



## Self Similarities in Cyber Physical Systems

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## Introduction and Motivation

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- ▶ **A suggestive *hypothesis* motivated by a number of similarities between different levels in cyber physical systems.**
- ▶ **Cyber physical systems will work in tight contact with humans, thus must satisfy requirements on:**
  - ▶ **safety**
  - ▶ **predictability, performance, efficiency, etc.**
  - ▶ **communication also at the cognitive level**
- ▶ **Examples that present these characteristics are:**
  - ▶ **single safe actuator**
  - ▶ **cognitive/manual tasks, e.g. surgical robotics**
  - ▶ **diagnostic/therapeutic process**

How do we extend and integrate current design paradigms to account for the recurrent needs and features of these systems?

# A Single Safe and Efficient Actuator

- ▶ Serial Elastic Actuator: series of motor and spring to achieve controlled stiffness:
  - ▶ embedded safety
  - ▶ resonance allows efficient actuation

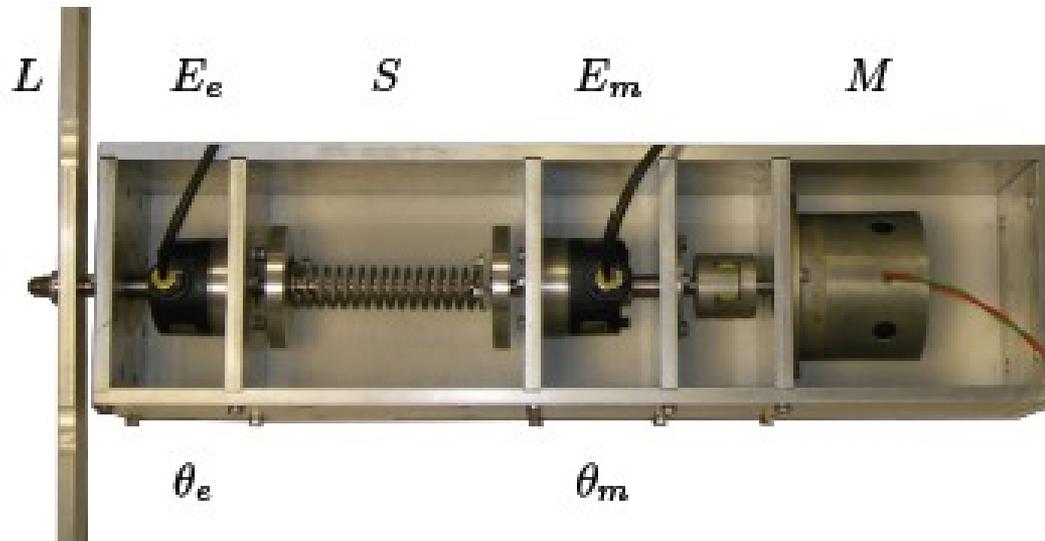
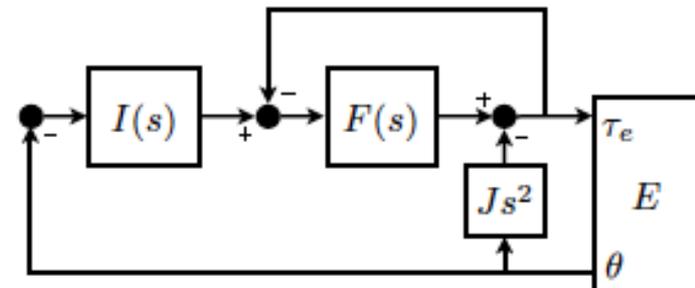
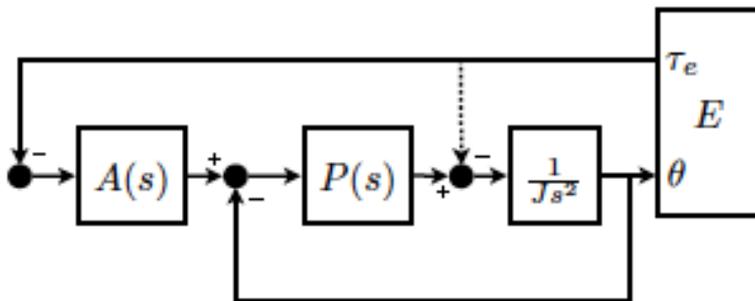
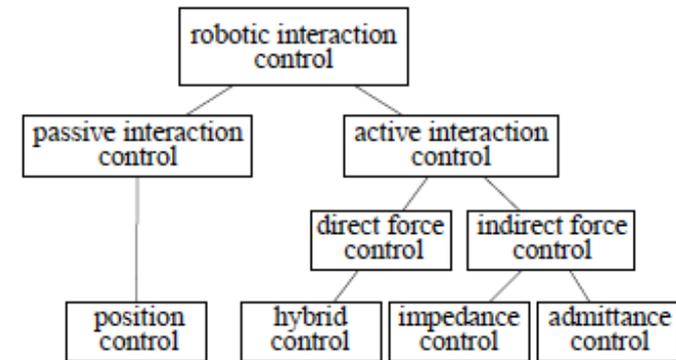
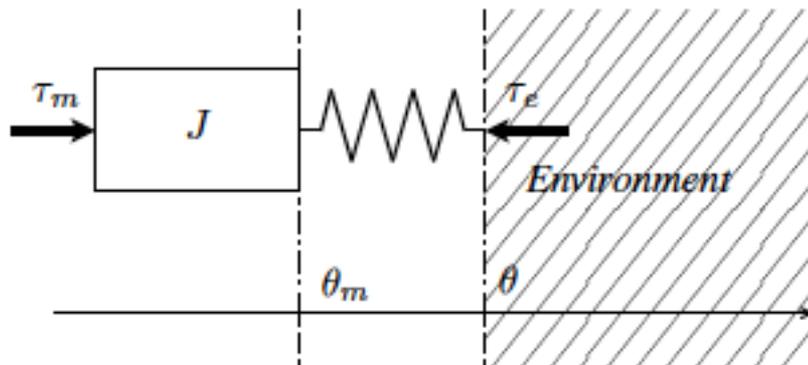


