

**Programme of advanced academic doctoral
training – academic year 2021 / 2022**

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Ethics and Academic Integrity in the Scientific Research and Dissemination of the Results

**Lectures based on the courses elaborated by
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Lecture 2

Lecture topics

Scientific research in engineering. A systemic approach.

1. Fundamental concepts: system and systemic approach
2. Technological systems
3. The systemic approach in scientific research
4. Inductive approaches, deductive approaches

1. Fundamental concepts

System – a set of real or abstract elements or entities which, due to the features of its component elements and entities and of the relation among them, is viewed or occurs in relation to the environment as a well-defined whole, with a specific purpose. Generally, the purpose of the system is to perform a certain function.

The set of objects and the relations among them form **the system structure**. It expresses the connection with the surrounding environment and allows for the expression of the function and its holistic nature. The structure confers identity to the system.

Fundamental concepts

FUNCTIONALITY = characteristic of being functional, the quality of being suited to serve a purpose well; practicality.

The functionality of a technological system shows that the system is capable of performing its function, under well-defined conditions, i.e. outputs coordinated with assumed objectives.

Systemic approach – a method of reasoning and analysis of a set, considered as a system with well-defined resources, considering, on the one hand, the relations among the objects of the system in time and space, and on the other hand, the analysis of each object in the system.

Model of a definite system - a physical or abstract system (logico-mathematical), similar to a given definite (original) system, by means of which the features and behaviour of the original system can be indirectly studied and foreseen.

Fundamental concepts

The interaction of the system with the environment (integration of the system into the natural, technical, economic, social, etc. environment) is achieved by :

- **INPUTS u** (influence factors, e.g.: command actions, resources)
- **OUTPUTS y** (response functions, e.g.: products, services, movement)



Causal approach :

- Temporal variation of inputs ($u(t)$) and the initial imbalances of the system are considered *cause* ;
- Temporal variation of outputs ($y(t)$) shows the response of the system to the cause and are considered *effect*.

2. Technological systems

In principle -

- systems able to transform a given **input set** (resources) into a definite **output set** (products)

TECHNOLOGICAL SYSTEM = [MAN + MACHINE] ↔ ENVIRONMENT

Technological systems are the main object of scientific research in engineering.

Man – biological being – spiritual and social, defined by the ability of designing and making ‘tools’ and of transforming, by their means, surrounding reality and, implicitly, themselves.

(Is man a system, too?)

Technological systems

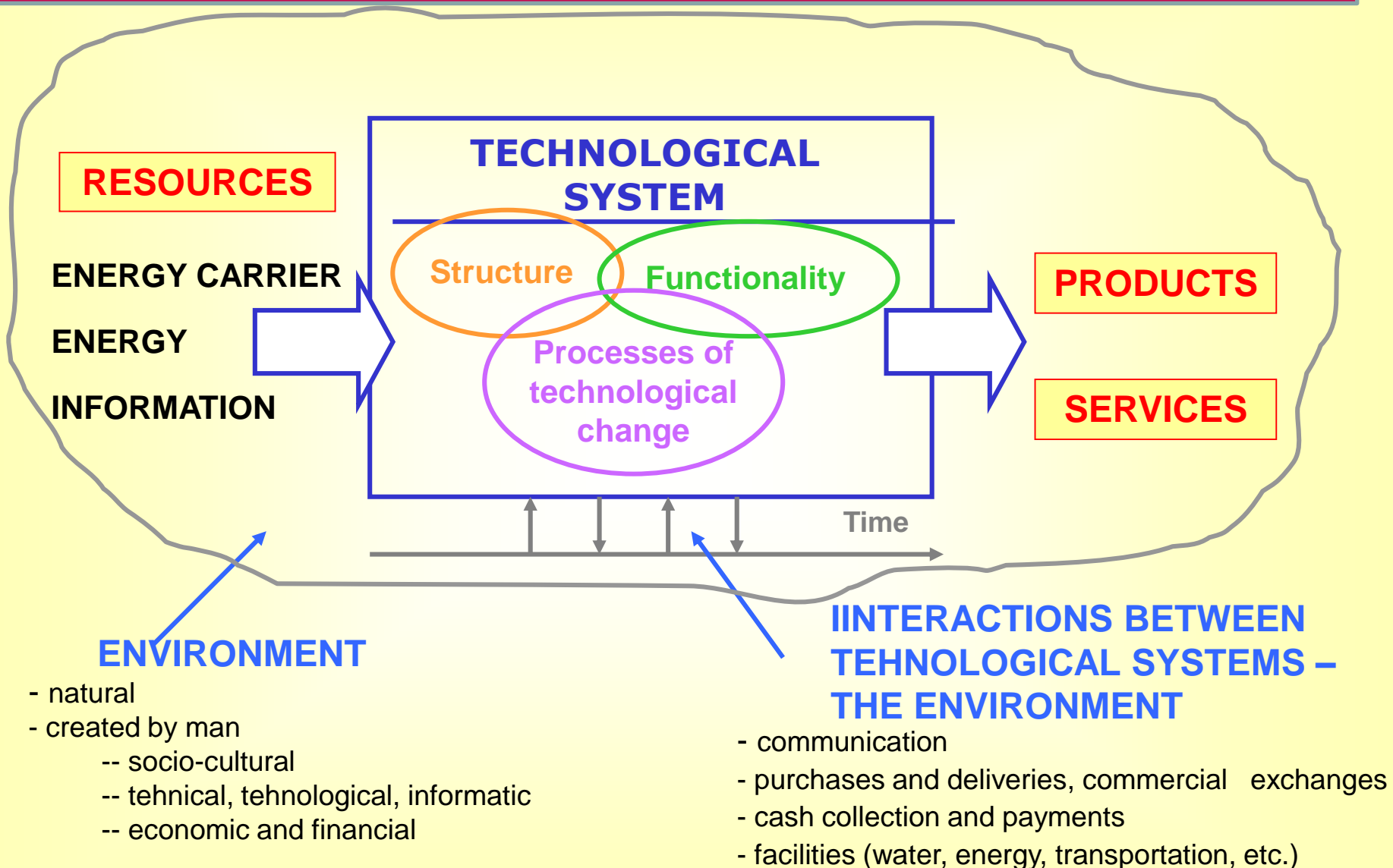
Machine – tools, devices, constructive structures, machines, apparatuses, machinery and apparatus systems, computers, etc.

