PEOPLE'S ROLE IN LARGE INTERCONNECTED SYSTEMS

PROF. GUY ANDRÉ BOY

FlexTech

CentraleSupélec-ESTIA Chair
Paris Saclay University, France

OUTLINE

- Complex systems

- Systems as representations… toward a human and machine systemic modeling language

- Task vs. activity

- The evolution of human factors & ergonomics

- Defining Human Systems Integration (HSI)

- PRODEC: operations-centered design toward HSI

INTERPENETRATION OF AUTOMATED SYSTEMS...
... BETWEEN AIR AND GROUND

- Large programs, e.g., NextGen & SESAR, in accordance with a **roadmap** (described in ASBU) of ICAO

- A first onboard implementation resulting from this work consists of exchanging the **aircraft's 4D trajectory** with ATC and AOC on departure and periodically in flight

- Another solution is based on concepts of **separation** between aircraft (ASAS based on ADS-B capabilities) which has the advantage over the previous solution of allowing separation between aircraft in a "relative" way (in terms of time difference) and not in an "absolute" way (in absolute time) which is more difficult to obtain given the hazards (delay and time variations of other aircraft...)

ASBU: Aviation System Block Upgrade
ASAS: Airborne Separation Assurance System
ASD-B: Automatic Dependent Surveillance-Broadcast
AOC: Aeronautical operational control
ATC: Air Traffic Control
NextGen: Next Generation Air Transportation System
SESAR: Single European Sky ATM Research

OUTLINE

- Human System Integration (**HSI**)

- Orchestrating Technology, Organization and People (the **TOP Model**)

- **FlexTech**… flexible Socio-Technical Systems (STS)

- Anticipation, preparation, creativity and experience

- From rigid automation to flexible autonomy

- Dealing with the **unexpected**

- Human-Centered Design of STS as complex life-critical systems

- Well-being, safety, sustainability and efficiency

- Put the artificial at the service of the natural, and not the other way around

MY WORLD FOR ~40 YEARS…

From correction…
… to interaction
… to integration

… and other things

HUMAN-CENTERED DESIGN (HCD)

HCD for whom?

- Pilots, controllers, maintenance personnel, airlines, etc.

- Engineering designers, developers, manufacturers, certifiers, etc.

HCD assumes that there is always the **human element** everywhere

- How do we consider the human element?

- What are the theoretical and practical methods and tools?
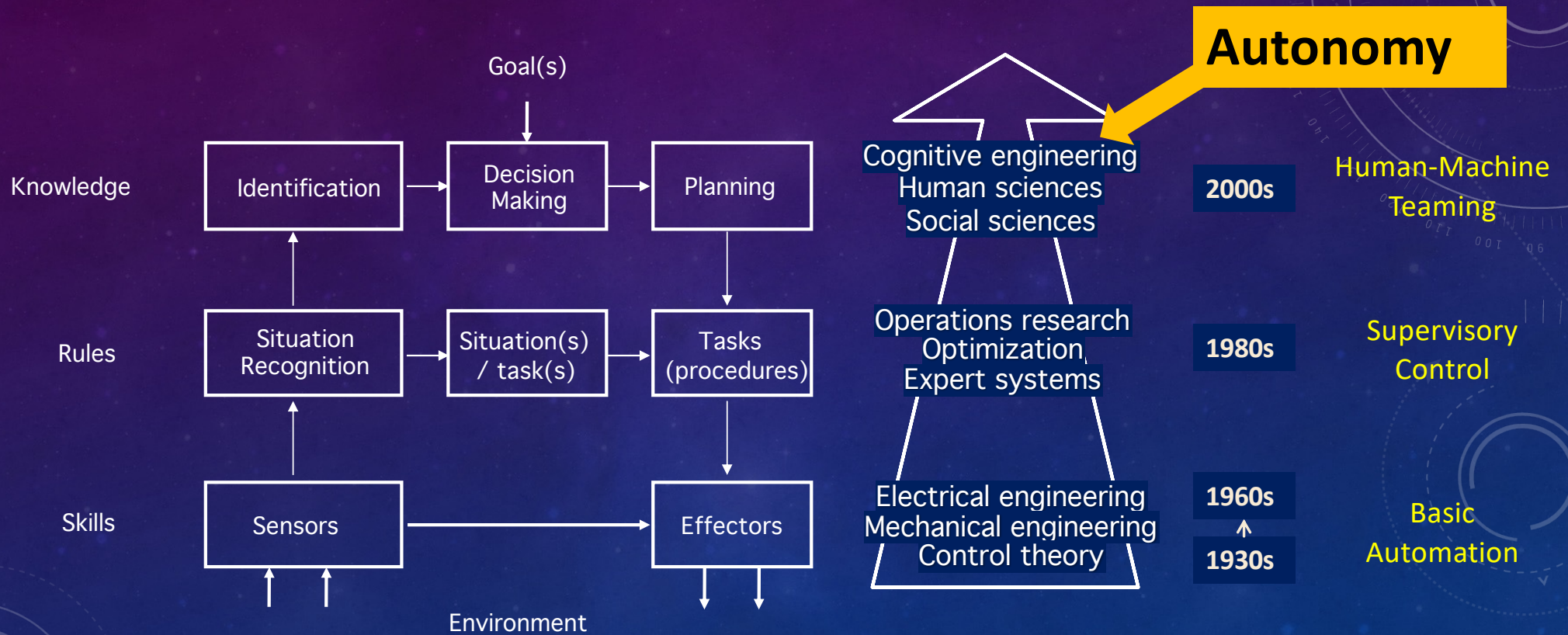
HCD of sociotechnical systems in a **digital world**

- Co-designing Technology, **Organization** and People's activities (TOP Model)
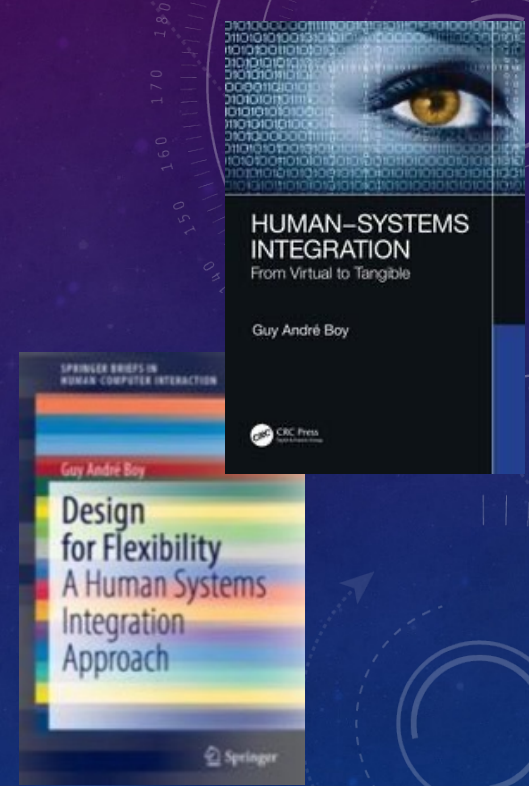
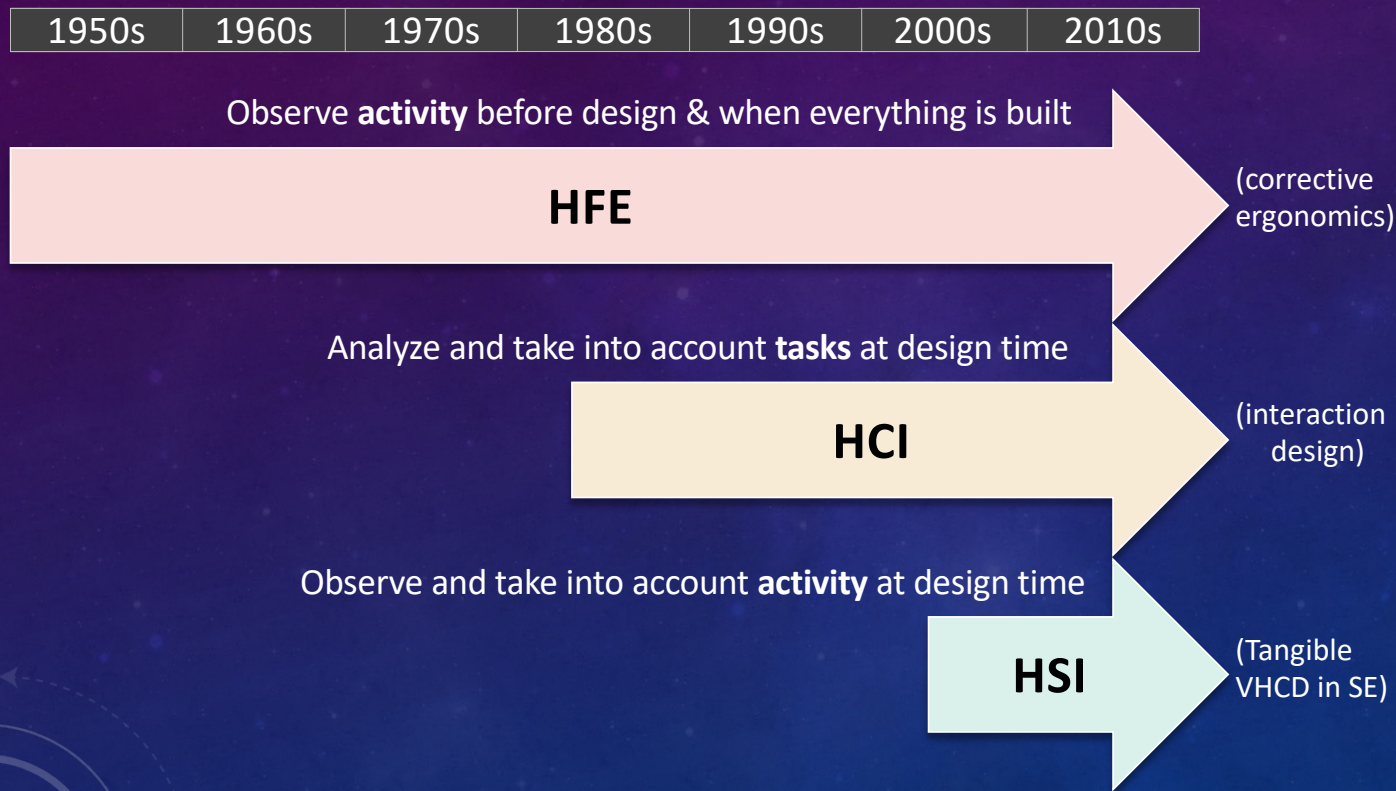- Think about the **life cycle of systems**

