MCT333/ MCT344: Mechatronic Systems Design Lecture 1: Review & Mechatronic Systems Design Philosophy

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Course Assessment

Assessment Scheme

|		
Mid-term Exam	=	20
Quiz(zes)	=	10
Assignments	=	10
Project Progress	=	20
Project Final Submission/Discussions	=	<u>40</u>
		100

Textbooks

1. S. Cetinkunt, *Mechatronics with Experiments,* John Wiley & Sons, 2015
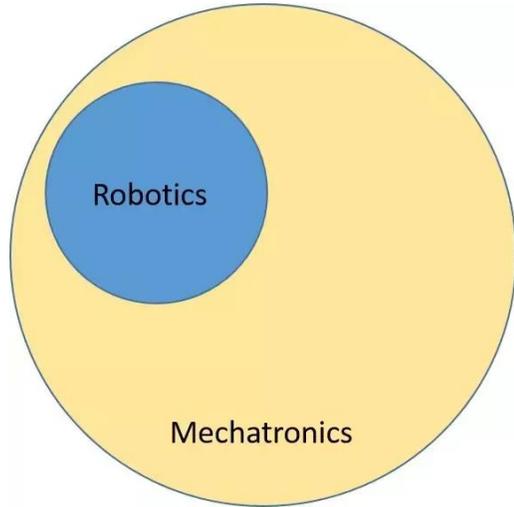2. *VDI 2206:2004-06: Design methodology for mechatronic systems, 2004*

Review

1. Where do you think Mechatronics started
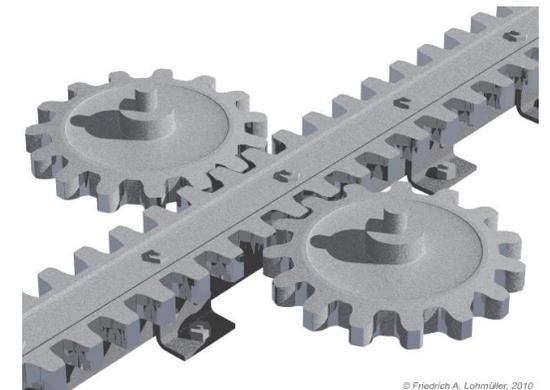2. Why did Mechatronics appear as a field? What problem was it trying to solve?

Yaskawa History
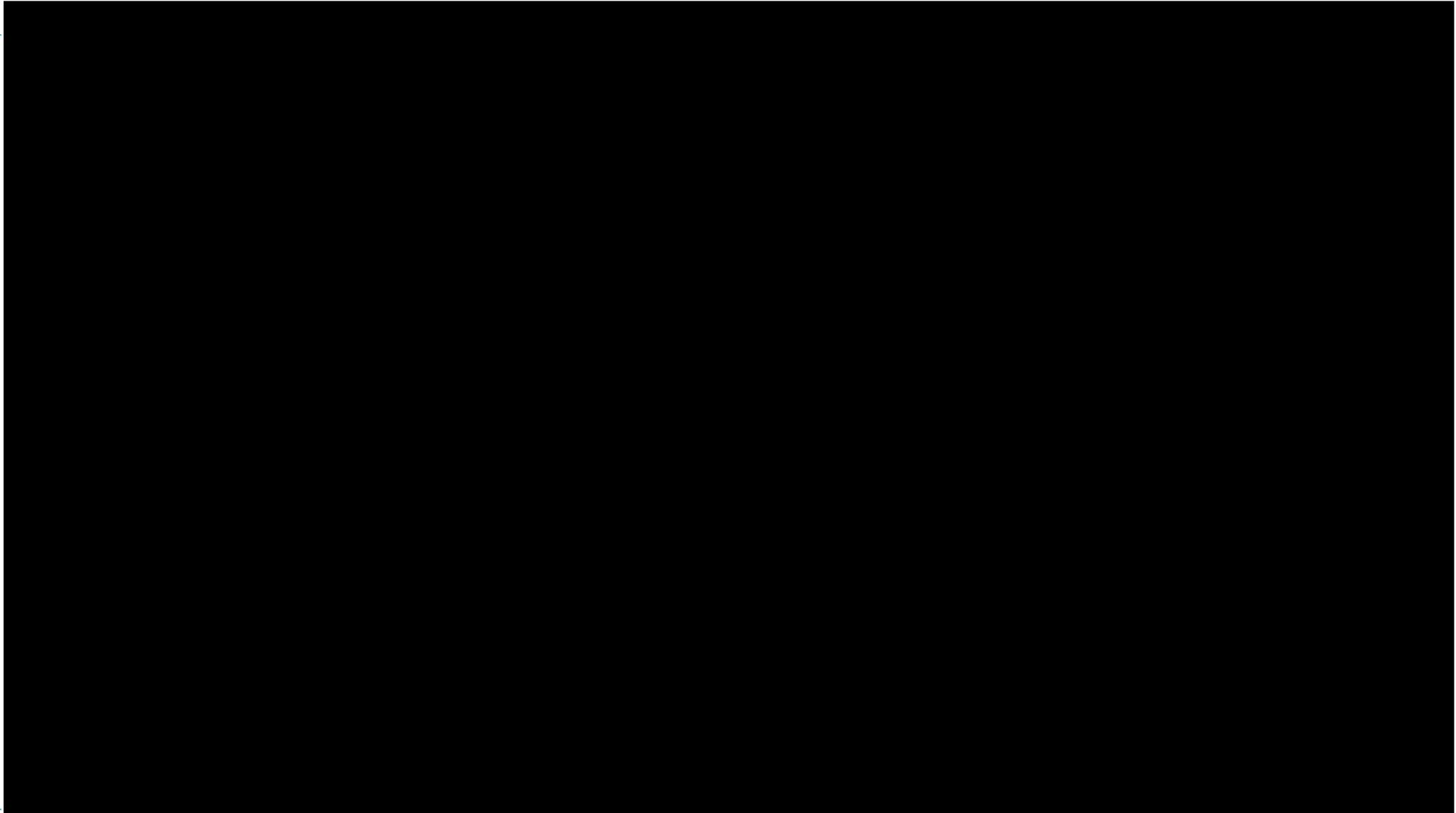
Mechatronics Background

Robotics is a subset of mechatronics – all robots are mechatronic systems.

© Friedrich A. Lohmüller, 2010
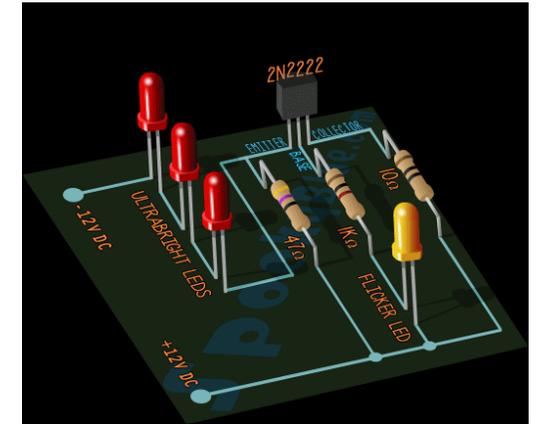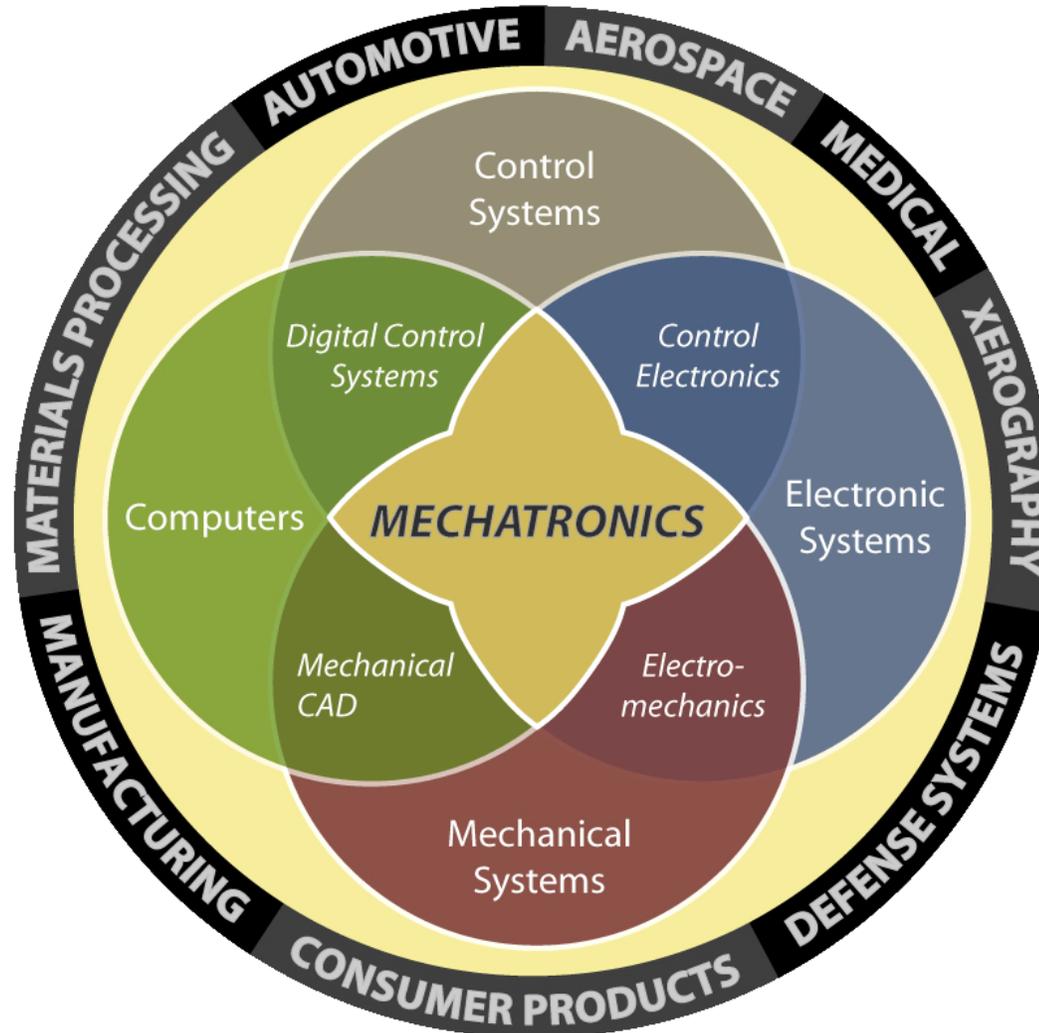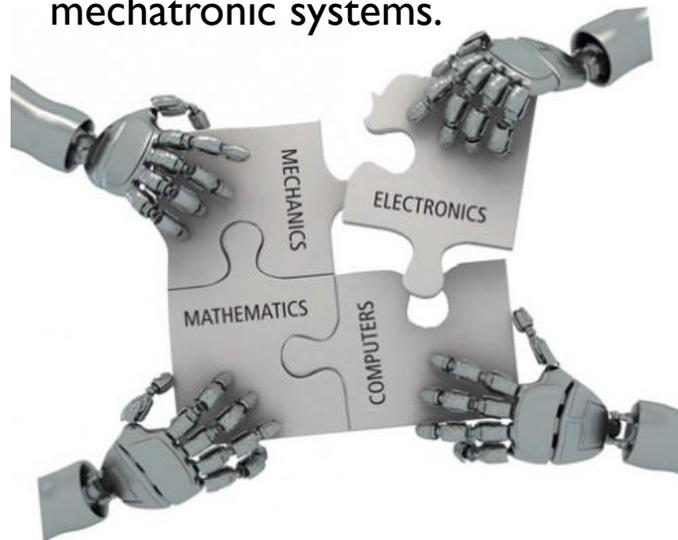
Mechatronics Background

