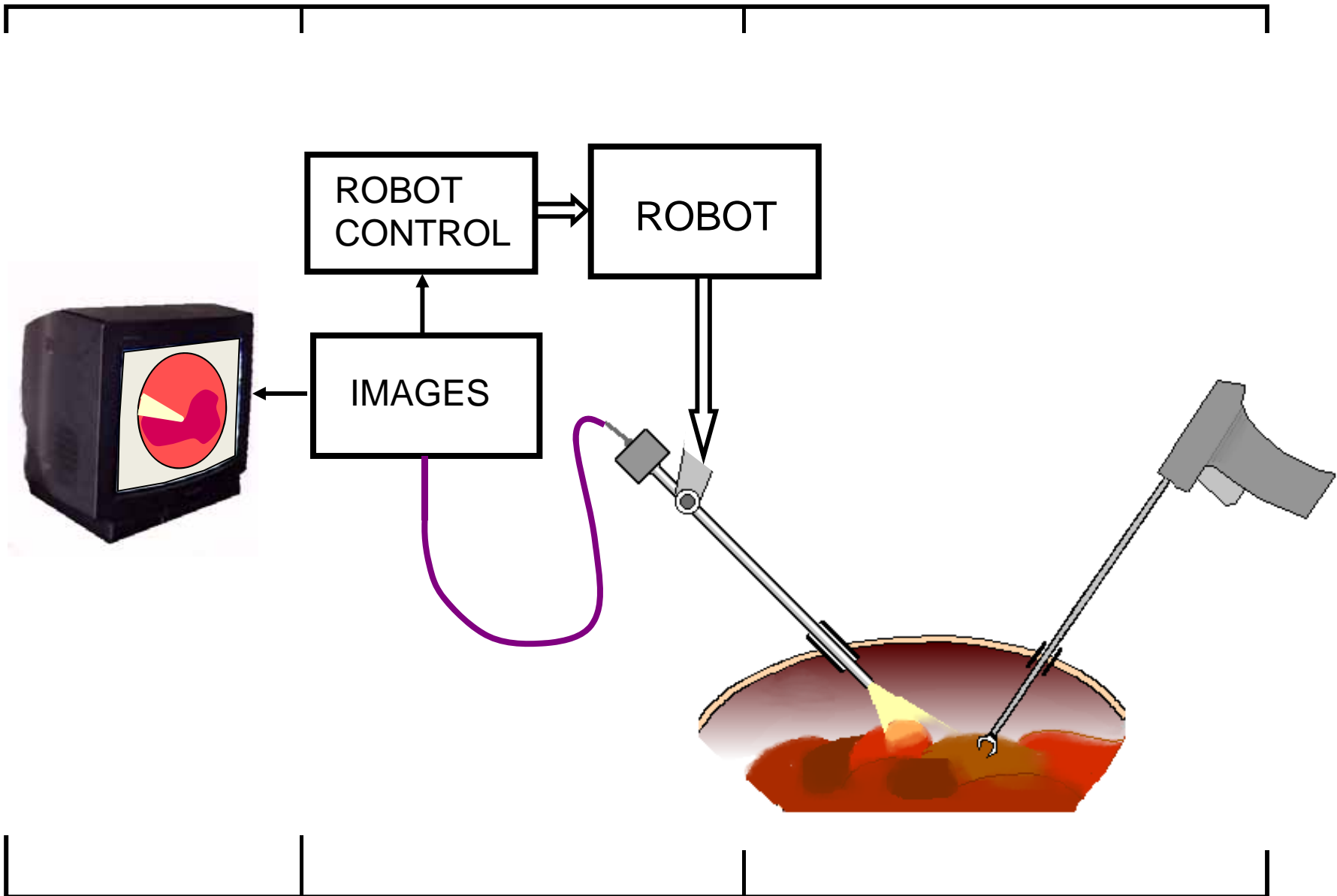
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
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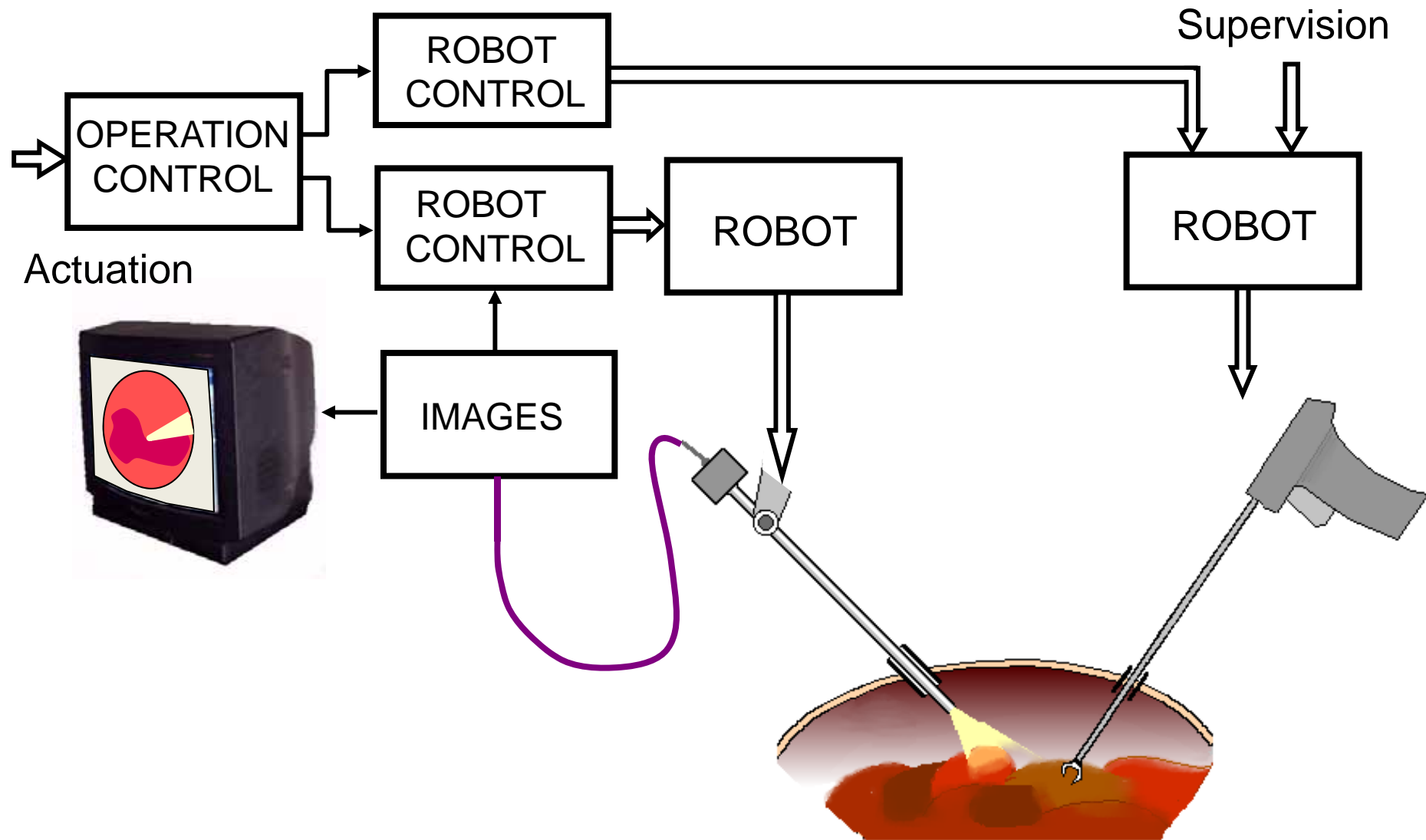