© Guy A. Boy – The Role of People in Large Interconnected Systems – 26 September 2024 – "New and Emerging Aviation Technologies" (NEAT) – FAA 7

FROM AUTOMATION TO AUTONOMY...
... and emergence of contributing disciplines (Rasmussen's model)

Autonomy

Goal(s)

| Knowledge | Identification | Decision Making | Planning |

| Rules | Situation Recognition | Situation(s) / task(s) | Tasks (procedures) |

| Skills | Sensors | | Effectors |

Environment

Cognitive engineering
Human sciences
Social sciences — 2000s — Human-Machine Teaming

Operations research
Optimization
Expert systems — 1980s — Supervisory Control

Electrical engineering — 1960s
Mechanical engineering
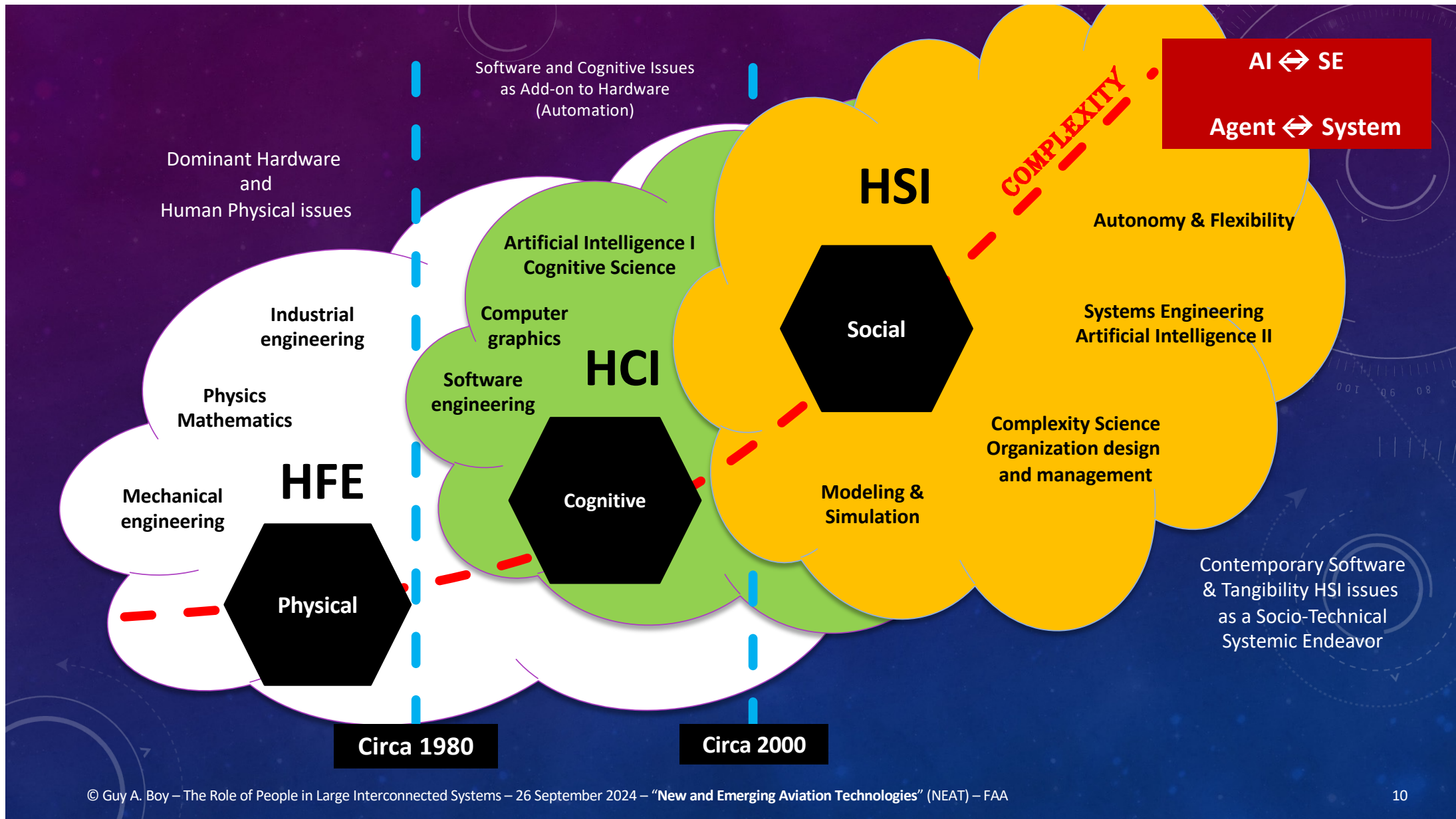Control theory — 1930s — Basic Automation

Boy, G.A. & Morel, C. (2022 to appear). The Machine as a Partner: Human-Machine Teaming Design using the PRODEC Method. WORK Journal.

TASK VS. ACTIVITY

1950s	1960s	1970s	1980s	1990s	2000s	2010s

Observe **activity** before design & when everything is built

HFE → (corrective ergonomics)

Analyze and take into account **tasks** at design time

HCI → (interaction design)

Observe and take into account **activity** at design time

HSI → (Tangible VHCD in SE)

HUMAN–SYSTEMS INTEGRATION
From Virtual to Tangible
Guy André Boy
CRC Press

Design for Flexibility
A Human Systems Integration Approach
Guy André Boy
Springer

HFE: Human Factors and Ergonomics
HCI: Human Computer Interaction
VHCD: Virtual Human-Centered Design
HSI: Human Systems Integration
SE: Systems Engineering

HFE

Mechanical engineering

Physics Mathematics

Industrial engineering

Physical

Dominant Hardware and Human Physical issues

Software and Cognitive Issues as Add-on to Hardware (Automation)

HCI

Software engineering

Computer graphics

Artificial Intelligence I Cognitive Science

Cognitive

HSI

Social

Modeling & Simulation

COMPLEXITY

AI ⟷ SE

Agent ⟷ System

Autonomy & Flexibility

Systems Engineering Artificial Intelligence II

Complexity Science Organization design and management

Contemporary Software & Tangibility HSI issues as a Socio-Technical Systemic Endeavor