The synergistic combination of mechanical, electrical, and computer engineering.
Emphasis on:
1. integrated design for products
2. Optimal combination of appropriate technologies

Mechatronics Compatibility/incompatibility
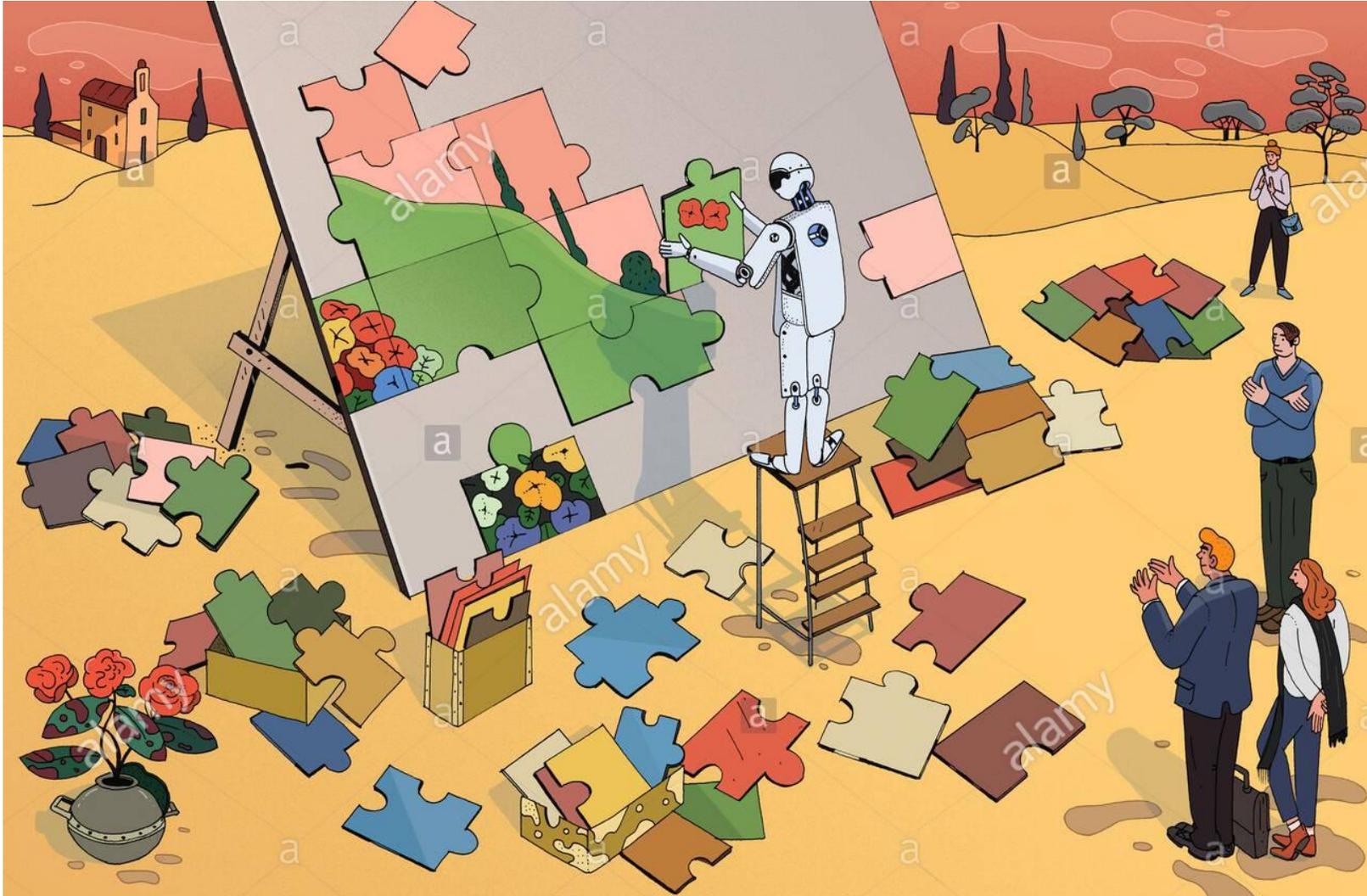
Incompatibility: inability of equipment, computer programs, etc. to be used in combination

Mechatronics Background

Mechatronics Compatibility/incompatibility

Incompatibility: inability of equipment, computer programs, etc. to be used in combination

Plug (can't support 120V, can support 3V)

Adapter

Socket that produces 120V

Adapter that can produce 3 volts, 12 volts and default 120 volts.
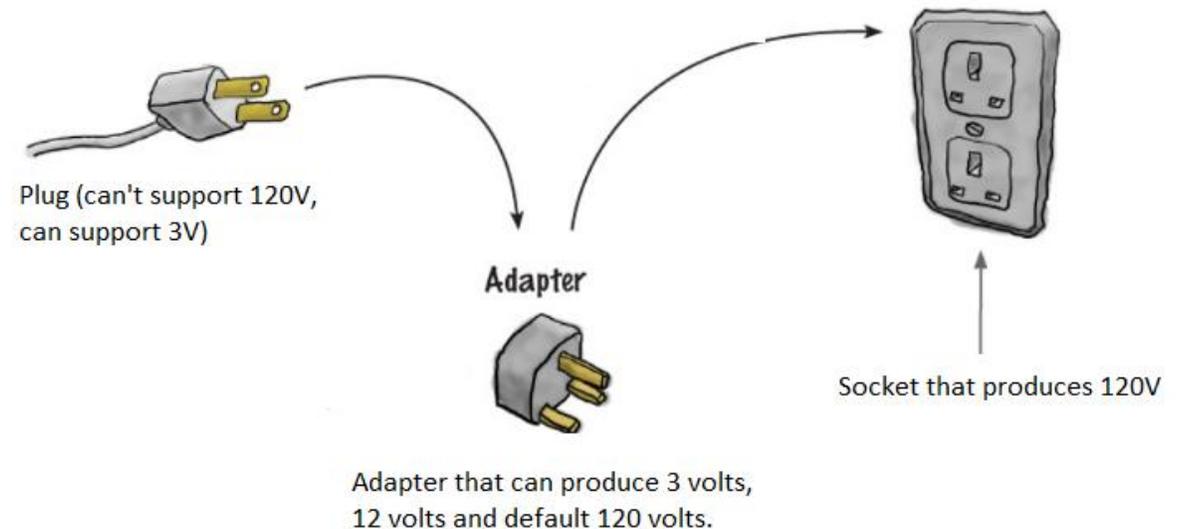
Mechatronics Background

❑ The word has taken a wider meaning since then, and is now widely used as a technical jargon word to describe a **philosophical idea** in engineering technology, more than technology itself.

Mechatronic is multifaced engineering context to enhance engineers' decision making skills and problem solving of engineering problems.
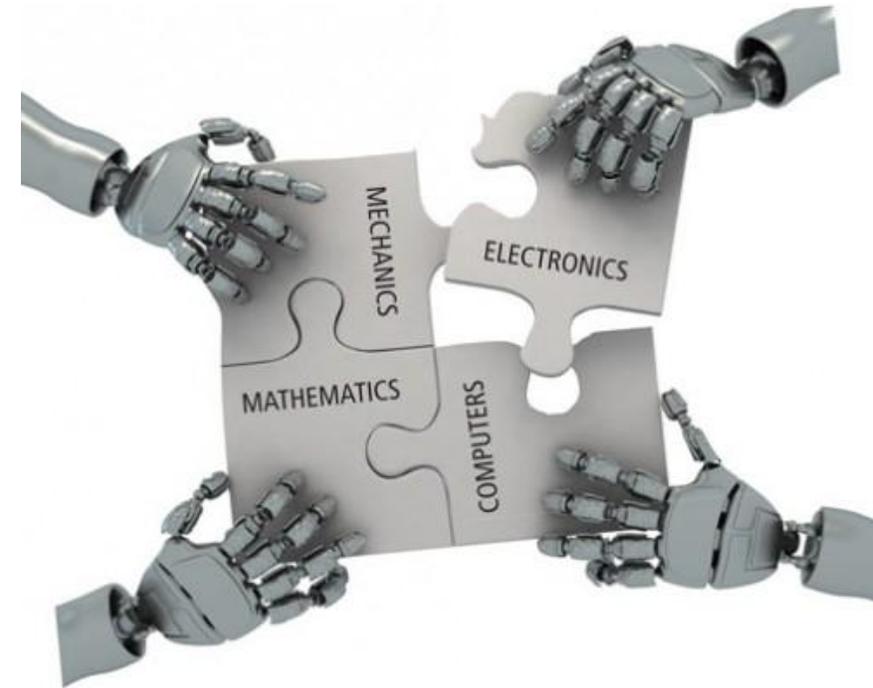
❑ *Mechatronics is a design philosophy*: an integrating approach to engineering design.
❑ *Mechatronics is a methodology used for the optimal design of* inter-disciplinary *products*.
❑ Through a mechanism of simulating interdisciplinary ideas and techniques, mechatronics provides ideal conditions to raise the synergy, thereby providing a catalytic effect for the new solutions to technically complex situations.