Environment – physical environment (objects, phenomena and processes existing in nature, or created by man) and social environment (set of interpersonal relations established during action)

Human action within the context of technological systems - conscious and systematic action of changing the relations between man and the environment

- conceived according to certain definite objectives specific to science, technology and knowledge
- carried out through work and supported by a creative spirit, reasoning, language, culture and affection

Technological systems



Technological systems

Production systems – manage computer-controlled energy changes, in order to determine major changes in the energy carrier, proper for producing a body product.

Energy systems – manage computer-controlled changes in primary energy carriers, in order to convert primary energy (chemical, mechanical, nuclear, solar, etc.) into ready to use electrical energy.

Information systems – set of elements involved in an electronic data processing and transmission process (computers, data transmission systems, other hardware, software, processed data, computer technology personnel, basic theories for processing algorithms, etc.), based on accurately controlled, fine changes in energy and carriers.

Competitiveness of technological systems (features)

- **Quality** (conformity with the designed product/service) and **reliability** ('ongoing functionality' under well-defined conditions)
- **Physical and chemical efficiency, technological capability and level automation** of carrier, energy and information transformation processes
- **Economic and financial profitability** of products and services on the market
- **Environment protection**, the guarantee of sustainable development, in harmony with nature.

Competitiveness = the quality of being as good as or better than others of a comparable nature; the characteristic of being competitive (ability of facing competition) in a given competitive environment, by high performance and the ability of being successful at least as much as the others.

3. The systemic approach in scientific research

A. Research project topics - Compulsory requirements

- to have as a starting point the necessity of solving certain real, important and current scientific and/or technical problems
- to allow a causal approach
- to be found in priority research-development-innovation strategies, promoted both nationally and internationally
- to be sufficiently complex, exhaustive and innovative
- to benefit from sufficient financial, material and human guarantees for approaching and achieving it
- to offer sufficient room for further research and a wide area of applicability and profitability (v. SNCDI)

➤ SNCDI 2014-2020: http://www.fonduri-structurale.ro/Document_Files//Stiri/00015839/xqwkk_strategia-cdi-2020_-_proiect-hg.pdf

➤ SNpC 2014-2020: http://www.minind.ro/PROPUNERI_LEGISLATIVE/2014/SNC_2014_2020.pdf

B. Sources of information in order to establish the topic

- **experience - one's own**, personal experience or research team experience – preferential option for researchers deeply anchored in the national and international scientific, technical and economic reality
- **specialised literature**, compulsory in order to be up-to-date with significant developments and trends in science and technology, and to increase progress-making ideas, theories and technologies
- **relevant theories** – already existing or that are to be verified or/and or generalized – preferential option for theoretical researchers, involved in the elaboration of new mathematical theories and models

The systemic approach in scientific research

C. Types of objectives in scientific research

Description

Understanding

Modelling

Prediction

Management

The systemic approach in scientific research

- getting new relevant data, information and knowledge relevant to the structure and functionality of the object of research
- highlighting the physical and chemical phenomena and the transformation processes induced by the action of the influence factors on the behaviour and development of the investigated object
- analytical, empirical and/or numerical mathematical modelling of the interdependencies specific to the system under investigation

The systemic approach in scientific research

- simulation and prediction of the specific state and development of a system
- optimization of the functioning of the research object against a given set of criteria and restrictions
- real-time management of the object of research
- assurance of the compatibility of the research object with the effects it may have on the natural and social environment

