Architecting Autonomy for Operations

Design for Flexibility, a Human Systems Integration Approach:
From rigid automation to flexible autonomy

The Infusion of
- **System Architecture**
- **Autonomy Design**
- **Mission Operation**

FlexTech

PROFESSOR GUY ANDRÉ BOY

CentraleSupélec | université PARIS-SACLAY

ESTIA INSTITUTE OF TECHNOLOGY

IRT SystemX, Paris Saclay – October 19, 2023

MY WORLD FOR OVER 40 YEARS...

... in engineering design
and in operations

From correction to interaction to integration
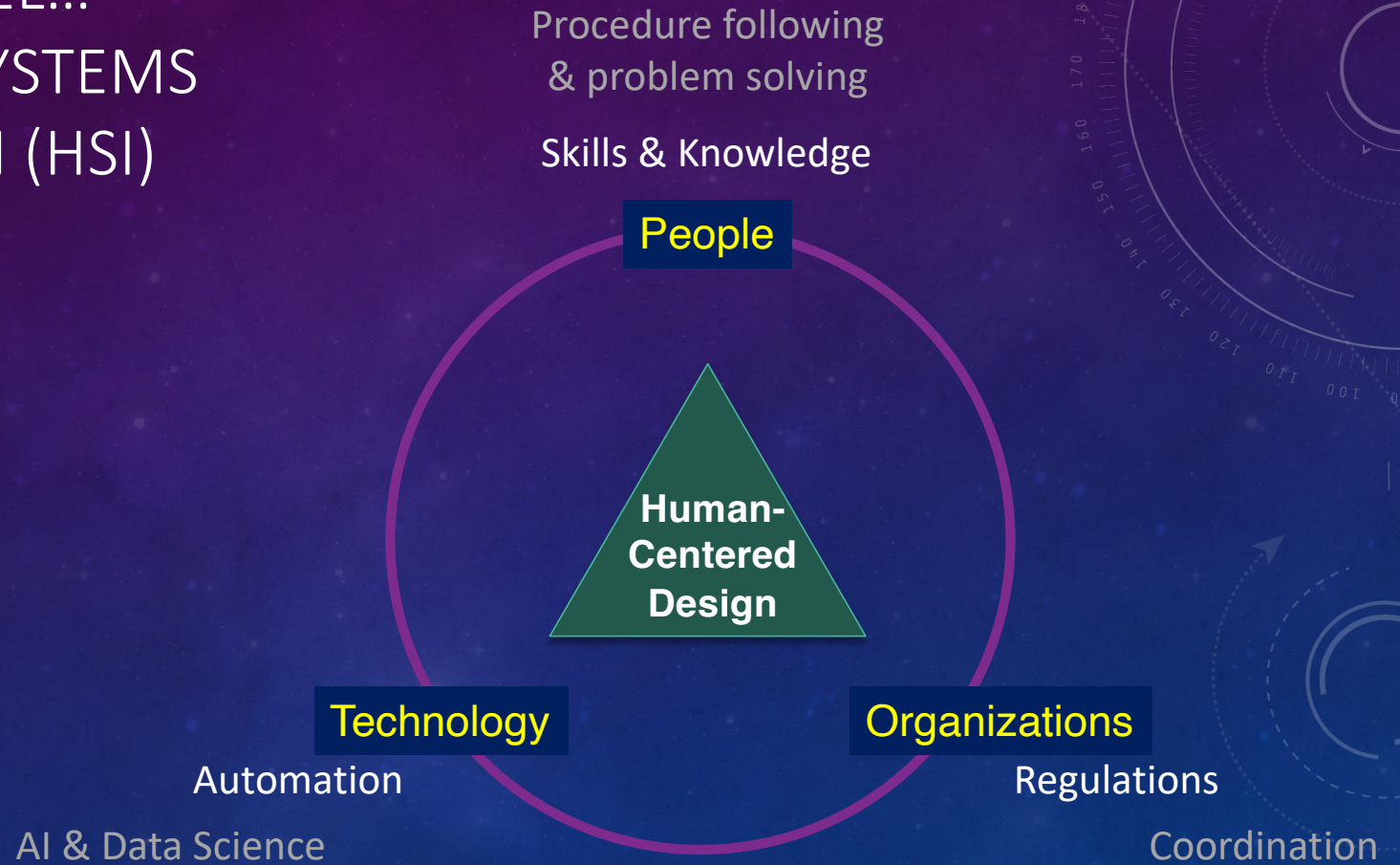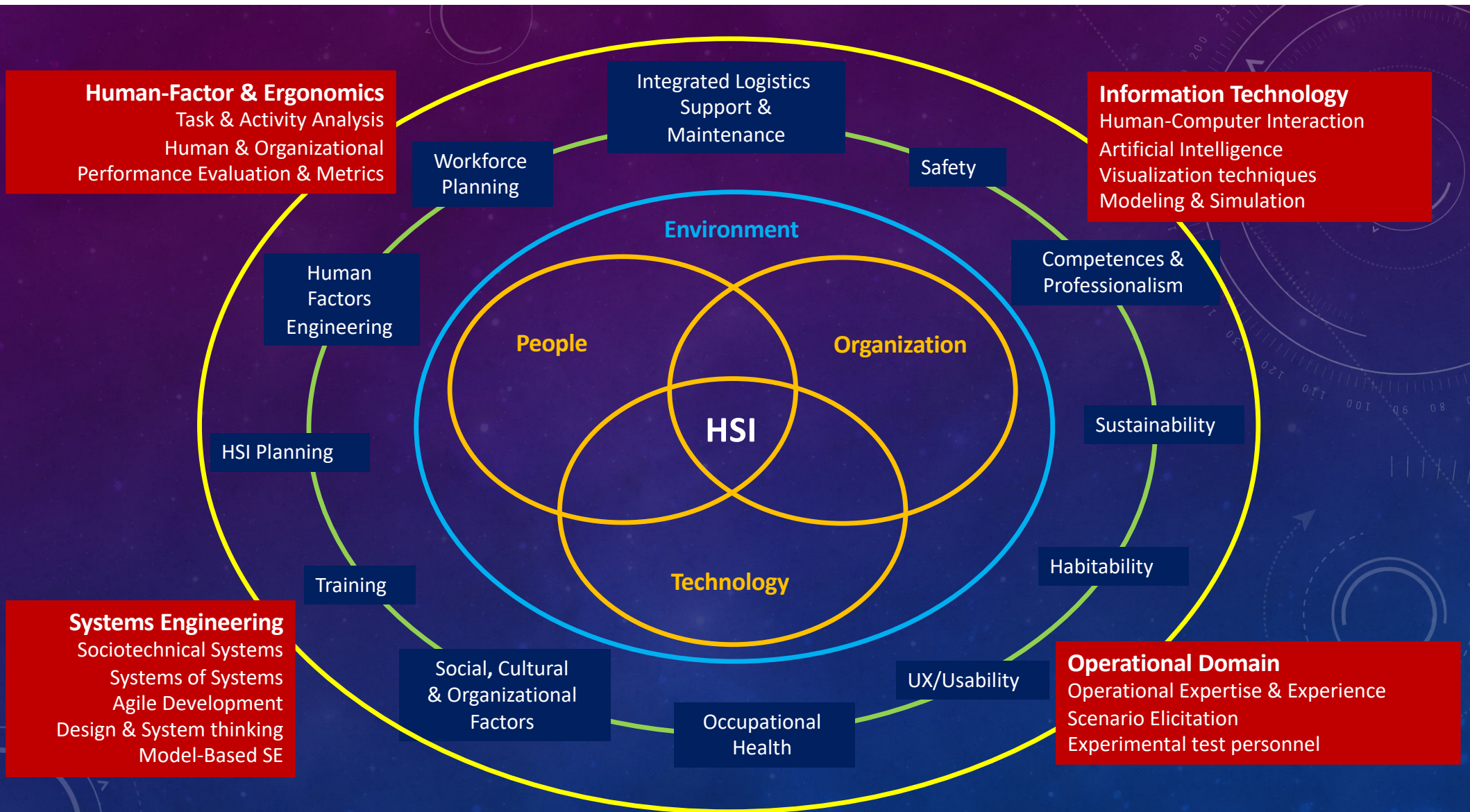
Human Factors & Ergonomics...
Human-Centered Design...
Human Systems Integration...