Mechatronics System Components

MECHANICAL SYSTEM
- system model
- dynamic response

ACTUATORS
- solenoids, voice coils
- DC motors
- stepper motors
- servo motors
- hydraulics, pneumatics

SENSORS
- switches   - strain gage
- potentiometer - thermocouple
- photoelectrics - accelerometer
- digital encoder - MEMs

INPUT SIGNAL CONDITIONING AND INTERFACING
- discrete circuits   - filters
- amplifiers   - A/D, D/D

DIGITAL CONTROL ARCHITECTURES
- logic circuits   - sequencing and timing
- microcontroller   - logic and arithmetic
- SBC   - control algorithms
- PLC   - communication

OUTPUT SIGNAL CONDITIONING AND INTERFACING
- D/A, D/D   - power transistors
- amplifiers - power op amps
- PWM

GRAPHICAL DISPLAYS
- LEDs   - LCD
- digital displays - CRT

Mechatronic System Design Key Elements
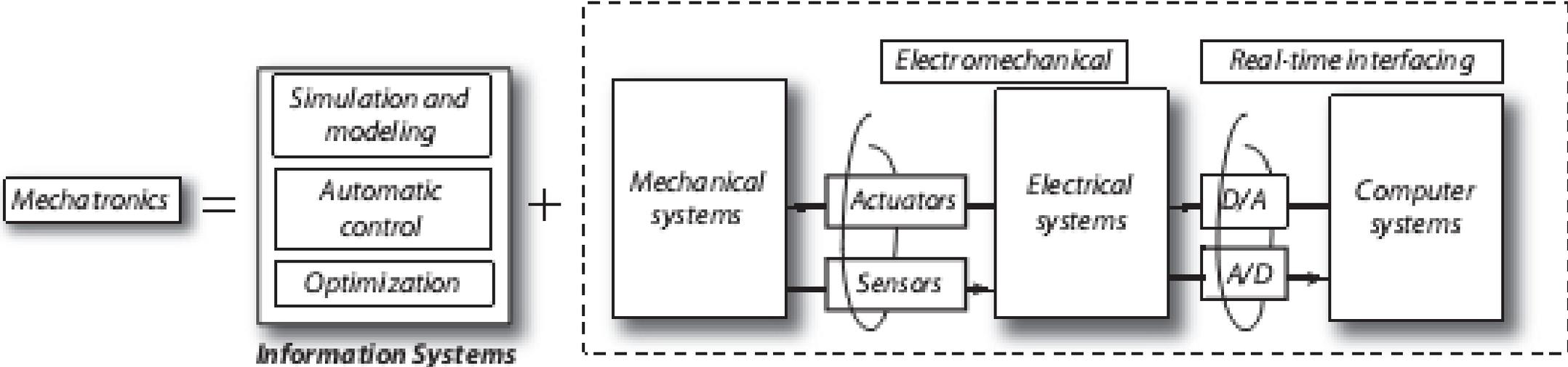
Industry Revolution and Automation

Cyber-Physical Systems (CPS) are integrations of computation, networking, and **physical** processes. Embedded computers and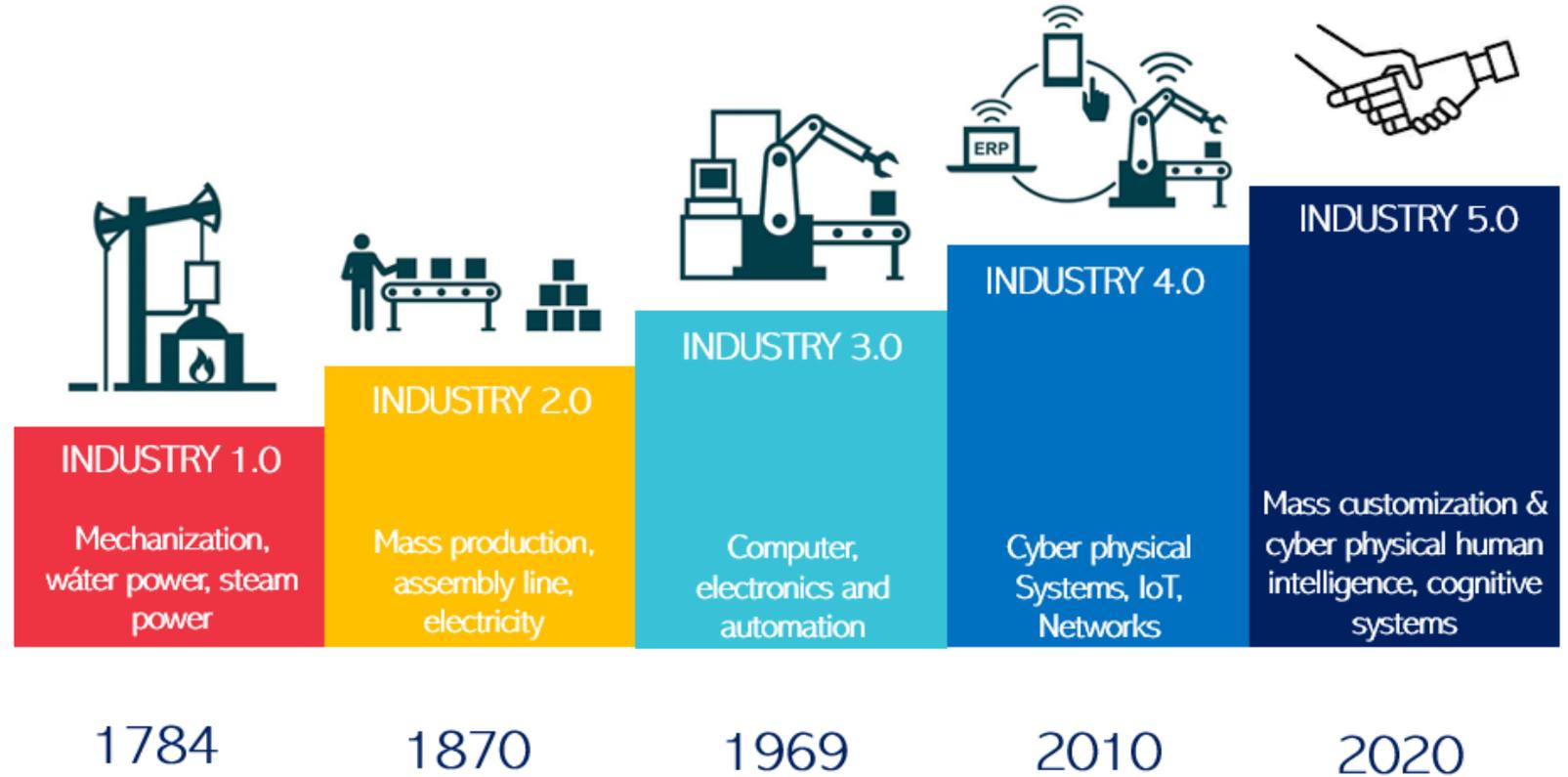 networks monitor and control the **physical** processes, with feedback loops where **physical** processes affect computations and vice versa.

INDUSTRY 1.0
Mechanization, wáter power, steam power

INDUSTRY 2.0
Mass production, assembly line, electricity

INDUSTRY 3.0
Computer, electronics and automation

INDUSTRY 4.0
Cyber physical Systems, IoT, Networks

INDUSTRY 5.0
Mass customization & cyber physical human intelligence, cognitive systems

1784   1870   1969   2010   2020

CPS integrates computation (software, AI algorithms, communication, control) directly with physical components (sensors, actuators, machinery), allowing them to interact seamlessly in real-time.

i³-Mechatronics (Smart Factory)

i³-Mechatronics solution concept Yaskawa combines classical mechatronics, information and communication technology with digital solutions such as artificial intelligence, big data and the Internet of Things. "i3" stands for integrated – intelligent – innovative.

About i³
integrated
Our smart products enable our customers to collect and analyze real-time data. It is open for further data analysis with specialized Big Data analysis and AI learning. Information on predictive maintenance and machine wear can be gathered directly from our components.

intelligent
Big Data analysis and AI learning of collected production site data offer new ways of optimizing the production process at every level.

innovative
Insights gained from the in-depth analysis of the production process are used to trigger improvements and create a better level of production and quality.

i³-Mechatronics
New value with "i cube", digital data solution

i³-Mechatronics (Smart Factory)

The **smart factory** is defined as a **factory** where physical production processes and operations are combined with **digital technology**, **smart computing and big data** to create a more opportunistic system for companies that focus on **manufacturing** and supply chain management.

i³-Mechatronics

Digital Twins

Physical twin
- Objects
- Processes
- Systems

Data Collection

Digital twin
- Representative models
- Data management
- Data analytics

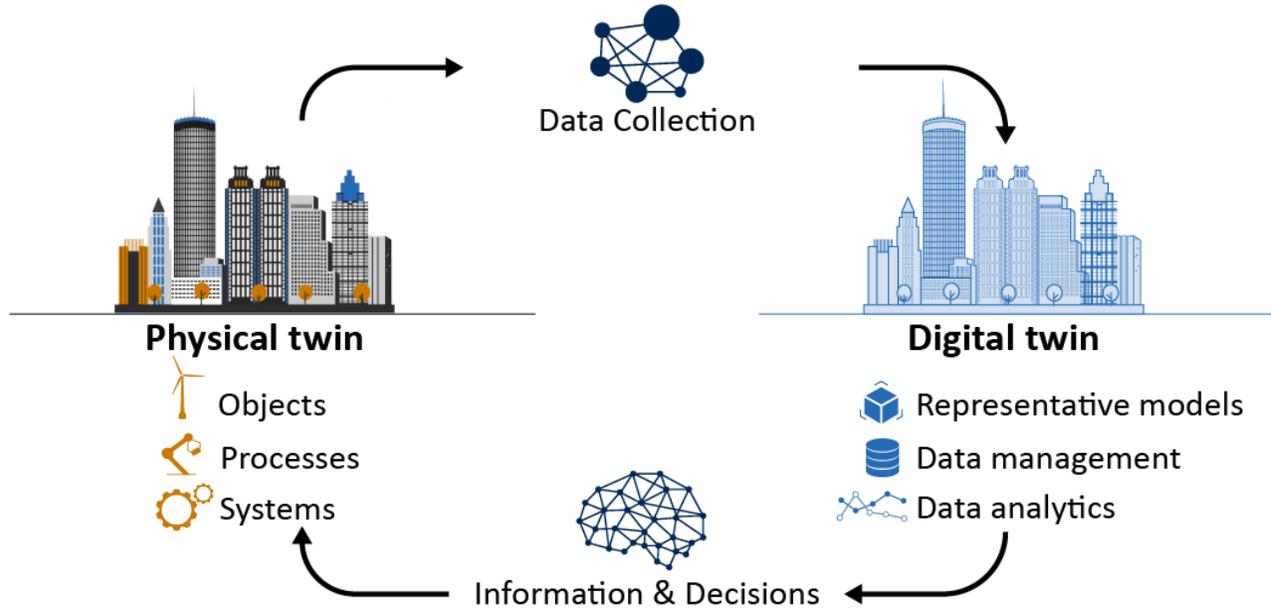Information & Decisions

Digital Twins are virtual representations (simulations) of physical assets or systems, continuously updated with real-time data collected from sensors on the physical counterparts. They provide insights, predictions, and enable testing scenarios without physically affecting the real system.