Intracavity	Ergonomic dexterity, anti stress operation and precision	Manual guidance, multiplexed arms

Human - Robot Cooperation

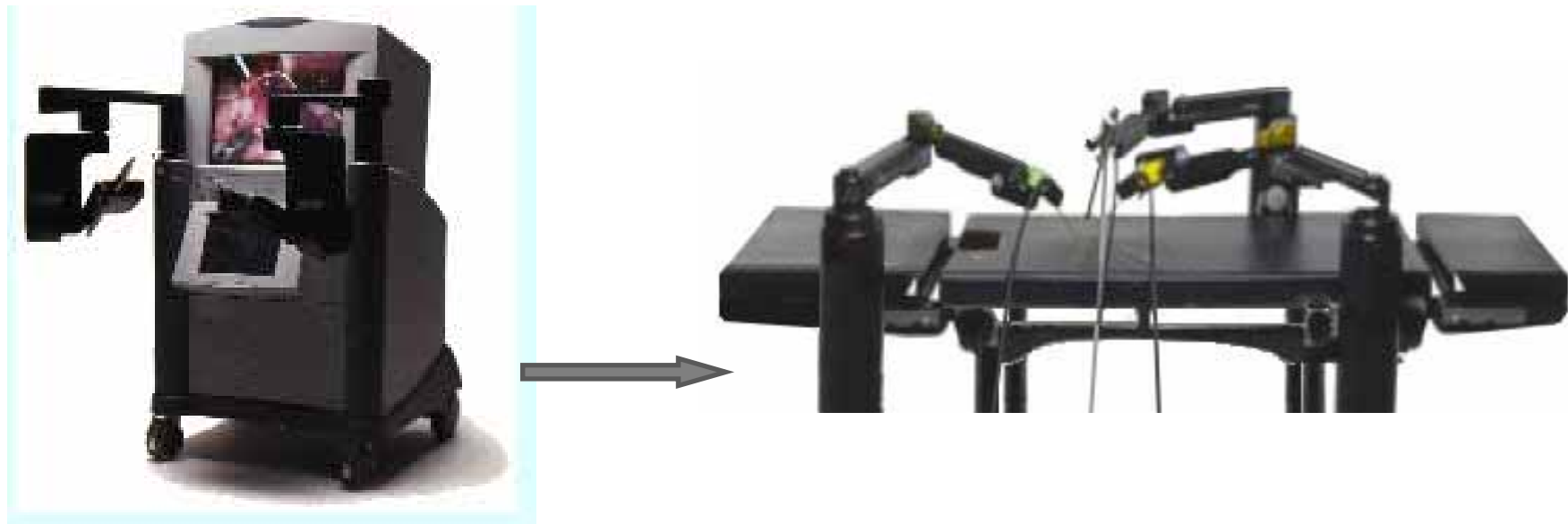


Human - Robot Cooperation



Human - Robot Cooperation

- Minimally Invasive Surgery(MIS)



Zeus (2001 – 2003)

Human - Robot Cooperation

- Minimally Invasive Surgery(MIS)



2000



2003



2007



2009

Da Vici (2000 -)

Human - Robot Cooperation

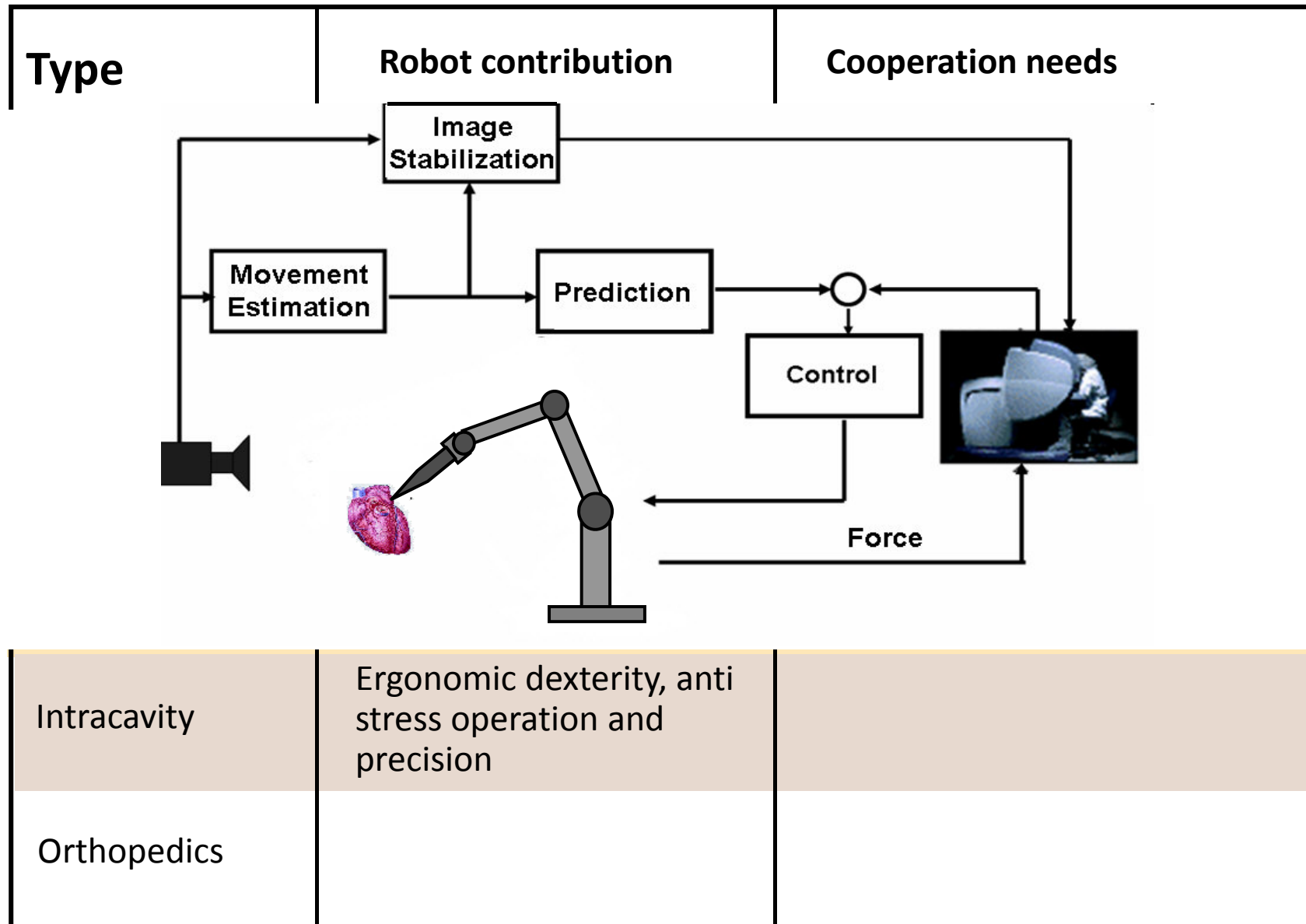
- Minimally Invasive Surgery(MIS)

