Cyber-physical systems. History, Challenges and Expectations

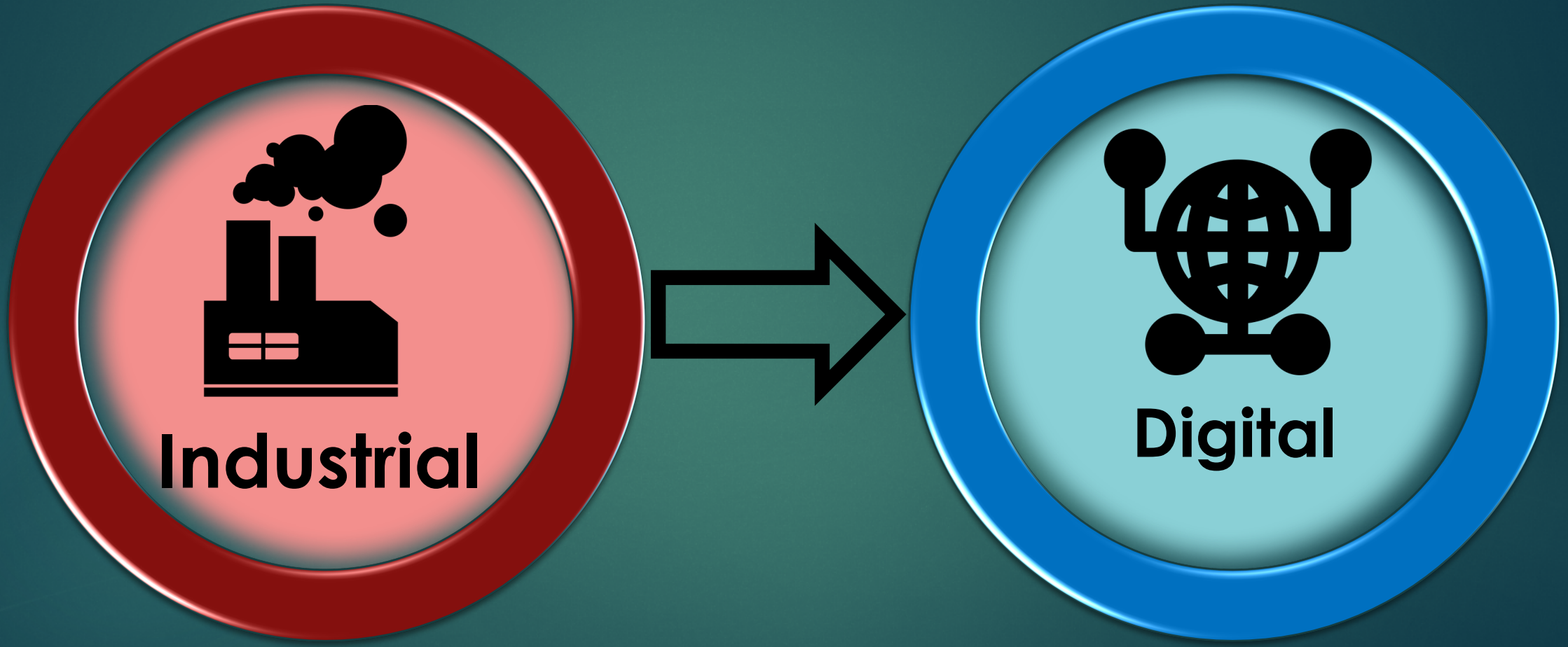
ILYA LEVIN

TEL AVIV UNIVERSITY

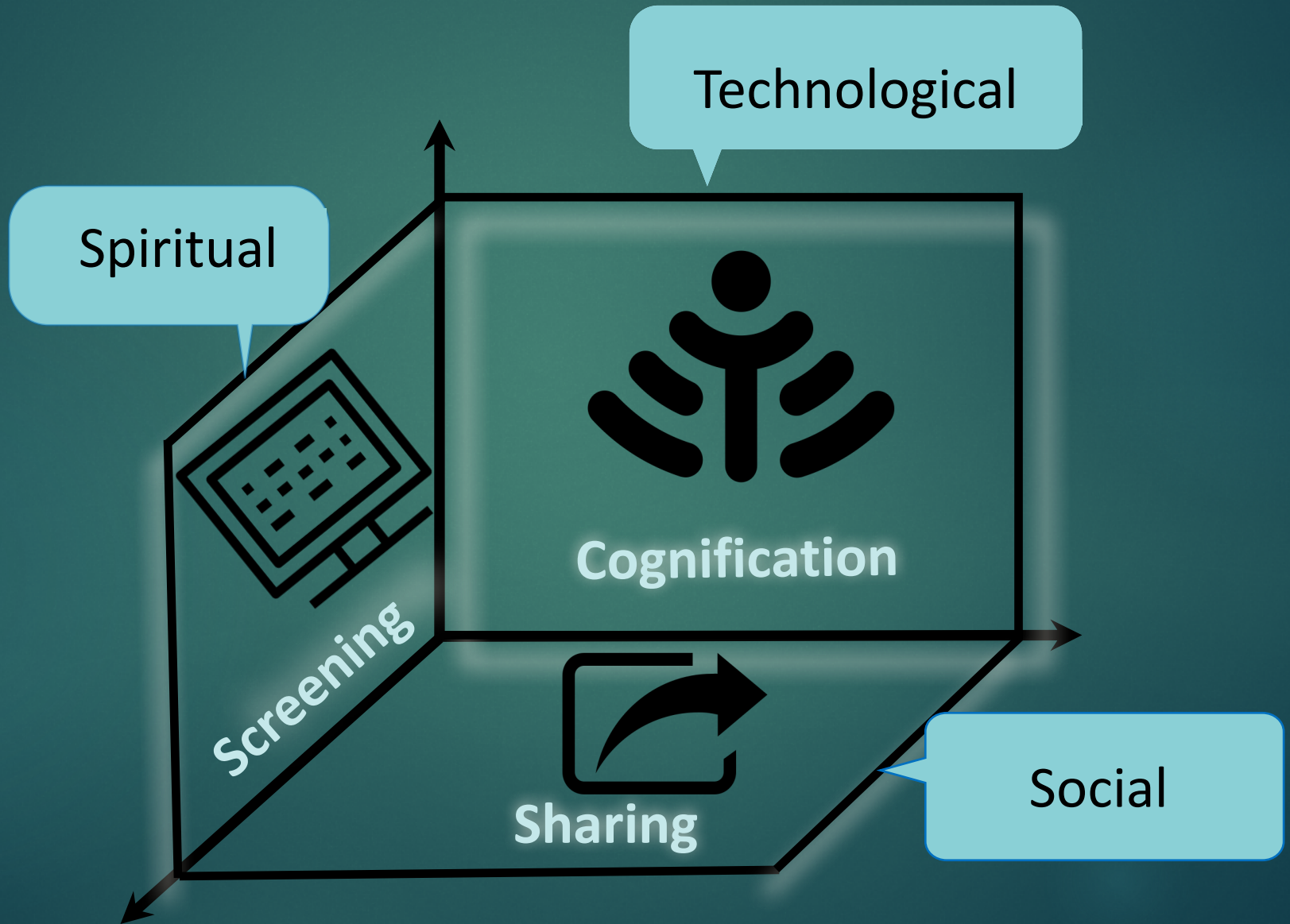
Outline

- Industrial revolutions
- CPS Predecessors
- Integrating Natural and Artificial Worlds
- CPS Interdisciplinarity
- CPS vs IoT
- Two Examples of Line Seekers
- Conclusions