PHYSICAL ASSET

DATA

INFORMATION

DIGITAL TWIN
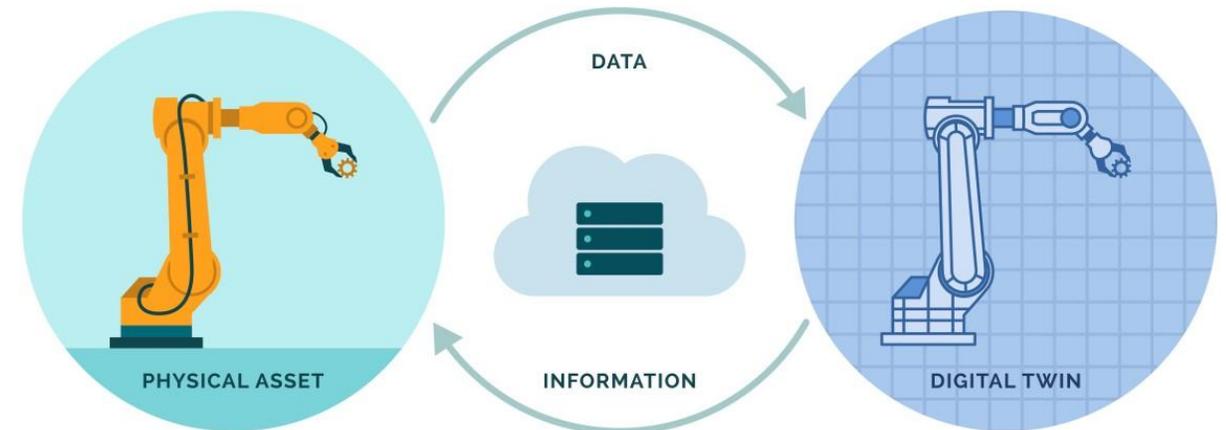
Recommended Videos to Watch

1- What is a Functional Design specifications (FDS)
https://www.youtube.com/watch?v=hV9--cPj_zA

2- How to build successful machines/robotics (Doctor Robocon)
https://www.youtube.com/watch?v=8qs7eBIthyo

3- Inside the lab: How does Atlas work?
https://www.youtube.com/watch?v=EezdinoG4mk

4- Microlecture - How to Engineer a Robotic Dog
https://www.youtube.com/watch?v=6igNZiVtbxU

Tips for Building Successful Machines through Proper Structure Connections and Interfaces

❑ Any machine usually has many limitations for example limitations of: **weight**, **size**, **energy**, etc. So, you have to design and develop a very light, strong, very low friction machine, etc.

❑ There are **five key elements** for efficient machine design:

1. shaft bearings and supports,

2. material and its cross section geometry,

3. machine rigidity,

4. degrees of freedoms and mobility,

5. power, and correct actuator sizing configurations.

How to Engineer a bio-inspired Robot

https://www.youtube.com/watch?v=6igNZiVtbxU
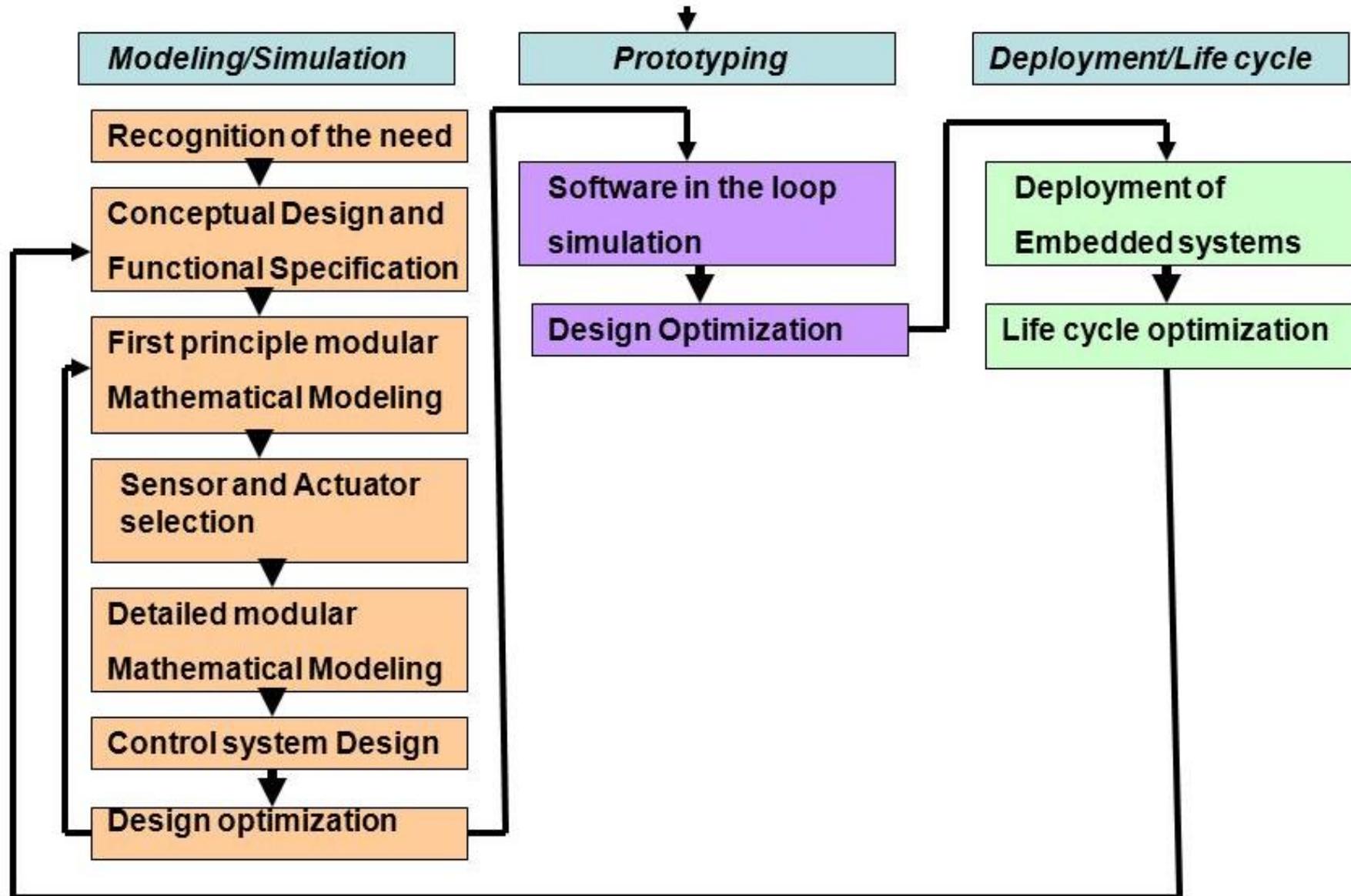
Mechatronic Systems Design Process

Mechatronics Design Process

Example on Identify Problem & Need

- Example

    - Need: Drivers have difficulty seeing obstructions in all directions

    - Objective: design system to avoid accidents

Example Needs Hierarchy

Figure 2.2 Objective tree for a portable audio device to be used by runners.
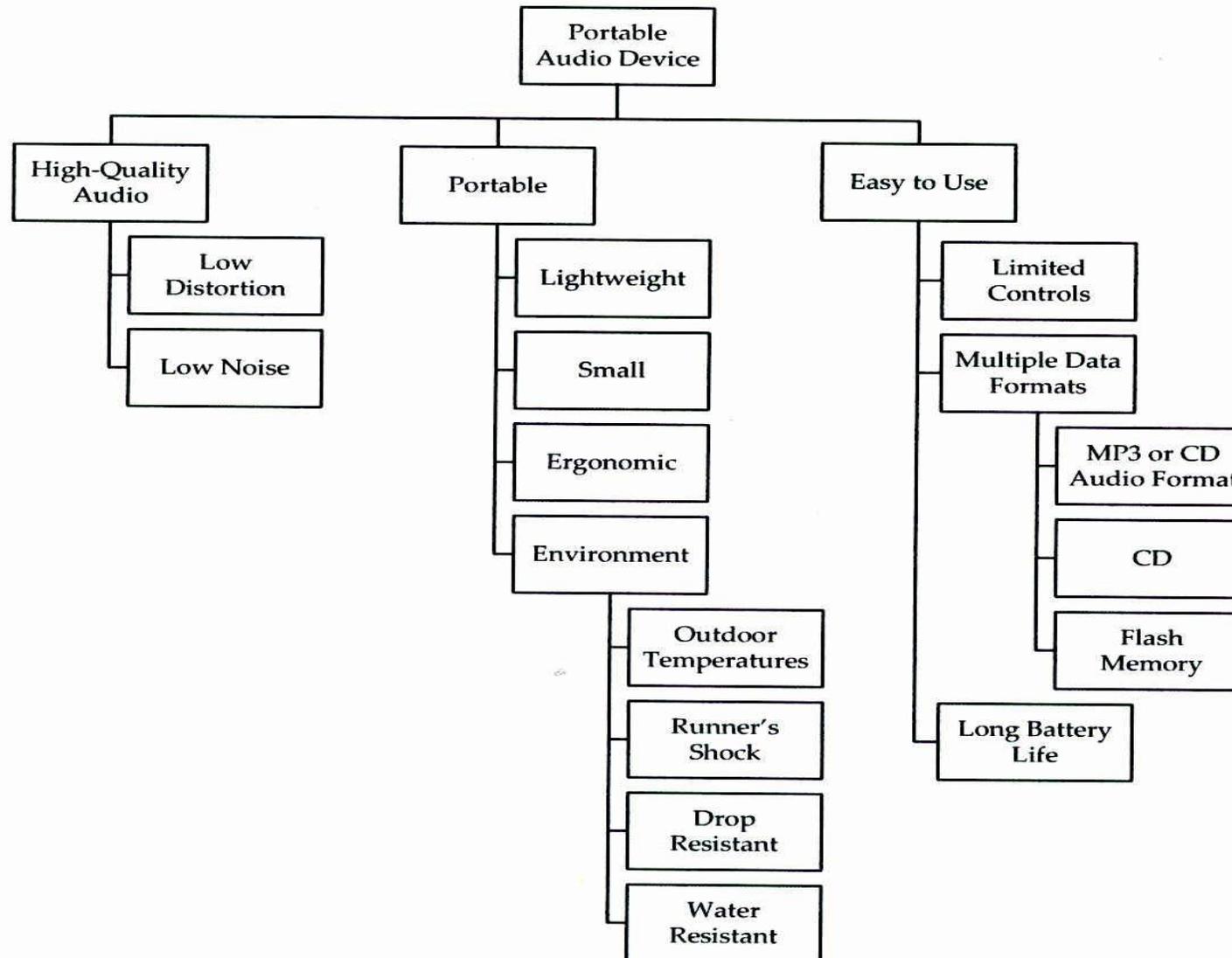
Requirements Specification

➢ Identifies requirements design must satisfy for success

1. Marketing requirements
   - Customer needs
2. Engineering requirements
   - Applies to technical aspects
   - Performance requirements

Methods for the Development of Mechatronic systems

❑ Introductory Task

You are part of the R&D team of the company „High Tech Washing Ltd." which produces washing machines on a high technological standard.

This morning your mates discovered that 15 minutes of washing by hand washed cleaner than 69 minutes wash time in a standard 'AAA' machine...

❑ What are the process for developing a new washing machine?