Challenges:

- Natural orifices (NOTES)
- Unique Port (SPL)



Human - Robot Cooperation



Da Vinci

Da Vinci Set Up



Da Vinci H-M interface



3D Vision

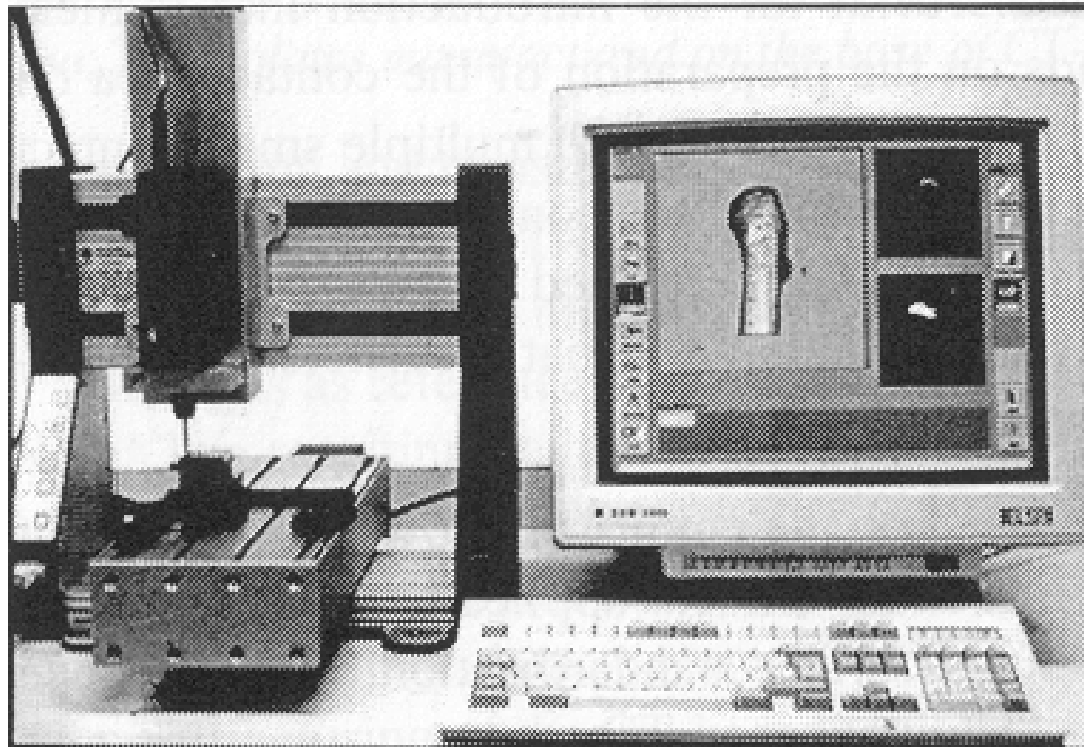


Haptic Interfaces

Tremor reduction, magnification,...

Human - Robot Cooperation

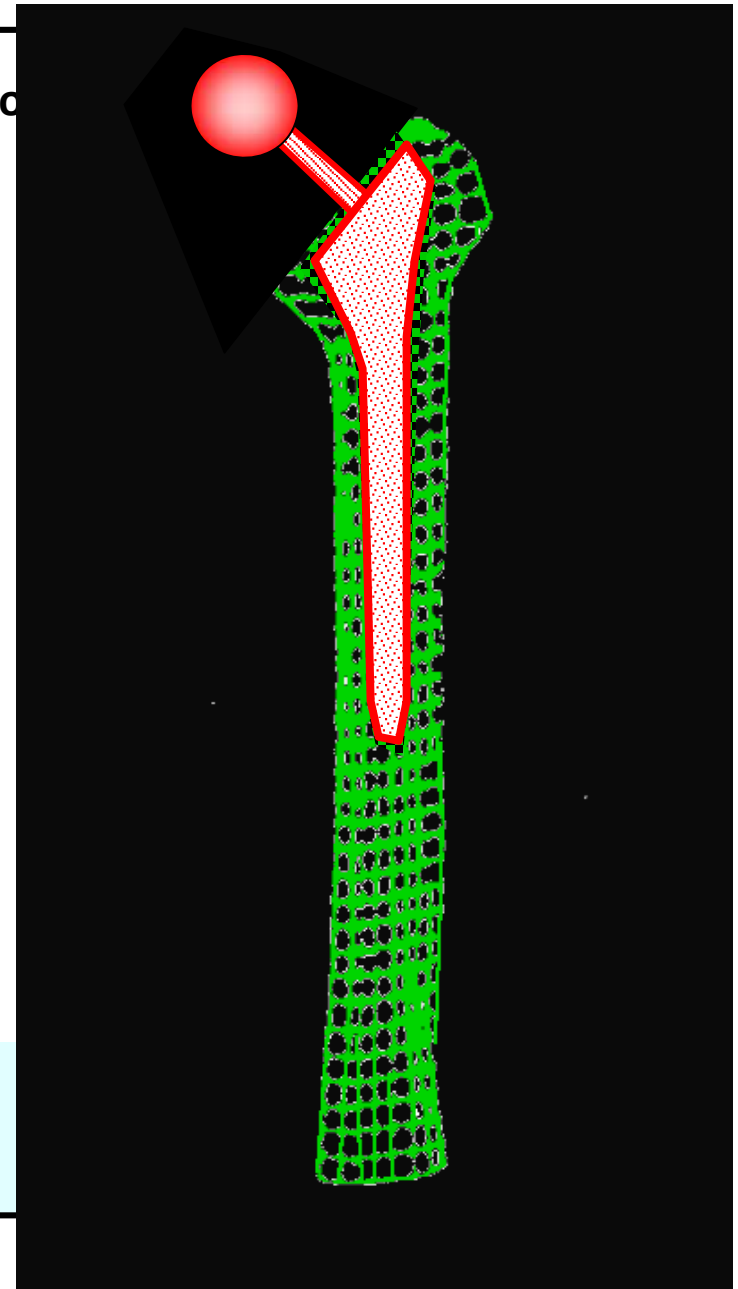
Type	Robot contribution	Cooperation needs
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Orthopedic	Precision, complex fitting, CAD/CAM	
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Human - Robot Cooperation