THE T.O.P. MODEL...
... IN HUMAN SYSTEMS
INTEGRATION (HSI)

Procedure following
& problem solving

Skills & Knowledge

People

Human-Centered Design

Technology

Organizations

Automation

Regulations

AI & Data Science

Coordination

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Human-Factor & Ergonomics
Task & Activity Analysis
Human & Organizational
Performance Evaluation & Metrics

Information Technology
Human-Computer Interaction
Artificial Intelligence
Visualization techniques
Modeling & Simulation

Systems Engineering
Sociotechnical Systems
Systems of Systems
Agile Development
Design & System thinking
Model-Based SE

Operational Domain
Operational Expertise & Experience
Scenario Elicitation
Experimental test personnel

Integrated Logistics Support & Maintenance
Workforce Planning
Safety
Human Factors Engineering
Competences & Professionalism
HSI Planning
Sustainability
Training
Habitability
Social, Cultural & Organizational Factors
UX/Usability
Occupational Health

Environment
People
Organization
HSI
Technology

LET'S INTRODUCE THE FLEXTECH CHAIR...

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HUMAN SYSTEMS INTEGRATION (HSI) IN INCREASINGLY AUTONOMOUS SYSTEMS

Digital Engineering of large life-critical complex systems

Role of people and organizations in life-critical complex systems

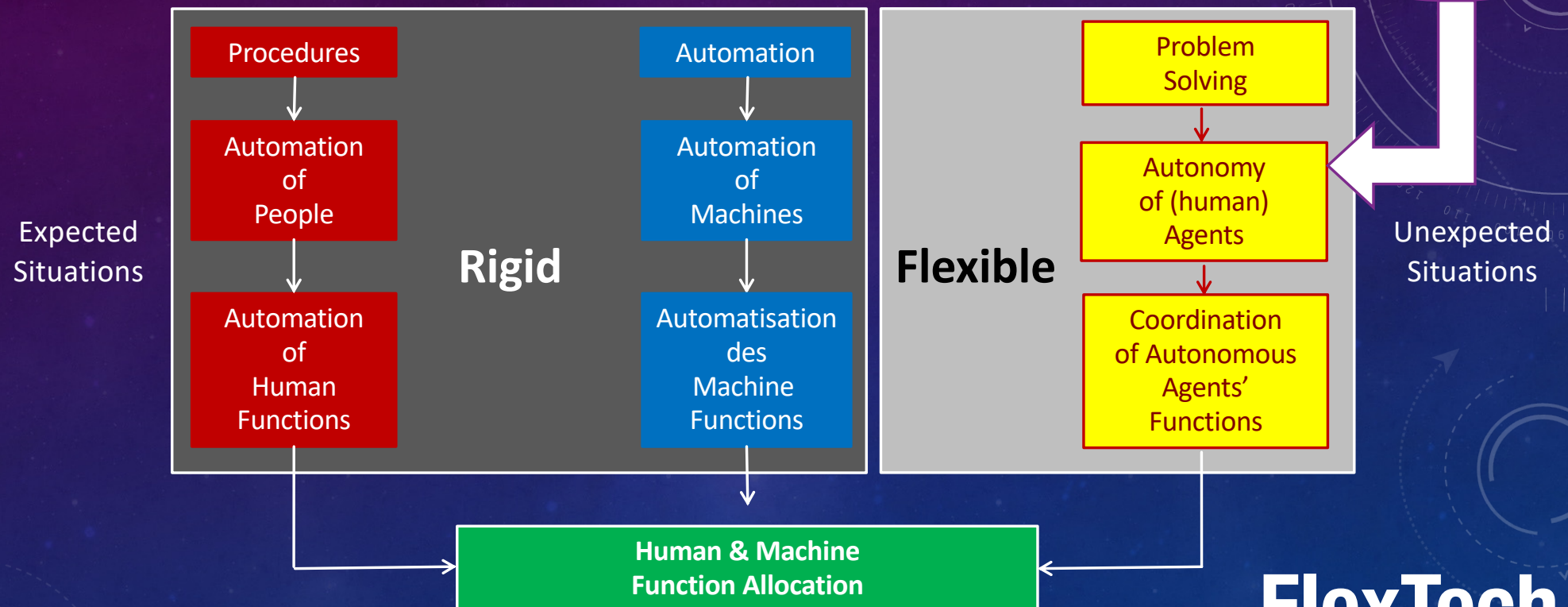Development of new approaches, methods and tools

Applications in various industrial sectors, e.g., aerospace, defense, oil-&-gas, health, automotive, nuclear, and others

FROM RIGID AUTOMATION TO FLEXIBLE AUTONOMY

Multi-agent

Expected Situations

Rigid

Procedures → Automation of People → Automation of Human Functions

Automation → Automation of Machines → Automatisation des Machine Functions

Flexible

Problem Solving → Autonomy of (human) Agents → Coordination of Autonomous Agents' Functions

Unexpected Situations

Human & Machine Function Allocation

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ACADEMIC PARTNERS

1. FlexTech
   - CentraleSupélec
   - ESTIA
2. External Partners
   - ENSC
   - ISAE-SUPAERO
   - ESCP Business School
   - Autres…

HSI Course taught at Master & doctoral levels

Created in September 2019

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INSTITUTIONAL & INDUSTRIAL PARTNERS

1. French Air & Space Forces

2. CS Group

3. Thales

4. Ingenuity

6. Clients via ESTIA (DGA, TotalEnergies, SAFRAN)

Cross-Fertilization of various HSI projects

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A MAJOR RESEARCH TOPIC EMERGED ...

PRODEC method emerged from various applicative research projects

PRODEC is currently developed:

to capture and analyze existing operations (AS-IS)	to overcome major obstacles, mainly information exchanges (TO-BE)	to dig technological, organizational and human gaps towards a successful digital transformation	to allow the analysis, design, and evaluation of data exchanges, and support the validation of all possible transformation

Towards a modeling platform that supports considering people and organizations

all along the life cycle of a system

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INDUSTRIAL USE CASES USING PRODEC

MOHICAN: trust & collaboration with a virtual assistant (DGA, Thales, Dassault Aviation)

Virtual air traffic control center (CS Group & French Air & Space Forces)

Increasingly autonomous trains (SNCF)

Future Combat Air System (Thales)

Off-shore robotics remote management (TotalEnergies)

Remote maintenance of helicopter engines (Safran)

INNOMED: a new health system with general practitioner at the center

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LET'S TAKE AN EXAMPLE...

THE MOHICAN PROJECT
VIRTUAL ASSISTANT IN AIR COMBAT AIRCRAFT

A RESEARCH EFFORT SPONSORED BY DGA,

AND SUPERVISED BY THALES AND DASSAULT AVIATION

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CentraleSupélec–ESTIA Chair

MONITORING HUMAN-MACHINE PERFORMANCE BY ANALYZING TRUST AND COOPERATION

Objectives

- Propose and test a method to evaluate the perf̶̶̶̶̶̶̶̶̶̶assistant teaming…

  … in the cockpit of a simulated f̶̶̶̶̶̶̶̶̶

- Define trust and co̶̶̶̶̶̶̶̶cs by

  - ̶̶̶̶̶̶̶̶environment

  - ̶̶̶̶̶̶̶rs based on operational experience

  - ̶̶̶̶̶̶ilding metrics based on tangible virtual prototypes

  - Developing virtual prototypes (virtual assistant) and experiments

Is the Virtual Assistant a Partner or a Tool?

Human-Machine Teaming

Method for the analysis of trust and collaboration

Operational skills & knowledge & HSI

Procedural & Declarative Knowledge on Systems being developed

Task Analysis (BPMN) + Function Analysis

2

Human-in-the-Loop Simulations

4

Structure-Function Analysis Potential Redesign

1

Prototype Development Preparation of a Simulation Facility

3

Activity Observation and Analysis Emergent Properties Detection

5

HSI objectives satisfaction in terms of operational performance

MOHICAN PRODEC

Task-based Procedural Knowledge → Task-based Declarative Knowledge → Emergence & Activity Analysis