Circa 1980

Circa 2000

THE COMPLEX-COMPLICATED DISTINCTION

DEALING WITH COMPLEXITY
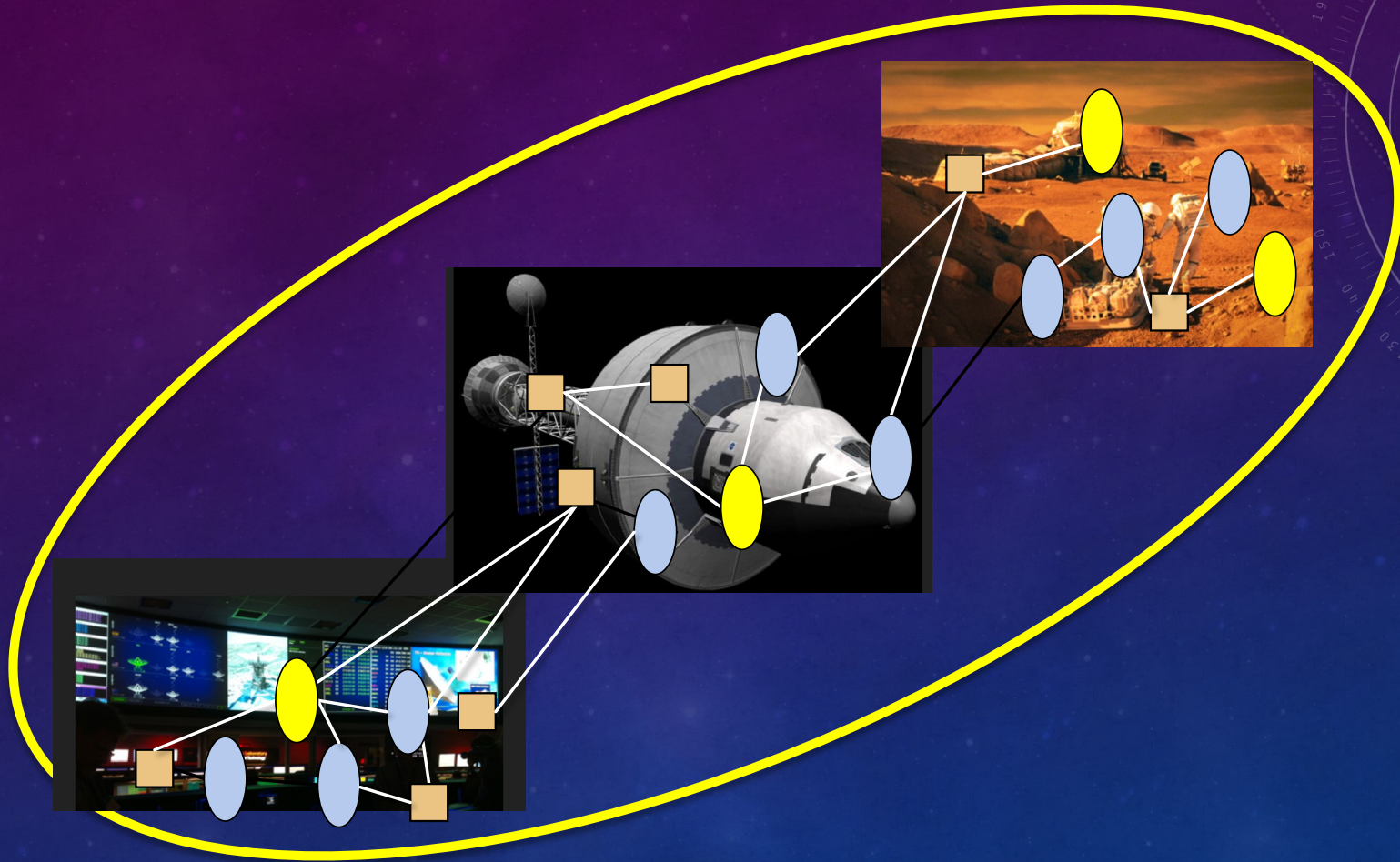
A COMPLEX SYSTEM AS A LIVING ORGANISM

Separability
a crucial issue

Complexity
in the connexions
as well as
in the agents themselves

Emergents Functions
&
the **maturity** issue
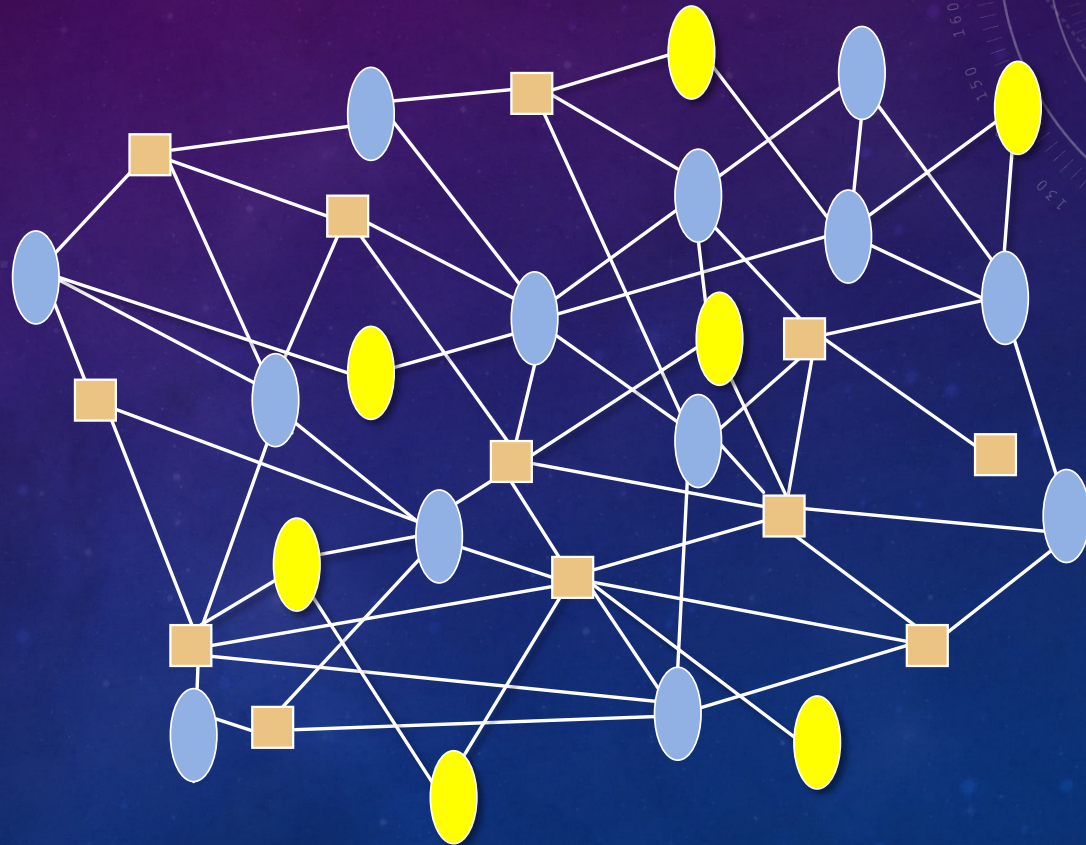
PROPERTIES OF A COMPLEX SYSTEM

- a large **number** of components and interconnections among them

- many people involved in its **life cycle**

  (design, development, manufacturing, operations, maintenance and dismantling)

- **emergent** properties and behaviors not included in the components

- complex adaptive mechanisms and behaviors (**adaptability**)

- nonlinearities and possible chaos (**unpredictability**)