Type	Robot contribution	Co
Orthopedic	Precision, complex fitting, CAD/CAM	



Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
Orthopedic	Precision, complex fitting, CAD/CAM	





IMAGE
ACQUISITION

3D
RECONSTRUCTION

SEGMENTATION

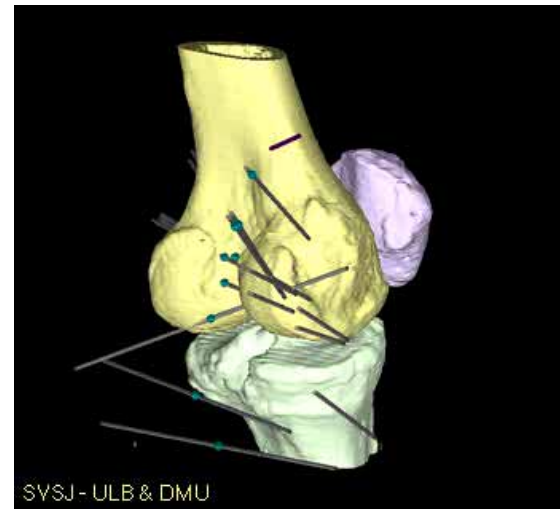
INTERVENTION
PLANNING

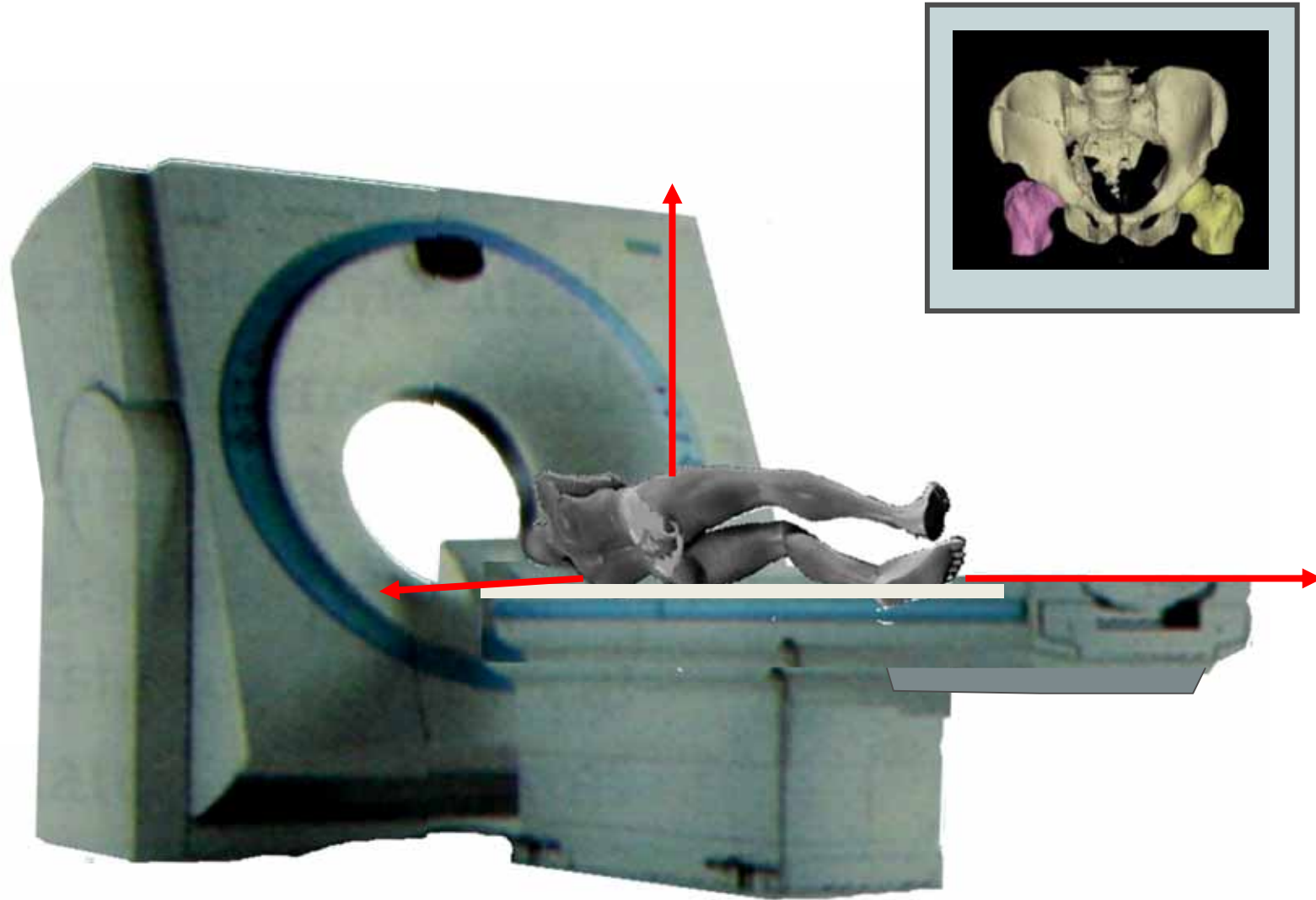


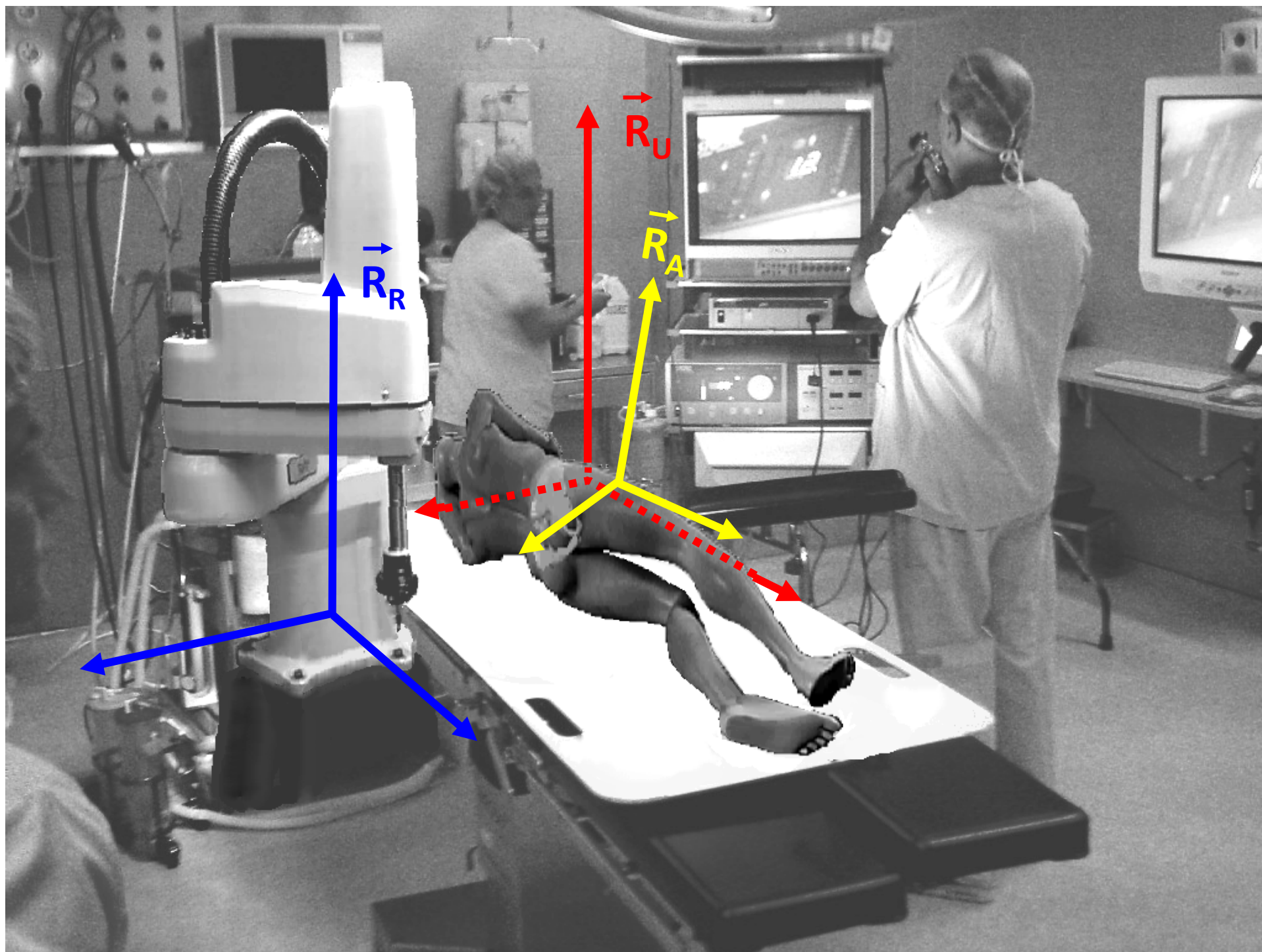
Intervention
Planning &
