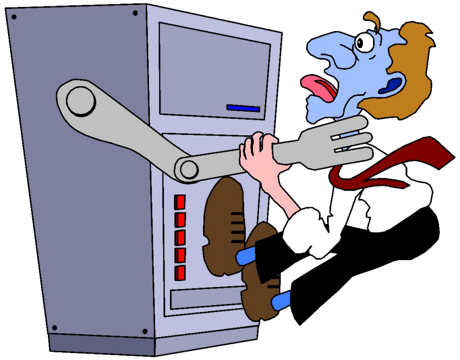

Human factors in control – a pipe dream or a real solution? – From Structures to functions

(thinking small – WAI) (thinking big – WAD)

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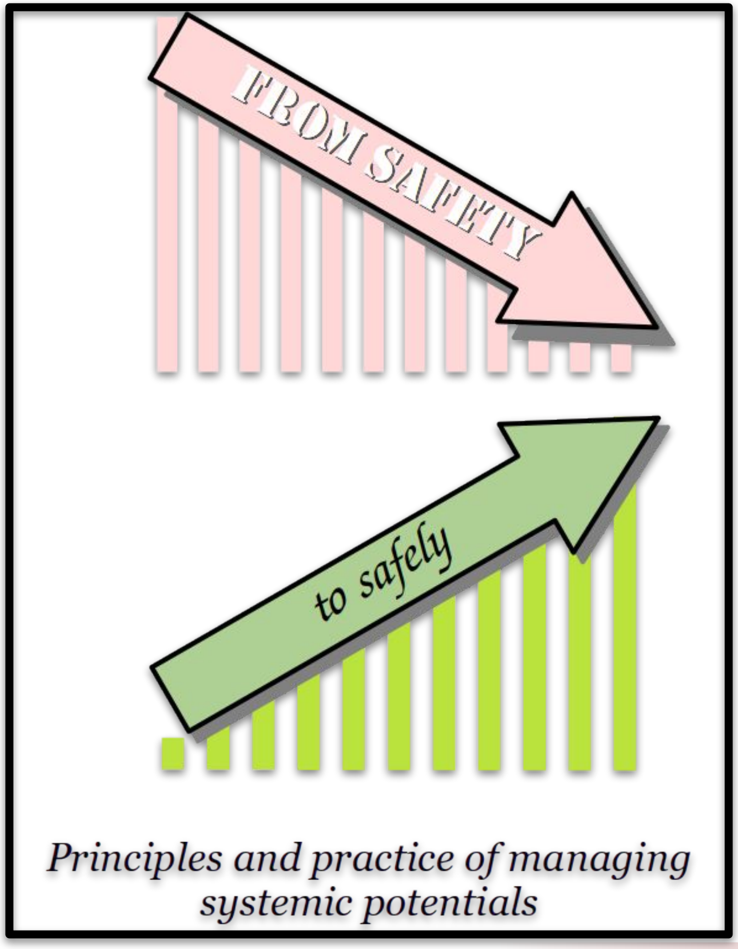
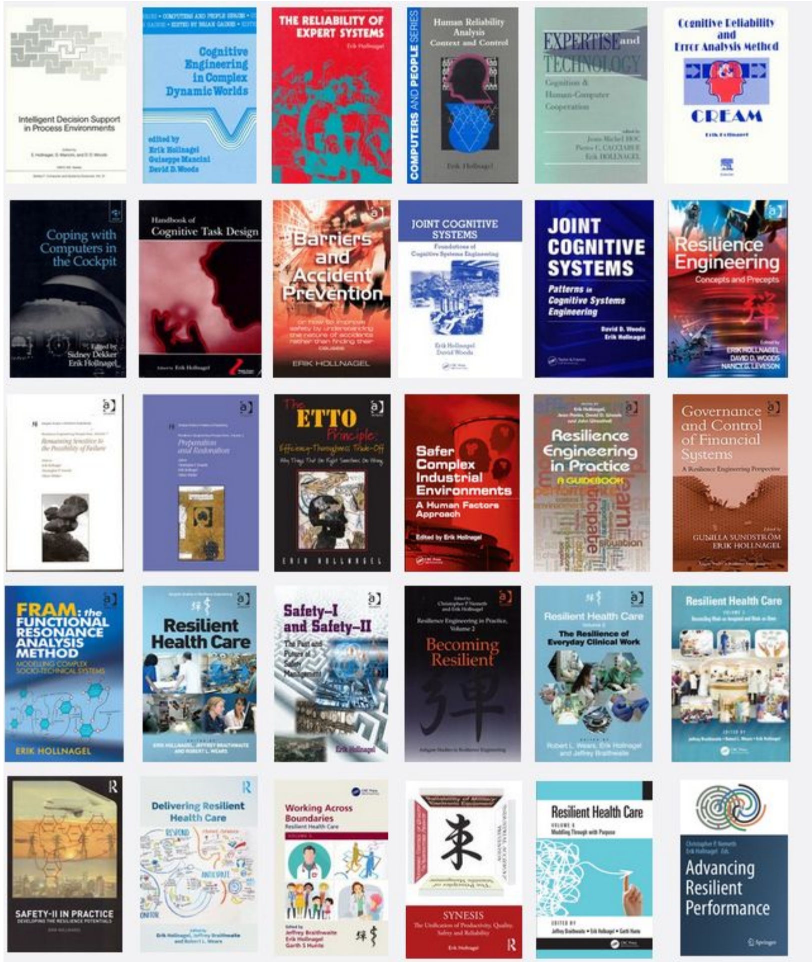




SESAR ATM Master Plan 2015

Trying to define a Human Centred System or WAI !

> *As in past and present operations, ATM performance will remain the result of a* ***well-designed interaction*** *between human, procedural, technological, environmental and organisational aspects. ATCOs would thus be allowed to concentrate on tasks where human cognitive skills have added value*

Single European Sky ATM Research (SESAR)

HALA (Higher Automation Levels in Automation?), 2010:
Automation should not be Human versus machine, automation should be seen as human-machine coordination as a team.

SESAR's vision builds on the notion of trajectory-based operations' and relies on the provision of air navigation services (ANS) in support of the execution of the business or mission trajectory — meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations.

Managing *ATM-as-imagined*

SafetySynthesis

1.Procedures

"Runway incursions will be substantially reduced and aviation safety improved through the use of **clear, unambiguous phraseologies** related to surface
related to surface operations."

2.Audits

During a normal work, on different sectors and different positions. a controller has to consider around about 70 – 100 restrictions – although NOT all at the same time .

To ensure that safety in the provision of ATS is maintained, the ATS authority has to implement formal and systematic safety management programmes for ATS under its jurisdiction. Furthermore, one of ICAO's requirements is the regular conduct of safety audits of ATS by trained, experienced and qualified personnel.

Performance targets (SESAR goals for 2020)

enable threefold increase in capacity
improve safety by a factor of 10
cut ATM costs by half
reduce environmental impact by 10%

Actual ATM Phraseology (WAD)

“DLH123, Langen Radar identified, cleared OSMAX 25 Transition, high speed approved”

Standard phraseology (4.7 sec)

Time saved: about 1.7 seconds

Non-standard phraseology (3.0 sec)

“Gude, DLH123, OSMAX 25 Transition, high speed”

There are about 14 transmissions per arrival – not including the time for readbacks.

With 50 arrivals/hour this means more than 700 transmissions/hour on frequency.

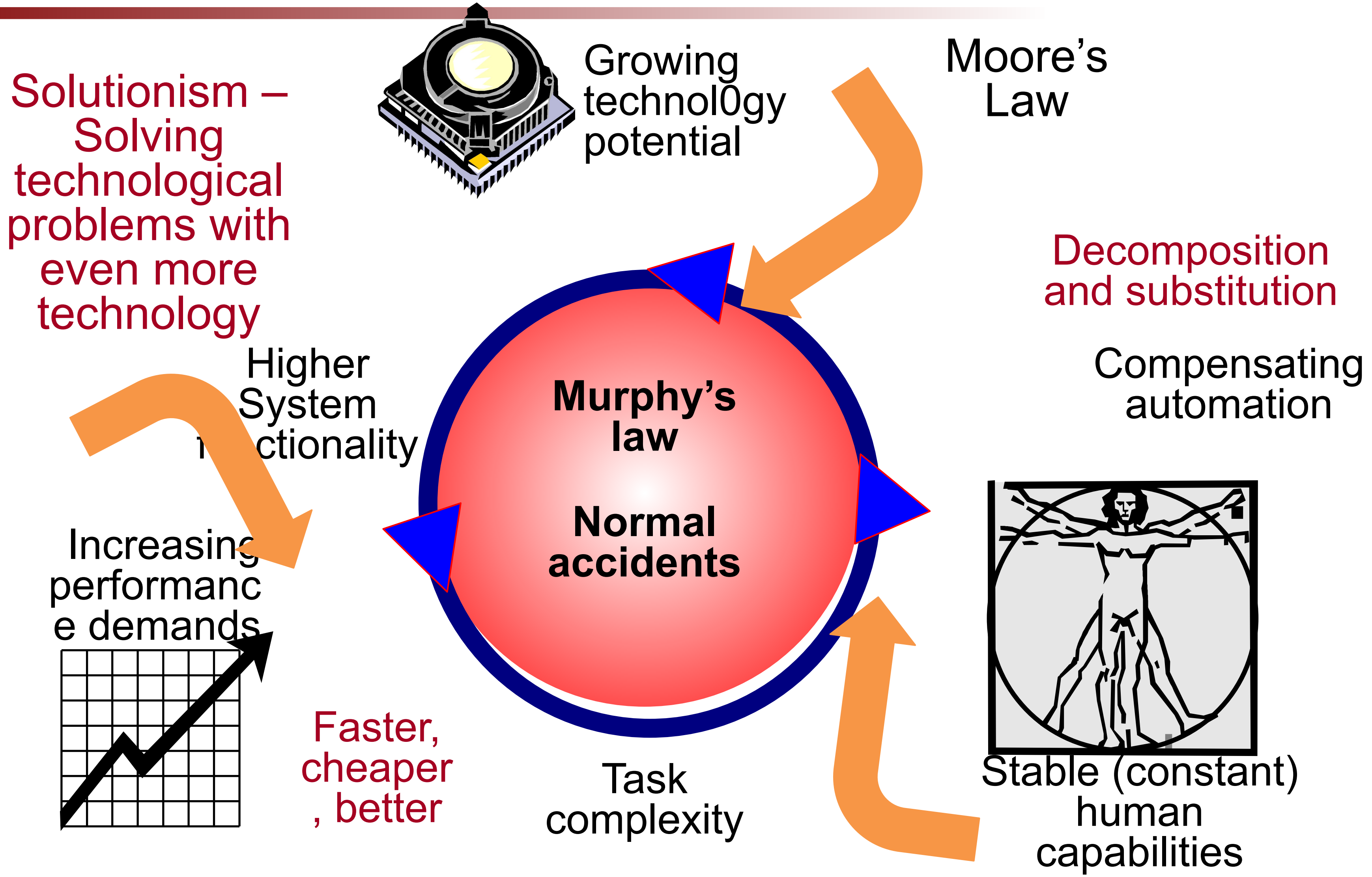
Saving just 1 second per transmission corresponds to 11 minutes saved per hour.

Detailed SESAR performance targets

Safety	Effectiveness of safety management Application of severity application scheme based on the Risk Analysis Tool (RAT) methodology. SESAR: Improve safety by a factor of 10
Environment	Horizontal flight efficiency - Using last filed flight plan - Using radar data for the actual trajectory SESAR: Reduce environmental impact by 10%
Capacity	En route ATFM delay per flight SESAR: Enable threefold increase in capacity
Cost-efficiency	Determined unit cost for en route air navigation services Determined unit cost for terminal air navigation services SESAR: Cut ATM costs by half

Is it possible to achieve all four targets at the same time?

Ever growing system complexity



Conventional HF thinking

"Human error" causes accidents.

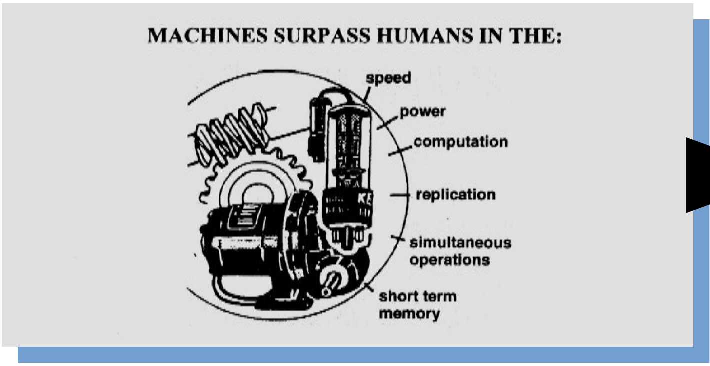
Humans are too imprecise, variable, and slow.