The systemic approach in scientific research

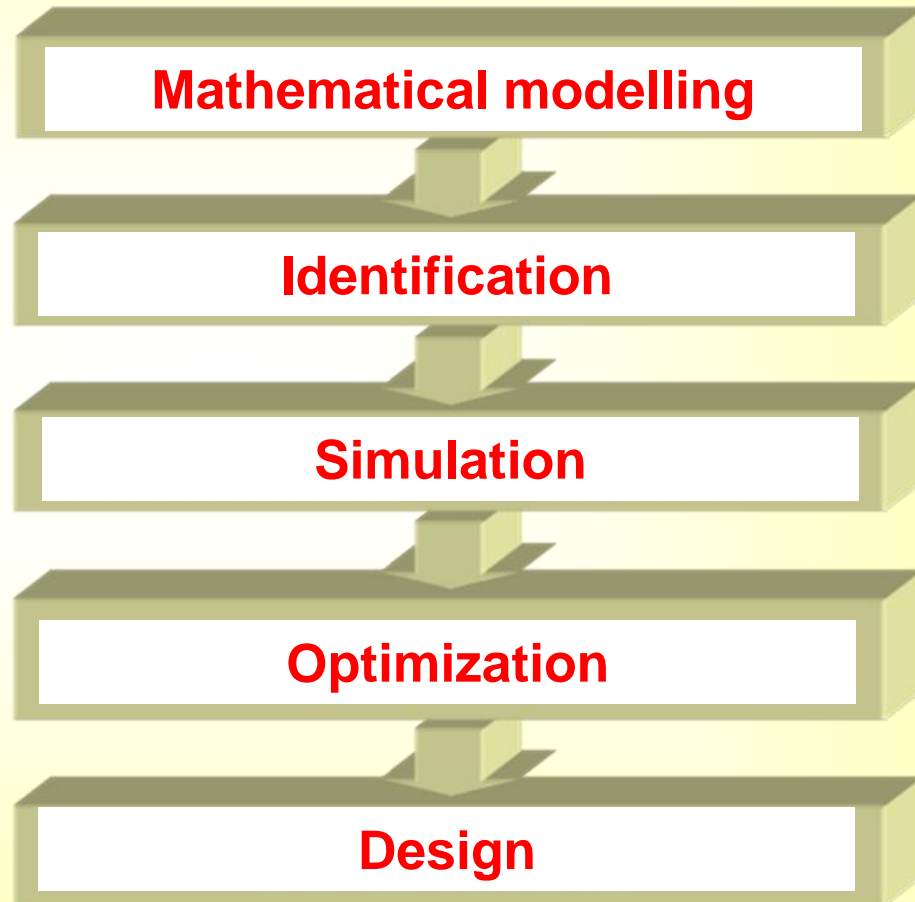
D. Example of strategy in scientific research in engineering

T: **Strategy**

(figurative)

= the art of using all available means to ensure success in an activity;

= a plan of action or policy designed to achieve a major or overall aim



The systemic approach in scientific research

Mathematical modelling – description of a real system/process by means of a mathematical model that shows the interdependencies (mathematical, logical or symbolic) specific to the behaviour of a system / process; whenever possible, it is associated with intuitive graphic representations.

Identification – determination of the parameters of a system/process model, in particular, of the parameters of the mathematical model, by using data and information related to its behaviour, in case we do not have sufficient and valid *a priori* information about its structure / functioning.

The systemic approach in scientific research

Types of models:

- From a structural perspective: Input – output models
Input – state – output models
- From a dynamic perspective: Inertial models
Non-inertial models

Origin of used models:

- ❖ Models acquired through one's own investigations
- ❖ Existing models found in scientific publications

Modelling and identification techniques:

- based on conceptual models of the research object
- based on specific experiments carried out on the object of research, figured as proper for the function performed
- hybrid

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The conceptual model

Conceptual modelling is defined as the activity of formal description of certain physical and social aspects of the surrounding world with the purpose of understanding them and of communication.

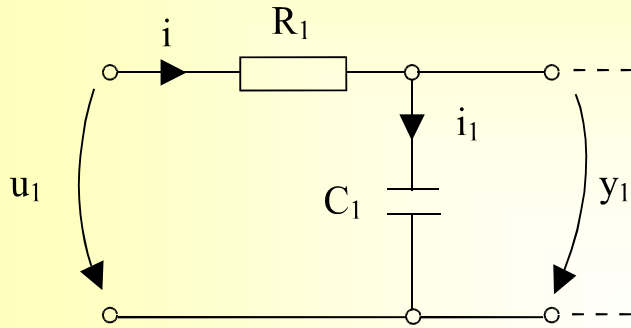
The primary object of the **conceptual model** is the transmission of the fundamental principle and function realized by the system the model is associated to. **The conceptual model** should facilitate the interpretation of the system.