METHODS & TOOLS

- Design thinking: creativity & ideation

- Task analysis & Scenario-based design

- Conceptual modeling

- **PRODEC**

- Rapid prototyping

- Human-in-the-loop simulation

- Evaluation methods and tools

- Agile development

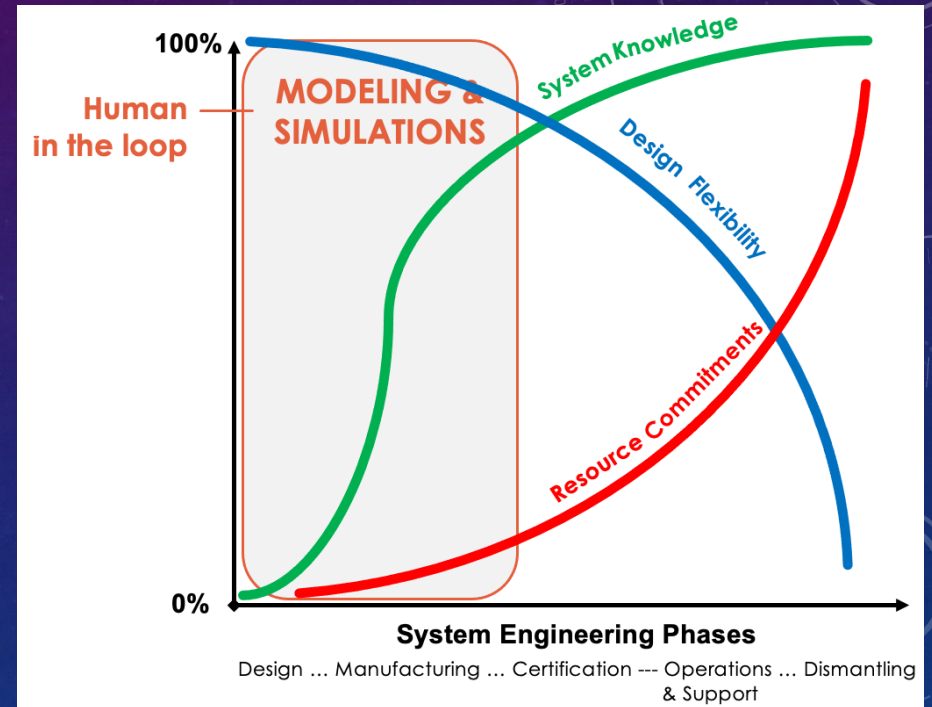- Organizational design & management

INTEGRATION

INTEGRATION

FROM THE EARLY STAGES OF DESIGN

LIFE-CYCLED HUMAN SYSTEMS INTEGRATION
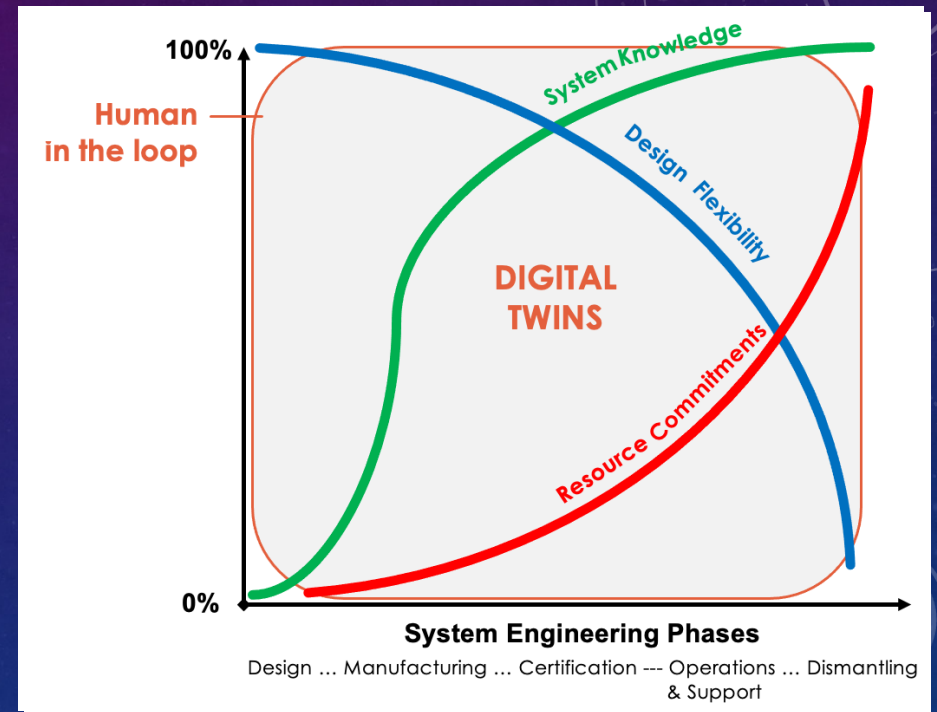
Technology-centered
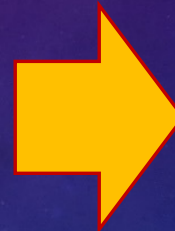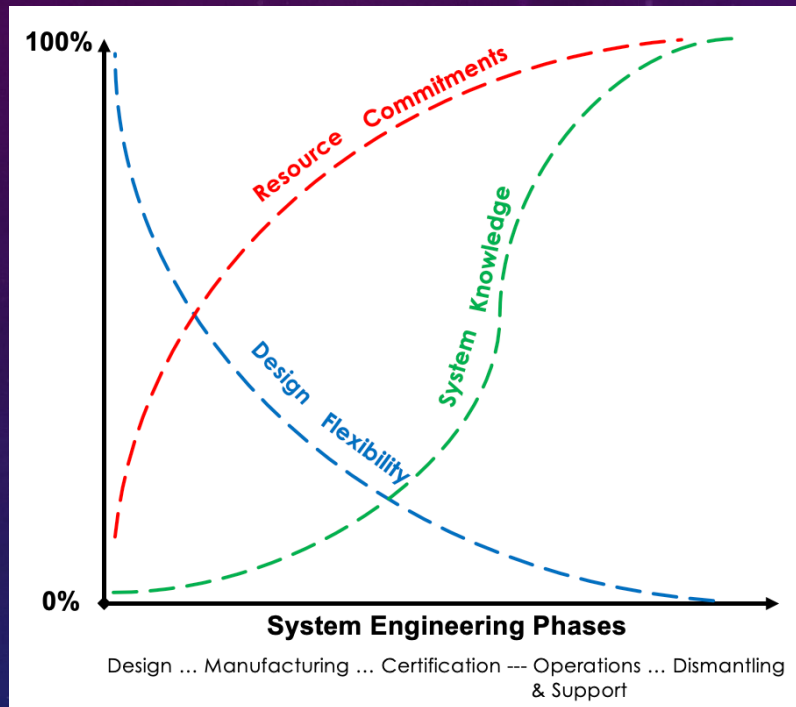
Human-centered

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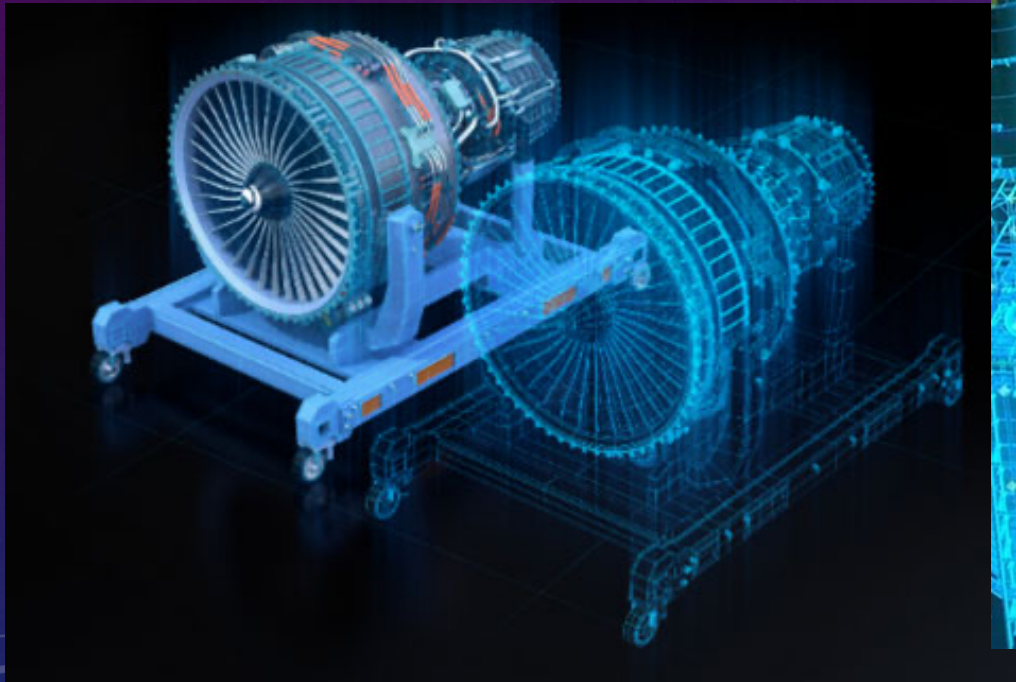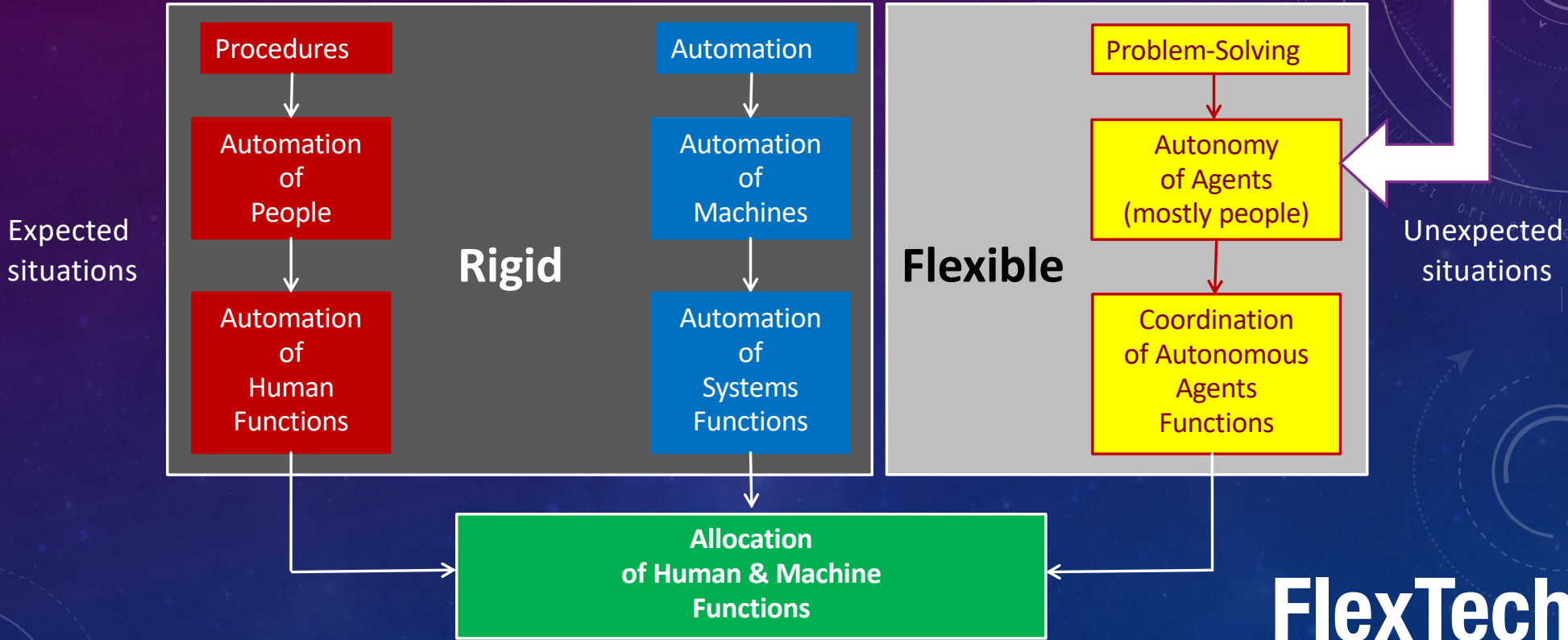
DIGITAL TWINS

- Expanding HITLS
  - During the whole life cycle
  - "what if?"
- Vivid documentation
  - Integration of experience feedback
  - Organizational memory
- Digital twins as virtual assistants
  - Multi-agent collaboration
  - Mediators for collaborative work

FROM RIGID AUTOMATION TO FLEXIBLE AUTONOMY

Multi-agent

Expected situations

Rigid

Procedures	Automation
Automation of People	Automation of Machines
Automation of Human Functions	Automation of Systems Functions