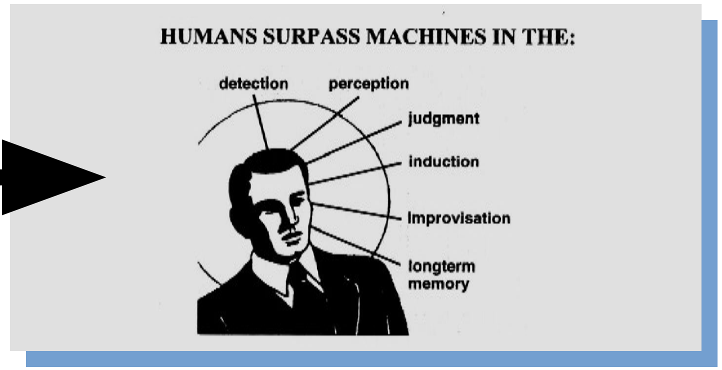
Train humans to fit tasks.
Design the HMI.

Automation can compensate for human limitations

Training
Design
Automation

Fitts, P. M. (1951). Human engineering for an effective air navigation and traffic control system. Ohio state University Foundation Report, Columbus, OH





cybernetics

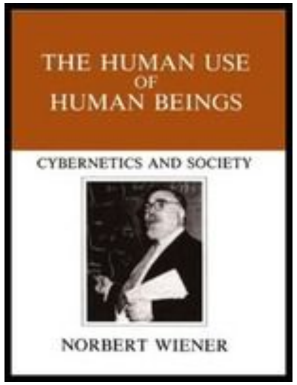
Humans are too imprecise, variable, and slow.

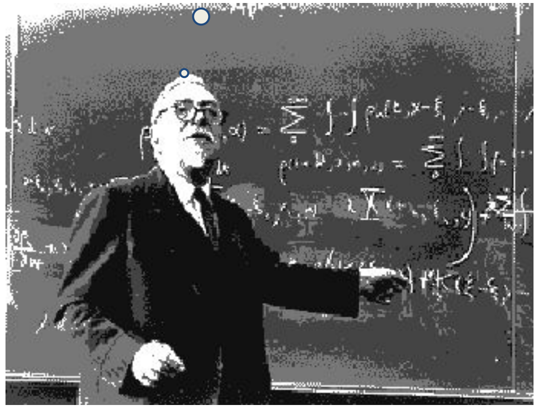
Human performance variability is cause of accidents.

Automation is used to overcome specific limitations

Automation is used to take over human tasks

Training + Design + Automation





Gadget worshippers, who "regard(ed) with impatience the limitations of mankind, and in particular the limitation consisting in man's undependability and unpredictability"

Norbert Wiener, 1950.

Technology and Solutionism

Gadget worshippers, who “regard(ed) with impatience the limitations of mankind, and in particular the limitation consisting in man’s undependability and unpredictability”
Norbert Wiener, 1964.

Law of Stretched systems (Lawrence Hirschhorn):
Every system is stretched to operate at its full capacity; whenever improvements are made, for whatever reason, they will be used to achieve a new intensity and tempo of activity – to stretch the system a bit further.

“Solutionism” (Evgeny Morozov):
An intellectual pathology that recognizes problems as problems based on just one criterion: whether they are “solvable” with nice and clean technological solutions at our disposal.

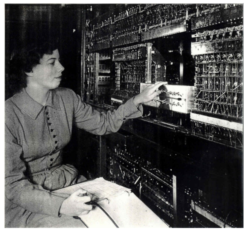
Train, design, and automate

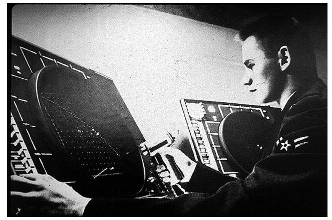
Design Design the workplace so that human limitations (perceptual, motor, cognitive) do not become a hindrance for system performance.

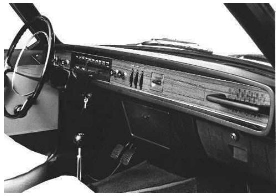
Human factors engineering

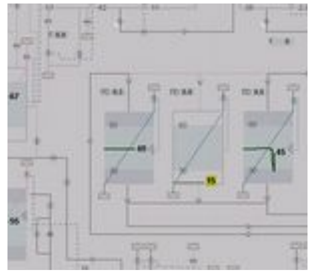
Ergonomics

Cognitive ergonomics









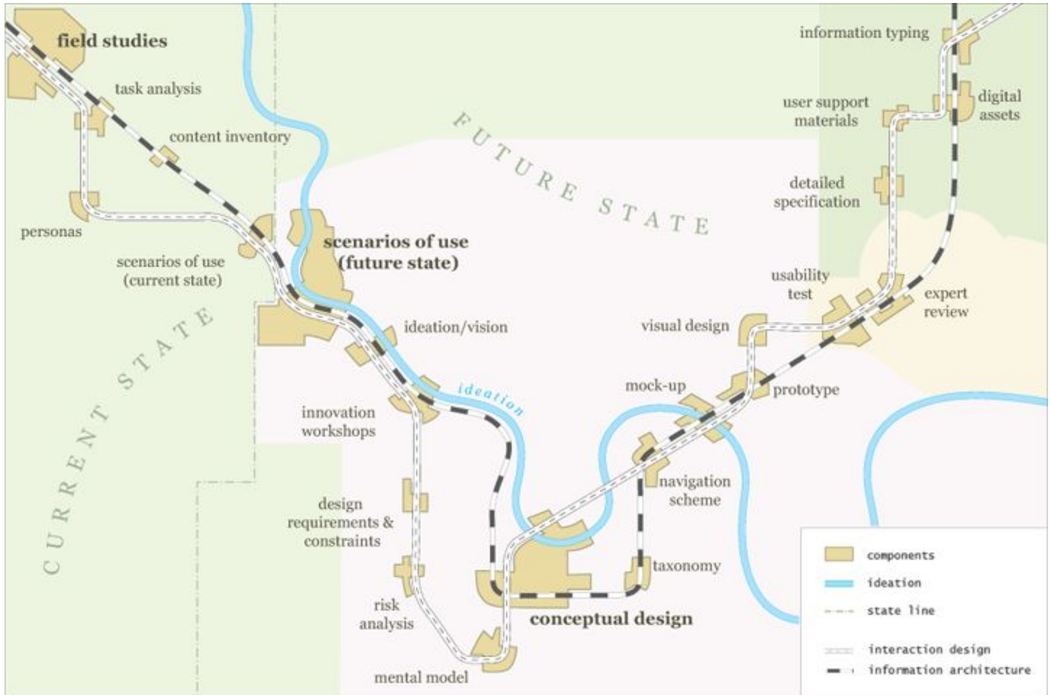
Human-computer interaction

Designing for simplicity ⟷ *Designing for complexity*

Design, the "Envisioned worlds" problem

Design is telling stories about the future ("envisioning")

To design is to speculate about the impact of the object-to-be-realized as a source of change in a field of practice.



Properties of "envisioned worlds"

Plurality: there are always multiple versions of effects of proposed changes.

Underspecification (imprecision): necessarily vague about future field of practice.

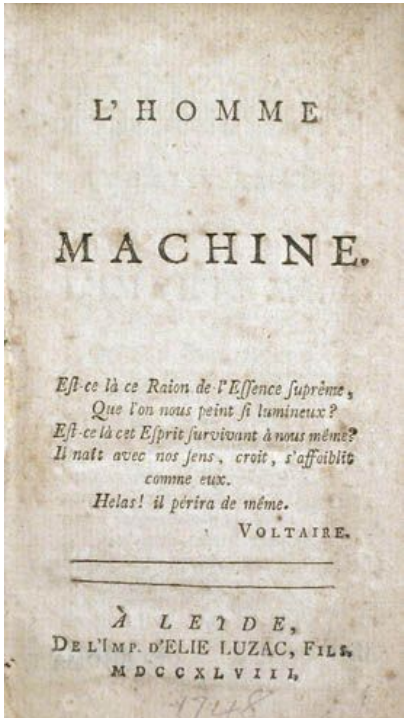
Groundedness: degree of support from empirical research base or based on hopes/hype alone.

Calibration (confidence): predictions can be miscalibrated and overconfident, disregarding possible negative effects.

Train, design, and automate

HF has traditionally relied on Training, Design, and Automation to reduce variability and enhance reliability.This is based on a strong but wrong analogy between machines and people. But the analogy is much older than Human Factors.

Man a Machine or *l'homme Machine* is the work of materialist philosophy by the 18th century French physician and philosopher Julien Offray de la Mettrie, first published in 1747



L'HOMME

MACHINE.

Est-ce là ce Raion de l'Essence suprême,
Que l'on nous peint si lumineux?
Est-ce là cet Esprit survivant à nous même?
Il naît avec nos sens, croît, s'affoiblit
comme eux.
Helas! il périra de même.
VOLTAIRE.

À LEYDE,
DE L'IMP. D'ELIE LUZAC, FILS.
MDCCXLVIII.

Julien Offray de la Mettrie (1709-1751)

Train, design, and automate

Train "Two rather different ... approaches may be distinguished in efforts to optimize the performance of MMS. One seeks, through the training of the operator, to adjust the human component to the requirements of the system. The other attempts to enhance system performance by adjusting the mechanical elements to fit the man."

Taylor, F. V. and Garvey, W. D. (1959). The limitations of a 'Procrustean' approach to the optimization of man-machine systems. Ergonomics, 2, 187-194.

Procrustes, whose name means "he who stretches", kept a house by the side of the road where he offered hospitality to passing strangers, who were invited in for a meal and a night's rest.

As soon as the guest lay down Procrustes went to work upon him, stretching him on the rack if he was too short for the bed and chopping off his legs if he was too long.

"In many instances it is possible, through operator training, to eliminate performance differences among man-machine systems of different intrinsic merit. This might lend one to choose an inferior design in the place of a better one since, under normal operation, they would all appear to be equivalent. However, if tho operators wore stressed, the fundamental inferiority of the chosen system might reassert itself."

The Procrustes' limitations

Adaptation through training

"Making shorter" aims to limit what people should do, i.e., by using less than their full potential (e.g. Scientific Management)

"Making longer" aims to stretch human capabilities to meet task demands through long and specialised training.

When the situation deteriorates, people revert to their "normal" behavior

They do more than they should do, hence may render the system incapable of functioning as planned (e.g., intervening, management by exception, too much and too early).

They do less than they should do, hence may render the system incapable of functioning as planned (e.g. default actions, wrong procedure, too little and too late).

The baseline – "normal" skills – is what people knew and did before training, modified by what they have learned through practice and experience.

Design, train, and automate

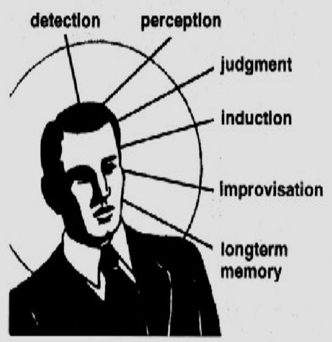
Automate

We begin with a brief analysis of the essential functions … We then consider the basic question: Which of these functions should be performed by human operators and which by machine elements?

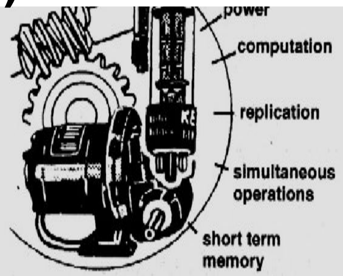
Fitts, P. M. (1951). Human engineering for an effective air navigation and traffic control system. Ohio state University Foundation Report, Columbus, OH

Men Are Better At – Machines Are Better At (MABA-MABA)

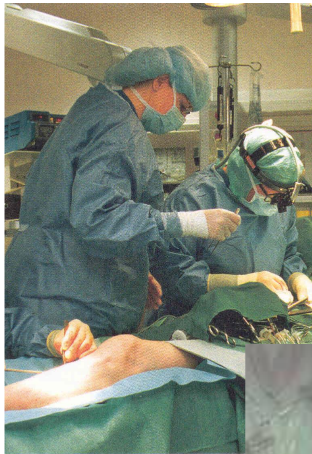
HUMANS SURPASS MACHINES IN THE:



- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures



- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle highly complex operations, i.e., to do many different things at once.



Reasons for automation

Evolutionary design	Reactive design
Improvements are introduced whenever possible to increase system effectiveness	Human-related causes of accidents are eliminated by automating manual functions
Automation is driven by technological innovation	Automation is driven by need to avoid past failures

?