Figure 13. A SEA prototype. The motor  $M$  is connected to the spring  $S$  and the angular quantities  $\theta_m$  and  $\theta_e$  are measured by encoders  $E_m$  and  $E_e$  respectively. A custom load  $L$  is used as particular instance of environment.

## A Single Safe and Efficient Actuator

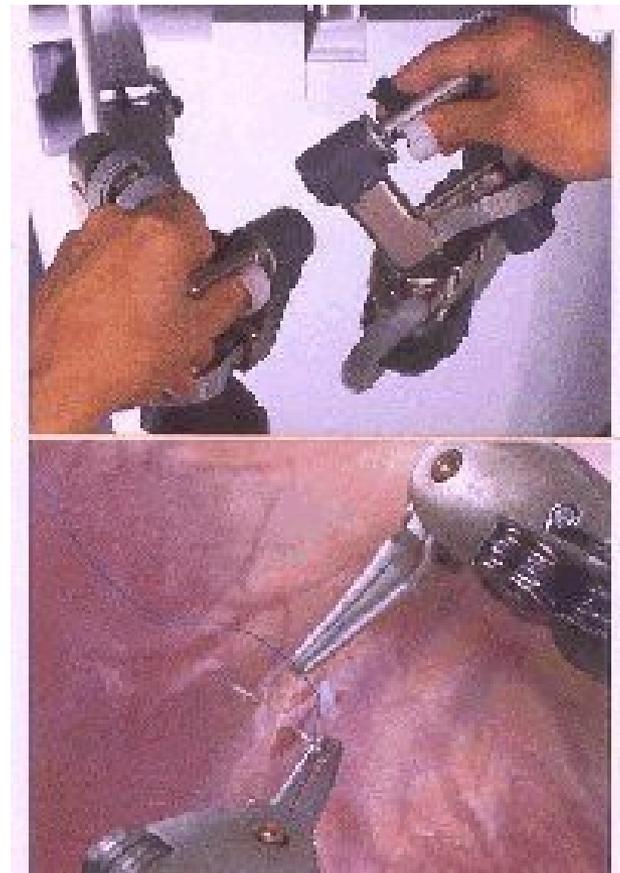
- ▶ Controlled interaction with the environment
- ▶ **This structure supports a large number of control**