▶

1- Pre-Study Process

❑ **Basics and Analysis: What is it all about?**
   ❑ Developing a washing machine which uses a technique similar to hand washing. A product like this would be more efficient and ecological and would operate on lower costs.

❑ **Study of Product, Customer and Market**
   ❑ Product: A washing machine with this technology has the potential to be faster, more ecological and more cost-efficient.
   ❑ Market: In a first step, the target market is Europe, Northern America and Japan, households in well-developed countries.
   ❑ Customer: In the beginning, the target group will consist of people with average (or high) income and a sense for cost-efficiency and ecology.

2- Requirement List

Requirement	Value	Unit	Type	
Size	Height: 120 Width: 60 Length: 60	cm	FF	quan
Time of 40° washing	< 50	min	BF	quan
Water use for each washing	< 12	l	BF	quan
Type of detergent	standard detergent	-	FF	qual
Color	bright	-	BF	qual
…				
…				

FF: Fixed Requirement (Festforderung)
BF: Range Requirement (Bereichsforderung)

quan: Quantitative Requirement
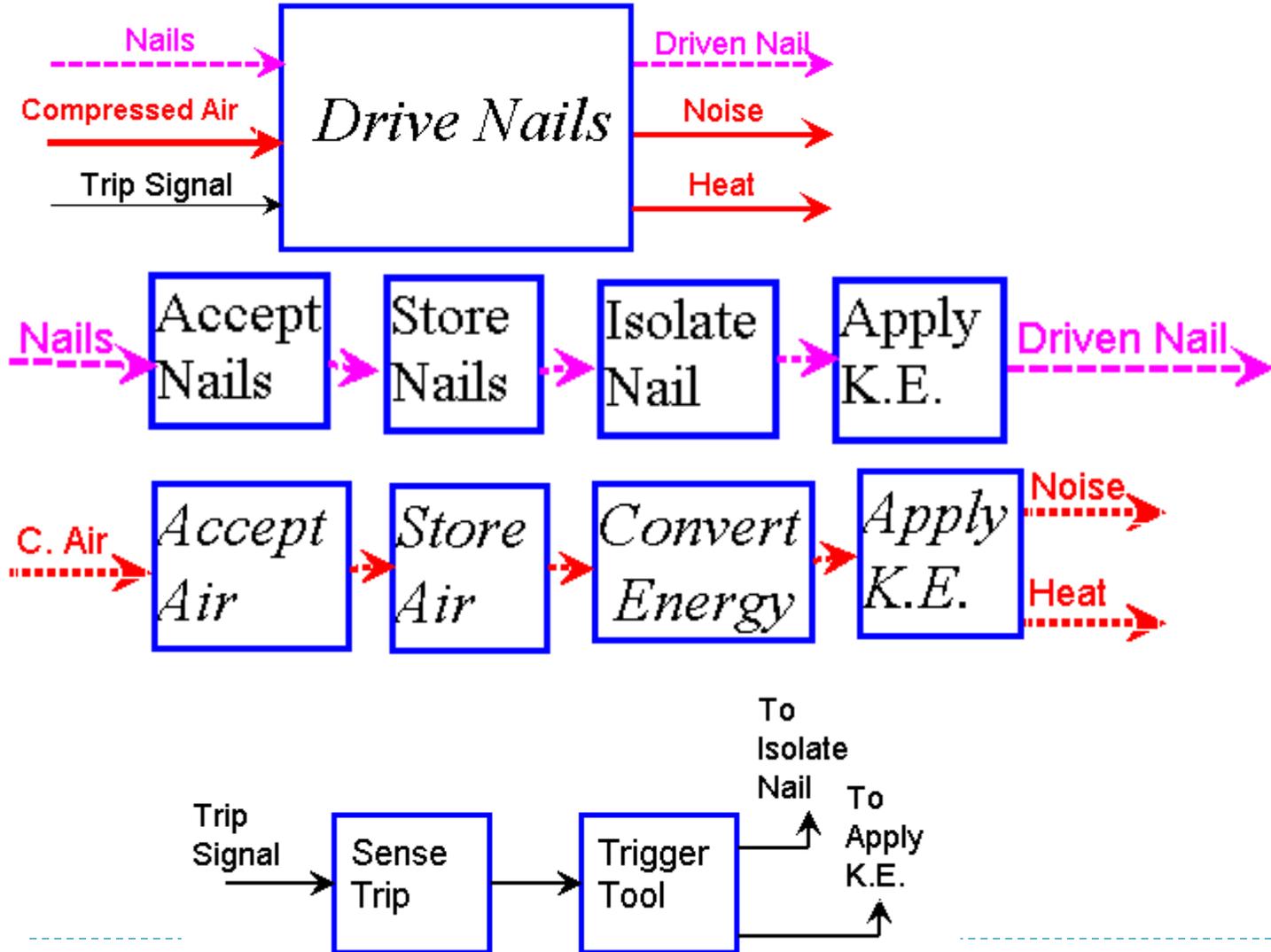qual: Qualitative Requirement

3- Functional Structure Diagram

A Function Structure Diagrams (FSD) is a graphical representation of the functions a product performs on its inputs and outputs.

3- Functional Structure Diagram

3- Functional Structure Diagram

3- Functional Structure

Dryer

Water cold

Electrical Energy → **Heat up Water**

Water warm

Merge Water and Detergent — Water with detergent →

Electrical Energy → **Convert energy** — Mechanical Energy →

Encase laundry

Transport water trough system

Information ▸   Energie ▸   Stoff ▸

Laundry dirty

Merge laundry and hot water

Laundry in water

Knead laundry

Laundry clean   Laundry clean

Water → **Rinse laundry**

Laundry rinsed
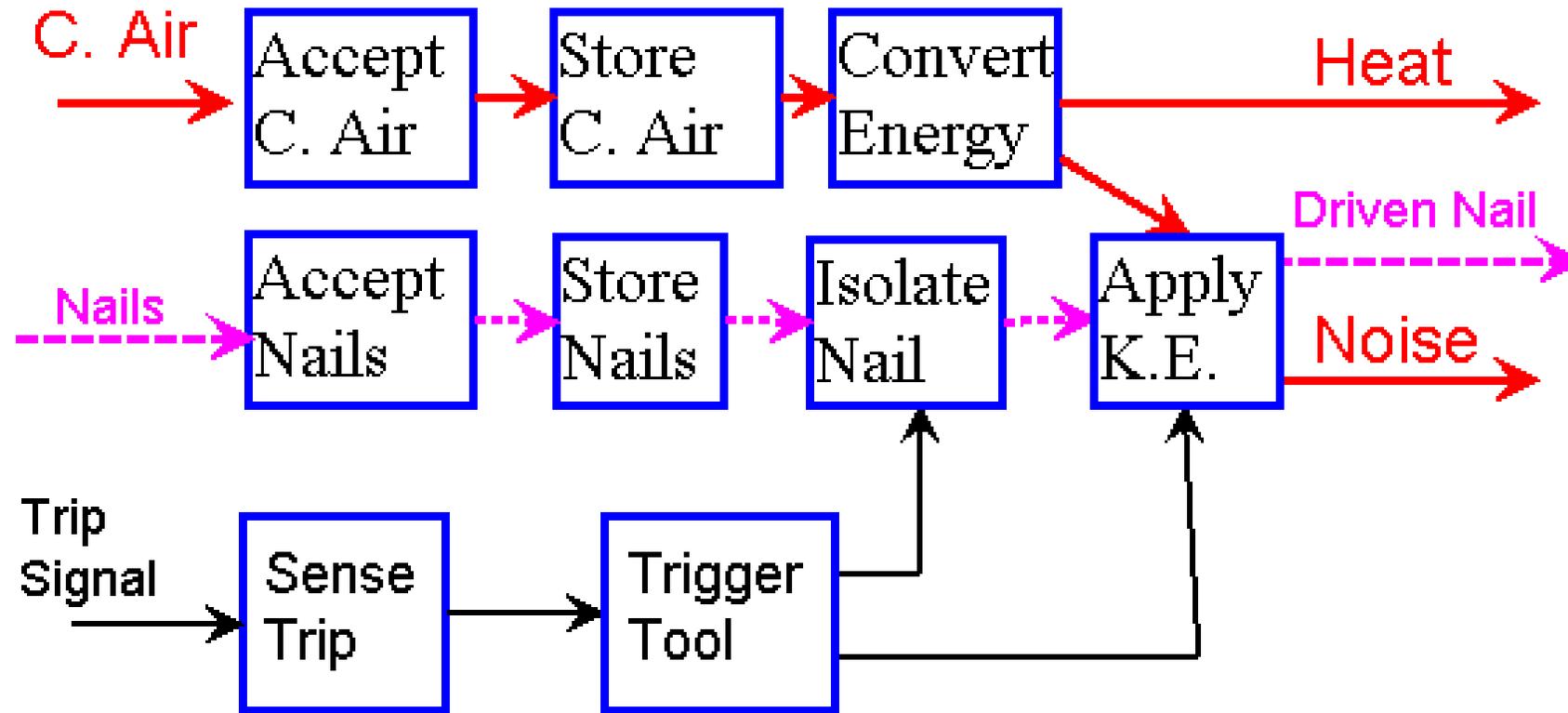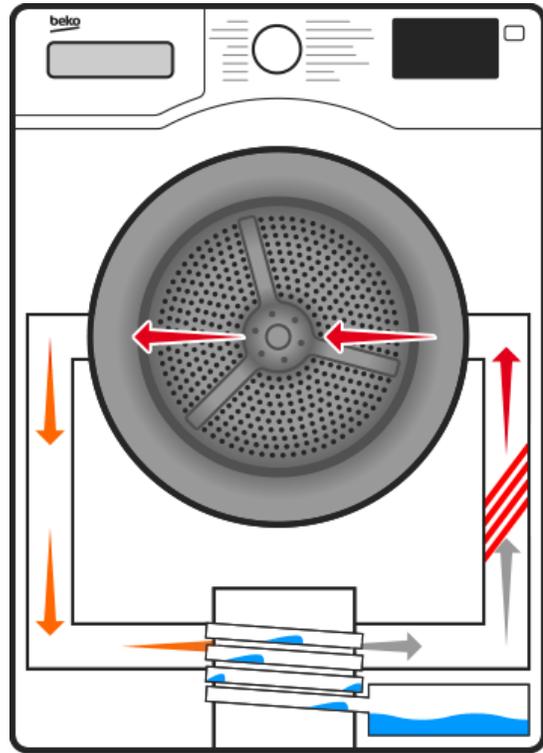
4- Finding solutions for each function

❑ **Solutions for each function trough creativity methods**
  ➢ **Brainstorming**
      ✓ Generate many ideas
      ✓ Evaluate against PDS (product design specifications)
      ✓ Select one to engineer
❑ **Filtering the solutions**
  ➢ **Ask the following questions for every solution:**
      ❖ **Does the solution satisfy all the requirements of the requirement list?**
      ❖ **Is there a solution which is really similar or even the same? Condense them to one solution.**
  ➢ **If there are more than 6 solutions left for one function:**
      ❑ **Evaluate the worst and get rid of it.**