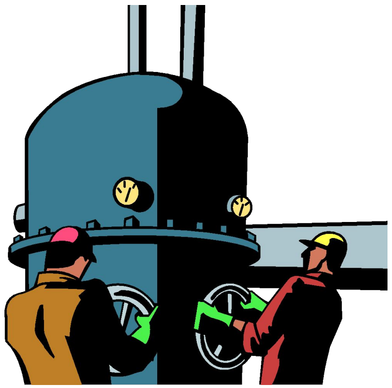
Common problems

- Little concern for effects on working conditions
- Subsystems and functions are treated in (relative) isolation, no consideration of interaction / overall effects

Compensatory principle of automation

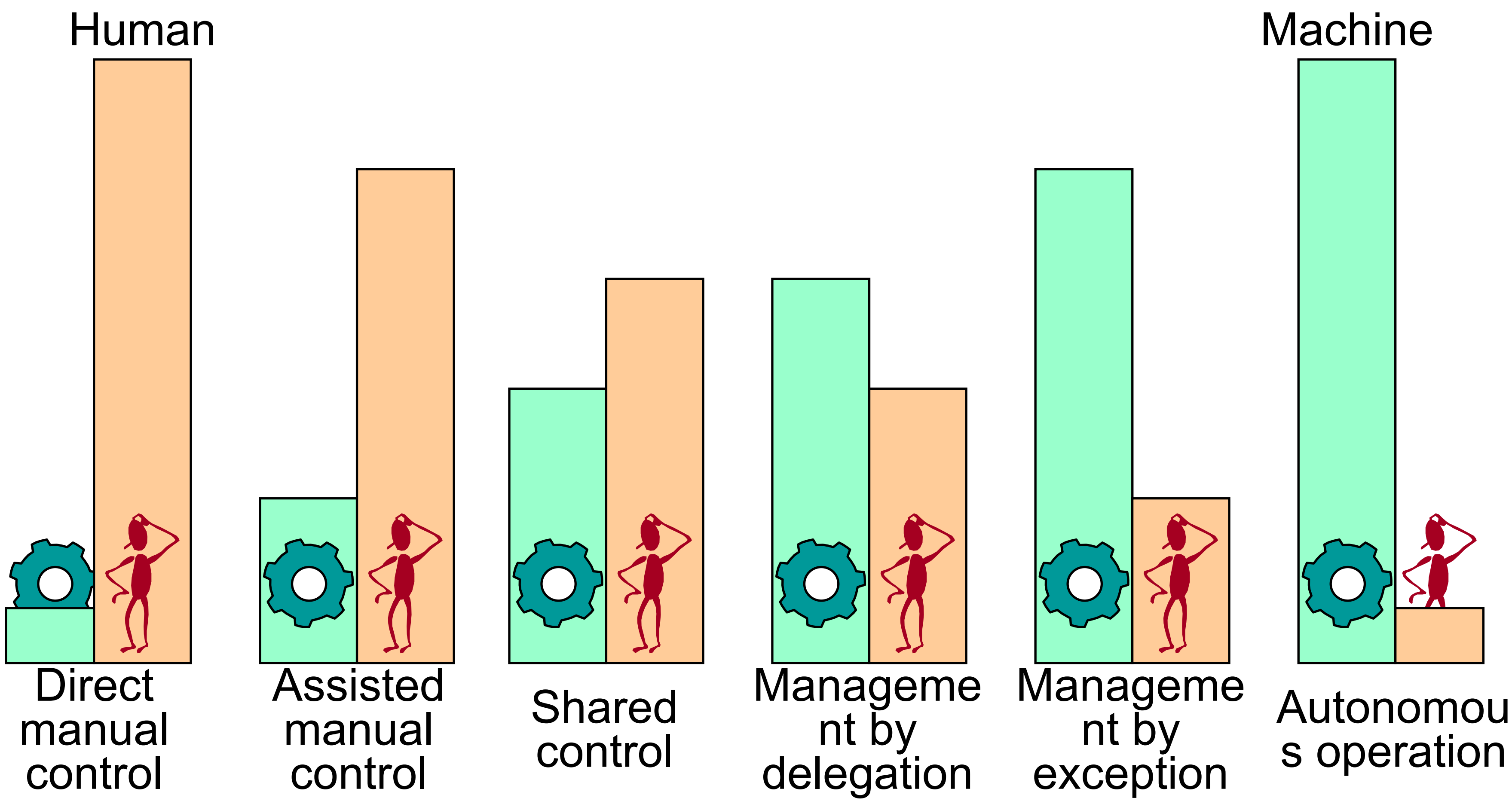
MABA – MABA
Men Are Better At – Machines Are Better At

- Speed
- Memory
- Sensing
- Perceiving
- Reasoning
- Consistency
- Computation
- Power output
- Information capacity

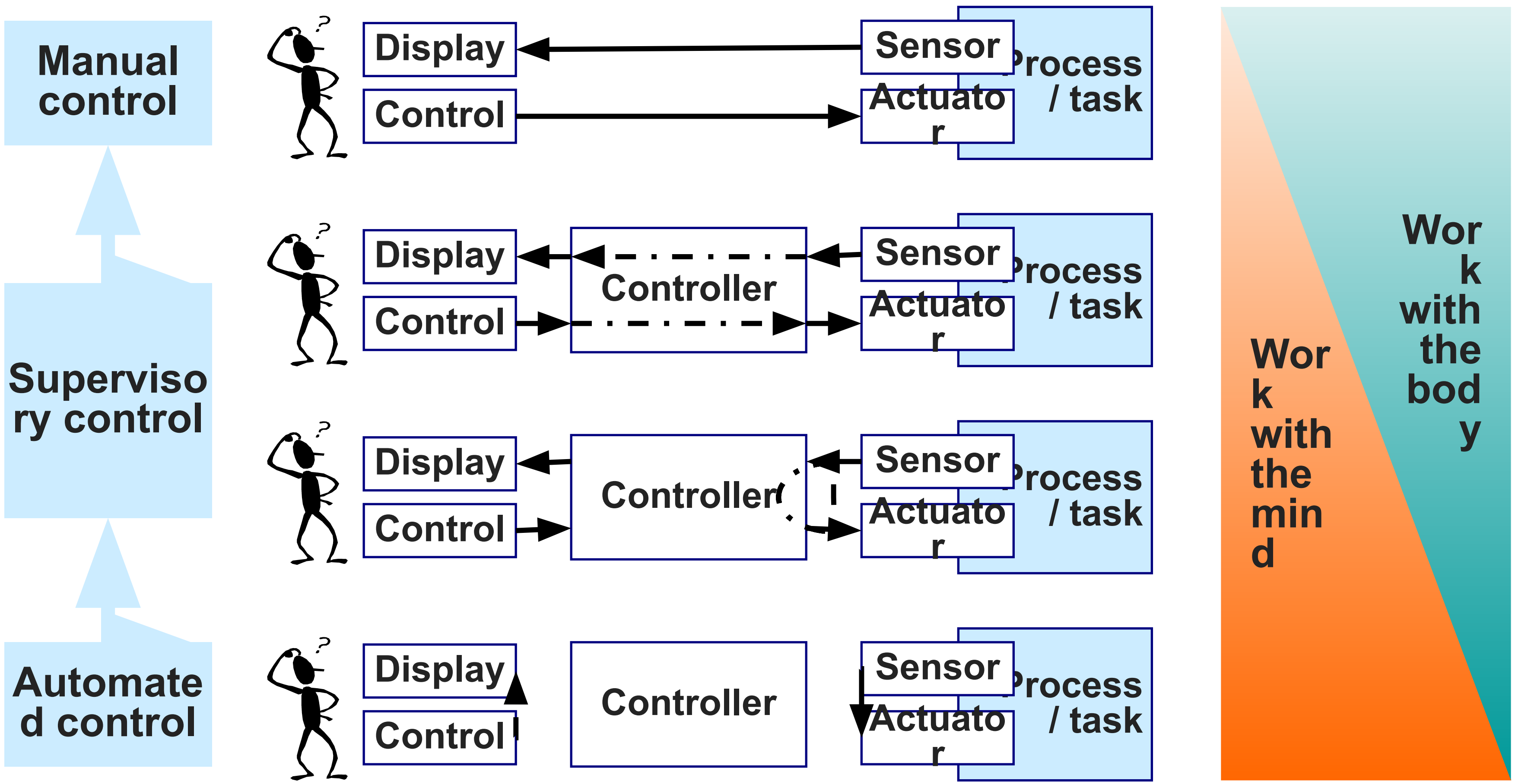


The Fitts List, 1951

- Different types of delegation

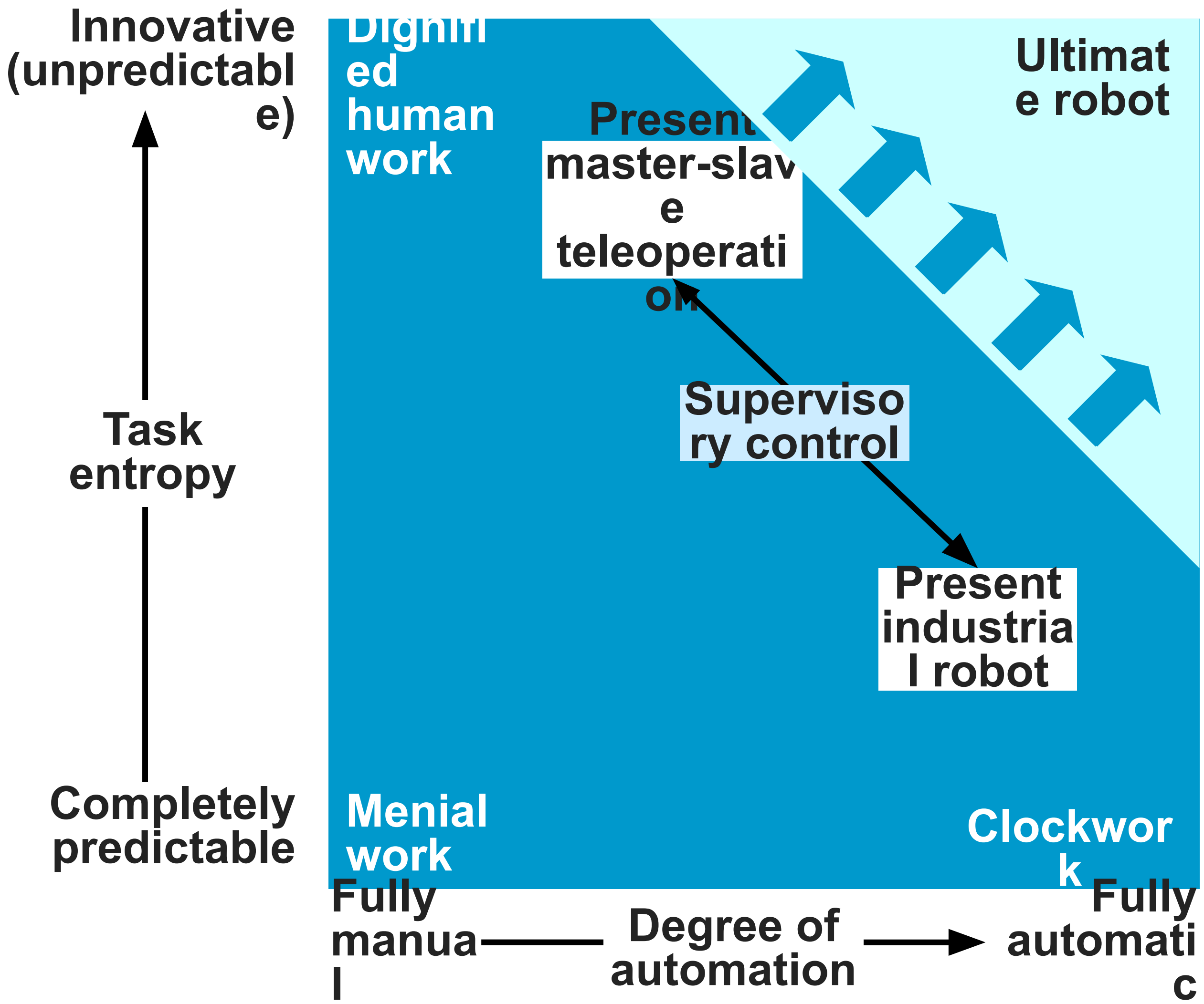


Sheridan’s classification



Supervisory control and automation

Source: Sheridan (1992)



Main automation "philosophies"

Left-over principle (proto HF)

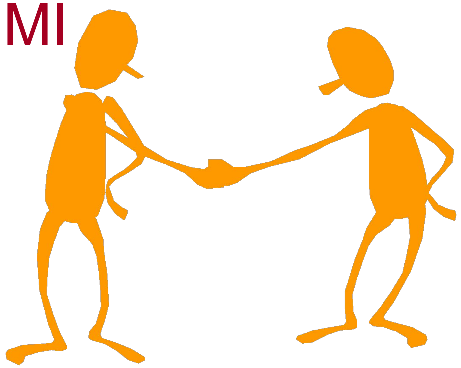
Functions that cannot be assigned to machines are left for operators to carry out.

Main concern: efficiency

Compensatory principle (HF, HMI)

Functions are assigned based on juxtaposing human-machine capabilities

Main concern: usability of HMI



Complementarity principle (CSE)

Function allocation aims to sustain and strengthen human ability to perform efficiently

Main concern: remain in control of situation

Complementarity - congruence

Complementarity principle:

Functions are allocated to retain skills and to support human control over the process

Function congruence (or function matching):

Capabilities and needs vary over time and depend on the situation.

Functions are therefore assigned to humans and machines deliberately to overlap.

This provides the ability to redistribute functions according to need, hence to choose from a set of possible function allocations.

Function congruence is based on an analysis of goals and required functions of the joint system

Basic assumptions

Any human-machine systems (HMI) or human-computer system (HCS) can be described as composed of two principal components: the human (user) and the machine (application or computer).

IMPLICATION #1

There is a clearly identifiable, and therefore also clearly describable, boundary between the human-machine system and its environment.