## Robotic Surgery with the “da Vinci” robot

- Intuitive and easy operation
- Simple training
- Marketing to patients
- Creation of high-tech image
- Supportive intervention data
- Inaccessible hardware and software interfaces

However, the robot is part of surgical process and all the elements interact with each other



Safros Hypothesis: a seamless data flow in which we can establish a “control loop” to prevent errors

Robotic execution



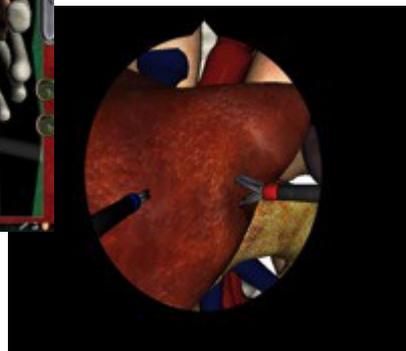
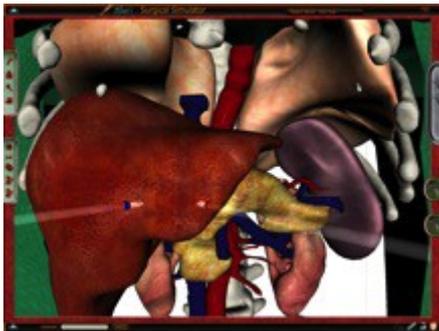
CT scan



Image registration

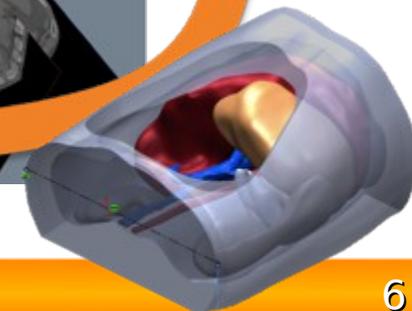
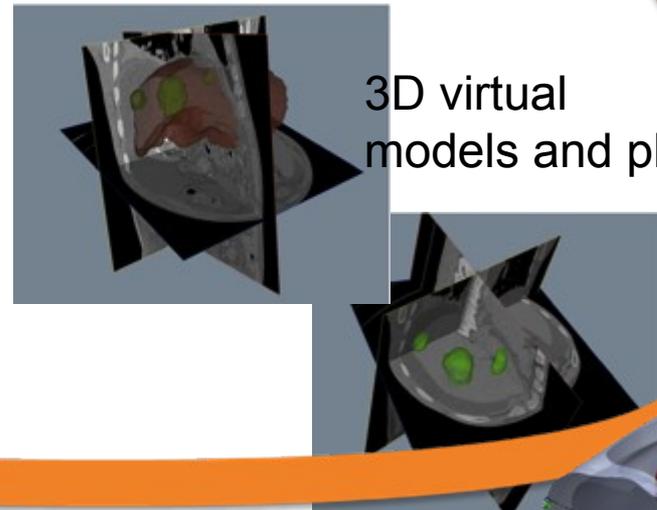