AS-IS   TO-BE   *Human-in-the-loop simulations*
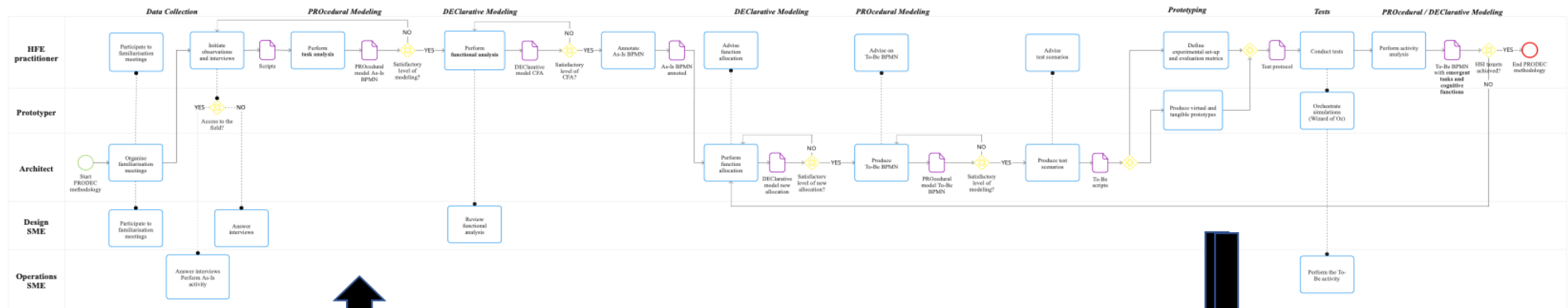
TO-BE becomes AS-IS ← TO-BE ←
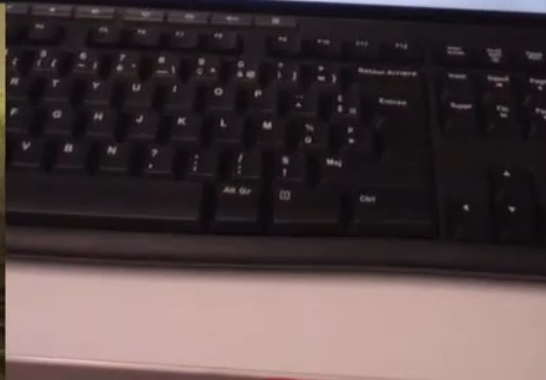
Activity-based Procedural Knowledge

DCS WORLD + TACVIEW + ADD – ON DECISION SUPPORT JOBS

SIMULATION SET-UP

DCS WORLD

AV

TACVIEW

DCS WORLD

AV
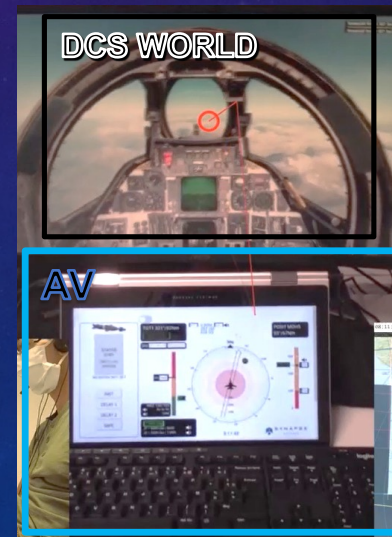
CAPTURE AND ANALYSIS TOOLS

Heart rate monitor : GARMIN watch
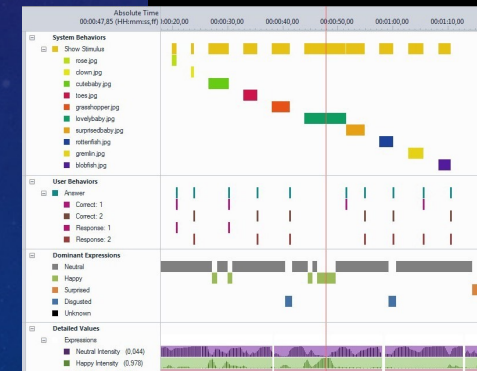
- More reliable than wrist measurement
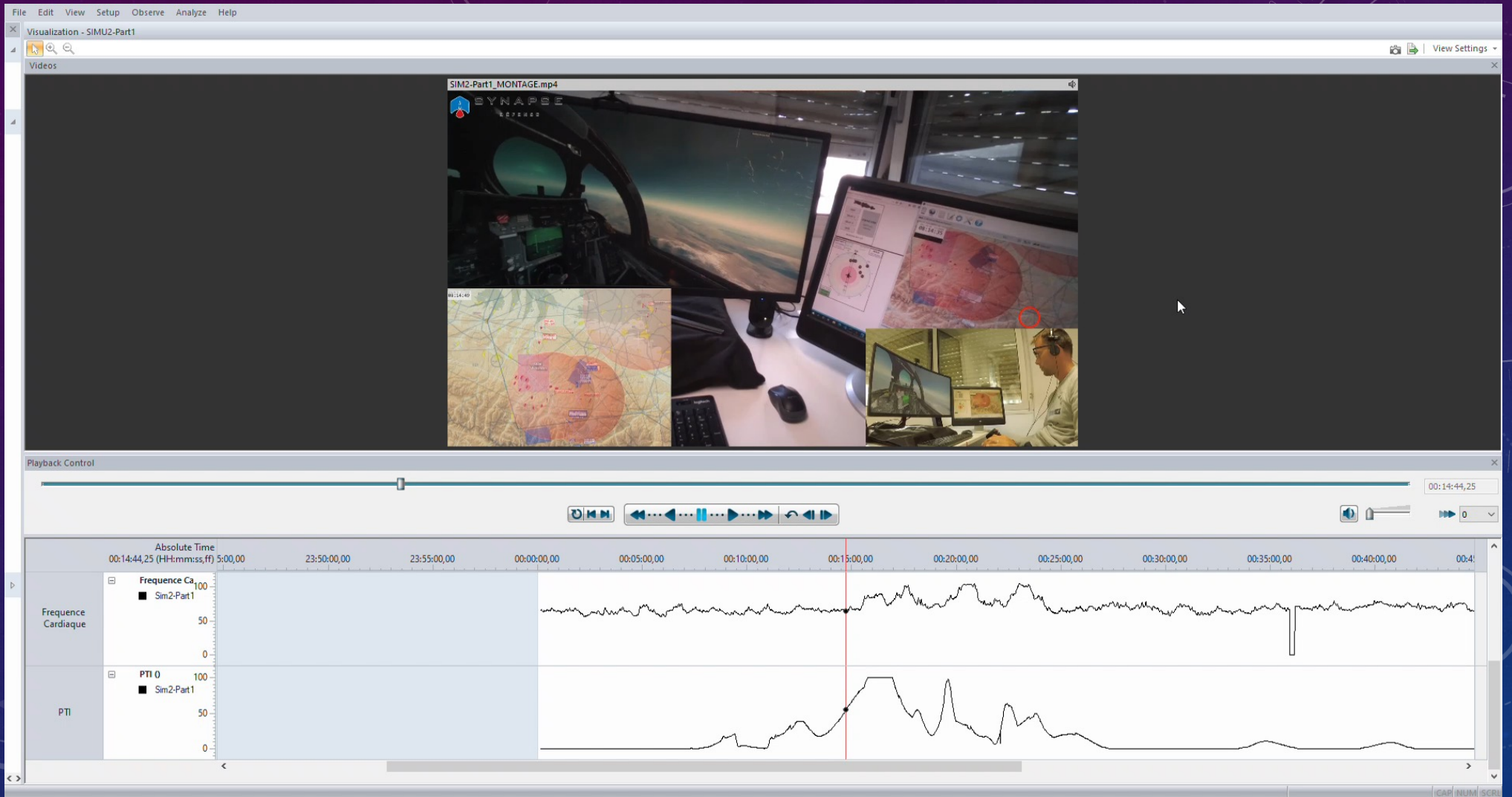- Less intrusive