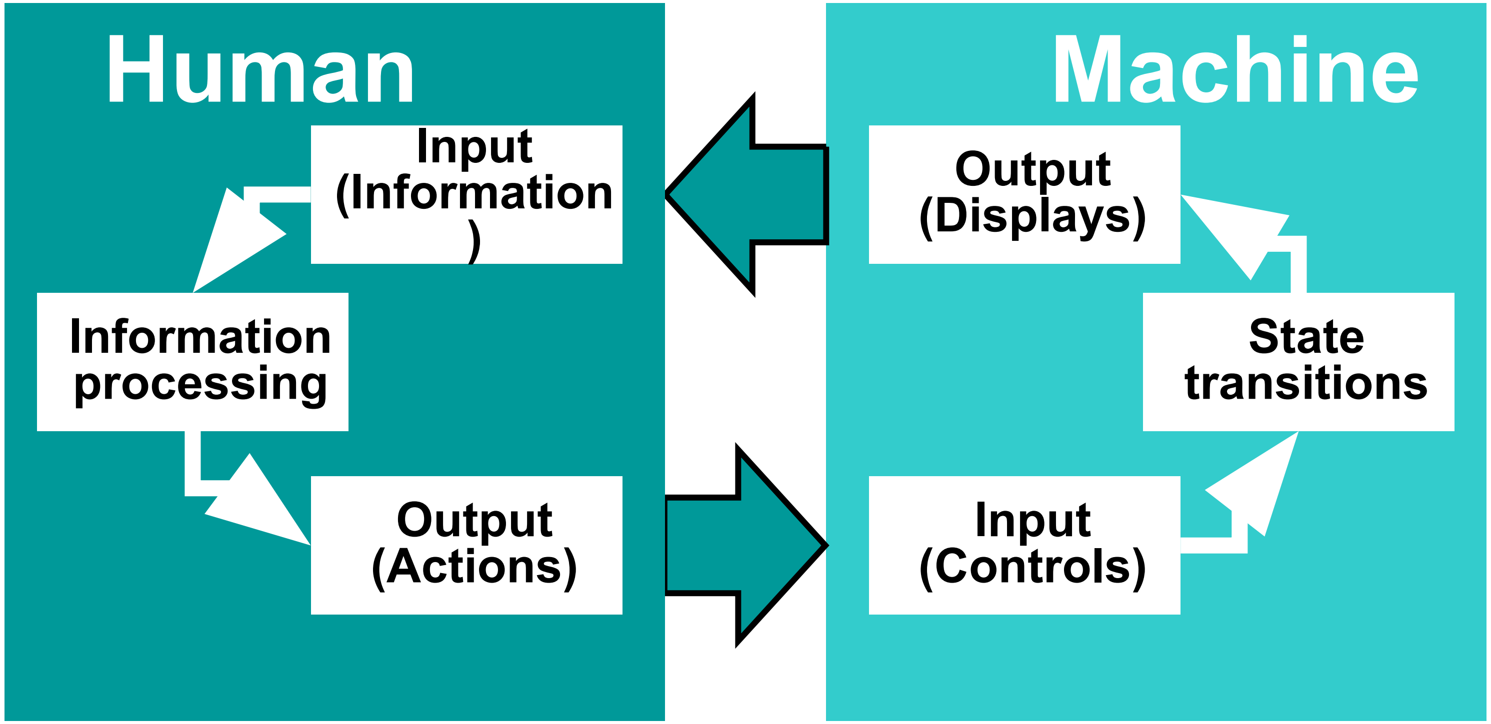
IMPLICATION #2

The interaction between the HMS/HCS and the environment can be described in the same way as the interaction between the human and the machine, i.e., in terms of input and output.

IMPLICATION #3

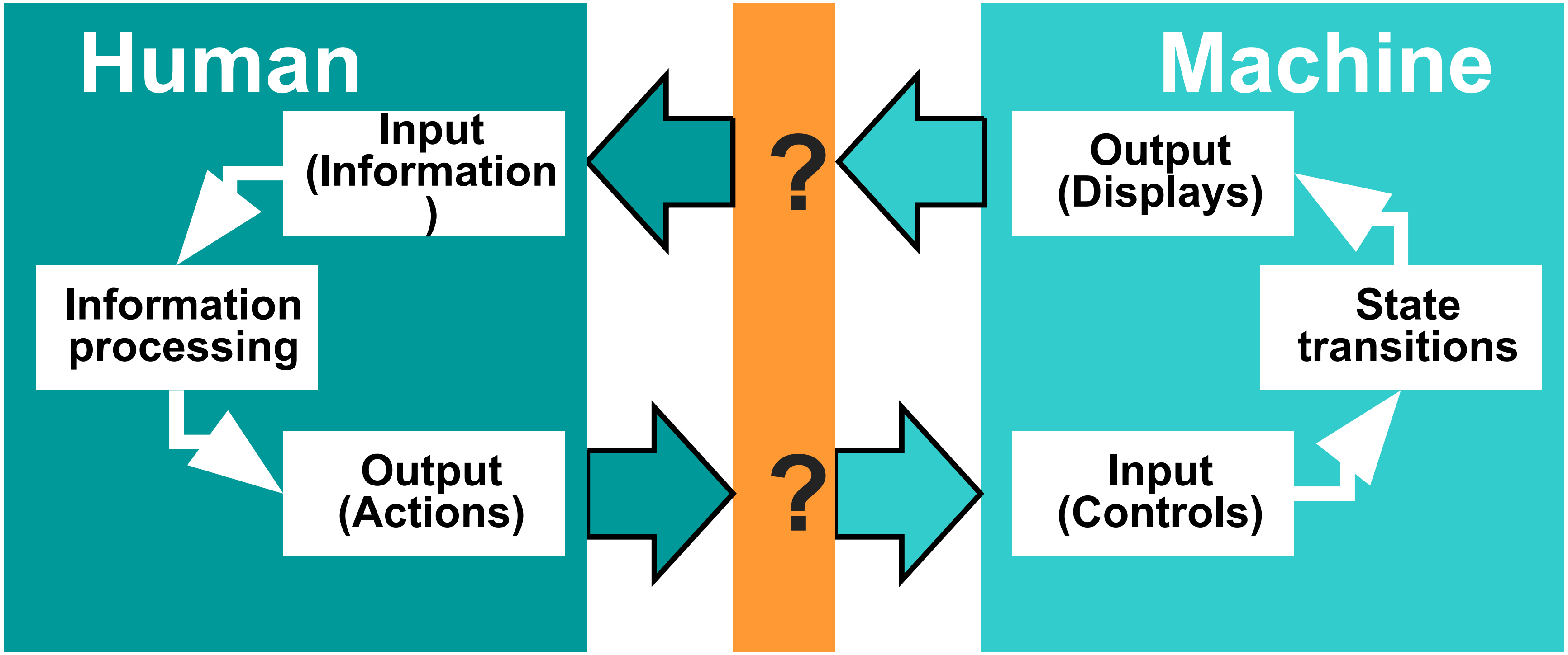
Both human and machine are reactive, which means that the interaction can be described as taking place in a closed-loop.

Classical human-machine view



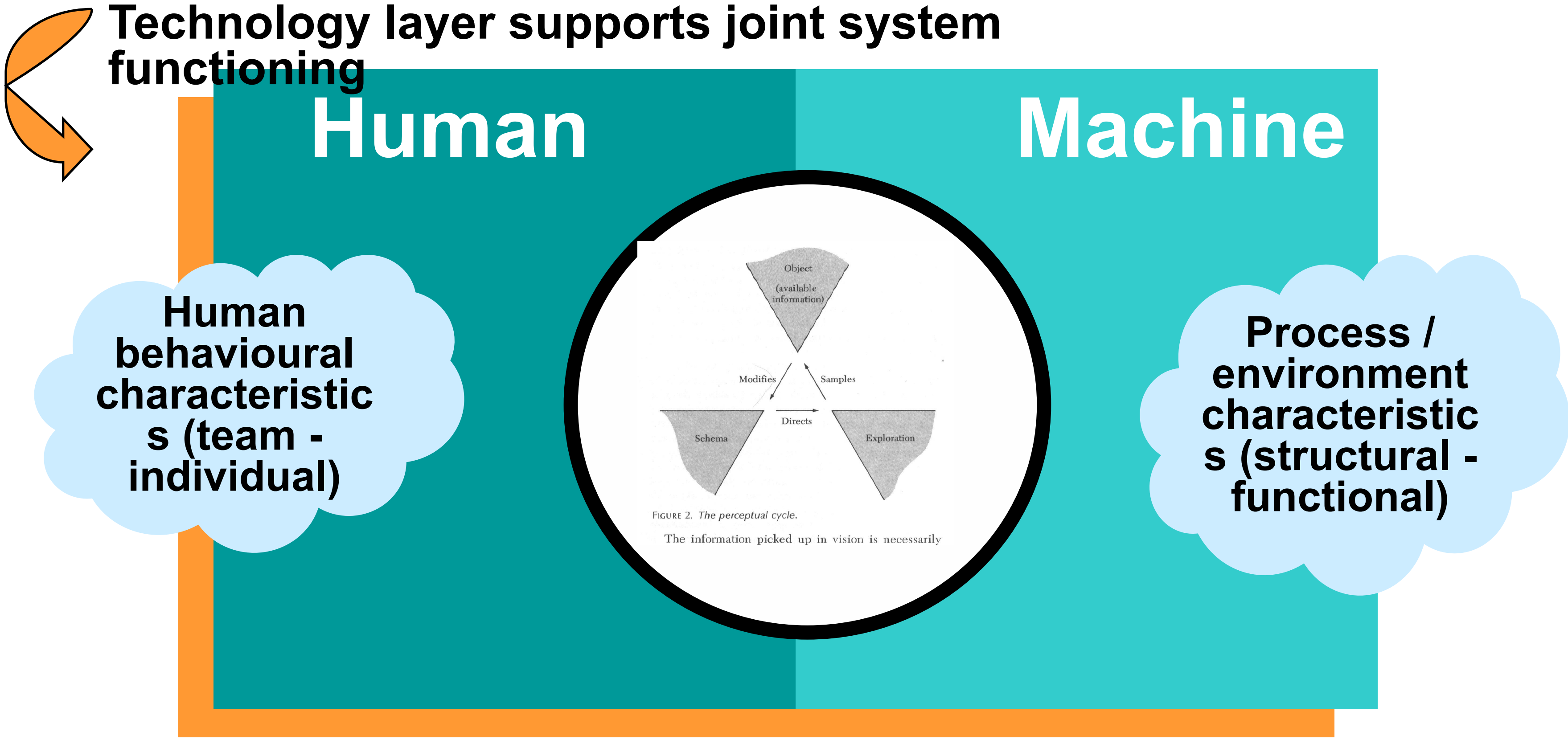
Closed-loop.control system based on the Shannon-Weaver communication paradigm.
Human and machine are seen as separate, interacting units.

Structural human-machine view



Human information processing tended to focus on "inner" processes of the human mind, and to describe these isolated from the work context.

Functional human- machine view

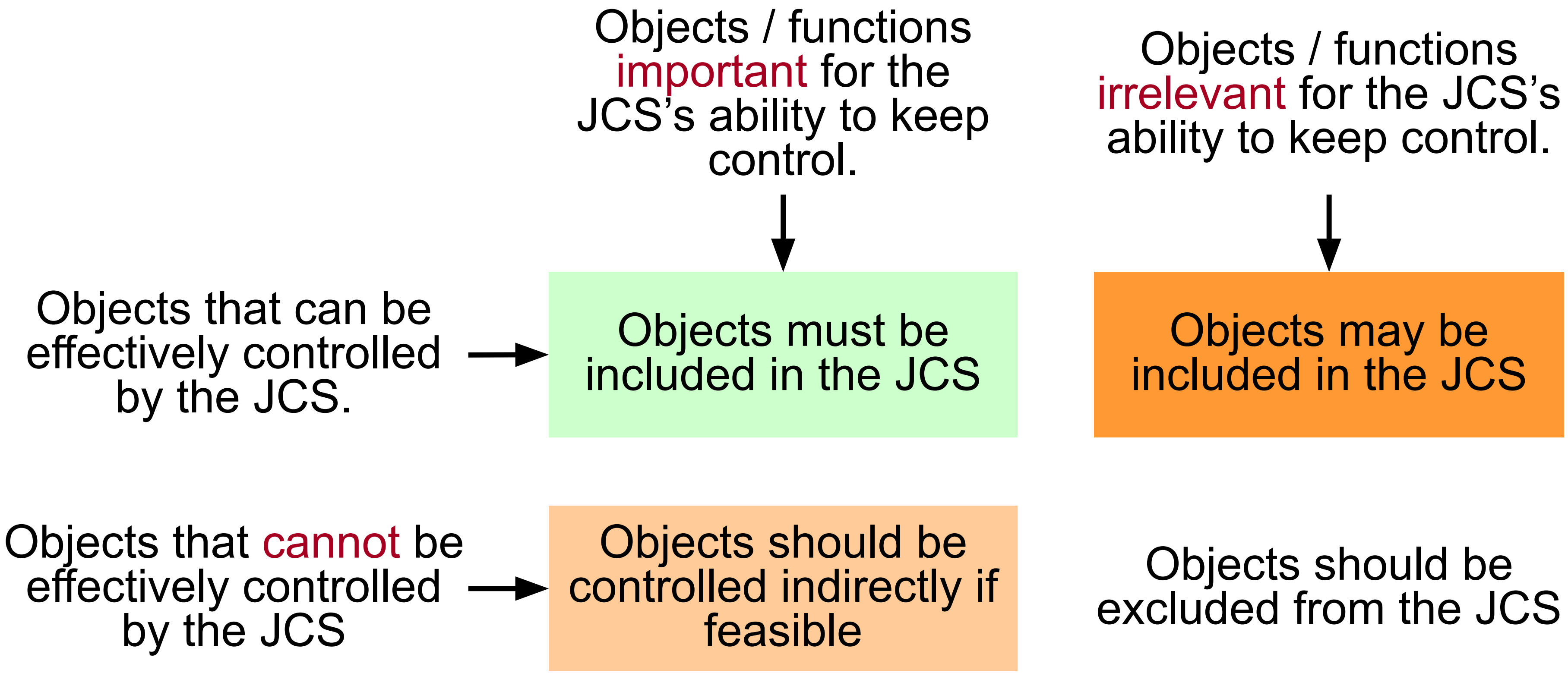


Instead of focusing on the interaction between human and machine, they can be seen together as constituting a joint system.