Intervention planning

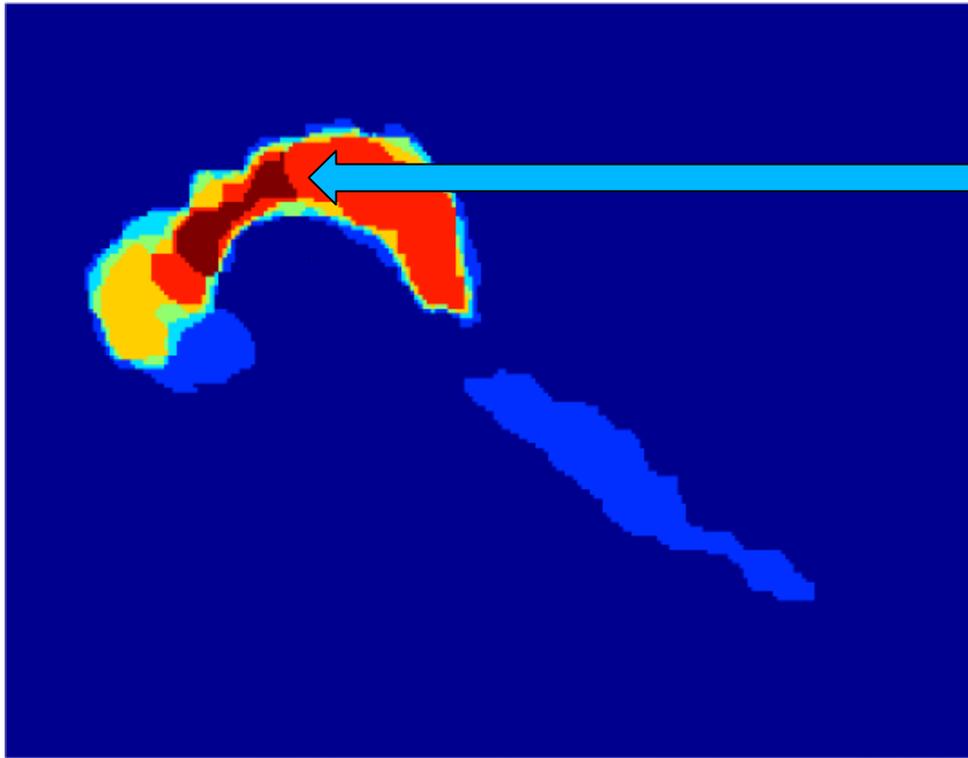


3D interactive virtual reality

3D virtual models and phantoms



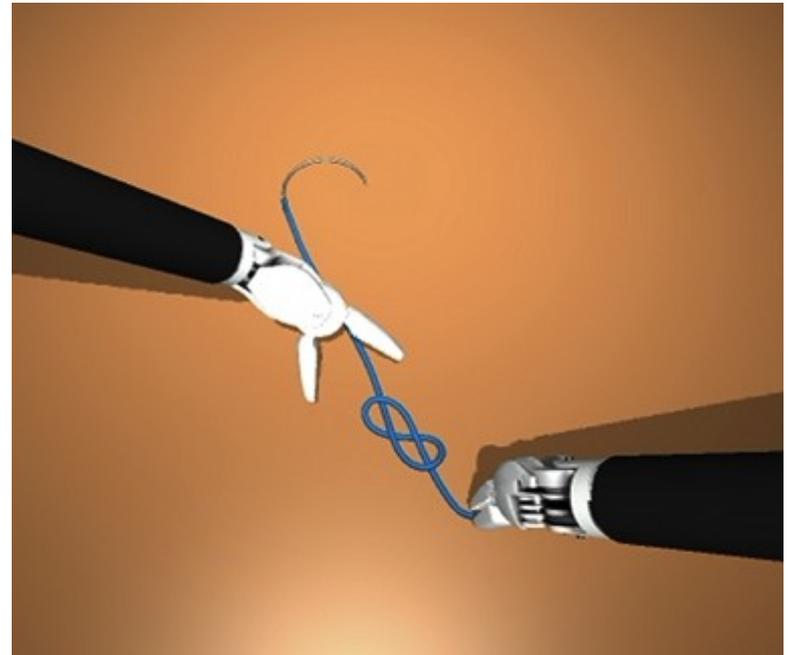
## Diagnostic Safety: pancreas segmentation