Eye tracking : Tobii glasses
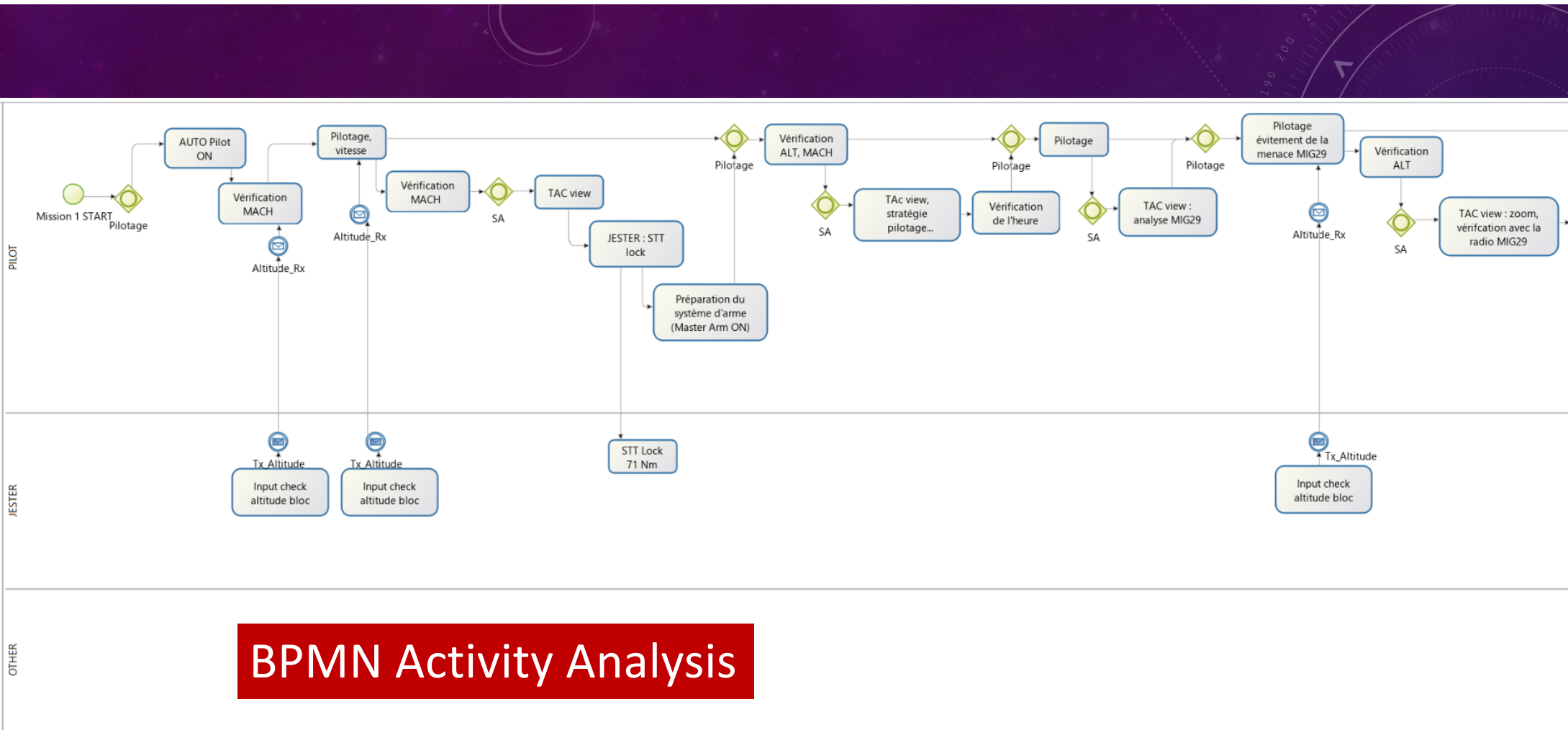
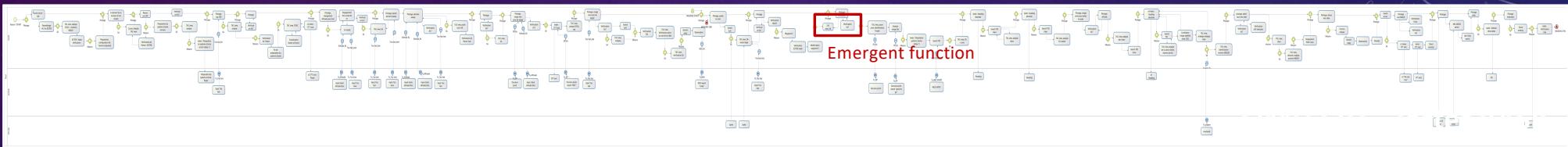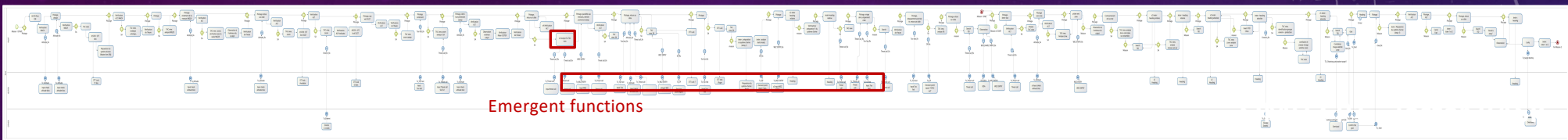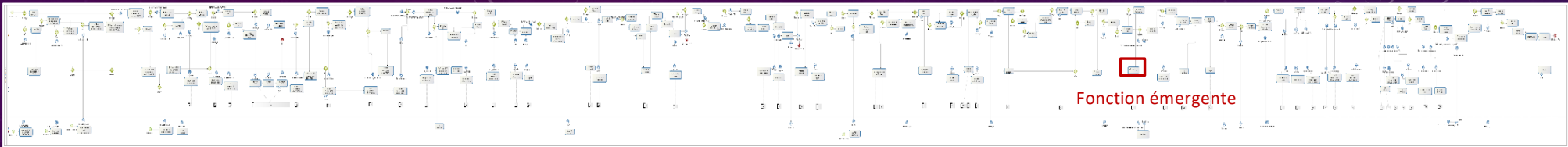- Goal: record in real time, user's eye gaze on screens

Noldus XT Observer

- Allows the observation of uses to be instrumented
- Represents behaviors in an accurate and quantitative manner
- Integrates behavioral and physiological data
- Create video clips of the most interesting data
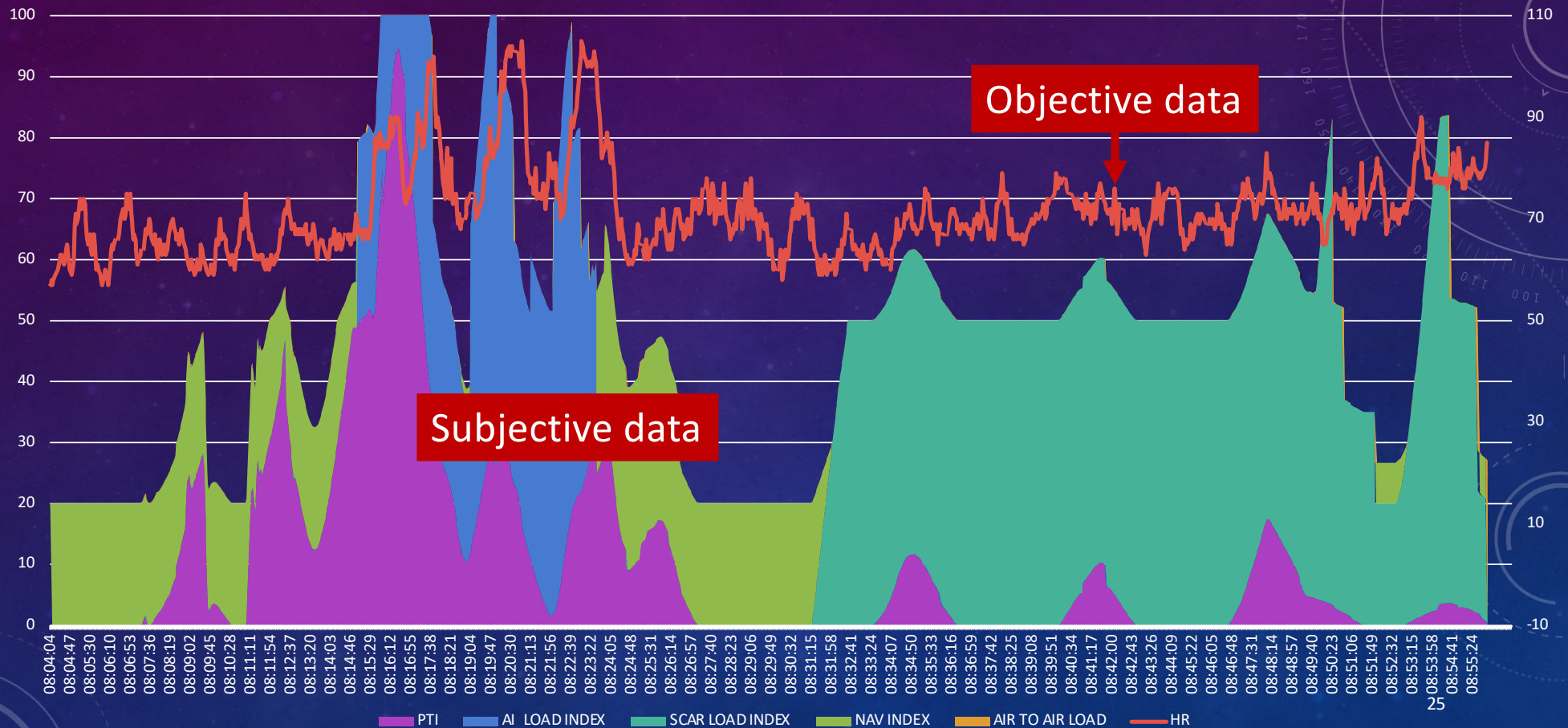- Create video clips of the most interesting data

BPMN Activity Analysis

Fonction émergente

Emergent functions

Emergent function

Emergent function

Emergent function

Emergent function

Emergent function

BPMN ACTIVITY ANALYSIS +

CORRELATION BETWEEN PILOT LOAD INDEX AND CFA RESULTS

SIMU2-P1-HR et LOAD Index (Stacked areas)