• Automation assumptions

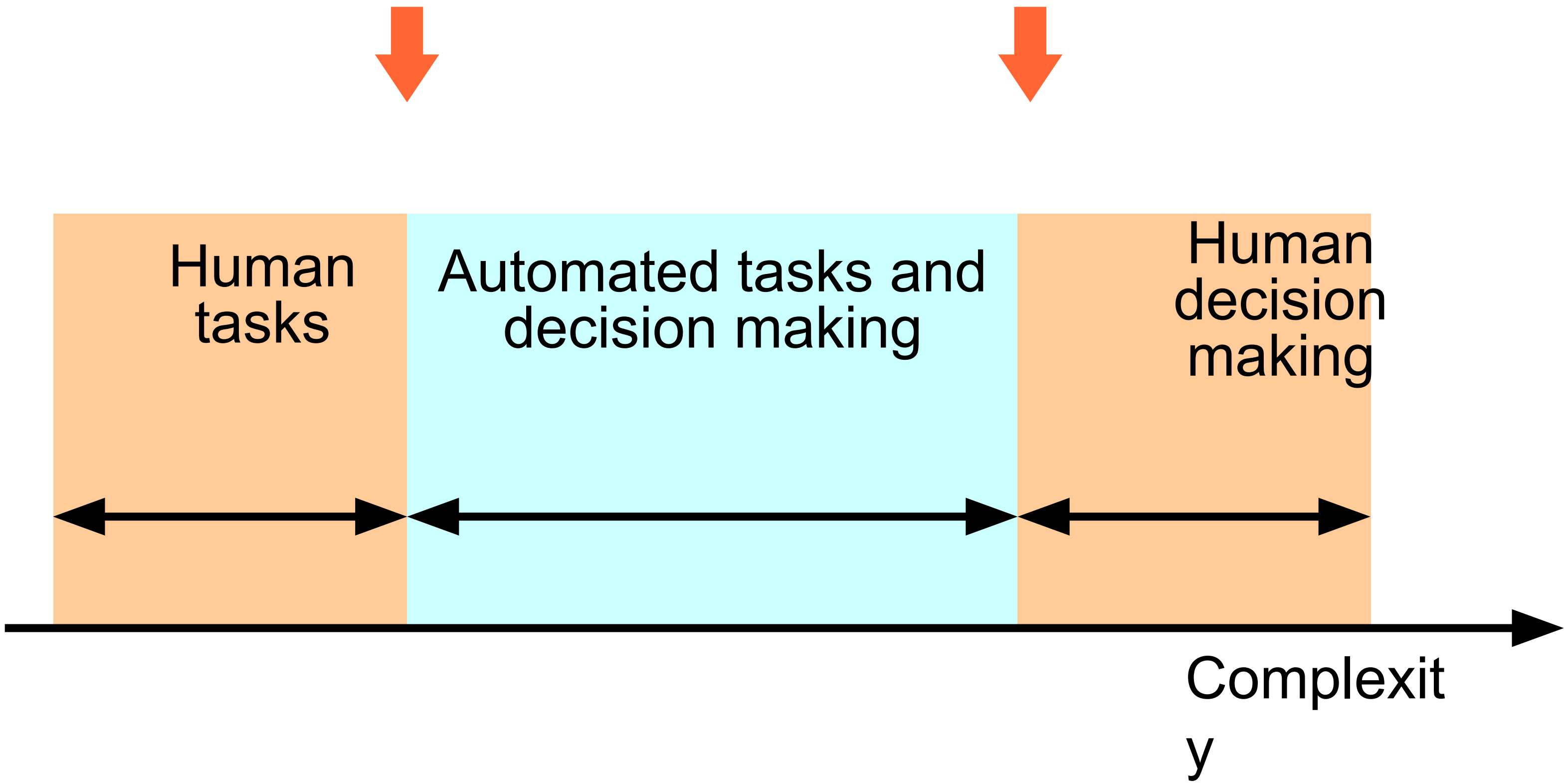
Human and machine capabilities can be described unambiguously, using a set of common characteristics.	but	Human and machine capabilities cannot be described independently of context.
The responsibilities/roles of people and machines can be clearly defined.	but	Transition from automation to manual operation is complex - people may intervene wrongly.
The consequences of introducing automation can be precisely predicted.	but	Automation changes the nature of the system; long-term effects on organisation of work are often missed.
Automation will reduce number of human errors, and make the system more reliable.	but	Automation does not reduce the number of failures but changes the failure modes.

Functional definition of boundaries



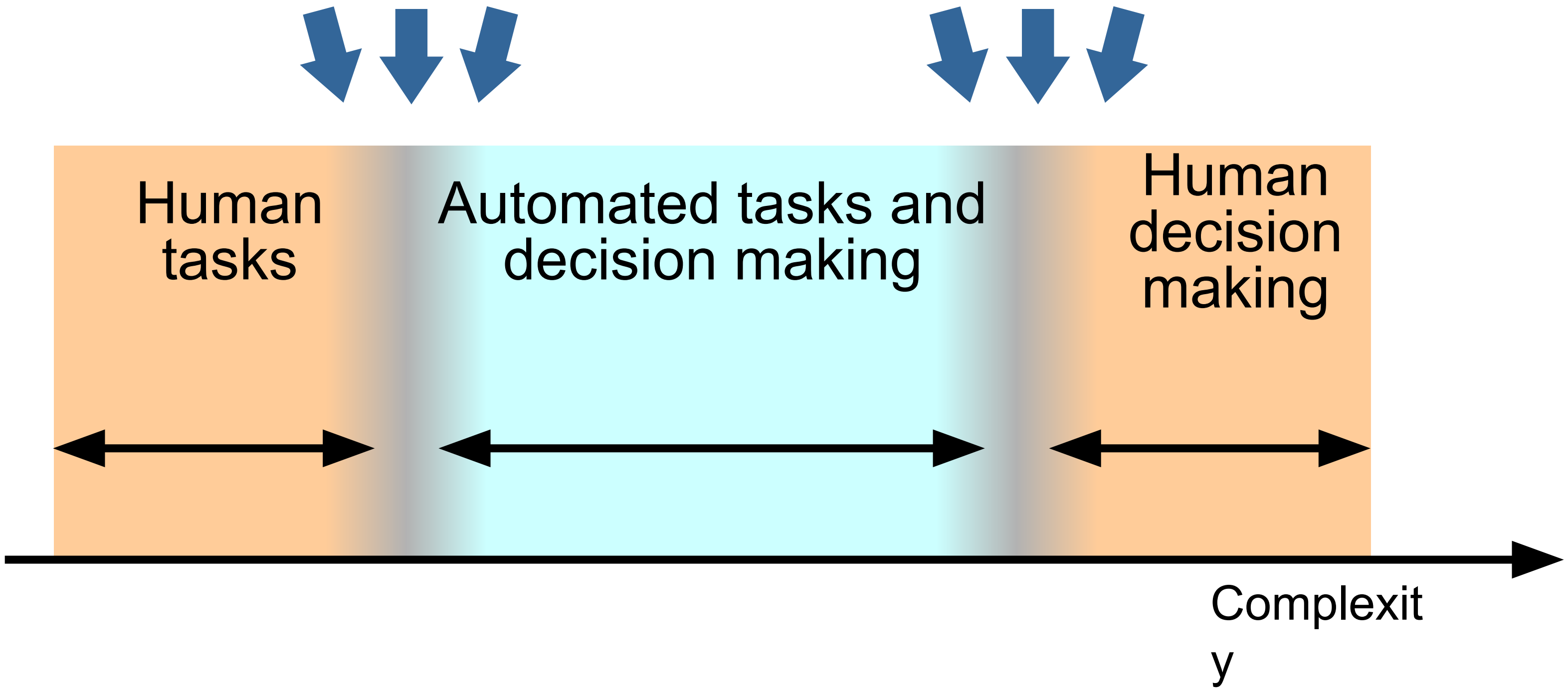
Simple transition to automation

System design generally assumes that transitions to-from automation are well-defined (crisp)



Complex transition to automation

In practice, the transitions are blurred, both because the conditions are imprecisely specified and because humans often act in anticipation of events.



Three premises for function allocation

It is meaningful to speak of essential human and machine capabilities, and use these as the “building blocks” for function allocation

Fitts’ list
Task analysis
Human as IPS

The boundary of the human-machine system (JCS) can be clearly defined, and is stable vis-a-vis the function allocation

Nature of human-machine system
Joint cognitive system
Distributed cognition

It is possible fully to specify the functions that are necessary and sufficient to provide a given service or activity.

Systems are linear
Context is stable (or controlled)

• Ironies of automation

L. Bainbridge (1987), "Ironies of automation"

The basic view is that the human operator is unreliable and inefficient, and therefore should be eliminated from the system.

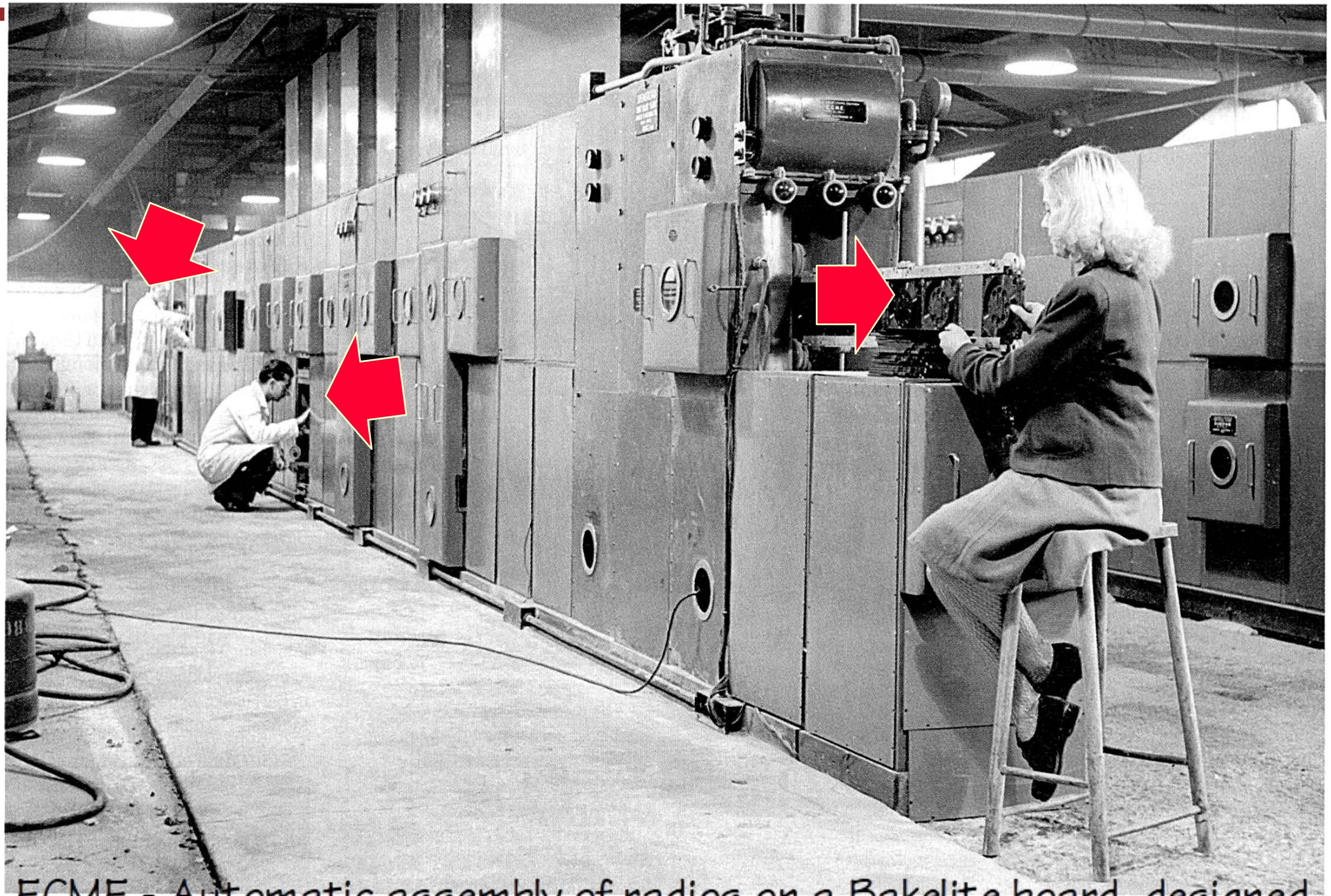
First irony

Designer errors can be a major source of operating problems.