A conceptual model implemented correctly should meet 4 fundamental objectives:

- to increase individual understanding of the system
- to facilitate the transmission of system-related details to interested parties
- to offer system designers a referential in order to get system specifications
- to document the system in order to formulate future reference points and to become a means of collaboration

The systemic approach in scientific research

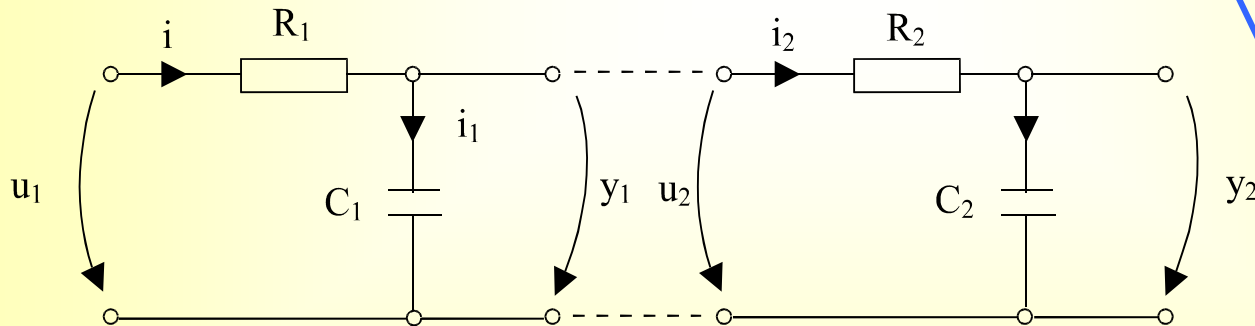
Example. Both systems have the same input-output orientation: $u_1 \rightarrow y_1$



$$R_1 C_1 \cdot \dot{y}_1(t) + y_1(t) = u_1(t)$$

Conceptual model

Corresponding mathematical model



$$R_1 C_1 R_2 C_2 \ddot{y}_1(t) + R_1 C_1 \left(1 + \frac{C_2}{C_1} + \frac{R_2 C_2}{R_1 C_1} \right) \dot{y}_1(t) + y_1(t) = R_2 C_2 \dot{u}_1(t) + u_1(t)$$

The systemic approach in scientific research

Black-box – general term for a system/process, viewed only from the point of view of inputs, outputs and function performed, considered, be the case, as a transfer feature from the input to the output, irrespective of the actual structure and phenomena within the system/process;

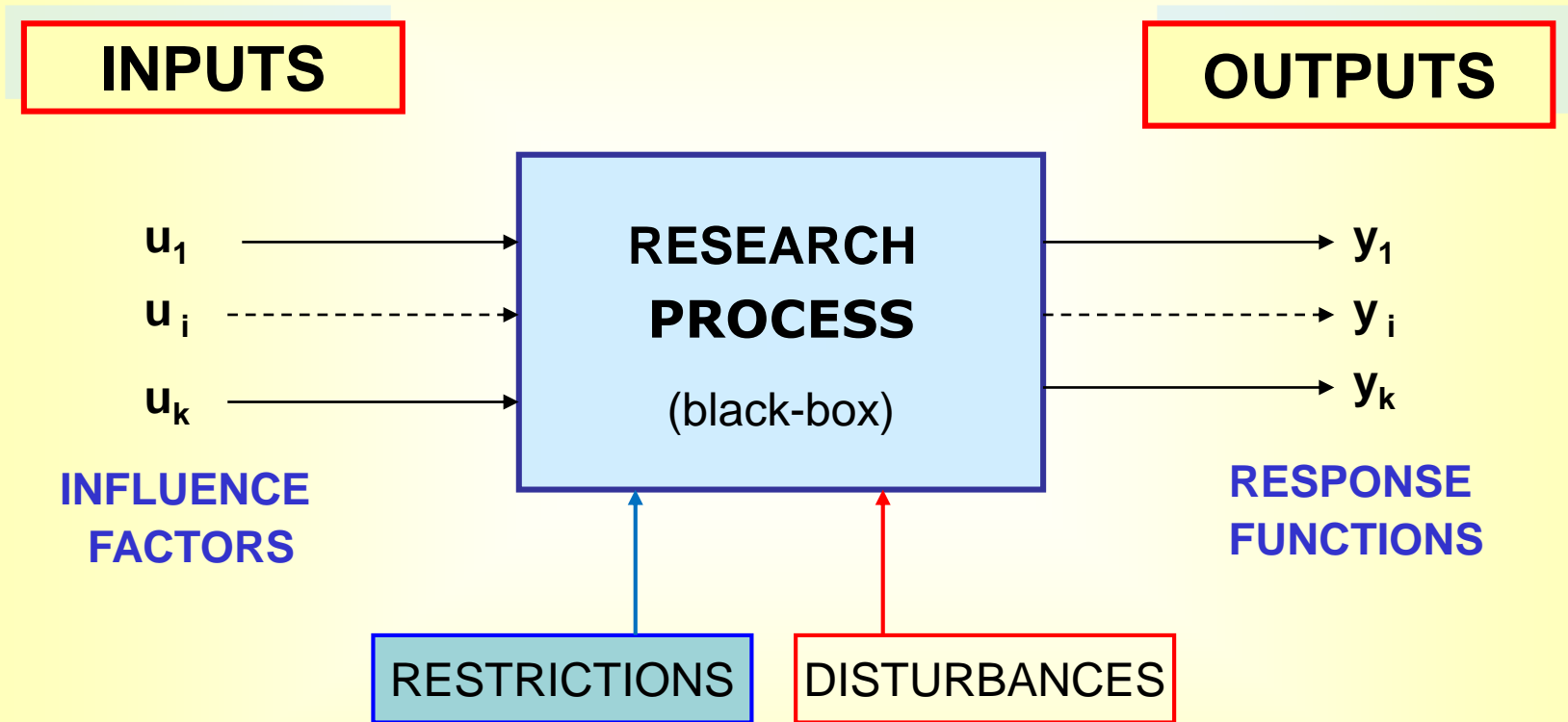
Simulation – virtual experiment on a mathematical model (usually, a numerical one) proper to an actual system / process with a view to studying behavioural features of the system /process;