Objective data

Subjective data

PTI   AI LOAD INDEX   SCAR LOAD INDEX   NAV INDEX   AIR TO AIR LOAD   HR

CORRELATION BETWEEN PILOT LOAD INDEX AND CFA RESULTS

Average HR = 71,86-8,71   Cumulated HR & Index – same scale   R=0,53 (strong correlation)

Search target 1 (No PID)

Threats + audio overload (PTI)

51 s   54 s   49 s

Search + shoot target 1 (AI Load)

No shoot target (SCAR)

shoot target 1 (SCAR)

Provide explanations on trust in the VA

(information flow to manage : Watch SITAC + concentration on announcement): simulation bias

Search PID - CDE

HR   Indice cumulé

ELICITATION & VALIDATION OF EVALUATION CRITERIA

Metrics	Criteria	Measures
Trust	Efficiency	Processed information (pilot actions)
		...eived information (eye tracking)
	Effectivity	Interaction time (Raw data - The Observer XT)
	Reliability/Robustness	Bug or functional default (experimenter)
	Relevance	Added value (pilot)
	Transparency	Perceived information (pilot)
		Interpretated/comprehended information (pilot)
Collaboration	Flexibility/Adaptability	Adaptability to the pilot or to context (pilot)
	Feedback quality	Quantity & nature of VA feedback (pilot)
	Perceived relief of the task	Perceived relief of pilot's workload (pilot)
	No discomfort	Discomfort introduced by usage/announcement (pilot)

Certification vs. Qualification…

DISCUSSIONS & PERSPECTIVES

Task Analysis

Prototype Development
Preparation of a Simulation Facility

Procedural & Declarative
Knowledge on Systems
being developed

High-level Metrics
Contextualized Criteria
Basic HF Measures

Human-in-the-Loop
Simulations

Activity Observation and Analysis
Emergent Properties Detection

Structure-Function Analysis
Potential Redesign

Tangibilization

Human Factors Ergonomics

PRODEC

Formative Evaluations

Agile Development & HCD

Systemic ontology development enables optimal definition of HSI metrics (e.g., trust, collaboration & operational performance)

WHAT IS FUNDAMENTAL HERE?

FIRST THING TO UNDERSTAND

- There is a structuring space
    → the System Space
- There is a functional space
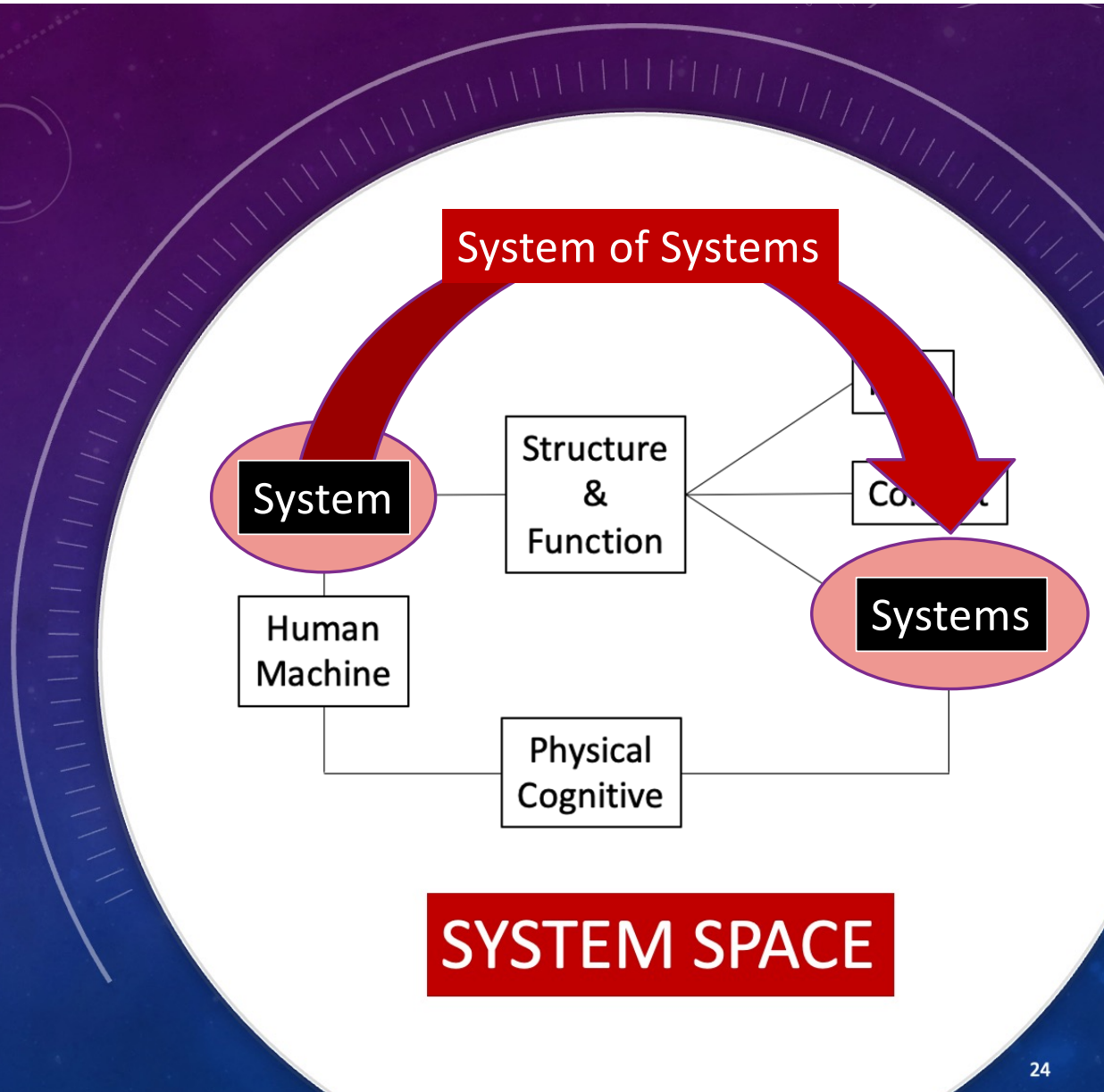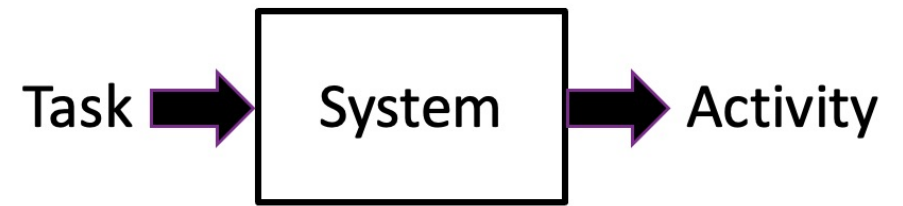   → the Context Space
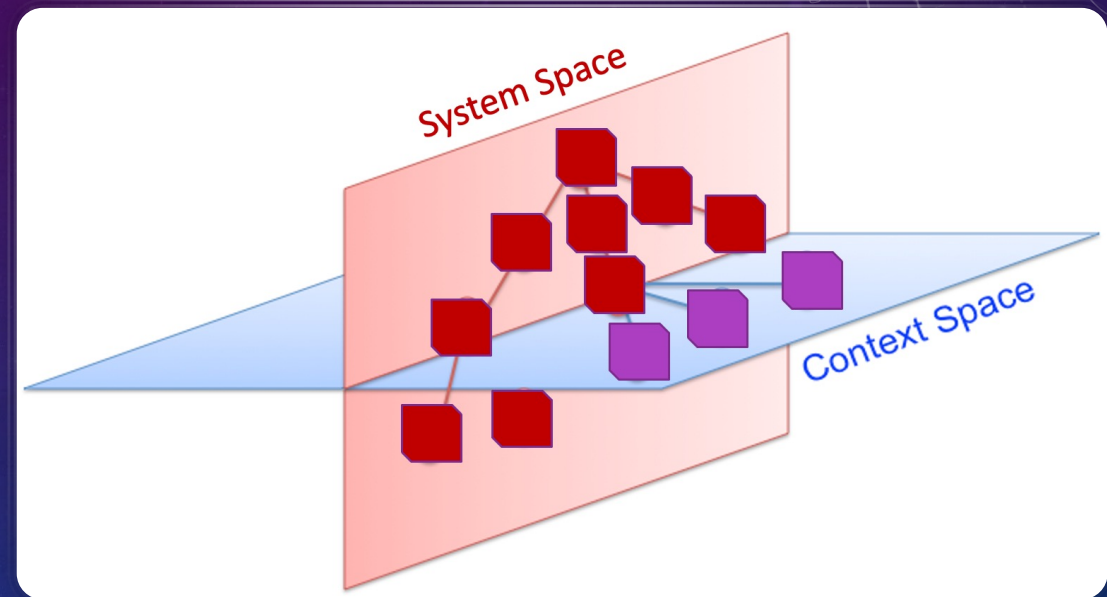
A SYSTEM REPRESENTING A DECLARATIVE ENTITY