Second irony

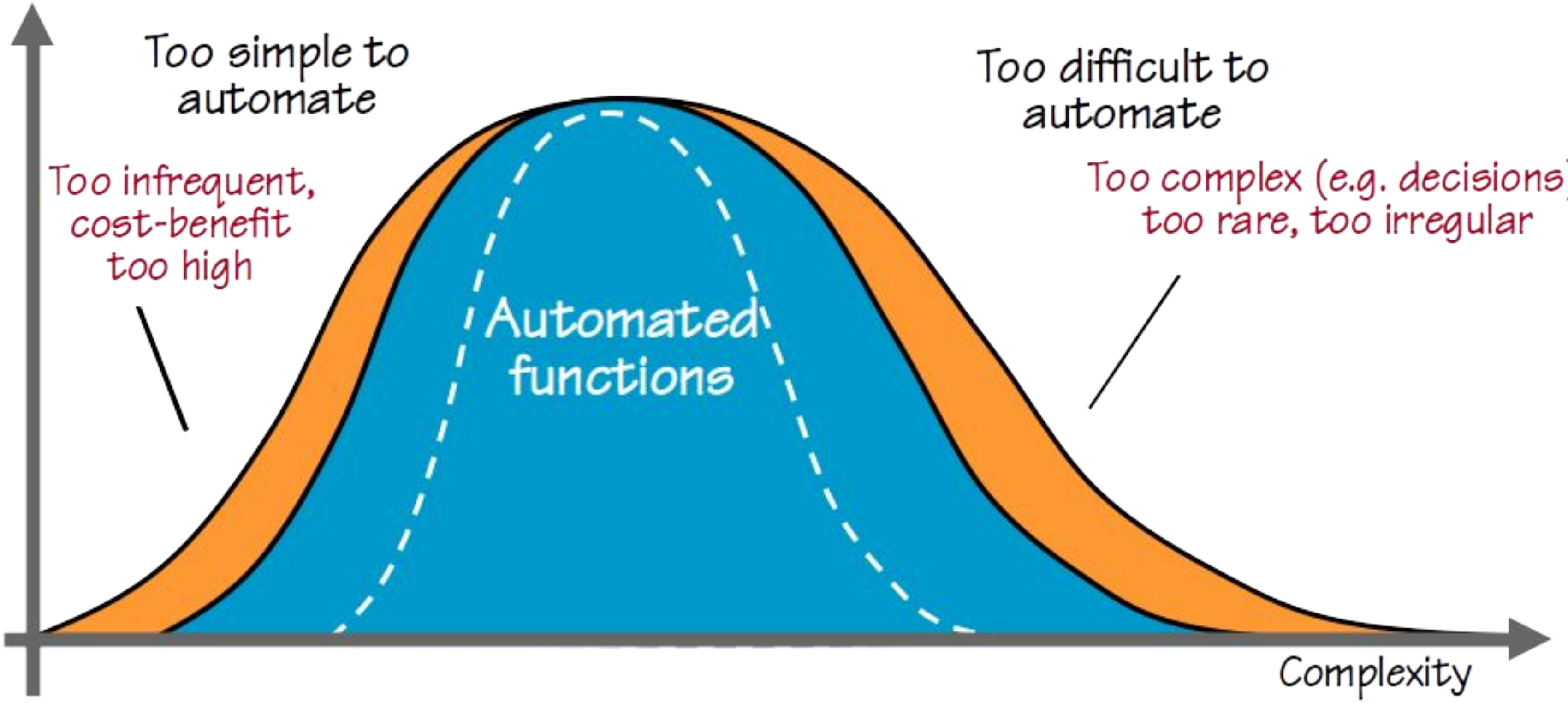
The designer, who tries to eliminate the operator, still leaves the operator to do the tasks which the designer cannot think how to automate.

The second irony in practice



ECME - Automatic assembly of radios on a Bakelite board, designed by John Sargrove, 1948. (Average production rate: 20 seconds)

The problems at either end



Tasks that are not automated are left for the operator to do. The lack of meaningful activities may cause a loss of skills and proficiency (de-skilling).

Implications of automation principles

	View of operator (model)	Assumptions about interaction	Assumptions about nature of process	Assumptions about "human error"
"Left-over" (proto HF)	None	Independent entities	Decompositional ("Tayloristic")	Wholesale category
"Compensatory" (Human Factors, HMI)	Limited capacity IPS (with stable capabilities)	A priori descriptions valid (stable functions)	Structural approach (state based)	"Error mechanism"
"Complementarity, congruence" (CSE)	Cognitive system (cyclical model)	Dynamic equilibrium	Joint systems (functional approach)	Cognition-in-the-world. Loss of control

Performance variability is necessary

Most socio-technical systems are intractable. Conditions of work are therefore underspecified.

Resources (time, manpower, materials, information, etc.) may be limited or unavailable

People (individually and collectively) must adjust what they do to match the conditions.

For the very same reasons, the adjustments will always be approximate.

The approximate adjustments are the reason why everyday work is safe and effective.

But the approximate adjustments are also the reason why things sometimes go wrong.

Performance variability

Acceptable outcomes

Unacceptabl
e outcomes

• Coagency view of automation

Focus on how the joint (cognitive) system can accomplish its functions.

Descriptions should be in terms of goals and functions, rather than pre-defined tasks.

Automation design should aim to support the control capabilities of the joint system.
Humans are good at anticipatory control.
Automation (technology) is good at compensatory control

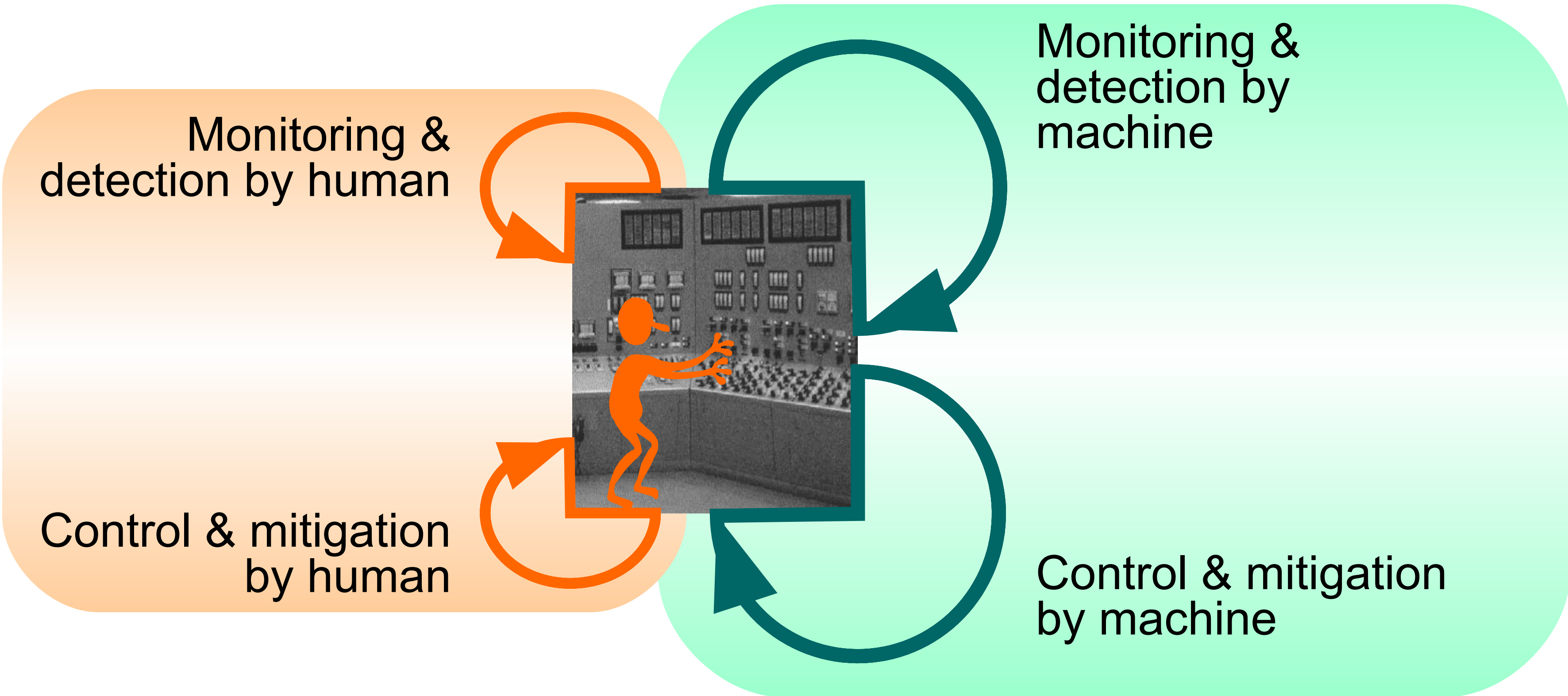
Functions should be distributed in the joint system so that it always has sufficient capabilities to achieve goals while being able to anticipate and predict future events (resilience).

• Automation and coagency

SafetySynthesis

		Monitoring & detection	
		Human operator	Technology / automation
Control & mitigation	Human operator	Conventional manual control.	Automation amplifies attention/recognition.
		Operators are in-the-loop.	Reduced monotony.
		Operators may become overloaded and delay system.	Automation dependency, degraded attention.
	Technology / automation	Automation amplifies performance	Automation takes over.
		Improved compensatory control.	Effective for design-base conditions.
		Automation dependency - loss of comprehension	Loss of understanding and skills.

• Balancing use of automation

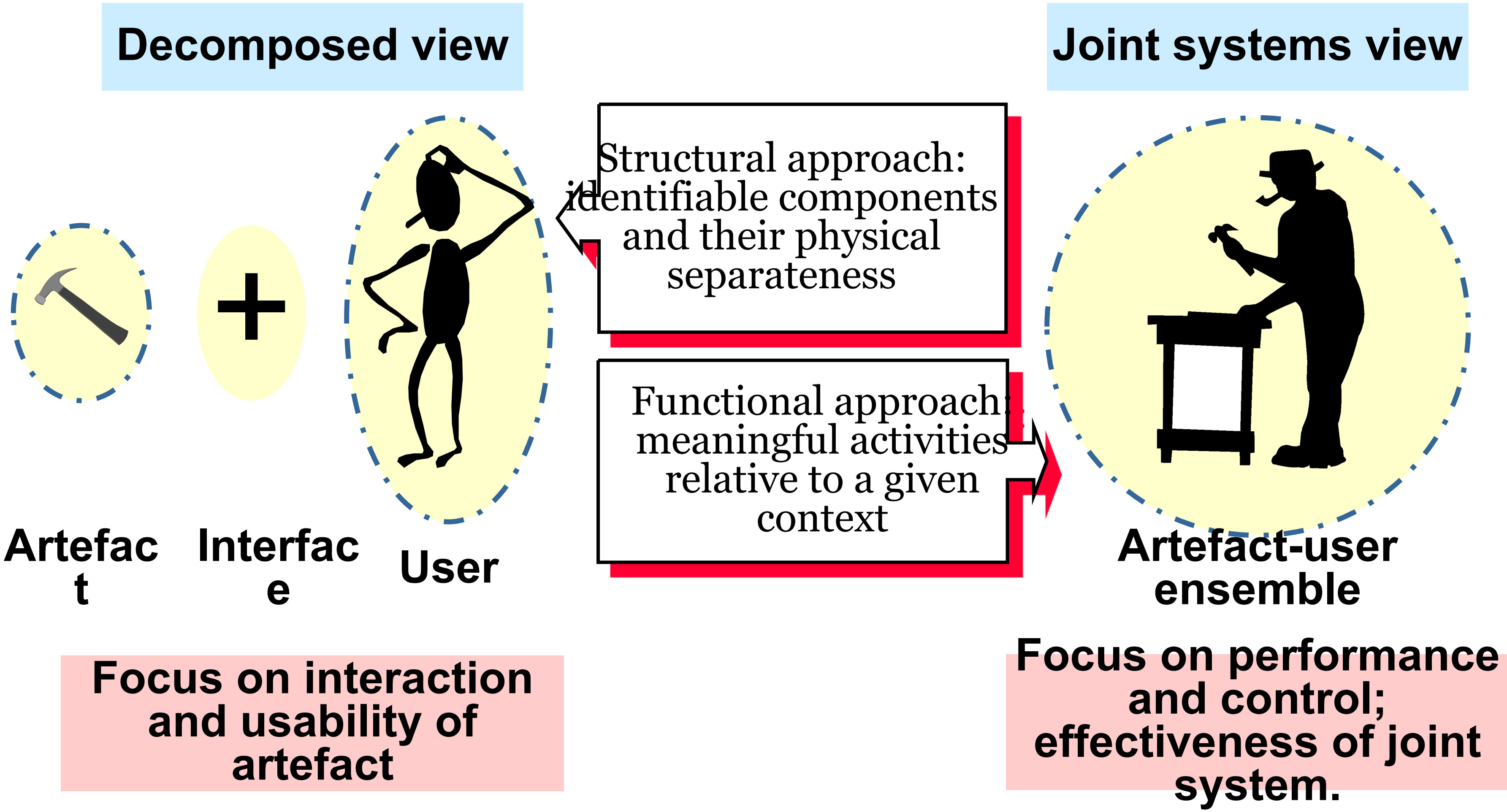


If automation takes over the detection-correction functions, people lose information about what the system does, hence lose control,