Supervision



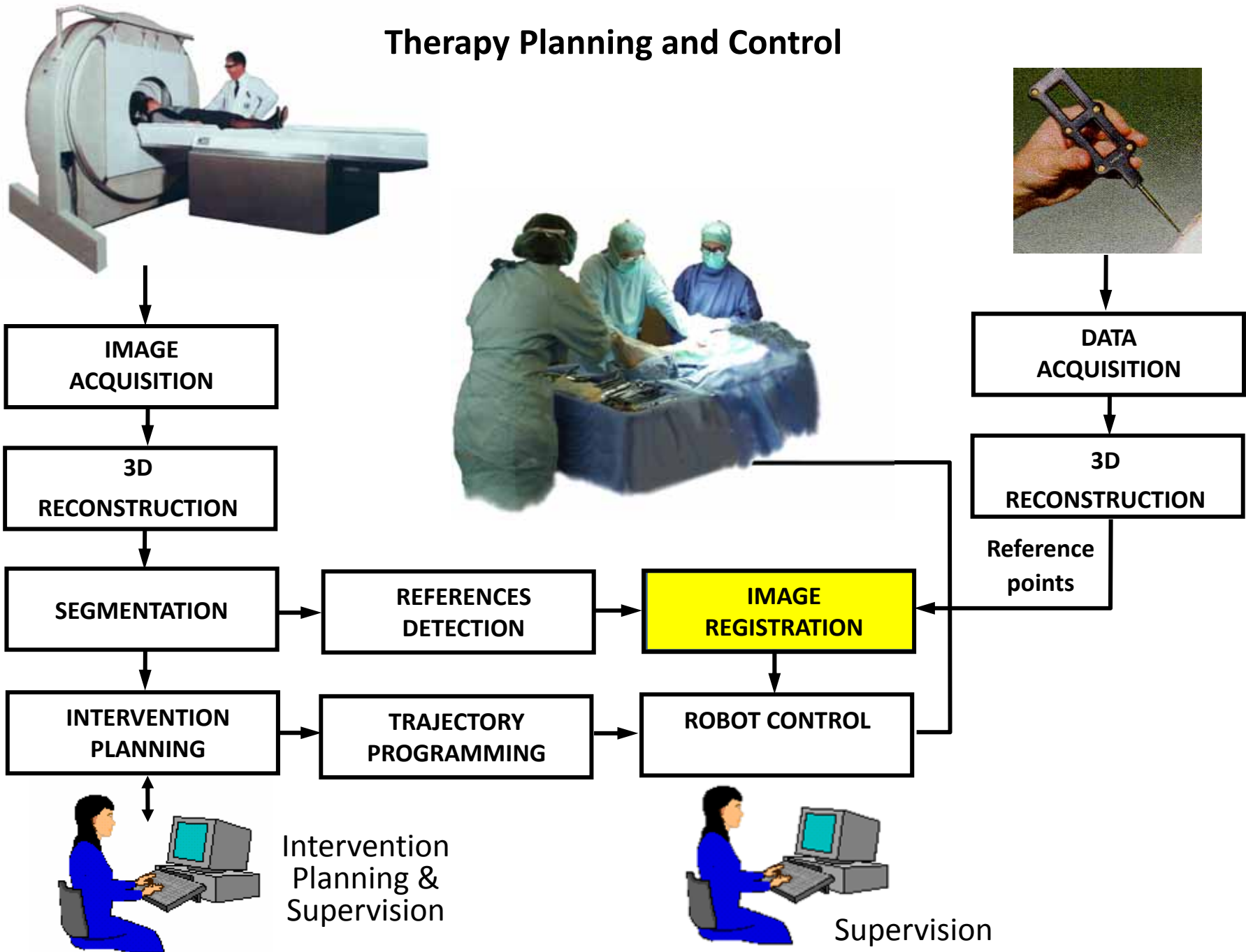
Monitoring



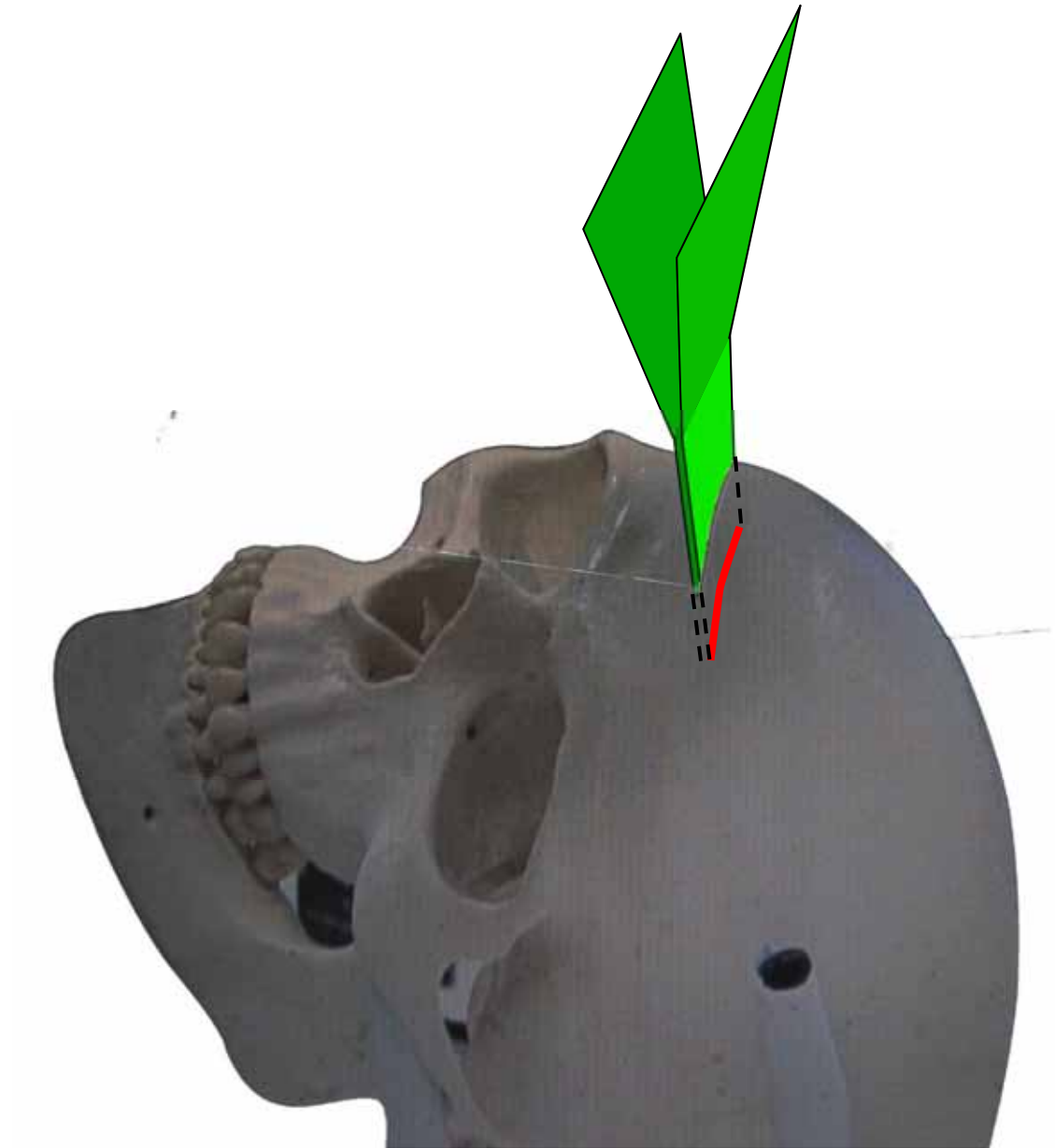


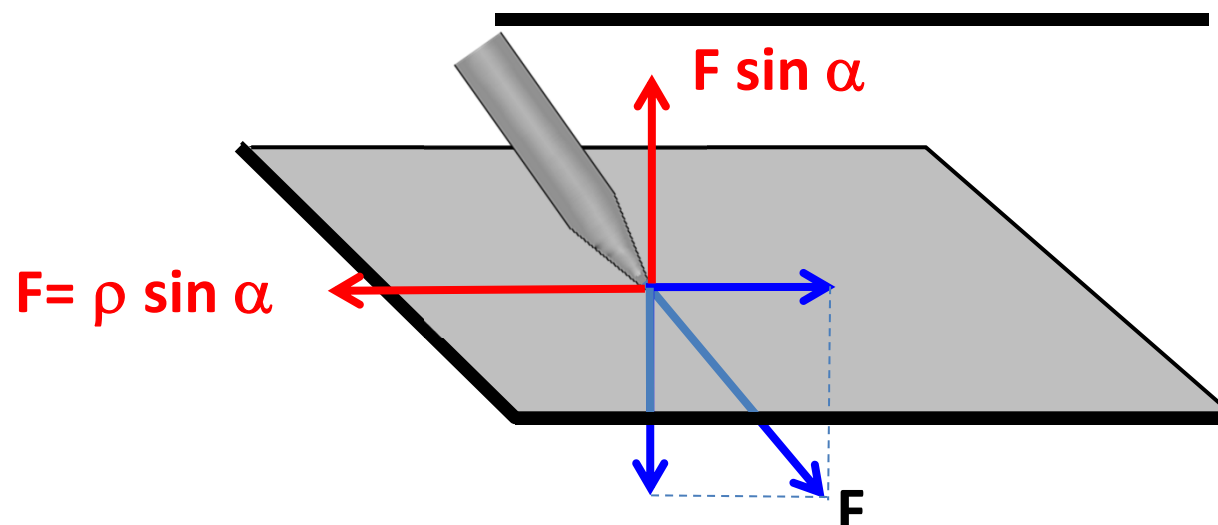
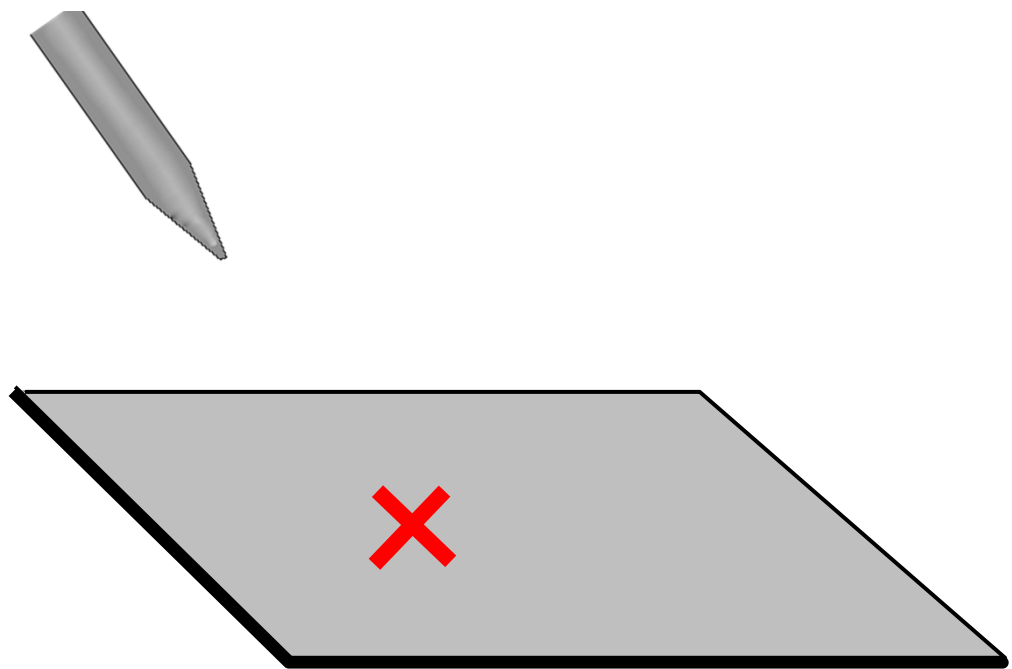