SYSTEM SPACE

A SYSTEM REPRESENTING A DECLARATIVE ENTITY

System of Systems

System

Structure & Function

Human Machine

Physical Cognitive
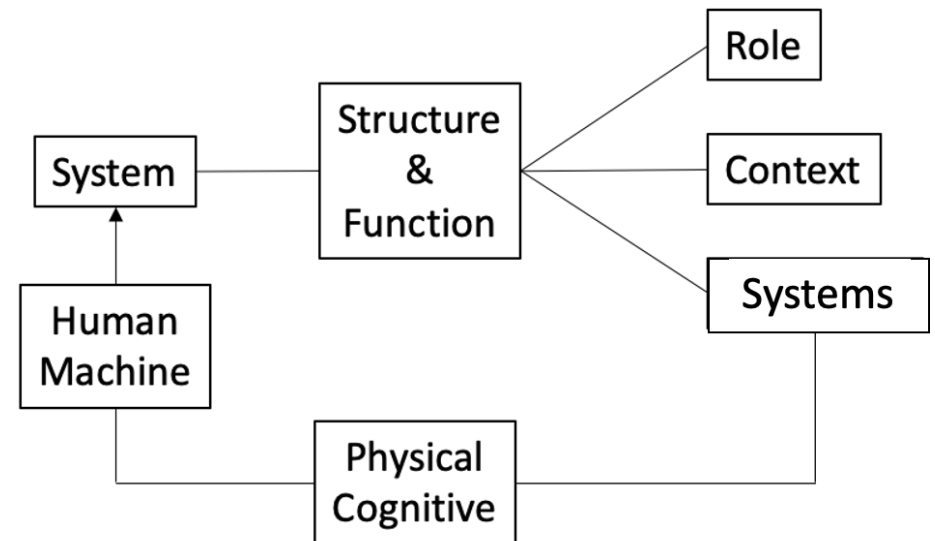
Systems

SYSTEM SPACE

A SYSTEM REPRESENTING A PROCEDURAL ENTITY

Task → System → Activity

CONTEXT SPACE

OPERATIONS

PROCEDURAL SCENARIOS

CONTEXT ARCHITECTURE...
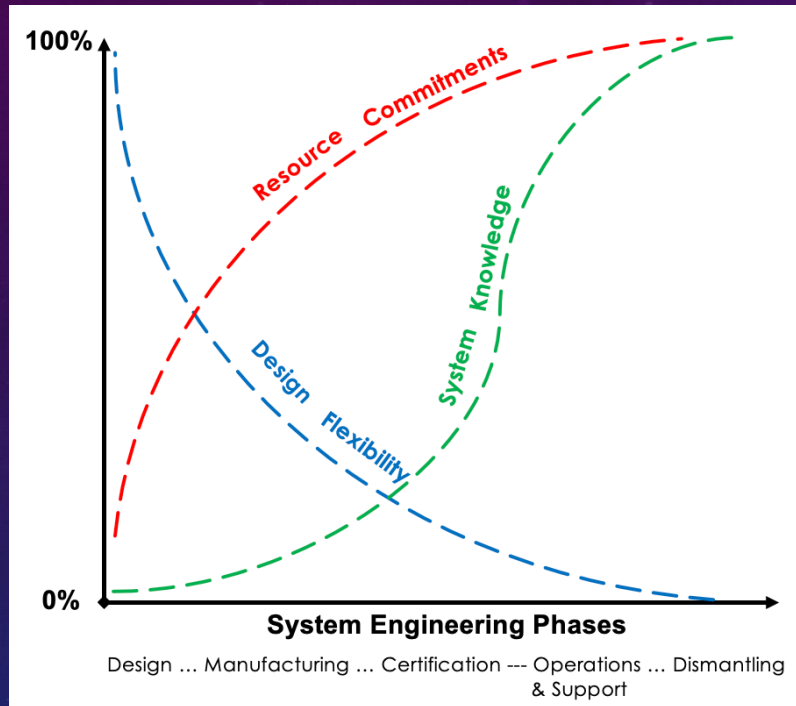
... SYSTEM ARCHITECTURE

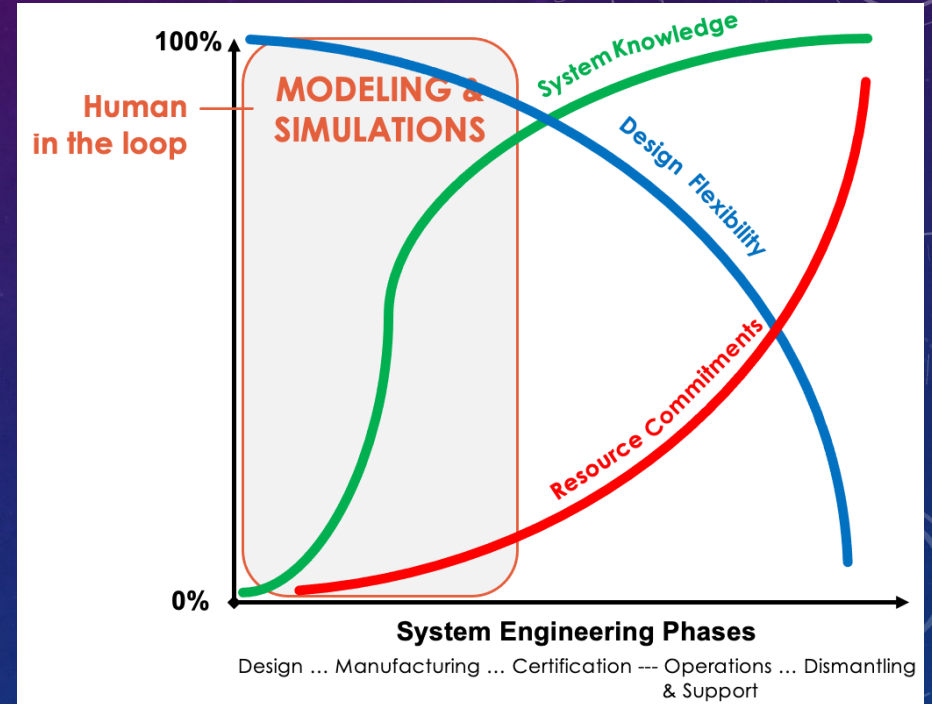DECLARATIVE CONFIGURATIONS

ENGINEERING DESIGN

SCENARIO-BASED DESIGN...
...HUMAN-IN-THE-LOOP SIMULATION
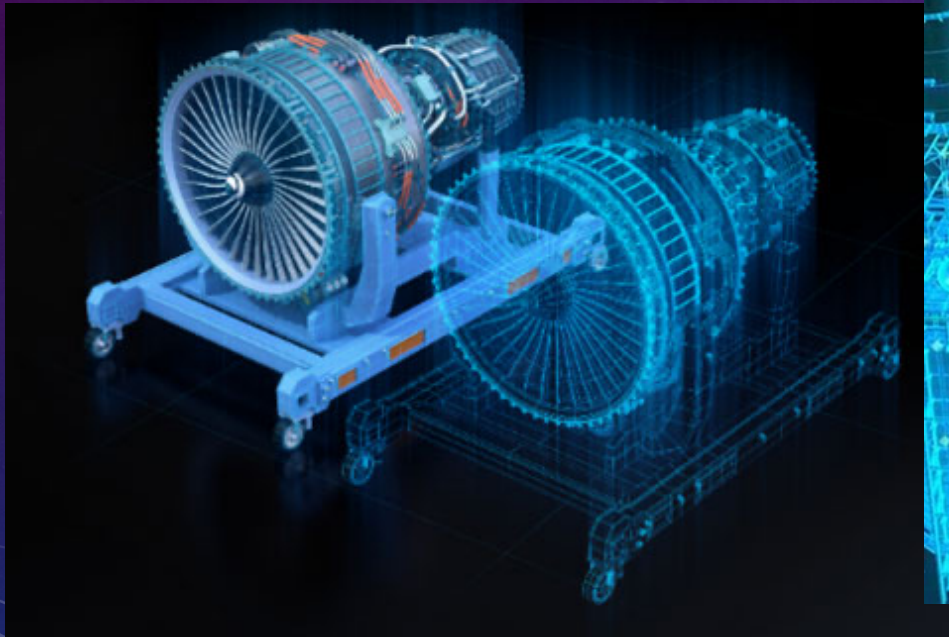
LIFE-CYCLED HUMAN SYSTEMS INTEGRATION