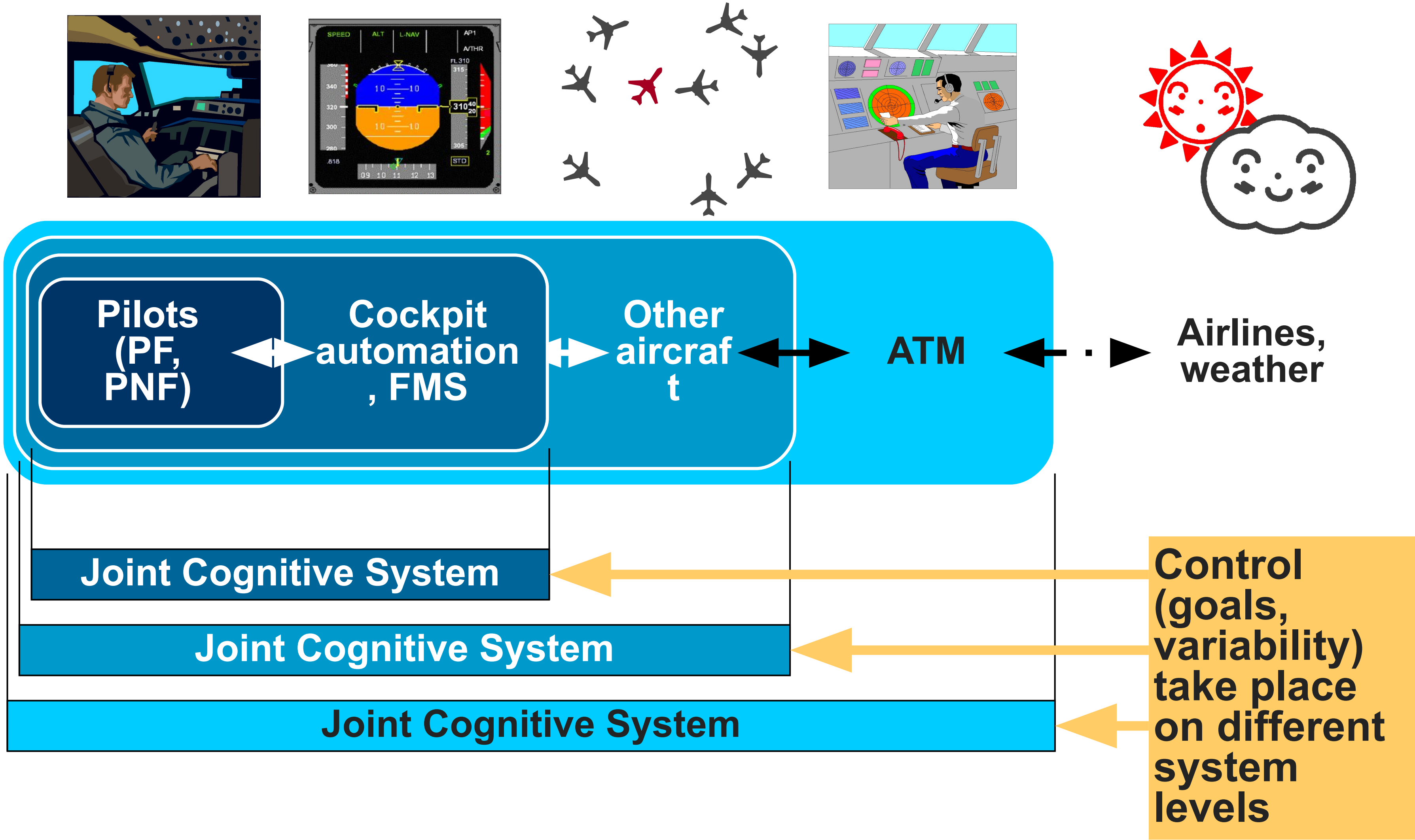
Automation as a solution?

Technocentric view		Cognitive engineering view
Humans are a major source of failure and should therefore be designed out of the system.	↔	Humans are adaptive - and can recover from unexpected situations.
Automatic control systems are more rigid, and therefore more reliable.	↔	Automation relies on software that is often not reliable, even when only moderately complex.
Automation permits a system to function when human capability has been exhausted.	↔	Automation is always incomplete, hence requires humans as back-up when system fails.
Automation is cost-effective because it reduces skill-requirements to operators.	↔	Only true for routine operations; operators must monitor automation, as an extra task.

Structural and functional views



Joint system perspective



Conclusions

Safe tySyn thesis

Thinking "small"	**Thinking "big"**
We commonly assume that …	But the fact of the matter is …
The boundary between the human-machine system and its environment is well-defined	Boundaries are relative rather than absolute
System-environment interaction can be described similar to the human-machine interaction (I-O)	System-environment interaction is different from the human-machine interaction
Humans and machines function in a reactive manner.	Machines are reactive, but humans are proactive.

“Thinking big when thinking small”: interaction design requires a good understanding of what determines performance (WAD) in a larger context

Conclusions (1)

Adequate performance in current and future work systems requires the effective interaction between social and technical factors.
This interaction comprises both linear (or trivial) ‘cause and effect’ relationships and ‘non-linear’ (or non-trivial) emergent relationships.

Adequate performance cannot be achieved by the optimisation of either aspect, social or technical, alone. Attempts to do so will increase the number of unpredictable or ‘un-designed’ relationships, which may be injurious to the system’s performance.
The basic function allocation problem was formulated more than 50 years ago.
The problem was meaningful for the tractable systems that existed at the time.
Since then the nature of work has changed due to “rampant technological and societal developments.”
The problem today is (perhaps) rather how to remain in control of self-created intractable systems – or how to make sure that these systems function efficiently and safely..

Conclusions (2)

Good system design requires the ability to think big while thinking small. It must at the same time ensure the stable functioning of the local system and the persistence and survival of the larger, global system.

This requires a revision of many commonly held design ideals, as well as the development of methods that do not rely on decomposition as their main principle.

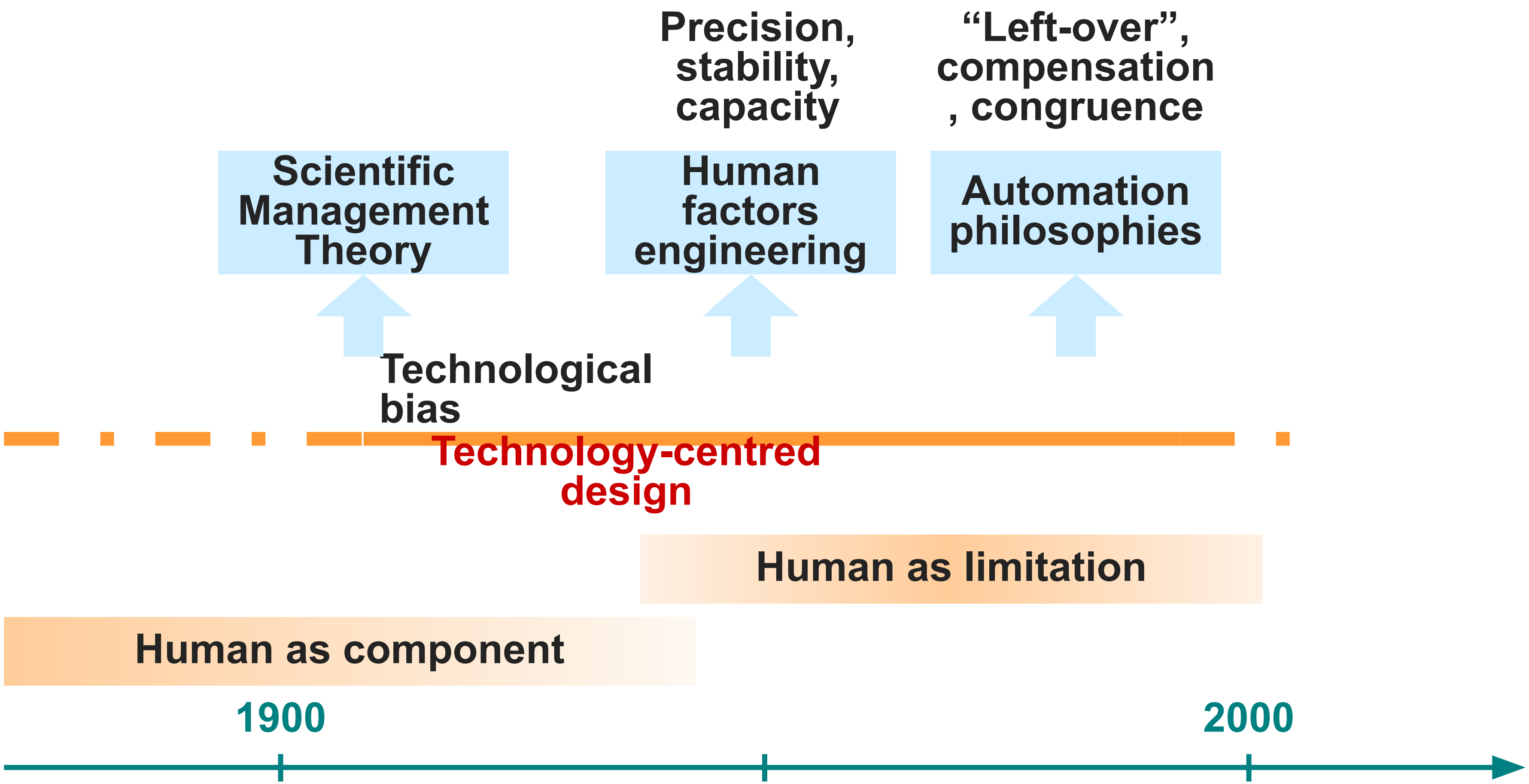
Human-machine interaction – and CSE – are less relevant today than 25-30 years ago. System design instead requires a perspective that emphasises the intrinsic ability of joint systems and organisations to adjust their functioning prior to, during, or following changes and disturbances, so that they can sustain required operations under both expected and unexpected conditions (= resilience).

If the goal is higher levels of automation, it will lead to more sophisticated ‘pockets’ that assume the substitutability myth.

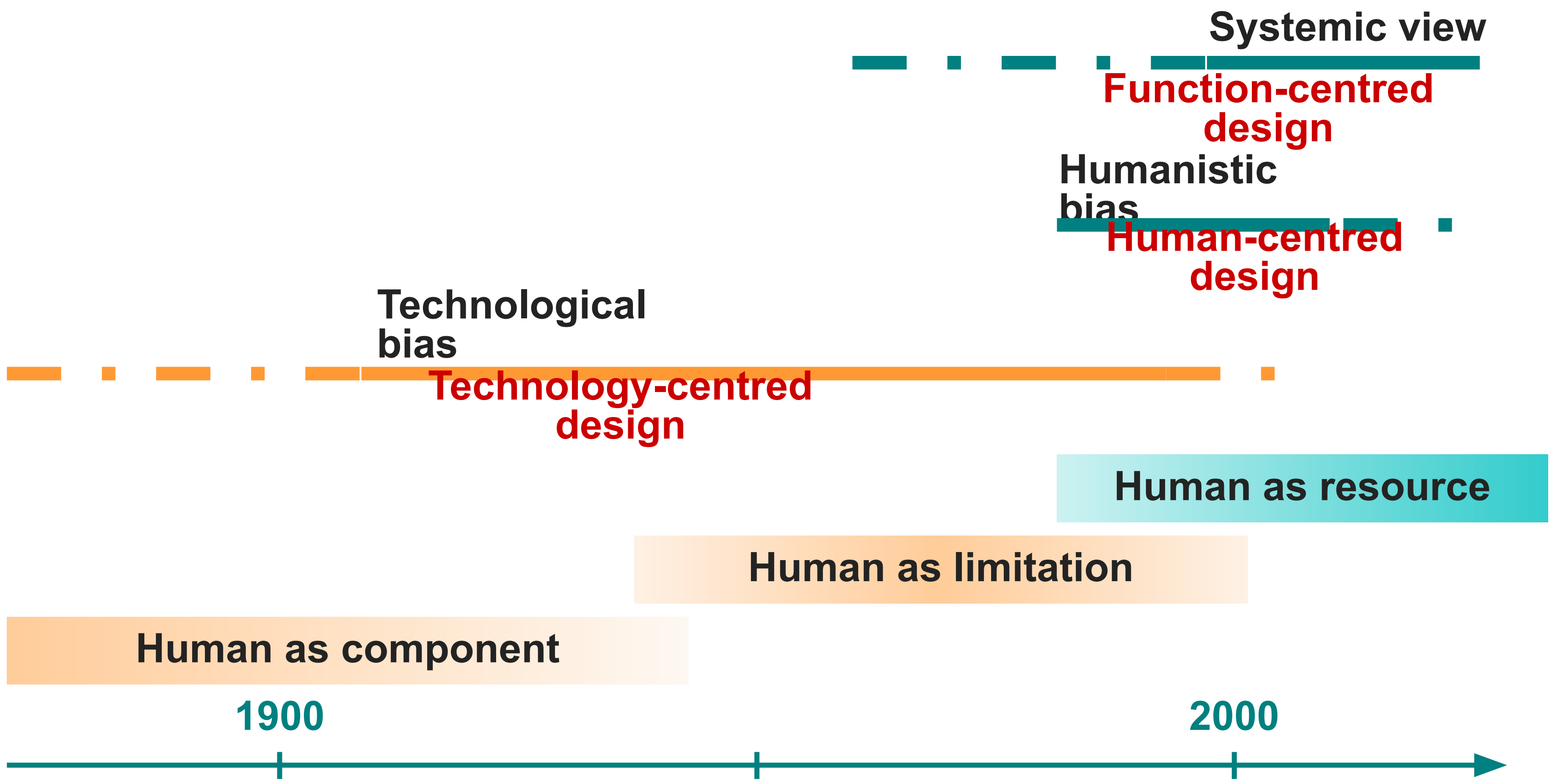
If the goal is more extensive automation, it will by itself makes systems more intractable, hence invalidate the very basis for automation.