Flexible

Unexpected situations

Problem-Solving

Autonomy of Agents (mostly people)

Coordination of Autonomous Agents Functions

Allocation of Human & Machine Functions

FlexTech
CentraleSupélec-ESTIA Chair

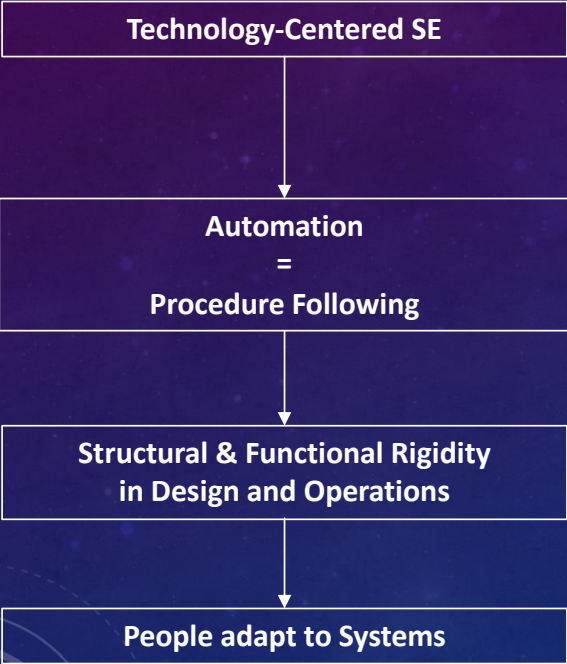**HSI** HUMAN SYSTEMS INTEGRATION

=

HCD HUMAN-CENTERED DESIGN

+

SE SYSTEMS ENGINEERING
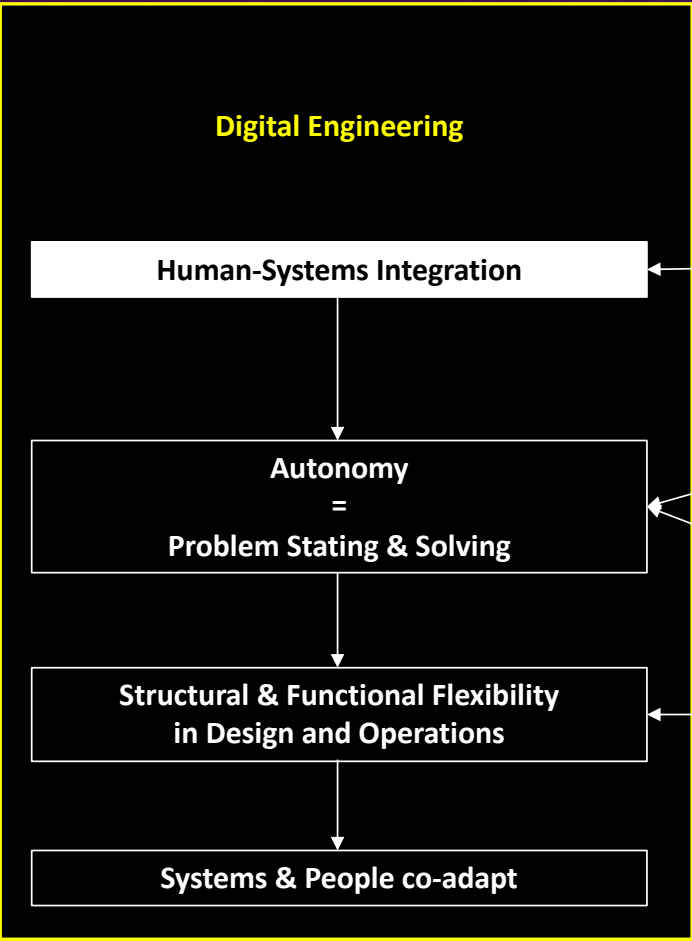
Toward more Autonomy & Flexibility

Traditional Engineering

Digital Engineering
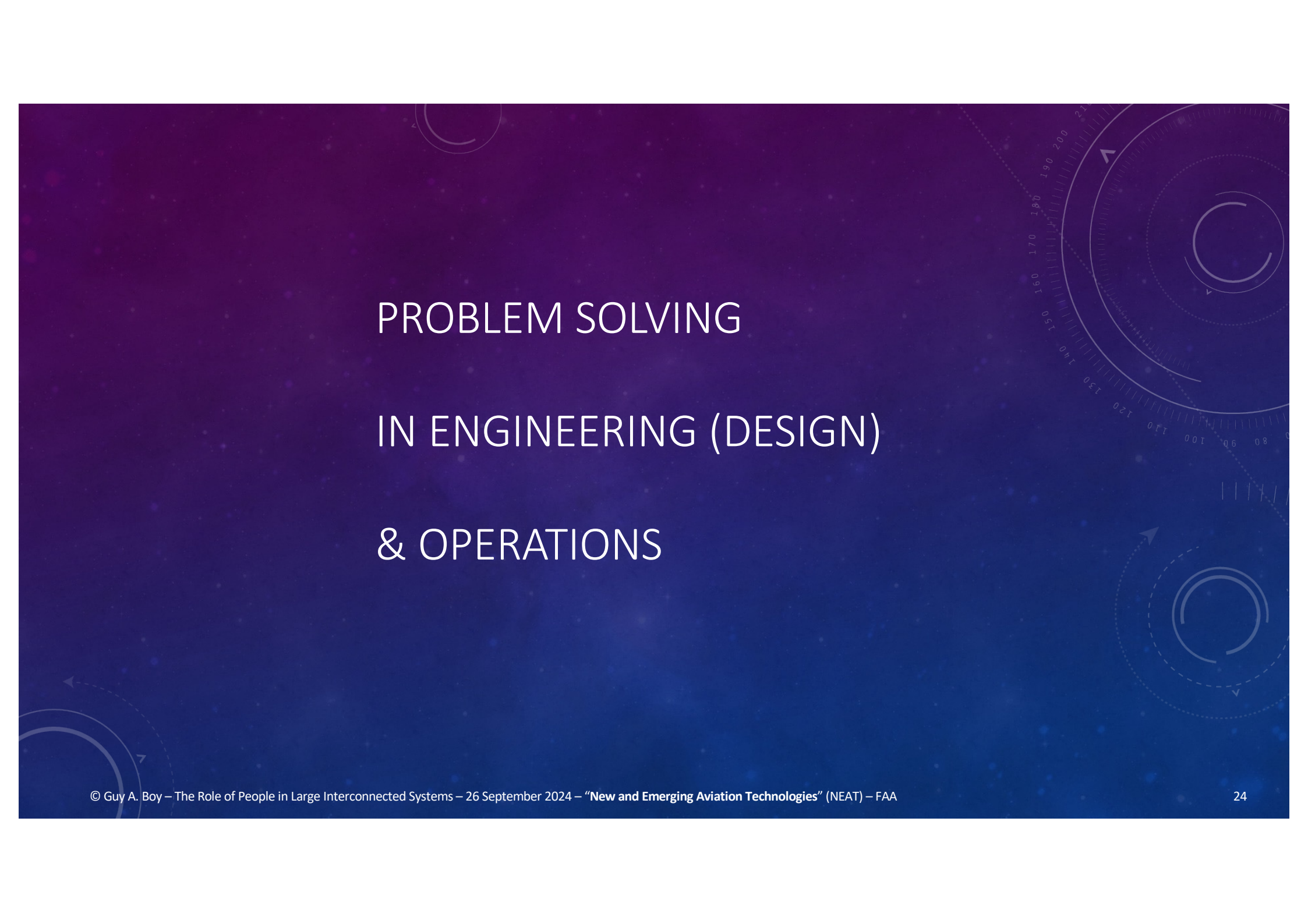
Technology-Centered SE

↓

Automation = Procedure Following

↓

Structural & Functional Rigidity in Design and Operations

↓

People adapt to Systems

Human-Systems Integration

↓

Autonomy = Problem Stating & Solving

↓

Structural & Functional Flexibility in Design and Operations

↓

Systems & People co-adapt

Human-Centered Design (HCD) combined with Systems Engineering (SE) contributes to improving Human-Systems Integration (HSI)

Human Factors, Modeling & Human-In-The-Loop Simulation

Data Science & Artificial Intelligence

Creativity, Complexity Analysis, Agility, Tangibility, Maturity

... HSI

PROBLEM SOLVING

IN ENGINEERING (DESIGN)