Therapy Planning and Control



Virtual fixtures

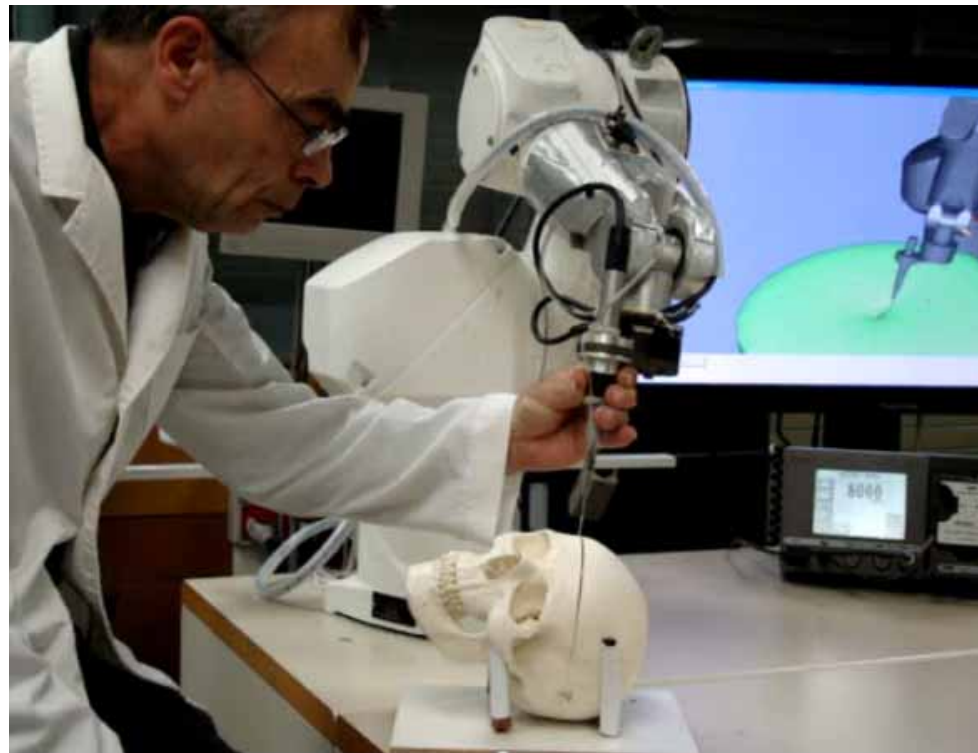




Physical reaction

Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
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Orthopedic	Precision, complex fitting, CAD/CAM	
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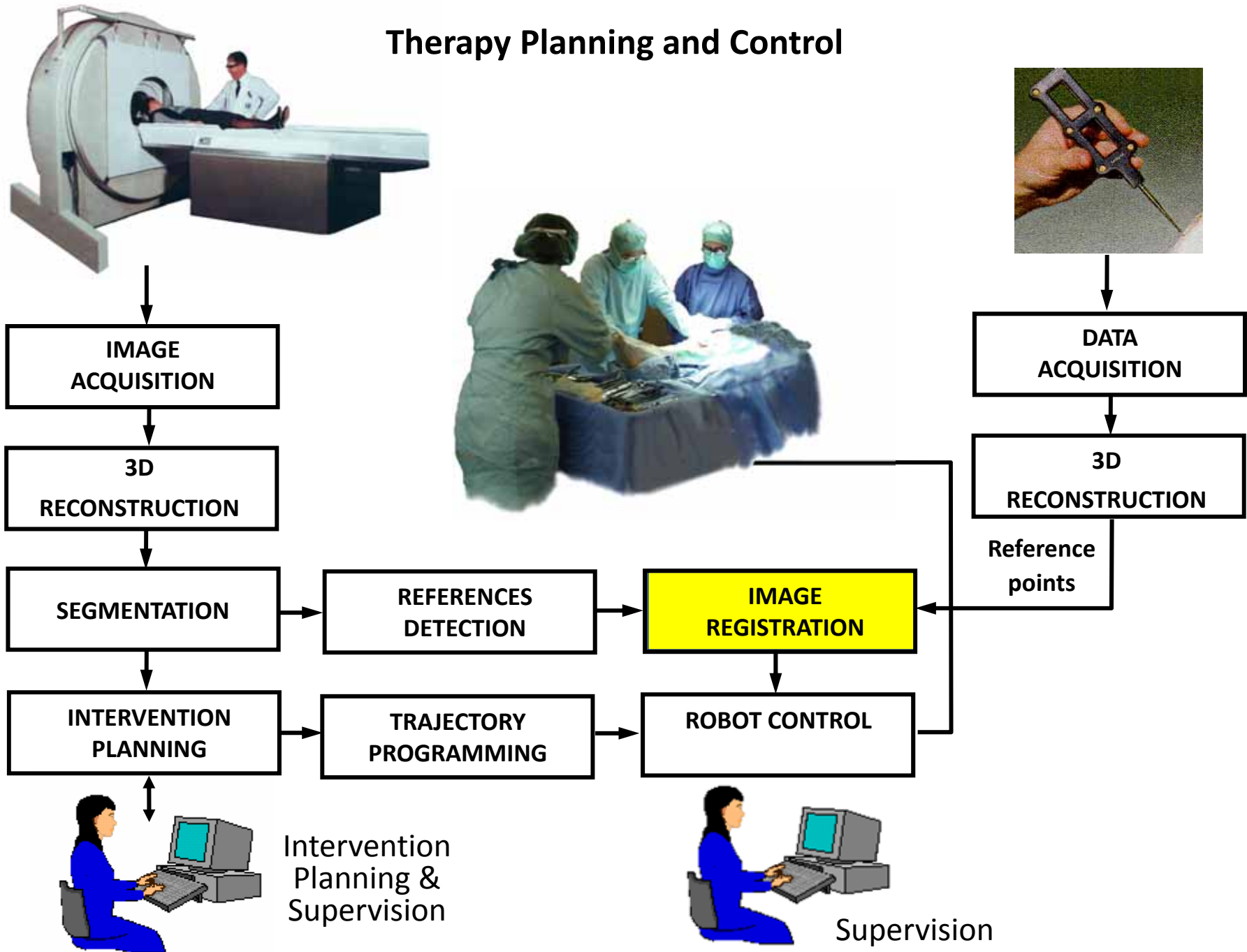
Human - Robot Cooperation