Optimization – determining and establishing the most favourable ratio between the outputs and inputs of a system/process, under given conditions and according to a given criterion;

Design – designing and developing new or improved constructive-technical components and systems.

The systemic approach in scientific research

E. The input - output research model



The systemic approach in scientific research

Influence factors – (independent variables) – methods and means of controlled influence on the behaviour and development of the research object, viewed as a system, according to the objectives aimed;

Research process – integrates the investigated system (a real technological system or a physical model corresponding to the system, *in extremis* a mathematical model) with a set of running /testing and measurement means necessary to assess the state, behaviour and development (in time) of the system / process in question;

Response functions – (dependent variables) – evaluate, quantitatively and qualitatively, under given conditions, the research process by means of the behaviour, states and development trends of the analysed system / process.

The systemic approach in scientific research

Restrictions – limitations resulting from the interactions within a system/process, or from its delimitation from the environment

Disturbances - inputs (independent variables) – **influencing**, in an uncontrolled manner, the behaviour and development of the research object, causing deviations from the objectives established

Influence factors:

- exercise a direct, unambiguous influence on the state and behaviour of the object of research
- they are independent of the other factors within the system
- they are compatible with the object of research, as they are fully controllable (quantity can be accurately measured, adjusted and maintained at available levels, depending on the research objectives and requirements, without causing dangerous effects on the object of research (admissible inputs)).

The systemic approach in scientific research

Response functions – variations of certain concrete/abstract sizes, which:

- can characterize, thoroughly and multilaterally, the physical essence, the performance or / and the efficiency of the research object
- have a clear physical significance, as simple as possible, easy to express by mathematical means
- can sometimes be expressed quantitatively, by associating a number (resulted from measurement or from an evaluation process) to each state of the research object
- should be unambiguous in nature (a state of the research object, determined by some set of influence factor levels, corresponds to one and only one value of the response function);

F. Mathematical models

The mathematical model of the system expresses the causality relations characterizing the functioning of the (technological) system investigated.

In a simplified, general form it can be represented as a system of equalities rendering the transfer of input-output data, for example:

$$\begin{array}{lll} y=F(u) & x = f(u) & dx/dt = f(x,u) \\ & y = g(u, x) & y = g(u, x) \end{array}$$

where:

- **u – input variables** (influence factors), capable of altering the system's functioning mode;
- **x – states variables** specific to the system, capable of characterizing the system's development trend
- **y - output variables** given by response functions; they can be:
 - directly dependent on the inputs
 - indirectly dependent, through state variables.

Building an empirical mathematical model – Work stages:

- determination of significant influence factors and of relevant response functions
- design and creation of a programme for specific data acquisition and primary processing (consisting of experiments and processing procedures), and experiment execution
- choosing the form of the mathematical model (usually, linear with variable parameters in time), proper to the relations between dependent and independent system variables
- numerical value estimation for the parameters of the adopted mathematical model, by processing experimental results
- model validation through tests, to evidence the interrelation between the data foreseen by the model and actual data (e.g. statistical validation)

F. Cause-effect graph (qualitative causality graph)

Defining elements:

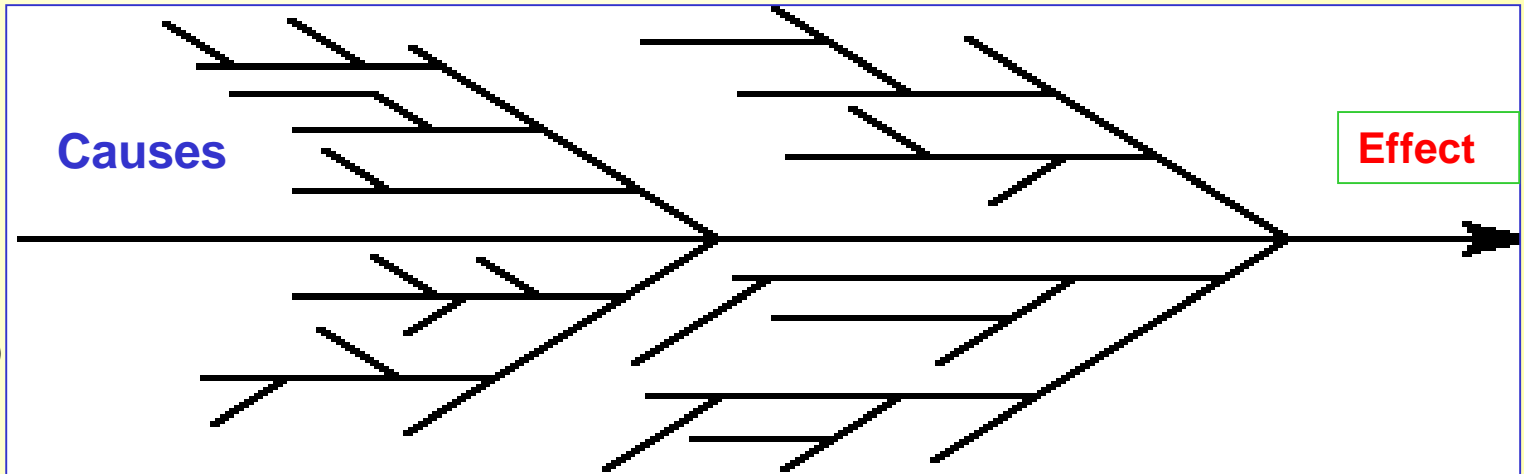
- **Purpose:** inventory, logical structuring and graphic visualization of the set of causes (inputs) potentially influencing / determining an established effect (unique output) ► correct expression of a (research) problem
- **Approach:** usually, in a research team
- **Work stages:**
 - analysis of the research object through brainstorming and determination of all factors, and, within them, of all the causes conditioning the problem/investigated effect
 - hierarchical listing of the factors and causes identified according to criteria of importance and priority, and their representation as a cause – effect graph
 - design and development of an action plan leading to the solution associated to the investigated effect

Cause – effect graph

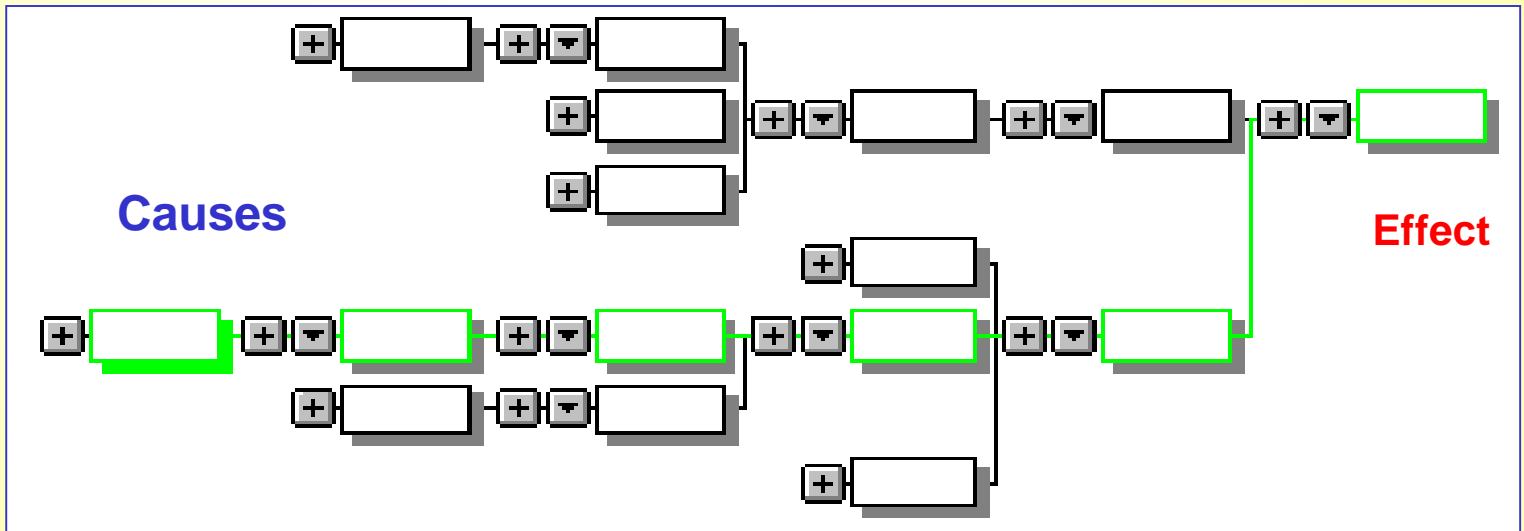
Possible graphic representations:

1. Fishbone

(http://en.wikipedia.org/wiki/Ishikawa_diagram, Ishikawa diagram)

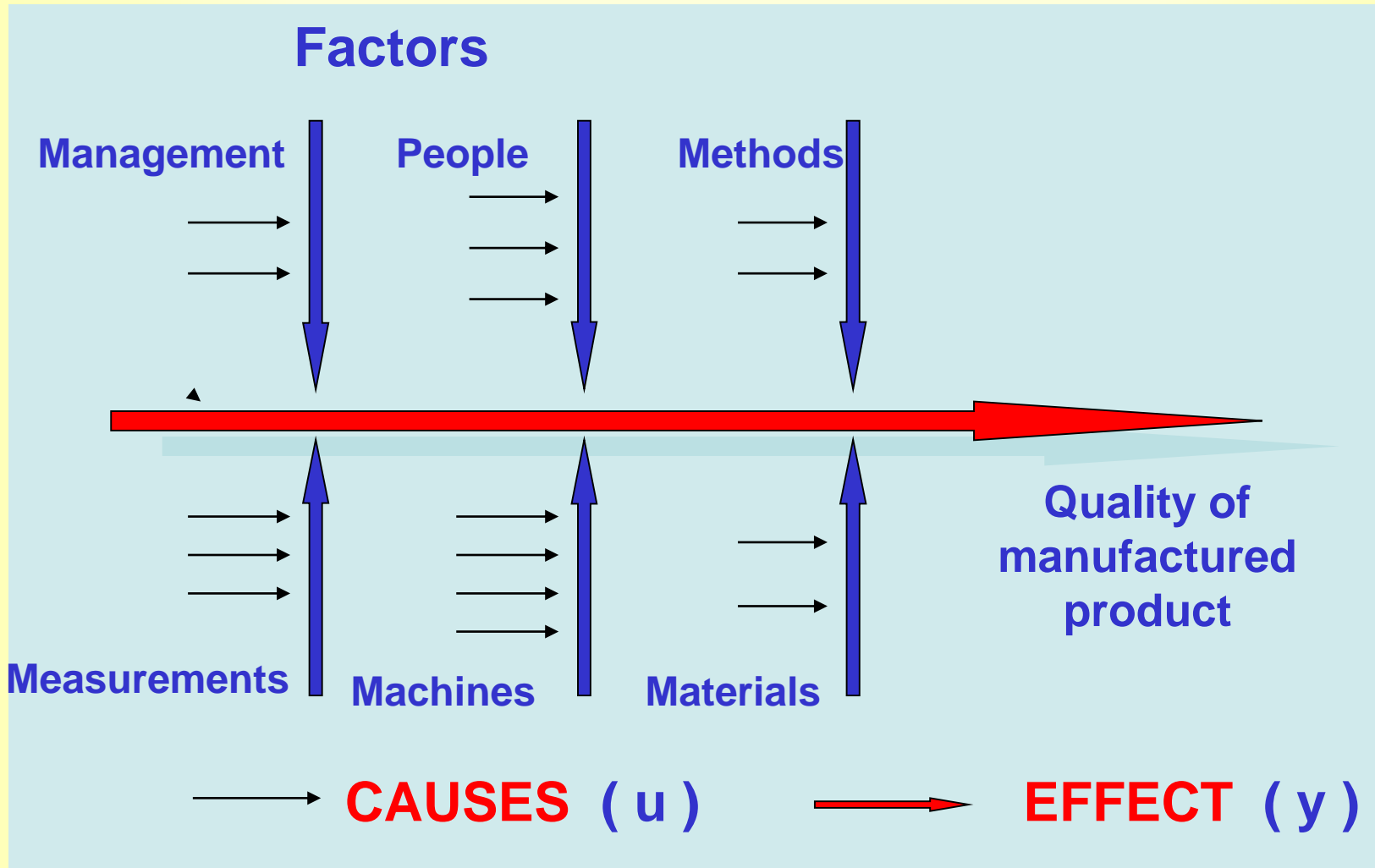


2. Tree diagram



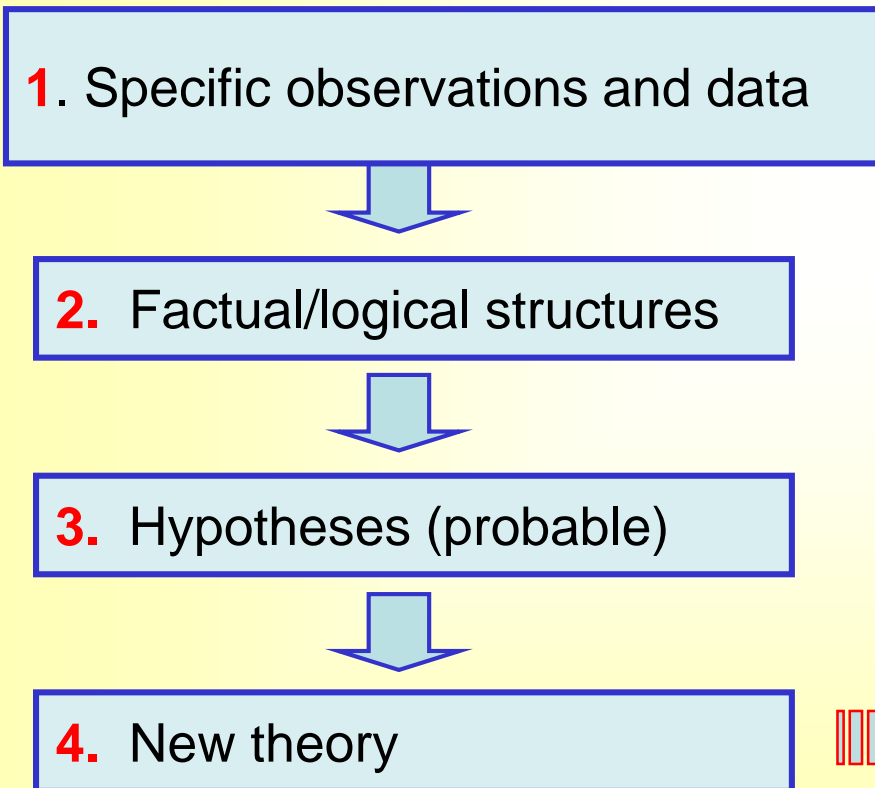
The systemic approach in scientific research

3. Structuring according to the nature of influence factors (example)

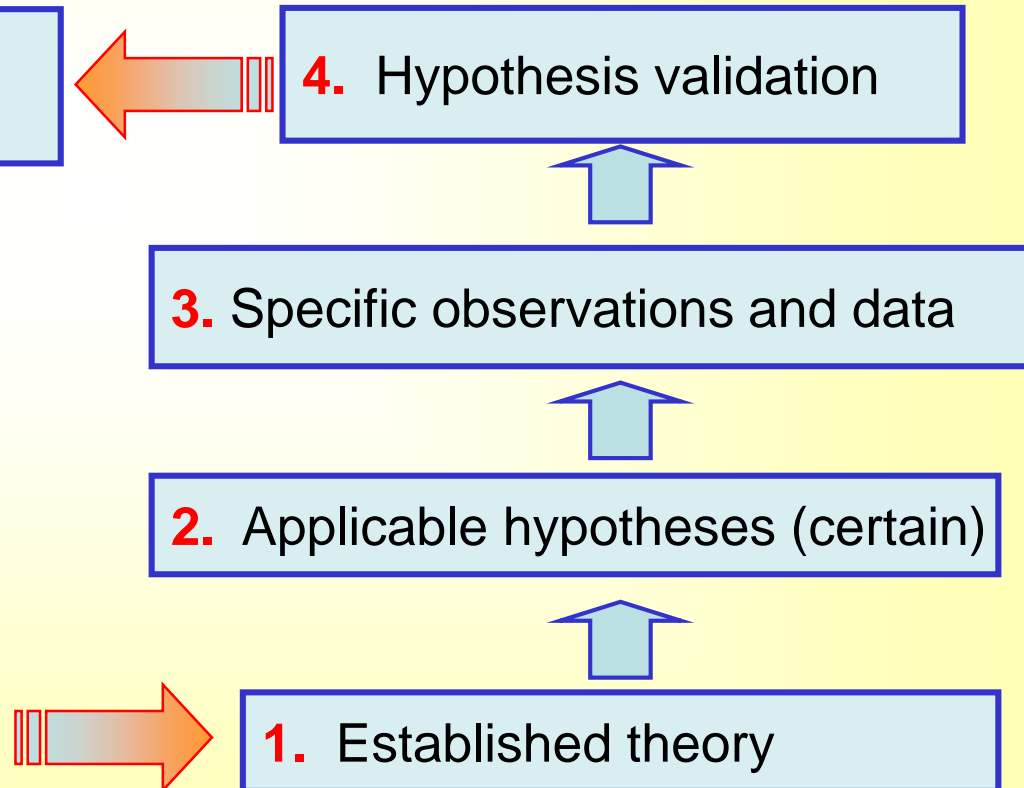


4. Inductive and deductive approaches

Inductive approach



Deductive approach



Inductive approaches, deductive approaches

Inductive approach

- **logical inference:** from singular statements (observations, experiments) to universal statements (hypotheses, theories)
- mainly empirical, resulting from controlled or natural experiments
- mainly applied to physics, chemistry, biology, etc.
- **Weak point: lack of rigour**

Deductive approach

- **logical inference:** from general statements (theories, laws) to specific statements (applications)
- predominantly based on reasoning
- mainly applied to logics and mathematics
- **Weak point: limited applicability of theories**

► In scientific research, inductive and deductive approaches are complementary

Inference – Reasoning activity by which one passes from a statement to another, deductively or inductively, directly (i. immediate) or indirectly (i. mediated).