& OPERATIONS

FLEXTECH

Design for Flexibility

What kind of support?
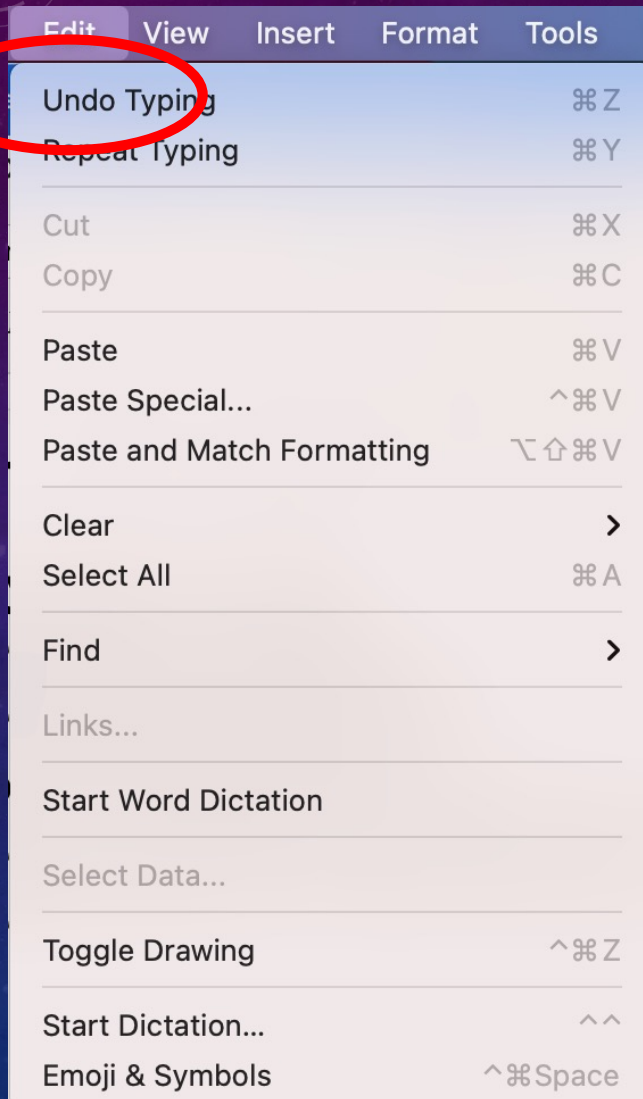
    technology

    organization

    competence

https://www.springer.com/gp/book/9783030763909
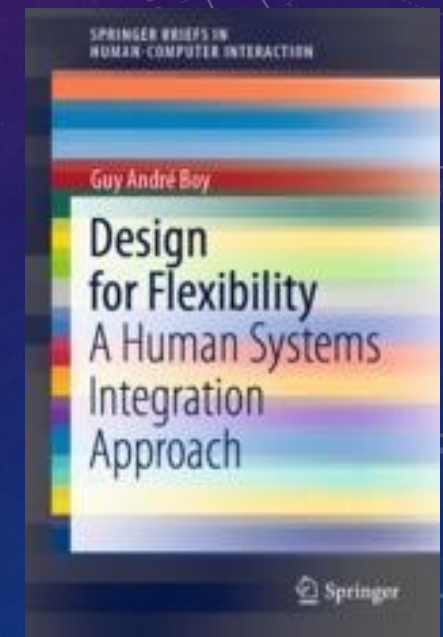
FLEXTECH

Design for Flexibility

Technological support

APOLLO 13 CO_2 …

Design for Flexibility

Organizational support

… collaborative problem solving!

FLEXTECH

Creativity & Experience

FLEXTECH

People

Human Centered Design & Operations

Technology   Organizations

Technology

- Problem-solving tool support
- e.g., undo

Organization

- Problem-solving team
- E.g., Apollo 13
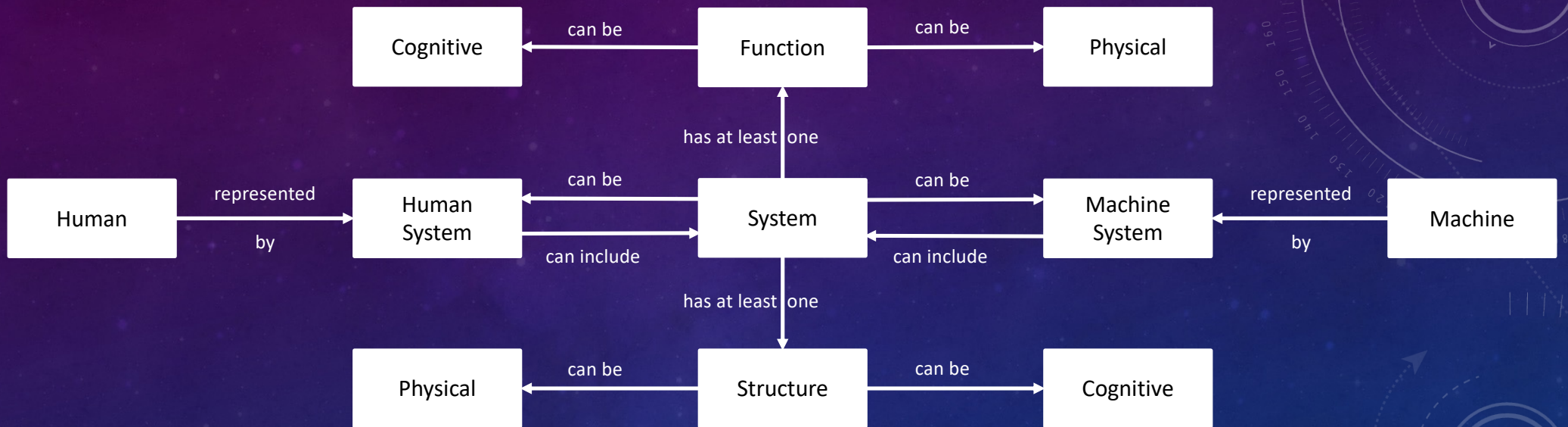
People

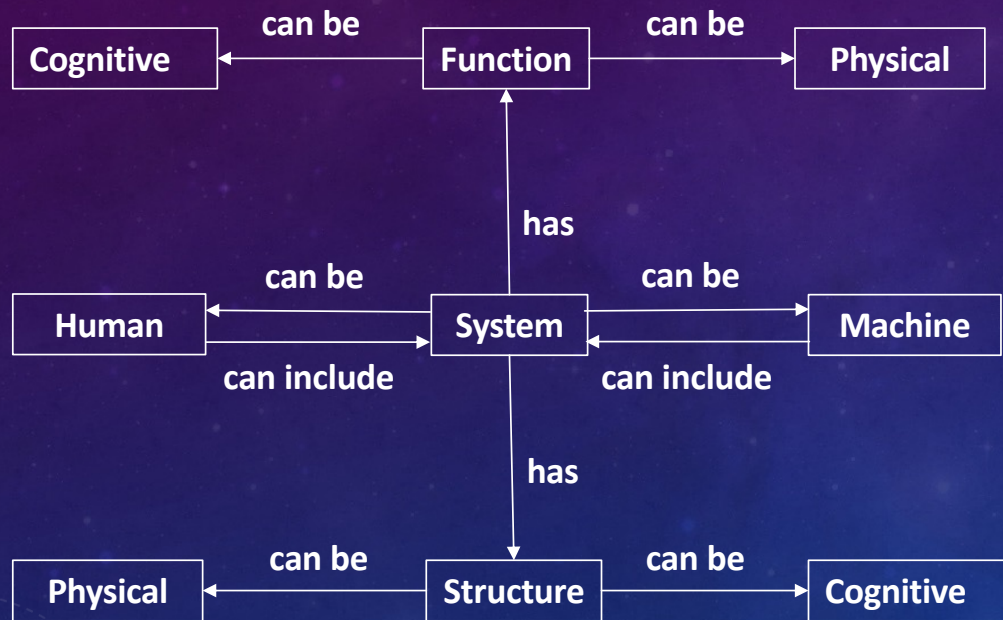- Problem-solving competence
- e.g., creativity & experience

INTEGRATION
THE NEED FOR A SYSTEMIC ONTOLOGY

SYSTEMS ARE REPRESENTATIONS OF NATURAL OR ARTIFICIAL ENTITIES

WHAT IS A SYSTEM?

Systems include Humans and Machines…
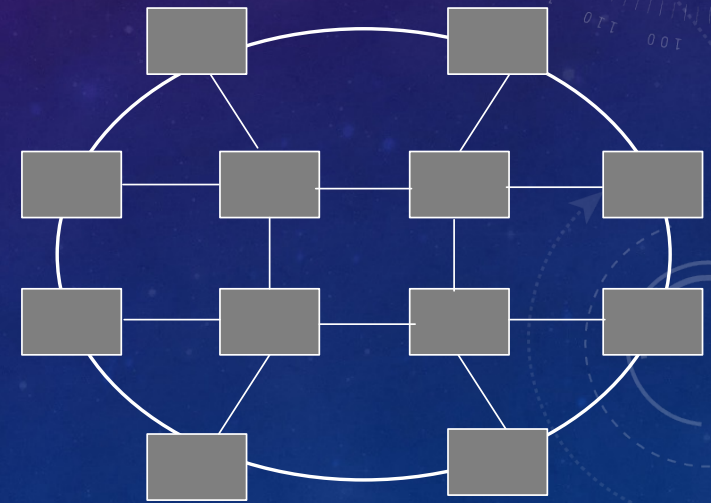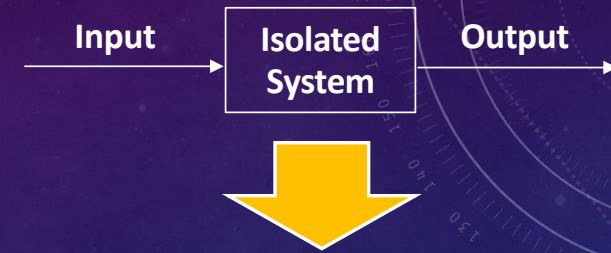
Interconnected System of Systems