This is the only area that all 6 radiologists agreed to be healthy

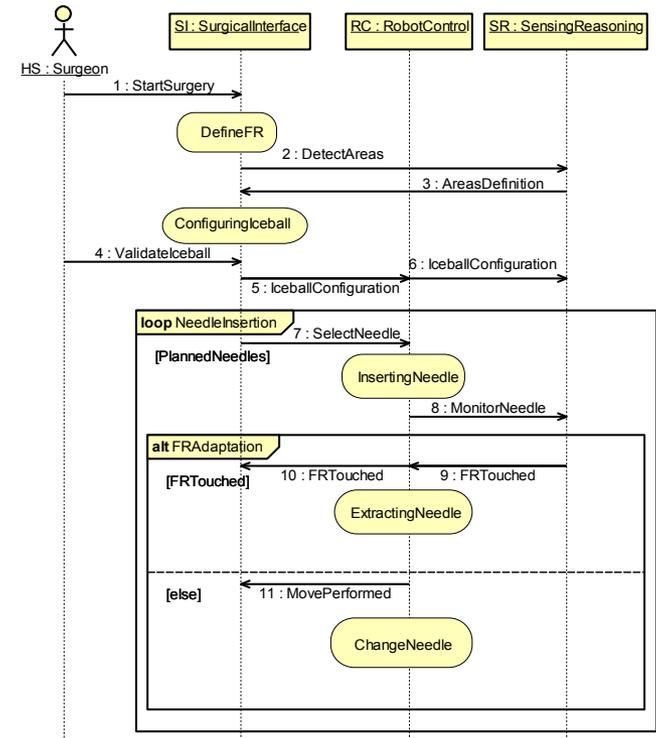
Model generation depends on the radiologist: unknown factors influence such largely different diagnosis