5- Evaluating the best solution

Evaluation

Evaluation	
Project	04/117
Product	Washing Machine
Team	Smith
Version	25.10.04, Sm

comparing rating (based on VDI Norm 2225)

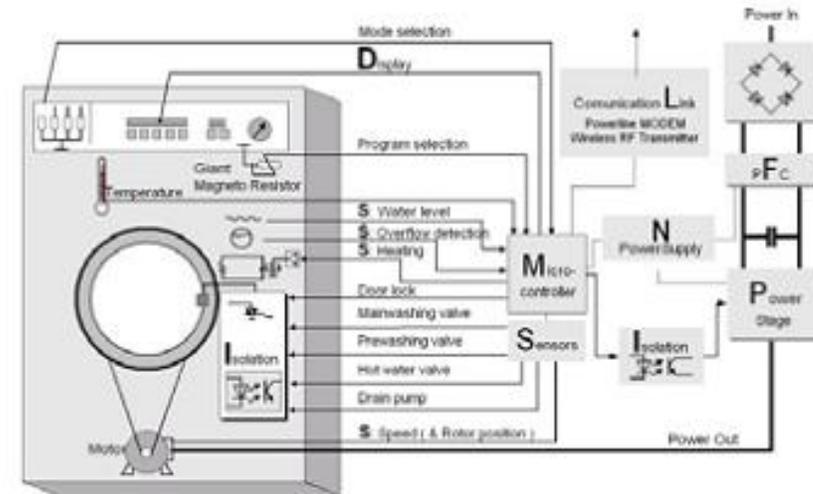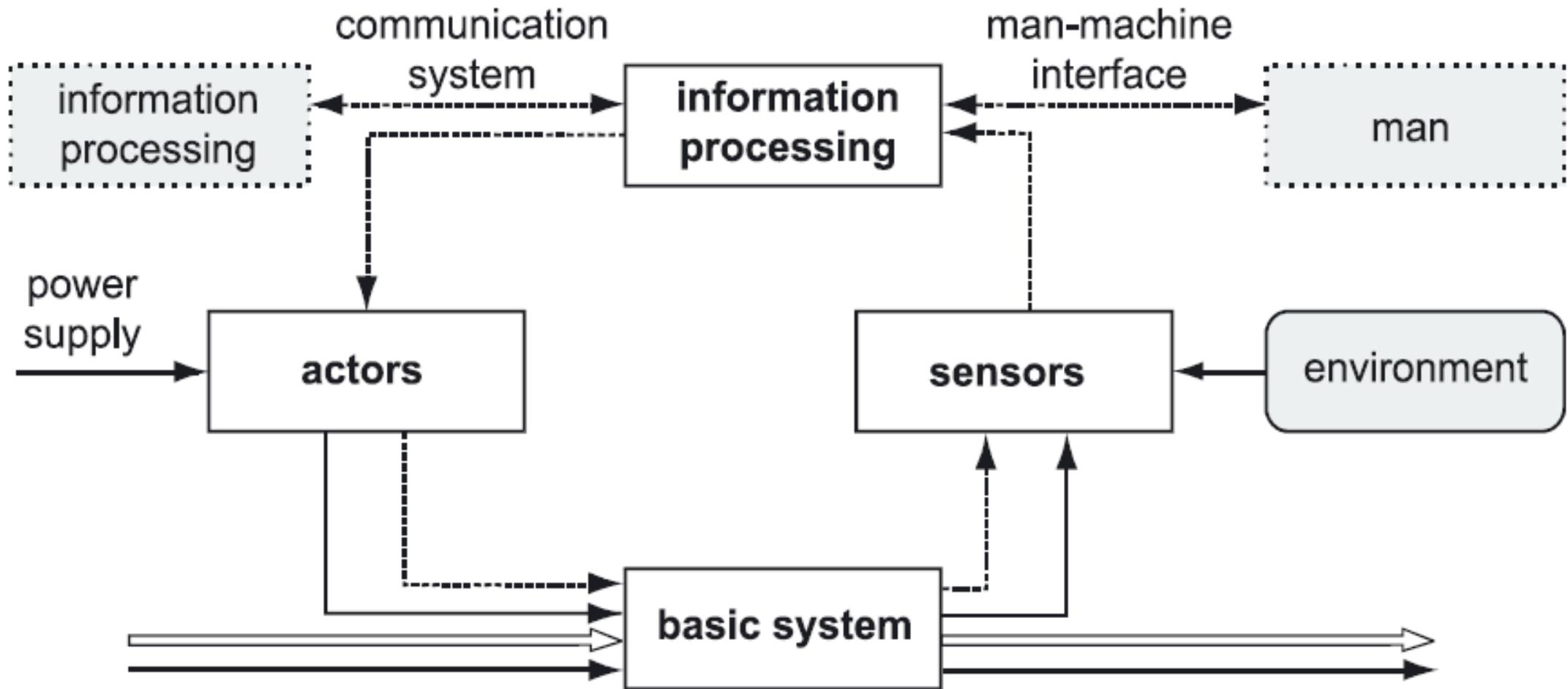|		evalution criteria	weight	solution 1 "classic"		solution 2 "2-drums"	
	No	name of criteria	g (0...1)	W (1...4)	W*g	W (1...4)	W*g
	01	Time of Washing	0.30	2	0.6	4	1.2
	02	Cleanness of Laundry	0.30	2	0.6	4	1.2
	03	Easy to handle	0.20	4	0.8	3	0.6
	04	Ecological	0.20	3	0.6	3	0.6
	05						
	Sum				**2.6**		**3.6**

6- Layout Process

— Defining product modules

— Designing the whole product including

  — Mechanics

  — Electronics

  — Software

Legend:
- ·····▶ information flow
- ──▶ engergy flow
- ⇨ material flow
- ▭ necessary unit
- ⌞⌟ optional unit

TRIZ: Structured Innovation for Better Solutions

Ideation

Mind Mapping (Brain Storming)
Triz (theory of inventive problem solving)
1- (40 Design Principles)
2- TRIZ Contradiction Matrix
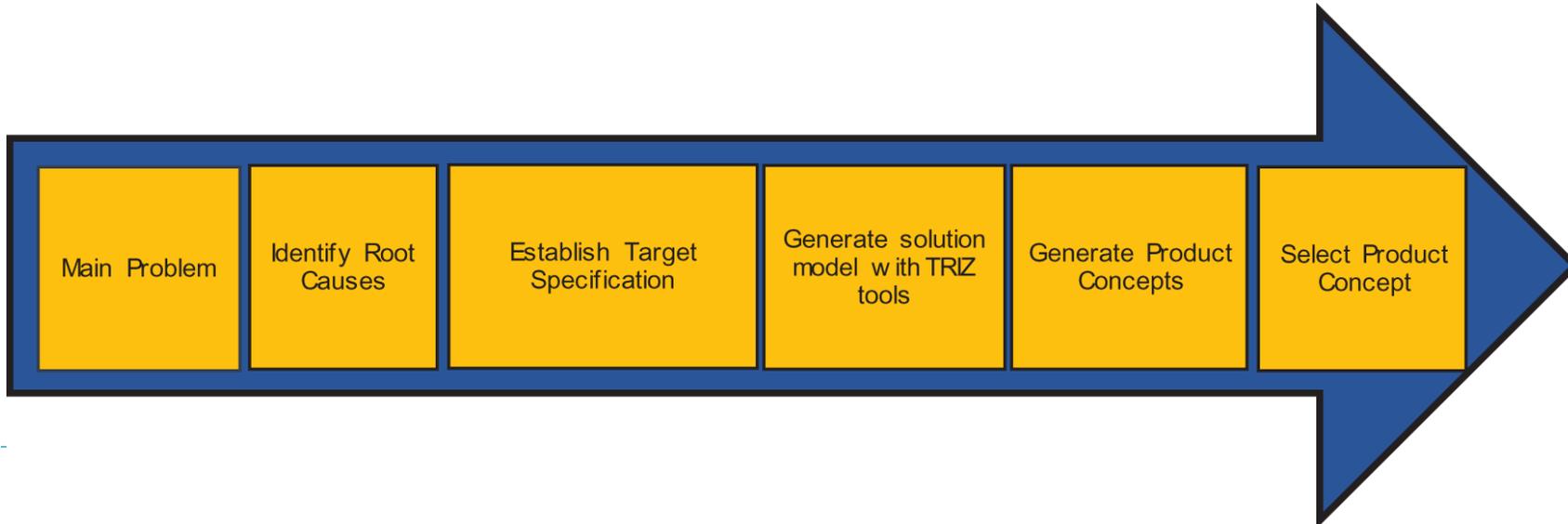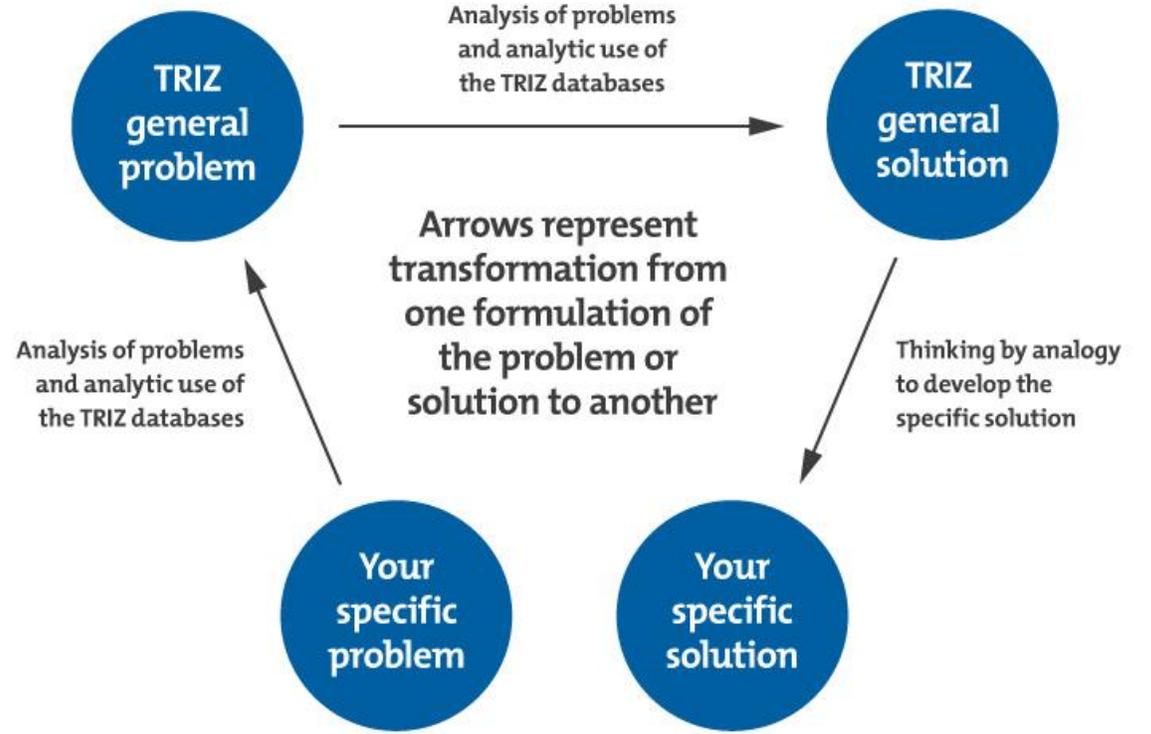
TRIZ general problem → Analysis of problems and analytic use of the TRIZ databases → **TRIZ general solution**