SYSTEM = FUNCTION + STRUCTURE

Emergent Structures

Emergent Functions

Overlapping Functions of Functions

Shared situation awareness
Speed & precision
Resilience
Trust & Collaboration

Interconnected Functions of Functions
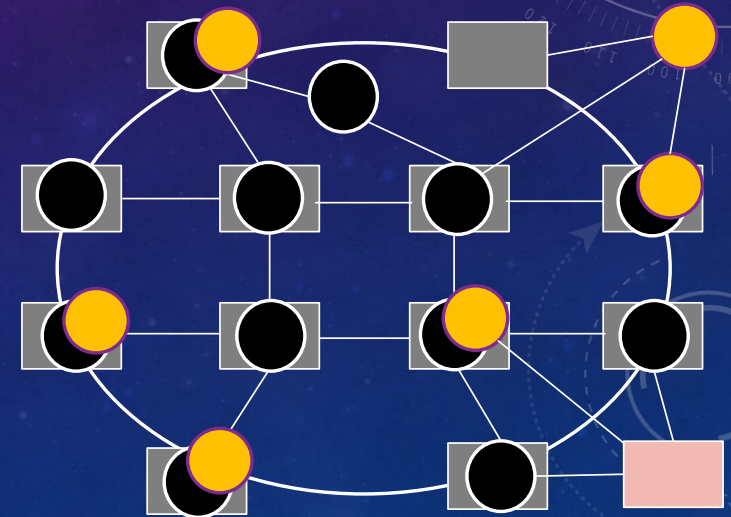
Interconnected Structures of Structures

SYSTEM = FUNCTION + STRUCTURE

Emergent Structures

Emergent Functions

Overlapping Functions of Functions

Shared situation awareness
Speed & precision
Resilience
Trust & Collaboration

Niveaux strat. & Ops.

C2 Air

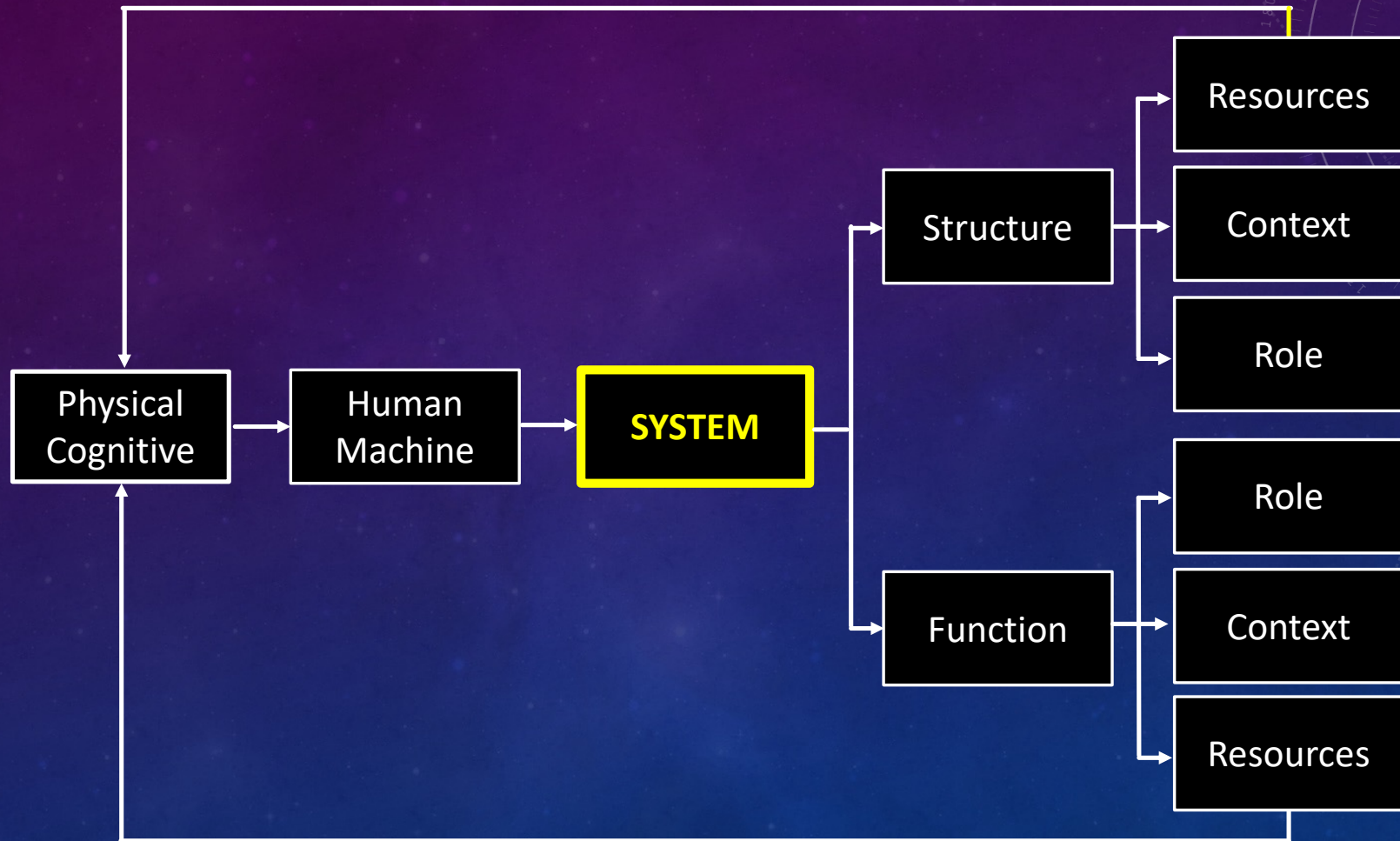Serveur ou relais de communication

Interconnected Structures of Structures

WHAT IS A SYSTEM?
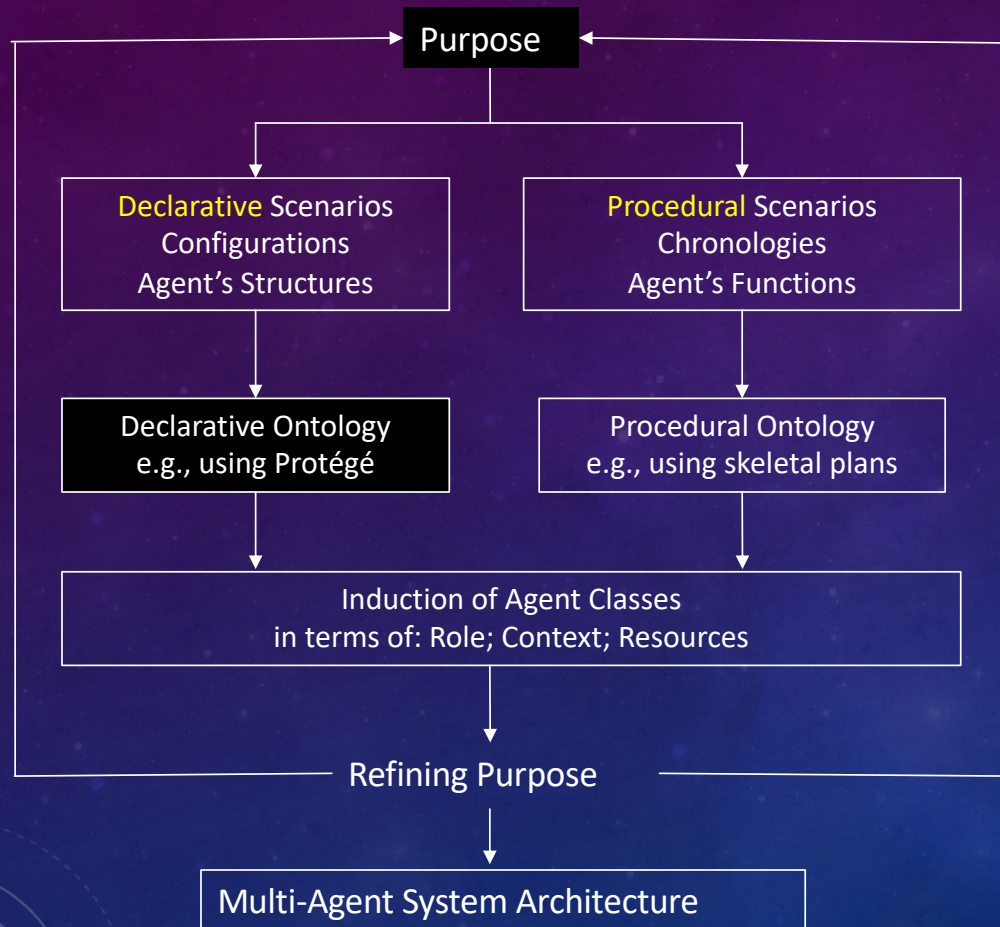
SYSTEMIC INTERACTION MODELS...
... AND AUTHORITY SHARING
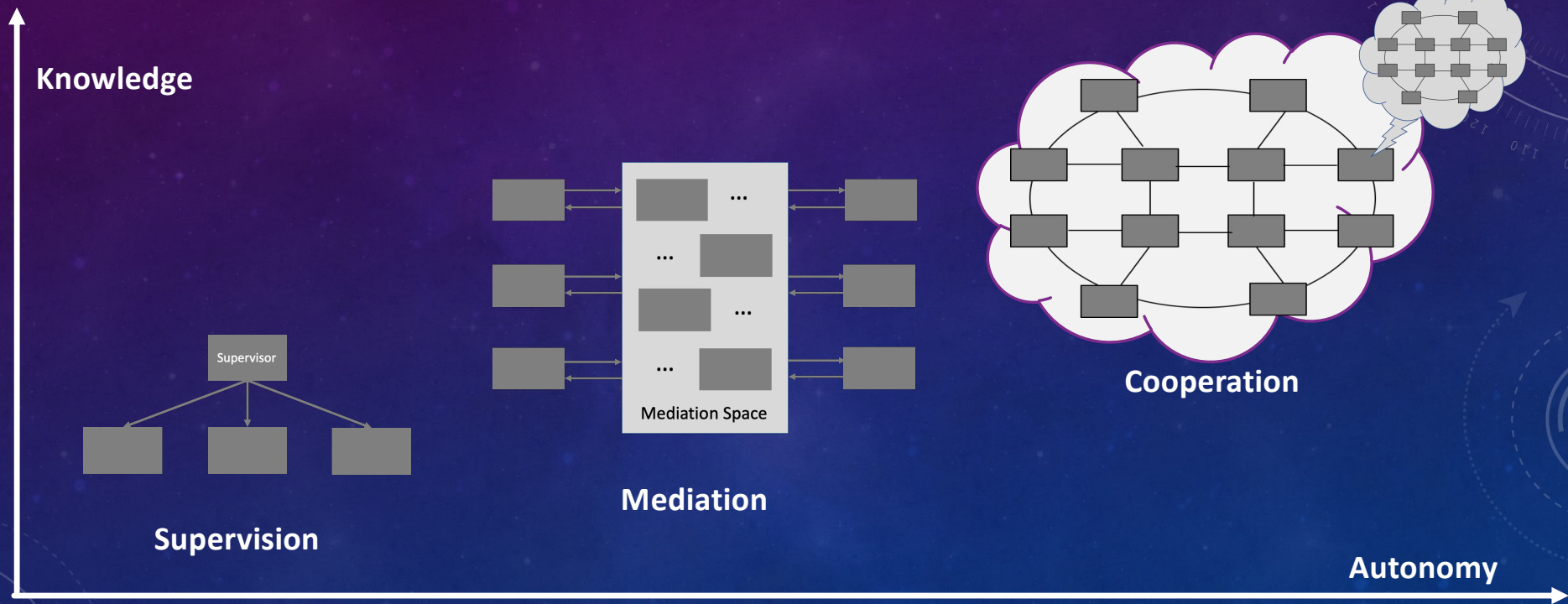
INTEGRATION
FROM PURPOSE TO MEANS