# Quantification and predictive value of training

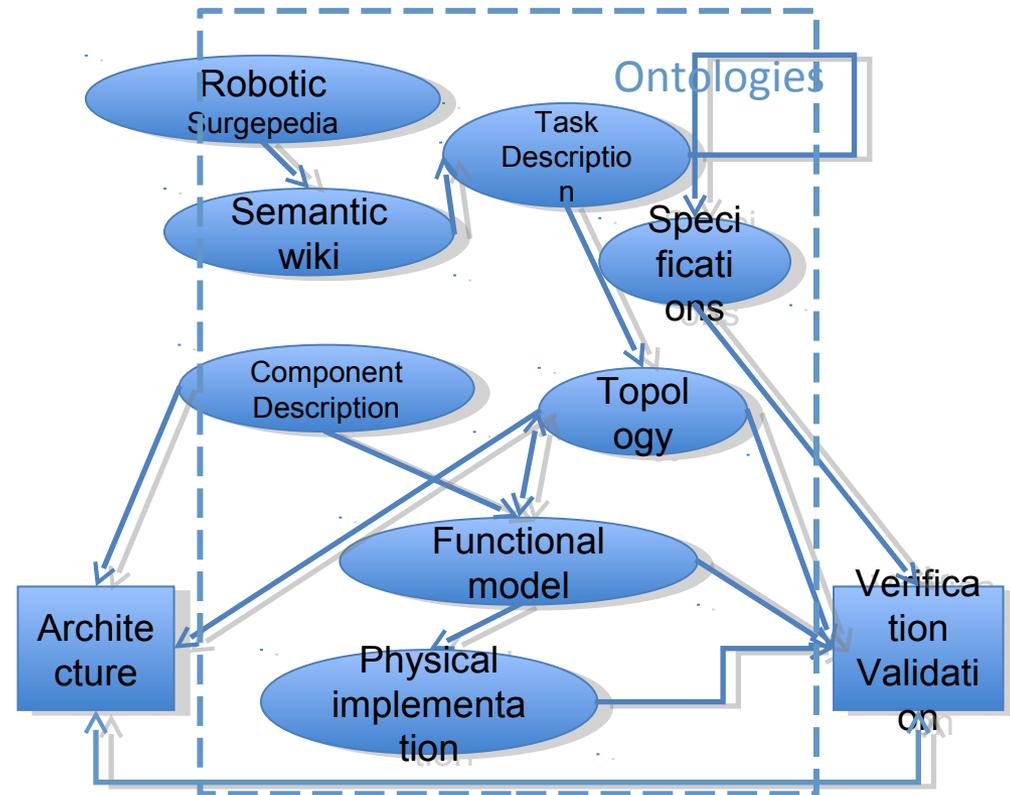


## Interaction among single tasks in a complex process

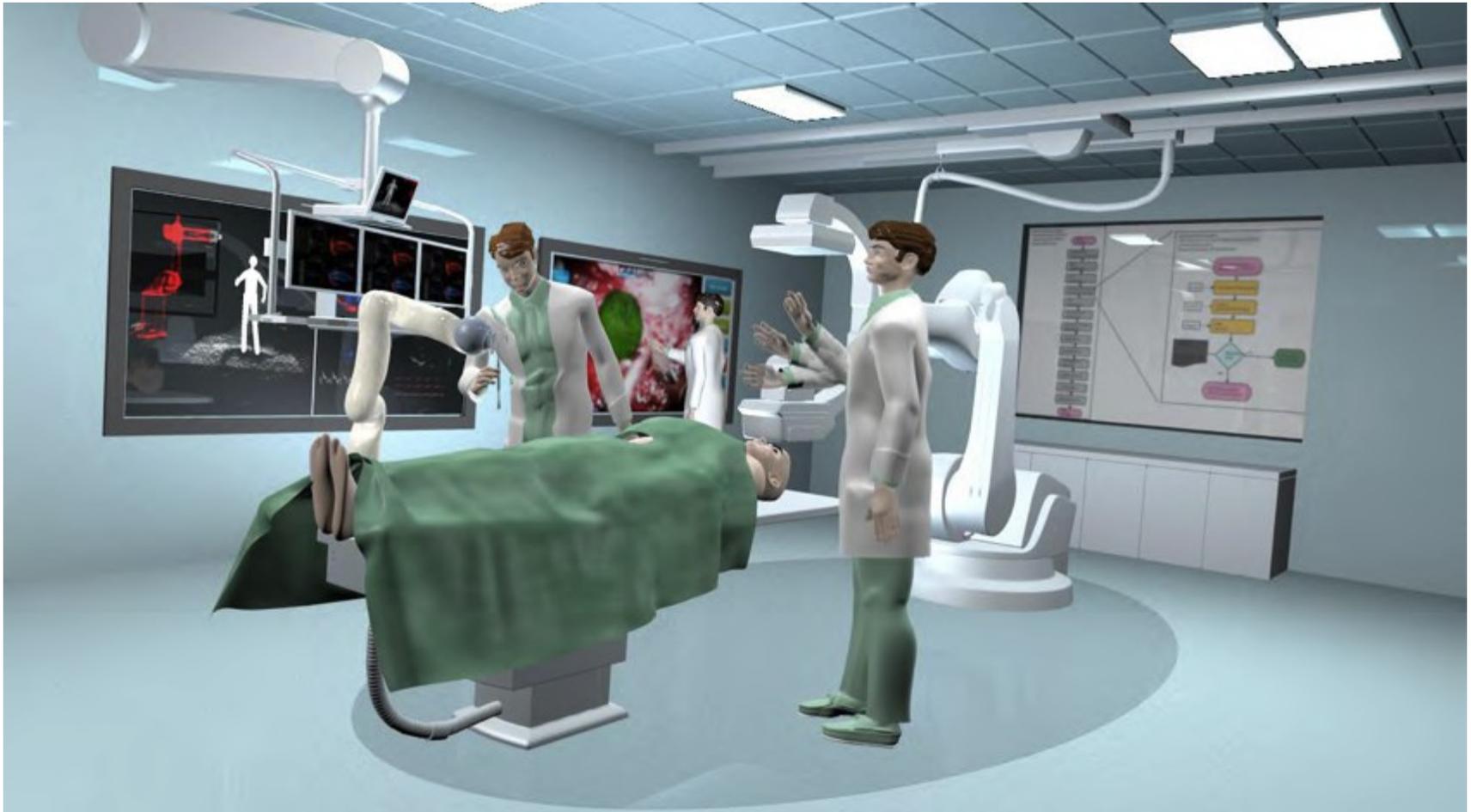
- Difficult to measure feedback parameters and identify input and output variables
- **Difficult to transfer results of one task to the next**
- **Difficult to model each task when adding automation**