Type	Robot contribution	Cooperation needs
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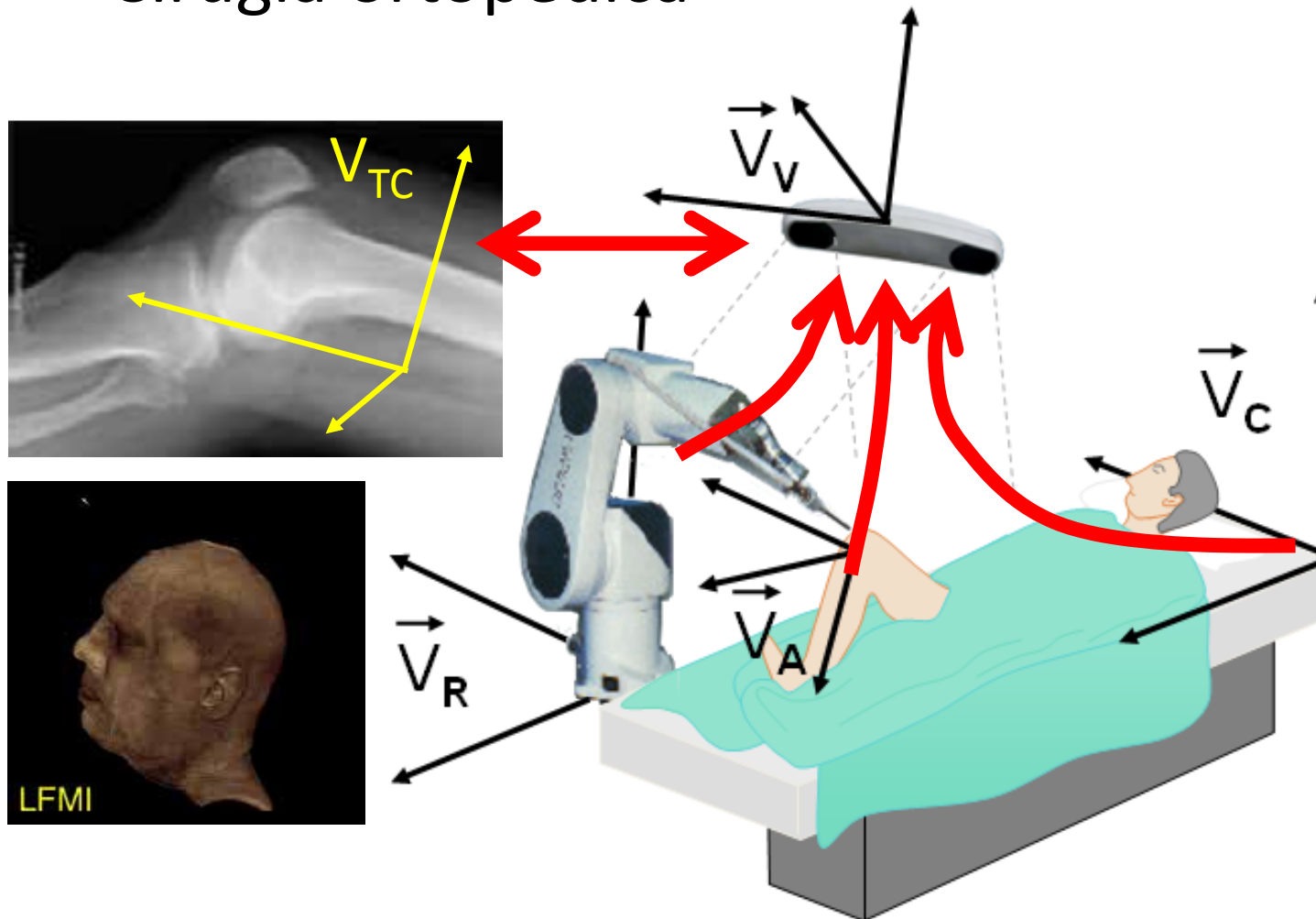
Orthopedic	Precision, complex fitting, CAD/CAM	
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Therapy Planning and Control



La robòtica en la cirurgia

- Cirurgia ortopèdica



Technical requirements

Type	Kinematics requirements	Positioning precision	Trajectory precision	Dexterity requirements	Sensor requirements
Microsurgery	Small space accessibility requirements	Very high precision	Very high precision	No critical requirements	Low haptic requirements
Neurosurgery	Small space accessibility requirements	Very high precision	Very high precision	High requirements	Low haptic requirements
Transcutaneous	Low accessibility requirements	High precision	No critical precision	No critical requirements	No Haptic requirements
Percutaneous	Large space accessibility requirements	High precision	No critical precision	Low requirements	No haptic requirements
Intracavity	Large space accessibility requirements	High precision	No critical precision	High requirements	High haptic requirements
Orthopedics	Large space accessibility requirements	High precision	High precision	Low requirements	High haptic requirements