Arrows represent transformation from one formulation of the problem or solution to another

Analysis of problems and analytic use of the TRIZ databases

Thinking by analogy to develop the specific solution

Your specific problem

Your specific solution

| Main Problem | Identify Root Causes | Establish Target Specification | Generate solution model with TRIZ tools | Generate Product Concepts | Select Product Concept |

Ideation
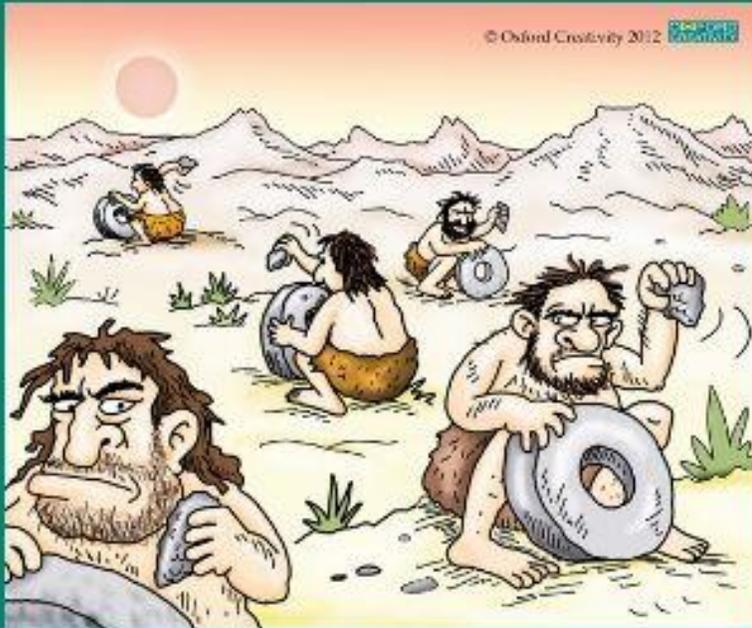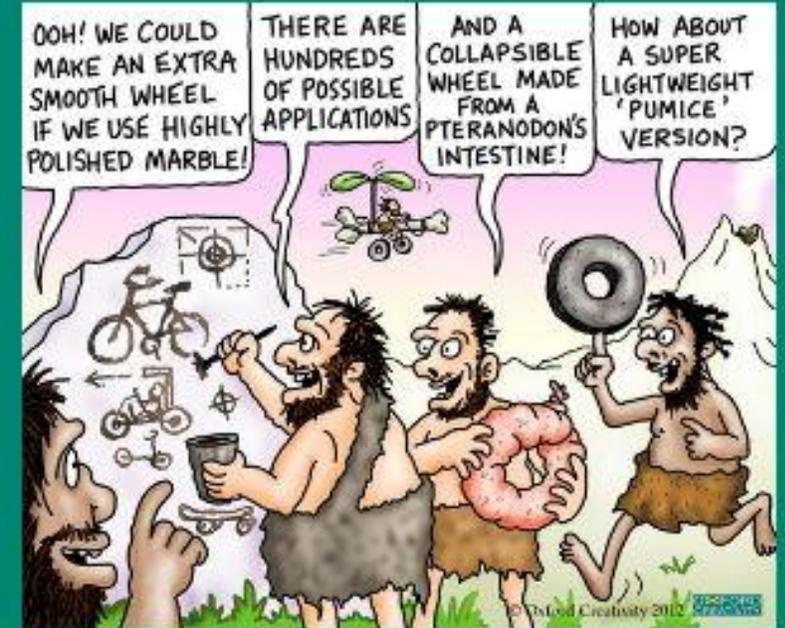
TRIZ Inventive Principles – 1 through 8

1 Segmentation	2 Taking Out	3 Local Quality	4 Asymmetry	5 Merging	6 Universality	7 Nesting	8 Anti-weight

Segmentation
Transfers a complex task into several simpler tasks

Taking Out
Eliminate the non-essential activities with no added value

Local Quality
Single out a specific object. Then improve it

Asymmetry
Asymmetric (rather than symmetric) solutions provide better functionality.

Merging
Bringing together things which happen at the same time or in the same place

Universality
An object can be eliminated by having another object perform the same function

Nesting
Putting one thing inside another.

Anti-weight
Identify a force that causes a negative shift, then apply a compensating force

1 Segmentation	**2** Taking Out	**3** Local Quality	**4** Asymmetry	**5** Merging	**6** Universality	**7** Nesting	**8** Anti-weight
9 Preliminary Anti-action	**10** Preliminary Action	**11** Beforehand Cushioning	**12** Equipotentiality	**13** Inversion	**14** Spheroidality	**15** Dynamics	**16** Partial or Excessive Actions
17 Another Dimension	**18** Oscillation	**19** Periodic Action	**20** Continuity of Useful Action	**21** Skipping	**22** Convert Harm into Benefit	**23** Feedback	**24** Intermediary
25 Self-service	**26** Copying	**27** Cheap, disposable objects	**28** Mechanics Substitution	**29** Pneumatics and Hydraulics	**30** Flexible shells or thin films	**31** Porous Materials	**32** Color Changes
33 Homogeneity	**34** Discarding and recovering	**35** Parameter change	**36** Phase transformation	**37** Thermal expansion	**38** Use strong oxidizers	**39** Inert environment	**40** Composite materials
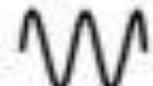
TRIZ – 40 Principles

1 Segmentation	21 Skipping
2 Taking out	22 Blessing in disguise
3 Local quality	23 Feedback
4 Asymmetry	24 Intermediary
5 Merging	25 Self-service
6 Universality	26 Copying
7 Russian dolls	27 Cheap short-lived objects
8 Anti-weight	28 Mechanics substitution
9 Preliminary anti-action	29 Pneumatics and hydraulics
10 Preliminary action	30 Flexible shells and thin films
11 Beforehand cushioning	31 Porous materials
12 Equipotentiality	32 Colour changes
13 "The other way round"	33 Homogeneity
14 Spheroidality - Curvature	34 Discarding and recovering
15 Dynamics	35 Parameter changes
16 Partial or excessive actions	36 Phase transitions
17 Another dimension	37 Thermal expansion
18 Mechanical vibration	38 Strong oxidants
19 Periodic action	39 Inert atmosphere
20 Continuity of useful action	40 Composite materials

https://www.innovationtraining.org/wp-content/uploads/2021/06/TRIZ-Principles-Training-Theory-of-Inventive-Problem-Solving.jpeg

01) DIVISION
a) a ship built, made of removable / replacable bulkheads
b) multi-engine aircraft
c) multi-piston engine of internal combustion
d) a toy made from Lego blocks
e) a chocolate broken into mini-tablets
f) multi-grip gators
g) a binded file of paper sheets
h) multi-blade cartridge razors
i) multi-blade airscrews of aircrafts, or wind power-plants

02) TAKING OUT
a) taking of notoriously noisy power aggregate out of the main boat
b) internal air ventilation system taken out of the building, i.e. placed on the building elevation
c) sound of predator bird, previously registered on a tape and played back, can be used scaring the birds, notoriously flying near or around the airports

03) LOCAL QUALITY
a) dustless excavation of coal
- the dust is captured by tiny droplets inside of the water cone
- bigger droplets outside of the cone keep the dust in a place
other examples:
b) weighed average from maps
c) weighed estimation produced for rankings of computers, printers, etc.

04) ASYMMETRY
a) pneumatic tyre asymmetrically reinforced from outside, due to contact with pavement curb
b) left- or right-handed rules of priority, in right of road
c) slanted concrete mixer, blender,
d) asymmetrically built conjuctions, handles
e) asymmetrically defined functionality of the "trap-the-door" mechanisms

05) MERGING
a) several computers combined into functionning network
b) a hedge made of pales
c) textiles made of wool/poliestre/cotton fibres
d) roofing tiles combined into coverage of house roof
e) mobile concrete mixer, mobile crane, refridgerator, merged into single mobile machine unit, combining of the stationary machines with mobile undercarriages

06) UNIVERSALITY
a) a helmet in use, within field conditions, rendered as:
a1) spade   a2) frying pane
b) universal "handy-tools", Swiss Army knife
c) sets of universal kitchen robots, mixers, with operating acuators (rasps, juice extractors, etc.)

07) EMBEDED STRUCTURES (nested "Dolls" - Matryoshka)
a)
b)
c) radiators of ultrasound welders

08) ANTI-WEIGHT
a) wind power plant (moment of inertia in set of smoothing gusts of wind)
b) anti-airscrews
c) fish bladder (fish submerged in water)
d) baloon filled with hot air
e) slipping hydrofoils' boats
f) concept of hoover crafts
$F_{spring-retraction} = kx$
$F_{of inertion} = \frac{2MV^2}{R}$
$V = 2\pi R\omega$

09) PRE-ELIMINARY ACTION
a) surrounding sounds, counter-acting acoustic waves
b) active earphones, piezoelectric anti-impact set for the tool

10) PRE-ELIMINARY ACTION
a)
b) parking of hard disc reading/writing heads
OFF (parking mode)
ON (operational mode)
blowing of the nozzles in printing catridges

11) BEFOREHAND CUSHIONING
a) for instance: a method of "dressing" of the cut tree branches (this action, actually forces a tree to beforehand reaction, to gather healing substances) a pressure band
b) driver's airbag
c) masking of the chosen elements, within patches on the object, before its painting

12) EQUIPOTENTIALITY
a) a sequence of linear movements is replaced by single seamless movement on section of arc a heavy element of the press, lifted up, and carried away usually in sequence of linear movements, is replaced with press deflected on remotely fasten long arm
b) dissolvable surgeon threads
c) rather to cool down stuck inner object, than to heat up other bigger outer object, which seizes the former one

13) INVERSION (UPSIDE DOWN)
a) for instance: reversing working mode of vacuum cleaner (then, vapour could be used in cleaning of carpets)
b) to turn mounted object upside down, on assembling line
c) turning (object in move, while motionless turning tool), against milling (mobile milling cutter)
d) binary tree's structure sought from root to leaves in one in-depth search algorithm, while tree sought from leaves to root in another