Technology-centered

Human-centered

HUMAN-CENTERED DESIGN OF A DIGITAL TWIN FOR HELICOPTER ENGINE MAINTENANCE
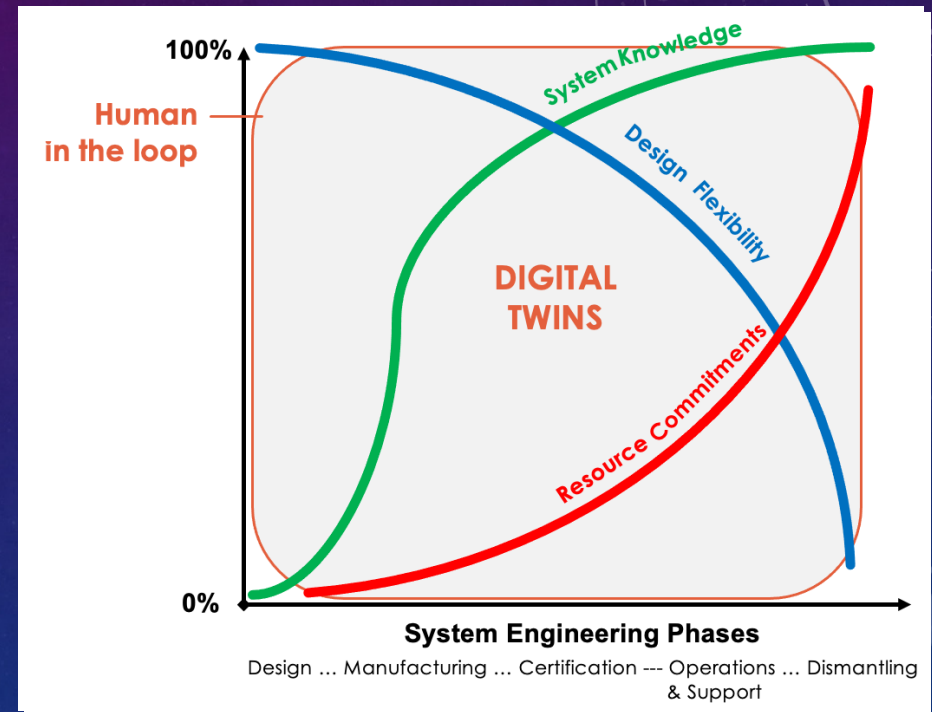
DIGITAL TWINS

Expanding HITLS

- During the whole life cycle
- "what if?"

Vivid documentation → MBSE

- Integration of experience feedback
- Organizational memory

DTs as virtual assistants → HMT

- Multi-agent collaboration
- Mediators for collaborative work

MBSE: Model-Based Systems Engineering
HMT: Human Machine Teaming
(where the machine is increasingly autonomous)

FROM MEANS TO PURPOSE

Engineering

Ergonomics
& Automation
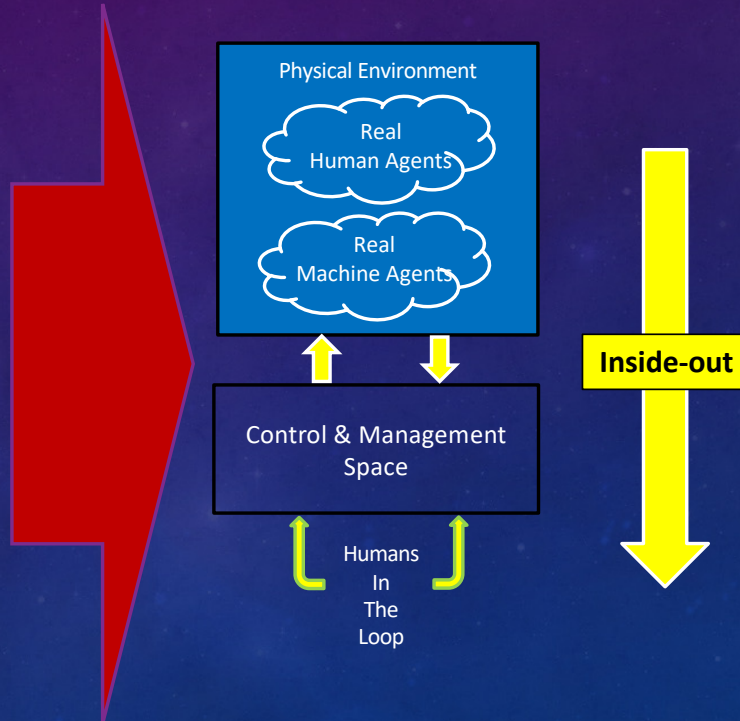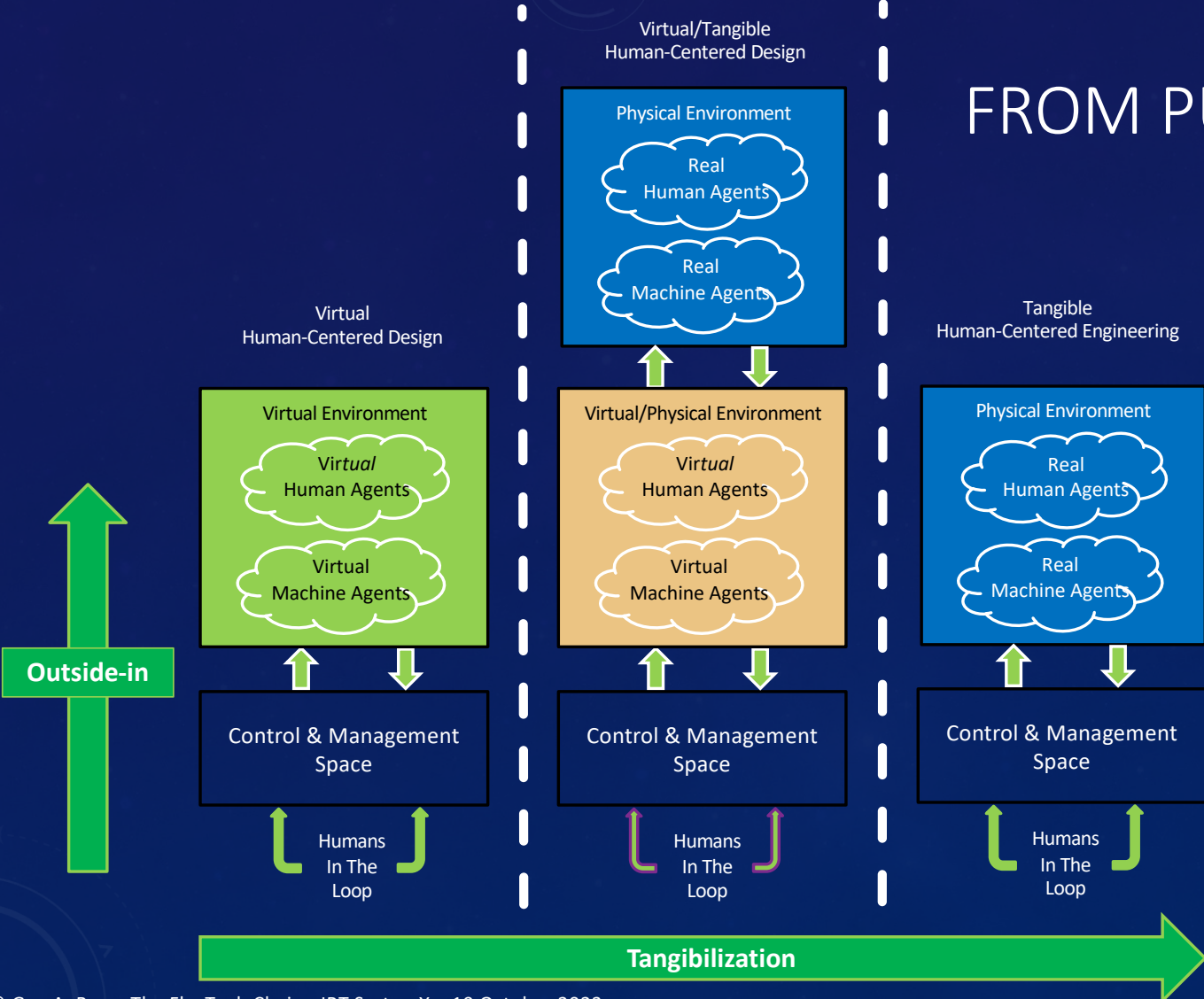
Human Factors