## Inverse Process: mapping modularity to a monolithic system



## The Operating Room Process



## The Whole Diagnostic/Therapeutic Process

- ▶ A complete medical process involves many people and long time
- ▶ **Information, actions, decisions and devices may interact unexpectedly**
- ▶ **Measurements, situation awareness, machine perception, automatic learning should be modeled and should interact (how? when?) with the humans acting on the process**

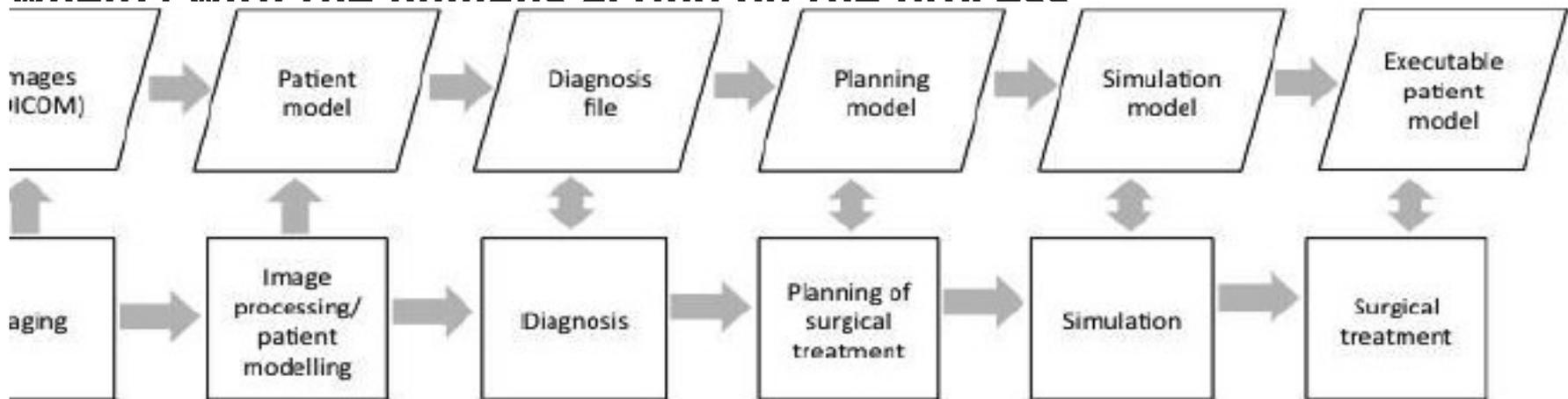
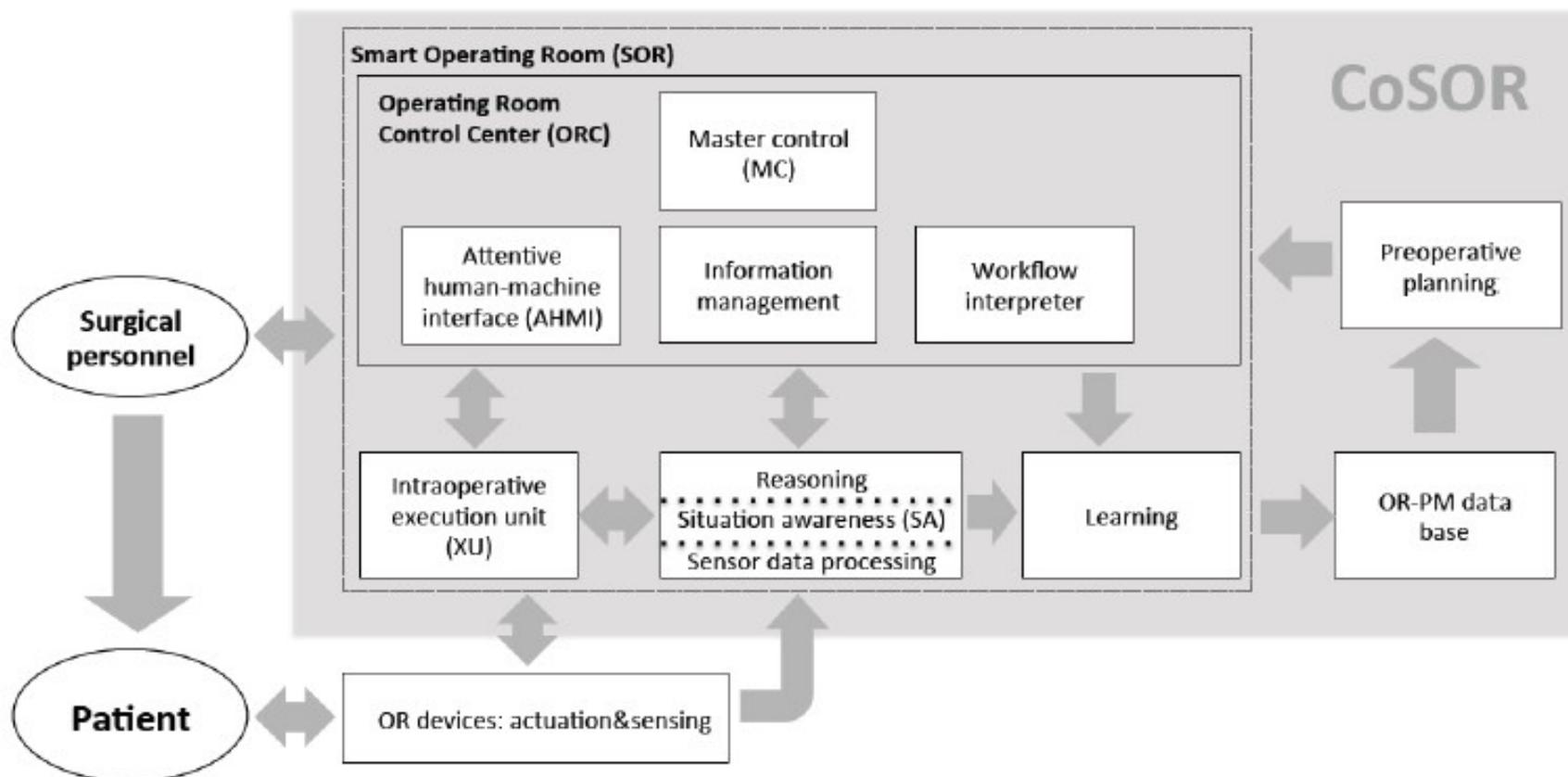


Figure 1.1 - Dataflow (upper row) along the physical workflow (bottom row)

# The Diagnostic/Therapeutic Process Model



Execution and control of a complex workflow

## Conclusions

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- ▶ **There are many similarities among different levels of granularity in a complex process, however these similarities are not exploited to reach a unified approach to modeling, simulation and control.**
- ▶ **Cyber physical systems are an important new area since they encompass so many real systems (Boundaries? What is not?).**
- ▶ **The grains of a CPS are not homogeneous thus requiring paradigmatic changes between one grain/level to another.**
- ▶ **Humans are always involved, thus needing cognitive**

# Thank You for Your Attention