14) SPHEROIDALITY, CURVATURES
a) applications of:
b) replacement of linear movements, bearing rollers, spirals, shafts, spheres, demi-domes
c) application of arcs in architecture demi-domes in vaults of buildings
d) circular accelators (synchrotrons / magnetrons), in place of concept of linear accelators of particles
e) extensible, retractable measuring tape

15) DYNAMICS
a) automatically extensible/opened doors, air-locks ,etc., reacting while in need
b) automatic gears in mobiles
c) undercarriages in cars of variable stiffness characteristics, tuned exactly to terrain conditions during the driving
d) fully electronically controlled operational mode of carburettor, electronically controlled fuel injection in dependecy of driving conditions

16) EXCESSIVE (OR PARTIAL) ACTION
a) in close fit of both piston and cylinder of the engine
material allowance left in fit on inner side of cylinder destined for lapping
b) to spray excessively paint, and then to remove the excess of the paint
c) to fulfill the fuel tank, and then to remove the excess of fuel

17) ANOTHER DIMENSION
a) a two tools colliding in 1D should be rearranged within 2D plane, likewisely tools colliding on 2D plane, should be rearranged in 3D space
b) to stack vertically containers, chairs, laptops, etc.
c) science of complex symmetries in crystallography
d) use of Lie algebra, in analysis of structures of atoms (in studying of electron shells, around atomic nuclei)

18) MECHANICAL SELF-INDUCED VIBRATIONS, IN RESONANCE
a) piezoelectric engine - conceptual design
electric circuit of inducement
spring based tightments for set of two discs
direction of relative movement of upper disc
direction of aerial wave & relative movement in lower disc
both sided metal plating of layer ceramic material fasten to lower disc
b) quartz generators, in electric circuits

19) PERIODICAL ACTION, OR PULSED ACTION
a) hammer drill
b) pulsed laser, against lasers of continous operational mode
c) "pseudo-analogue" driving (PWM) (Pulse Width Modulation)
d) pulse DC power unit, against conventional DC power unit
e) pulse amplifiers
f) step motors

20) CONTINUITY OF USEFUL ACTION
a) enlarging drill, operating in both directions
b) nozzles of catridge, printing also in returning direction (without idle mode)
c) steam turbines of generators for one power plants, working continuously (in optimal mode), while the others working, as pump-storage power plants, in aim of storing of energy for afternoon hours
(mode: pumping of the waters into upper reservoir on mornings, while emptying upper reservoir into lower one on afternoons)

21) SKIPPING, QUICK MODE, OR PACE OF REALIZATION
a) wood-borne materials in quick thermal processing
b) laser treatments of biological tissues or in processing of hardly processed materials (both extremely soft and extremely hard) without thermal deformations, scorching, burnings
c) pico-second pulsed lasers (femto-second lasers) against laser of micro- and nano-seconds pulses (various materials virtually have been vapoured, while treated with pico-second pulsed laser beam of energy)
d) steel hardening process in abrupt temperatures changes

22) "BLESSING IN A DISGUISE" (CONVERT HARM INTO BENEFIT)
a) burning out main in outskirts of the main fire, to cut of fire's fluel
b) to blow out the blazing fire from top of oil well in detonation blast, the material permafrost rapidly "liquefies"
c) permafrost materials are to be 'treated' with liquid nitrogen (N_2)

23) FEEDBACK PRINCIPLE
a) basically, as well as particularly:
input signal → object → output signal (indoor's temperature regulation)
closed feedback loop of (temperature) negative feedback
a) autopilot provided with 3-axis gyro system
b) robot arms movement's back-controlled in set of:
1) diode - 2) photodiode -3) semi-transparent either: protractor, or: linear scale - placed in between

24) INTERMEDIATE MEANS, "FITTING" PRINCIPLE
a) in electronic circuits fitting either of:
- impendance,
- or resistance,
of input source to the receiver
R_{input} (Z_{input}) → $R_{receiver}$ ($Z_{receiv.}$) (receiver's impedance)
E: fitting of input impedance to receiver's impedance
b) fitting in mean of:
- pressure-flowing (fluid mechanics),
- loading of force moments, in transmition gears (mechanical fitting)
- stress of two interfacing surfaces (endurance)

25) SELF-SERVICING PRINCIPLE
a) ferromagnetic on line, temp <0°C, paramagnetic on line, temp >0°C
self-servicing line's deicing system
b) constant regeneration of the glower of halogen lamp tungsten sublimates to halogens then, to redeposit on tungsten glower

26) COPYING, IMAGING RULE (application of optical mapping)
a) use of ultrasounds, ultrasound mapping
b) magnetic resonance mapping
c) X-rays radiography
d) application in mapping of material structures of:
- infrared
- ultraviolet
- basically of optical methods
e) use of fluoroscence and of scintilation's materials

27) INEXPENSIVE SHORT-LIVED OBJECTS (CHEAP CADUCITY, & OF DISPOSABLE MATERIALS)
a) kitchen utensils, dishes, cutlery made of plastic
b) disposable syringes, gloves, etc.
c) plastic bags, packaging wrappers, etc.
d) printing head integrated with ink catridge
(formerly, each printer possessed built-in printing head) (presently, each ink catridge has its own printing head)

28A) PRINCIPLE OF SUBSTITUTING OF MECHANICAL SYSTEM WITH FUNCTIONALLY EQUIVALENT ELECTRO-MAGNETIC SYSTEMS
electric field to substitute with interaction of:
mechanical pressure or fastening — magnetic field

28B) SUBSTITUTING OF MECH. SYS. WITH ELECTRO-MAGN. SYSTEMS
B) magnetic borne pressure of the machined materials
pneumatico-magnetic pressure cushion
C) mobile fields instead of static fields
D) heterogenous fields

29A) PNEUMATICS & HYDRAULICS
- pneumatic automobile tyre,
- pneumatics (air-tight) dampers,
- automobile airbags,
- pneumatic "discrete", driving of operational actuators, for instance: automatic welding of wrapping plastic packing films
on the figure above, in blue: approximate section of automobile pneumatic tyre

29B) PNEUMATICS & HYDRAULICS
- automobile brakes,
- in driving of plane elevator,
- where the precision is needed, as well as enormous force transition
hydraulics in communicating vessels
$F_2 >> F_1$
brake's block
$F_2 = \frac{S_2}{S_1} F_1$

30) FLEXIBLE FILMS AND FOILS, MEMBRANES
a) not wettable film prohibits evaporation of water
b) wrapping packaging based on plastic, air-pumped bubbles

31) POROUS MATERIALS
a) aerated concrete
b) porous abrasive tools
c) polyurethane foam
d) catalysing surfaces in chemistry
e) "vacuum" as a "construction building material"
f) openwork structures reinforcements
g) porous steam cookers getters
porous grinding wheel, pores in grinding wheel allows for: self-regenerating process, of abrasing heat, collecting and depositing of chips

32) COLOUR CHANGING (ALTERNATING)
in lapping process for inner surfaces of engine pistons & cylinders, the probing of phoshorescence distribution can be used

33) HOMOGENEITY
the two interfacing surfaces should be made of the same material
moreover, the similarities can be applied, regarding:
- comparable mat.'s hardness, chemical inertion, structures,
- comparable thermal expansion's coefficients, (in case of dental materials; metal-glass conjunctions),
- comparable electro-chemical potentials (in avoiding electro-chemical borne corrosion),
- same fatigue characteristics, and amortization specifics

34) DISCARDING, RECOVERING, PARTS REGENERATION
a) soluable medication capsules made of (biologically inert material)
b) IV stage, III stage, II stage, I stage rocket's stages subsequently discarded during the flight
c) cornstarch-based packages for dry products

35) CHANGING STATE, PARAMETERS, PROPERTIES OF MATERIALS
1) high temperature food processing temp >>0°C
2) low-temperature food preserving temp < 0°C
3) a product ready for further processing step (for submerging in liquid chocolate)

36) PHASE TRANSITION
a binary, phase transition cycle for refrigerator construction
heat flows from surrondings (red arrows directed to blue heat exchanger) compressor, liquefied ammonia, heat carrier, (freon, ammonia, etc.)
circulation of liquefied ammonia in heat exchanger
necking

37) THERMAL EXPANSION
1) thermal shaft fitting temp > 0°C
2) state of thermal ballance temp < 0°C

38) STRONG OXIDANTS
a) oxygen O_2
b) ozone O_3
c) (indirectly vapour) H_2O
in oxidation of metal's surface (iron with over-heated vapour under pressure, at 300°C degree) the surface with protection layer obtained due to oxydation

39) NEUTRAL ATMOSPHERES, INERT ENVIRONMENTS
a) CO_2 extinguishers
b) N_2 or He_2 protection atmospheres in processing, and production
c) N_2 or He_2 protection atmospheres in storing of products, and materials, both raw and processed

40) COMPOSITE MATERIALS
1) elements of blades, rotors, airscrews in wind turbines constructions;
2) yacht's & cataraman's constructions;
3) elements exposed to ultra-strong, severe stress

39 TRIZ Features

http://www.triz40.com/TRIZ_GB.php
https://www.innovation-triz.com/TRIZ40/TRIZ_Matrix.xls

Excel

1: Weight of moving object	14: Strength	27: Reliability
2: Weight of stationary object	15: Durability of moving object	28: Measurement accuracy
3: Length of moving object	16: Durability of non moving object	29: Manufacturing precision
4: Length of stationary object	17: Temperature	30: Object-affected harmful
5: Area of moving object	18: Illumination intensity	31: Object-generated harmful
6: Area of stationary object	19: Use of energy by moving object	32: Ease of manufacture
7: Volume of moving object	20: Use of energy by stationary object	33: Ease of operation
8: Volume of stationary object	21: Power	34: Ease of repair
9: Speed of object	22: Loss of Energy	35: Adaptability or versatility
10: Force (Intensity)	23: Loss of substance	36: Device complexity
11: Stress or pressure	24: Loss of Information	37: Difficulty of detecting
12: Shape	25: Loss of Time	38: Extent of automation
13: Stability of the object	26: Quantity of substance	39: Productivity

TRIZ Contradiction Matrix

		Worsening Feature				
		1. Weight of moving object	2. Weight of stationary object	3. Length of moving object	4. Length of stationary object	5. Area of moving object
Improving Feature	1. Weight of moving object	*	—	15, 8 29, 34	—	29, 17 38, 34
	2. Weight of stationary object	—	*	—	10, 1 29, 35	—
	3. Length of moving object	8, 15 29, 34	—	*	—	15, 17 4
	4. Length of stationary object	—	35, 28 40, 29	—	*	—
	5. Area of moving object	2, 17 29, 4	—	14, 15 18, 4	—	*
	6. Area of stationary object	—	30, 2 14, 18	—	26, 7 9, 39	—
	7. Volume of moving object	2, 26 29, 40	—	1, 7 4, 35	—	1, 7 4, 17

Questions

Thank You