Tangible
Human-Centered Engineering

Physical Environment

Real
Human Agents

Real
Machine Agents

Control & Management
Space

Humans
In
The
Loop

Inside-out

20th century
approach

Engineering,
Ergonomics,
HCI &
Automation

FROM PURPOSE TO MEANS

21ST CENTURY APPROACH

HSI

Virtual/Tangible Human-Centered Design

Physical Environment
- Real Human Agents
- Real Machine Agents

Virtual Human-Centered Design

Virtual Environment
- Virtual Human Agents
- Virtual Machine Agents

Virtual/Physical Environment
- Virtual Human Agents
- Virtual Machine Agents

Tangible Human-Centered Engineering

Physical Environment
- Real Human Agents
- Real Machine Agents

Control & Management Space
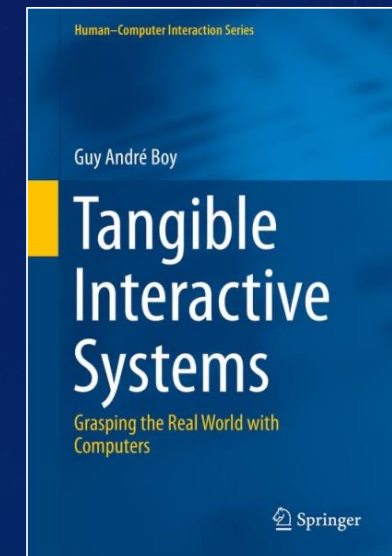
Humans In The Loop

Outside-in

Tangibilization

PHYSICAL & FIGURATIVE TANGIBILITY: SYSTEMIC ATTRIBUTES

- Complexity → separability, interconnectivity, collaboration, trust, …
- Maturity → TRLs & HRLs & ORLs
- Flexibility (design & operations) → safety nodes, reversibility, FlexTech, …
- Stability/Resilience → passive vs. active, resilience, crisis management, …
- Sustainability → design rationale, knowledge management, …

+ Social Factors →

**Shared situation awareness
Cooperative decision-making
Harmonized risk taking
Trust and collaboration**

Human–Computer Interaction Series

Guy André Boy

Tangible Interactive Systems

Grasping the Real World with Computers

Springer

MATURITY = READINESS LEVELS

TRL: Technology

TRL 9
- Actual system "flight proven" through successful mission operations

TRL 8
- Actual system completed and "flight qualified" through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported

MATURITY = READINESS LEVELS

HRL: Human

HRL	Description
1	Relevant human capabilities, limitations, and basic human performance issues and risks identified
2	Human-focused concept of operations defined and human performance design principles established
3	Analyses of human operational, environmental, functional, cognitive, and physical needs completed, based on proof of concept
4	Modeling, part-task testing, and trade studies of user interface design concepts completed
5	User evaluation of prototypes in mission-relevant simulations completed to inform design
6	Human-system interfaces fully matured as influenced by human performance analyses, metrics, prototyping, and high-fidelity simulations
7	Human-system interfaces fully tested and verified in operational environment with system hardware and software and representative users
8	Total human-system performance fully tested, validated, and approved in mission operations, using completed system hardware and software and representative users
9	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance

# MATURITY = READINESS LEVELS

ORL: Organization

ORL-0	**First principles where potential organizational models are explored.**
ORL-1	Goal-oriented research that requires making choices from first principles to practical fully digital organizational setups
ORL-2	Proof of principle development, and active R&D is started in a virtual environment
ORL-3	Virtual agile organizational prototype development and first HITLS (virtual HCD)
ORL-4	Proof of organizational concept development using concrete scenario-based design from fully virtual to more tangible environments
ORL-5	Assessing organization capability in terms of authority sharing (responsibility, accountability and control), trust, collaboration and coordination, for example
ORL-6	Real-world use-case tests in a wider variety of situations - tangibilization continues
ORL-7	Practical integration with respect to criteria such as safety, efficiency and comfort, at various levels of granularity of the organization – tangibilization continues
ORL-8	Readiness for effective implementation on a real site (fully tangible) based on personnel feedback for deployment approval
ORL-9	Deployment involving both personnel and real machines

AI4SE & SE4AI Workshop 2022
Washington, D.C., U.S.A..
September 21-22, 2022

IS THE MACHINE A PARTNER OR A TOOL?
A MAJOR ISSUE OF HUMAN-AI TEAMING

GUY ANDRÉ BOY

https://researchfeatures.com/human-systems-integration-time-take-centre-stage/
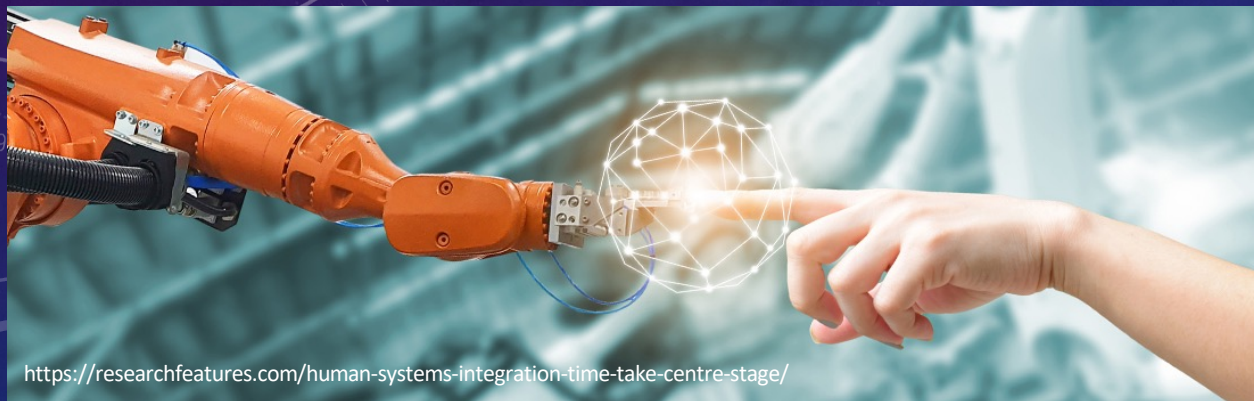
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Paris Saclay University, France

HUMAN SYSTEMS INTEGRATION KEYNOTE...

CSD&M

2023 Complex Systems Design & Management (CSD&M2023) Conference

Oct. 30-31, 2023
Beijing, China

http://2023.csdmconference.com/Data/List/PROGRAM

REFERENCES FOR THIS PRESENTATION

- Cognitive Function Analysis

- The Handbook of Human-Machine Interaction

- Orchestrating Human Centered Design

- Human Systems Integration

- Design for Flexibility

- Risk taking, Prevention & Design

- … be curious!

REFERENCES

- Boy, G.A. (2023). An epistemological approach to human systems integration. *Technology in Society Journal*, 102298. https://doi.org/10.1016/j.techsoc.2023.102298

- Boy, G.A. (2023). Uncertainty management in human systems integration of life-critical systems. In Griffin, Mark A., and Gudela Grote (eds). The Oxford Handbook of Uncertainty Management in Work Organizations (online edn, Oxford Academic, 20 Oct. 2022), Oxford University Press, UK, accessed 6 Dec. 2022.

- Boy, G.A. (2022). Model-Based Human Systems Integration. In the Handbook of Model-Based Systems Engineering, A.M. Madni & N. Augustine (Eds.). Springer, USA. DOI: https://doi.org/10.1007/978-3-030-27486-3_28-1.

- Boy, G.A. (2021). Design for Flexibility - A Human Systems Integration Approach. Springer Nature, Switzerland. ISBN: 978-3-030-76391-6.

- Boy, G.A. (2021). Socioergonomics: A few clarifications on the Technology-Organizations-People Tryptic. Proceedings of INCOSE HSI2021 International Conference, Wiley Online Lib.

- Boy, G.A. (2020). *Human Systems Integration: From Virtual to Tangible*. CRC Press – Taylor & Francis Group, USA (https://www.taylorfrancis.com/books/9780429351686).

2024 FlexTech Spring School
on **Human-AI Teaming (HAT)**
A Human Systems Integration Approach

27-31 May 2024 - Radisson Blu, Biarritz, Basque Country, France

Purpose

intensive week-long training and exchange seminar

introduction to Human Systems Integration

integrating artificial intelligence (AI), systems engineering, human factors & ergonomics, and human-computer interaction

through incremental tangibilization of virtual prototypes

Logistics

Radisson Blu Hotel, Biarritz, France

with the best senior scientists and practionners

limited to 60 participants worldwide

arrival Sunday evening & departure Friday afternoon

https://www.flextechchair.org/FTSpringSchool2024/about.html

HSI2024

INTERNATIONAL CONFERENCE
JEJU, KOREA
27-29 AUGUST 2024

THANK YOU FOR YOUR ATTENTION...

I am open to questions...