FROM PURPOSE TO MEANS

```
                           ┌──────────┐
              ┌────────────│ Purpose  │◄───────────┐
              │            └────┬─────┘            │
              │                 │                  │
      ┌───────▼────────┐  ┌─────▼──────────┐       │
      │ Declarative    │  │ Procedural     │       │
      │ Scenarios      │  │ Scenarios      │       │
      │ Configurations │  │ Chronologies   │       │
      │ Agent's        │  │ Agent's        │       │
      │ Structures     │  │ Functions      │       │
      └───────┬────────┘  └─────┬──────────┘       │
              │                 │                  │
      ┌───────▼────────┐  ┌─────▼──────────┐       │
      │ Declarative    │  │ Procedural     │       │
      │ Ontology       │  │ Ontology       │       │
      │ e.g., using    │  │ e.g., using    │       │
      │ Protégé        │  │ skeletal plans │       │
      └───────┬────────┘  └─────┬──────────┘       │
              │                 │                  │
      ┌───────▼─────────────────▼──────────┐       │
      │ Induction of Agent Classes         │       │
      │ in terms of: Role; Context;        │       │
      │ Resources                          │       │
      └───────────────┬────────────────────┘       │
                      │                            │
              Refining Purpose ───────────────────┘
                      │
      ┌───────────────▼────────────────────┐
      │ Multi-Agent System Architecture    │
      └────────────────────────────────────┘
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What do we want to do?

Analysis of the existing so far...
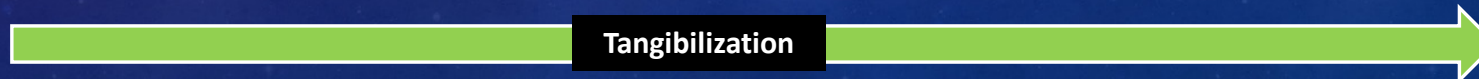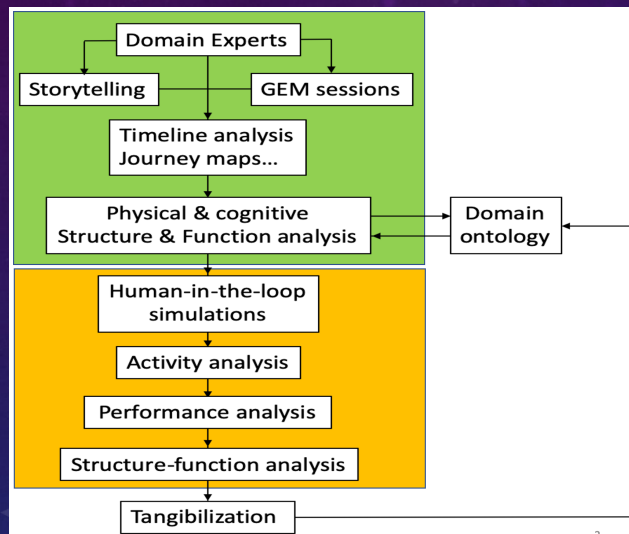*Anticipating possible futures...*

Making a Multi-Agent Ontology

Becoming more generic...

➡ **PRODEC**

OFF-SHORE OIL & GAS MULTI-AGENT TELEROBOTIC SYSTEMS

Using PRODEC method combined with HITLS

Tangibilization

CONCLUDING...

Awareness of the various possible contexts!
    scenarios
    human-in-the-loop simulations
    elicitation of emergent cognitive functions

Scenario-based design → solid conceptual models

Orchestra Model pour design, evaluation and operations
    Music theory → common framework (interaction models)
    Composers → scores = contracts + coordination
    Conductors → dynamic re-allocation
    Musicians → **competence + engagement + cooperation**
    Audience → constant communication and education

A FEW TAKE-AWAYS

- We live in a digital world → **tangibility** is a crucial contemporary issue

- Single-agent ergonomics is not enough → **Socio-ergonomics**

- Human-machine teaming → what **new human roles**?

- Rigid automation is what we know → **Flexible autonomy** is what we need to make

- How do we deal with the unexpected? → **problem-solving support**

- From means to purpose (people adapt) → **From purpose to means** (machines adapt)

- Collaborative work requires **education**, **openness**, **empathy** and **enthusiasm**!

This book is a follow-up of previous contributions in Human-Centered Design and practice in the development of virtual prototypes that requires progressive operational tangibility toward Human-Systems Integration (HSI). The book discusses flexibility in design and operations, tangibility of software-intensive systems, virtual human-centered design, increasingly-autonomous complex systems, Human-Factors and Ergonomics of sociotechnical systems, and systems of systems integration.

This is an attempt to better formalize a systemic approach to HSI. Good HSI is a matter of maturity… it takes time to mature. It takes time for a human being to become autonomous, and then mature! HSI is a matter of human-machine teaming, where human-machine cooperation and coordination are crucial. We cannot think engineering design without considering people and organizations that go with it. We also cannot think new technology, new organizations and new jobs without considering change management, especially in digital organizations.

The book will be of interest to industry, academia, those involved with systems engineering, human factors and the broader public.

Features:

- Discusses flexibility in design and operations of complex systems
- Offers tangibility of software-intensive systems
- Presents virtual human-centered design
- Covers autonomous complex systems
- Provides human factors and ergonomics of sociotechnical systems
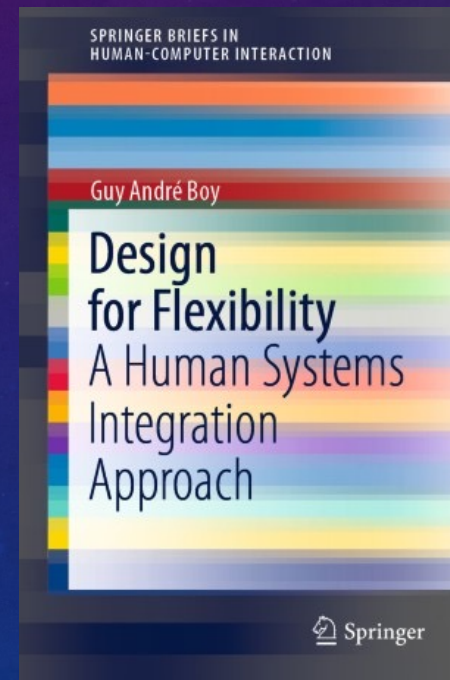
About the Author:

Guy André Boy is one of the pioneers and a world leader in the study and applications of human centered design and human systems integration. He is also the Chair of INCOSE Human Systems Integration Working Group worldwide.

Ergonomics and Human Factors

HUMAN-SYSTEMS INTEGRATION

Guy Andre Boy

HUMAN-SYSTEMS INTEGRATION

From Virtual to Tangible

Guy Andre Boy

CRC Press
Taylor & Francis Group

… and another one on flexibility!

Thank you!