The modern irony is that we want automation for situations that we cannot describe.

Technology-centred design



Thinking about humans and systems …



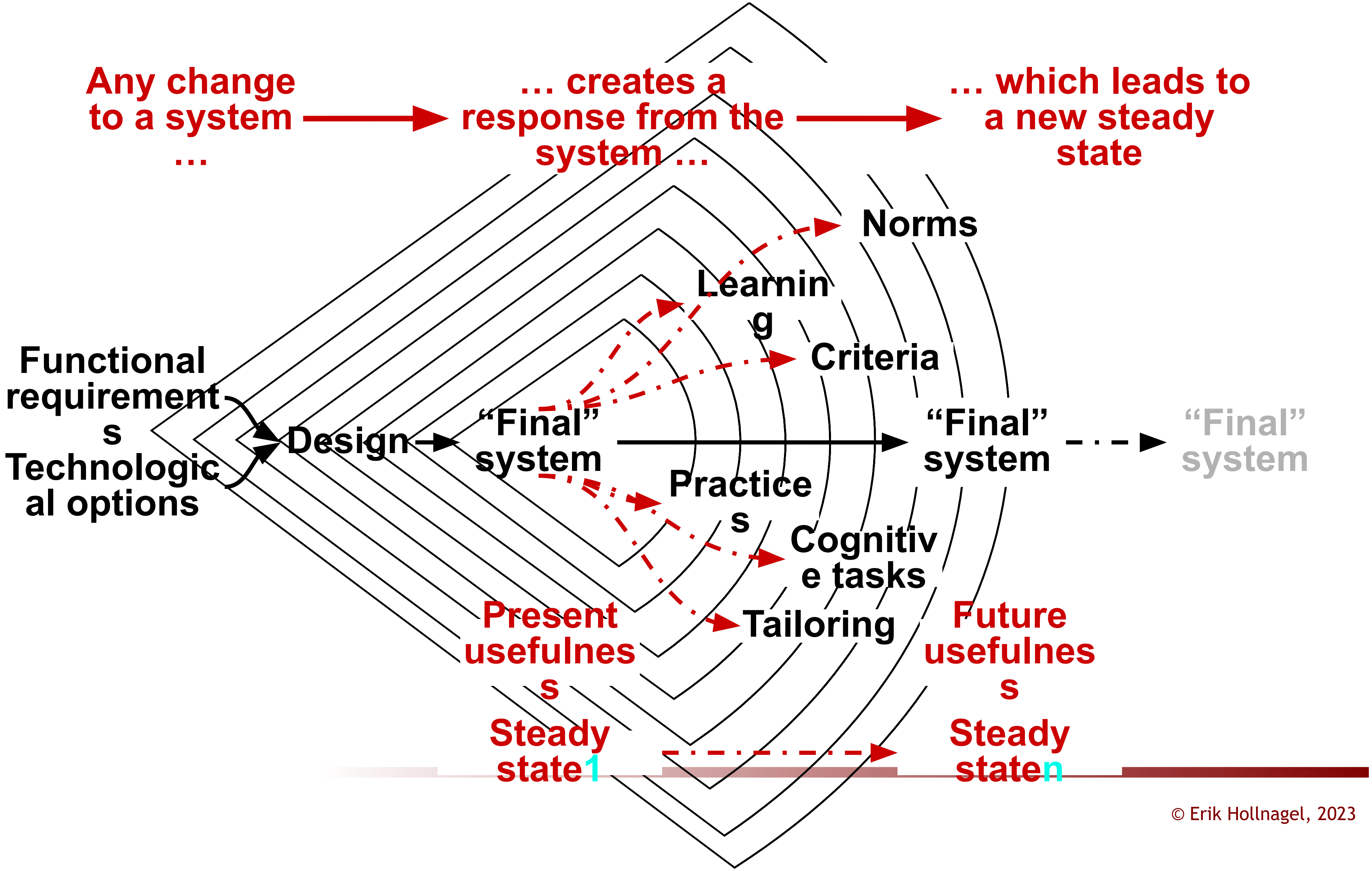
Cognitive task design

- Every change to a system – human, technology, organisation – leads to a change in tasks.
  - Design is traditionally concerned about intended changes …
  - … but should also be concerned about unintended changes.
- Examples:
  - New photocopier.
  - Automated braking in cars (safety distance).
  - Collission detection systems in ATC.
  - Mobile phones … … …
  - Fax – email.
- Homeostasis – systems respond to a disturbance / change by re-establishing equilibrium or finding a new equlibrium.

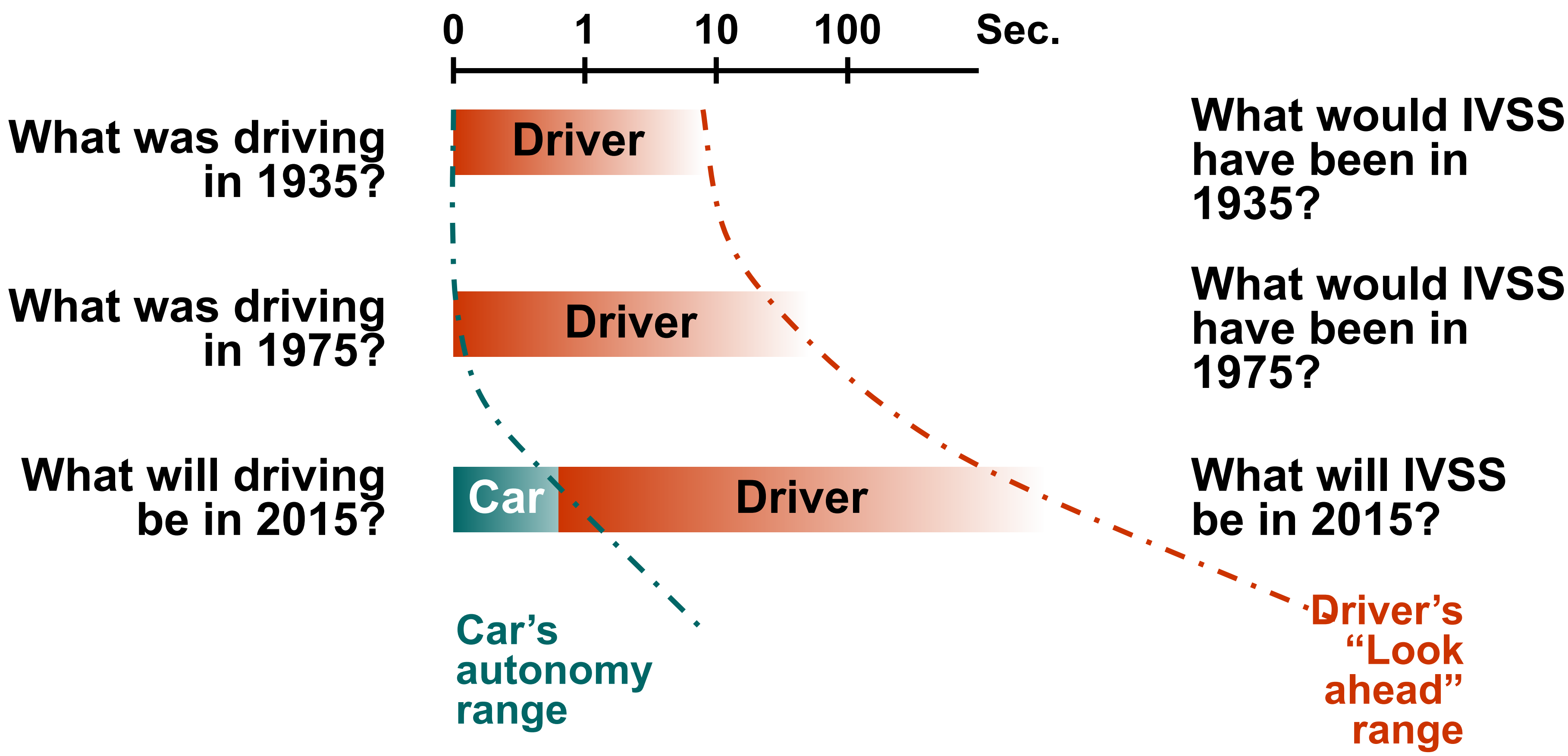
Cognitive task design

- Every designed artefact has consequences for how it is used.
  - Technological: gadgets, devices, machines, complex processes
  - Social: rules, procedures, social structures and organisations
- The consequences are seen in the direct interaction as well as in how the interaction is planned and organised
  - Introducing a new “tool” affects how work is done AND how it is conceived of and organised. This may lead to unforeseen changes with either manifest or latent effects.
- Design is focused on direct interaction (HCI / HMI).
- CTD is focused on the consequences that artefacts have for how they are used.

Cognitive task design



• Changes in nature of driving



An Irony of human factors?

Human Factors has from the very beginning tried to neutralise or eliminate the human as a source of "error", and variability

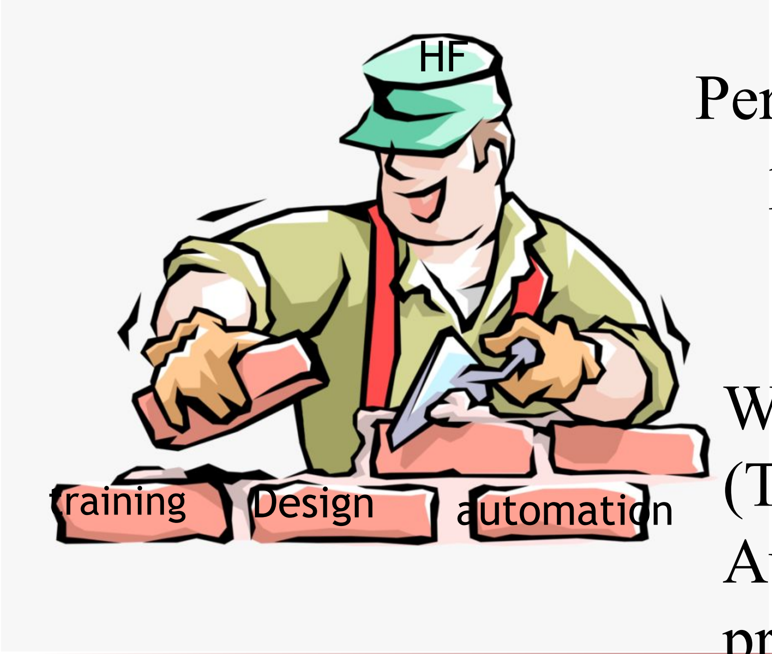
Mainly by training, design, and automation,cf. Fitts'List

The irony is that we now begin to understand that human performance variability is necessary and unavoidable because there will always be a WAI – WAD discrepancy!

Final Question?

Is the human factor an **asset** or a liability?

Performance variability is essential at both at the sharp end and the blunt end!

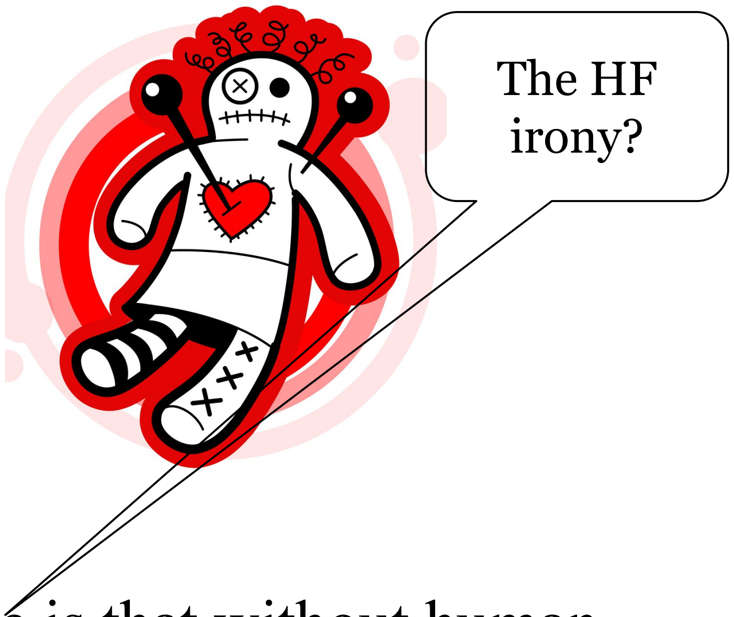


Performance variability is the putty that fills out the gaps between WAI and WAD!

Without that no HF solutions (Training, Design, & Automation) would work in practice

The revenge of the HF

The human factor used to be maligned and looked at as a **liability**



The revenge is that without human performance variability no system would be able to work. **The human factor is an asset!**