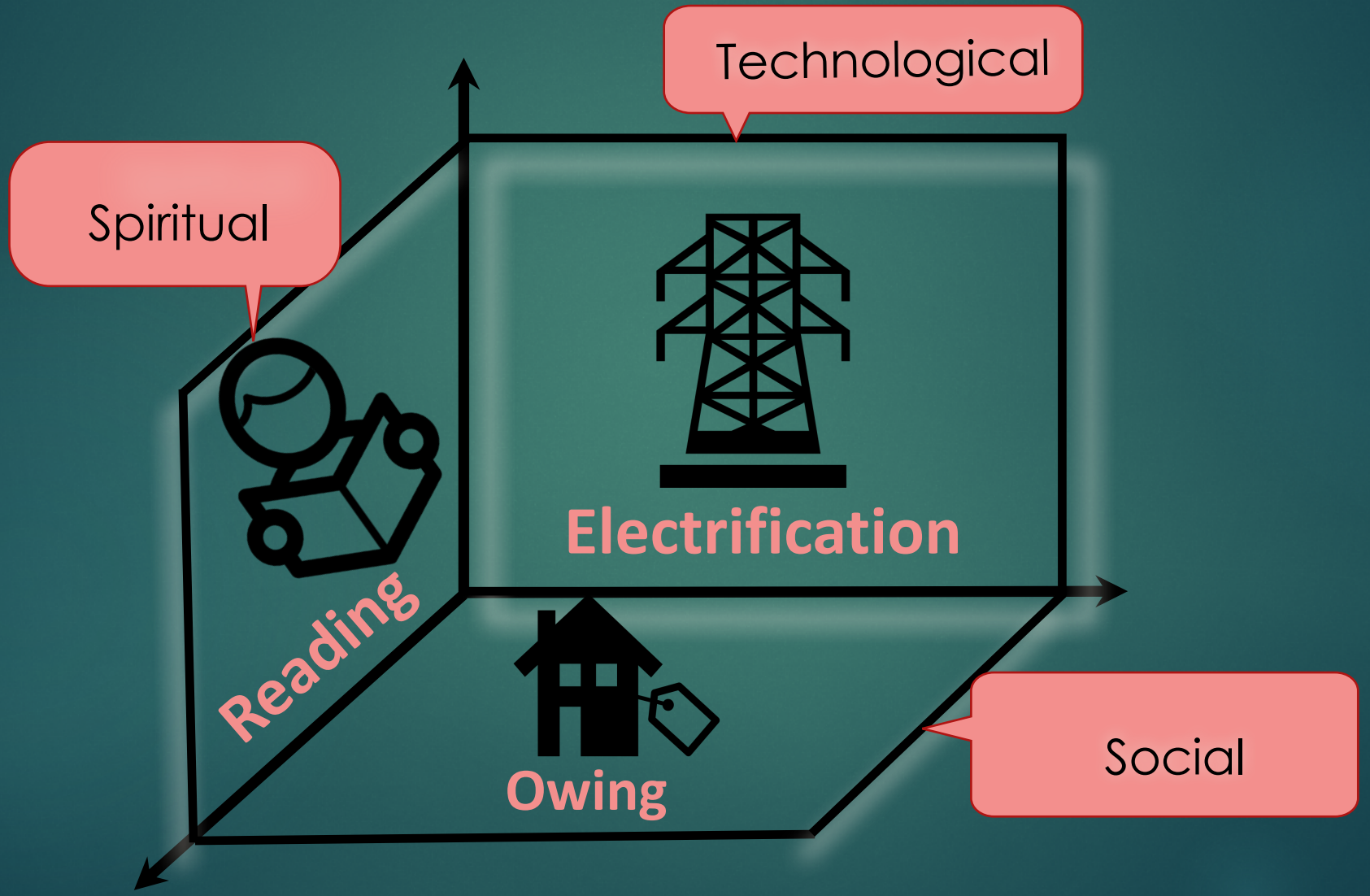
FROM INDUSTRIAL TO DIGITAL SOCIETY



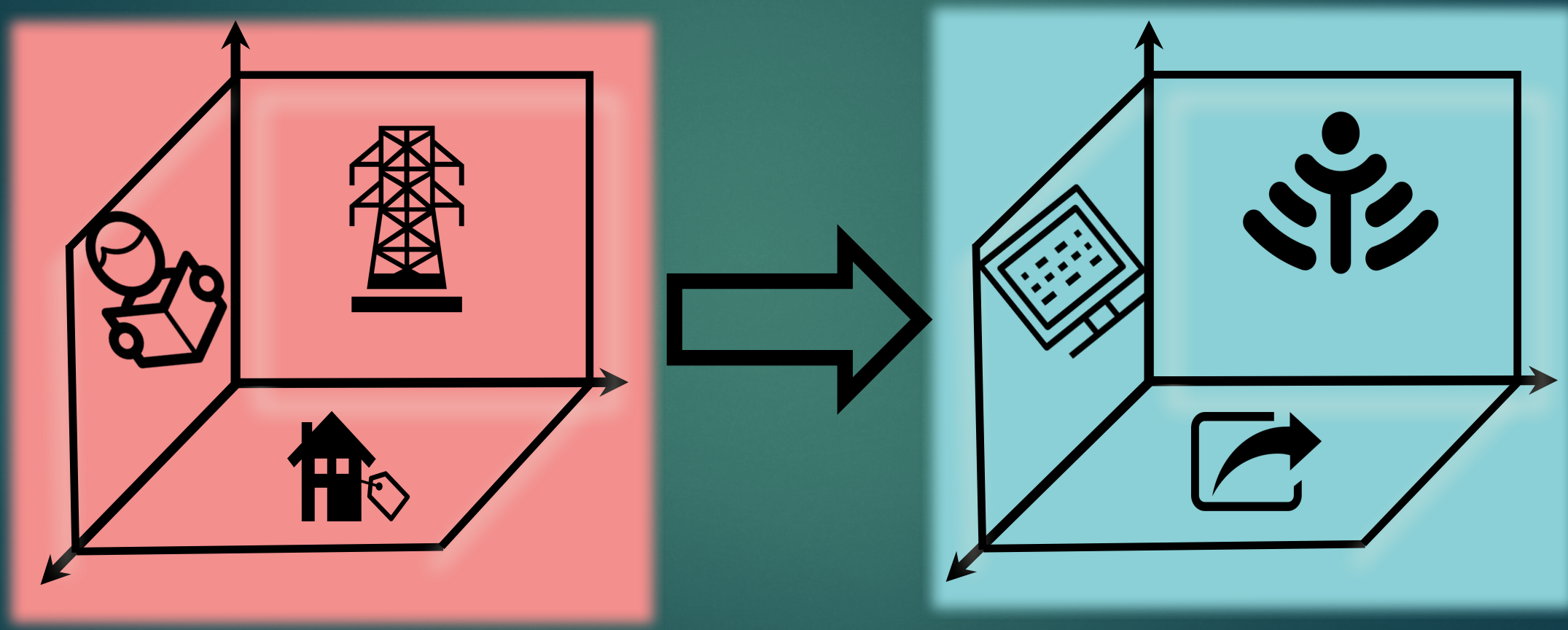
CULTURE OF DIGITAL SOCIETY



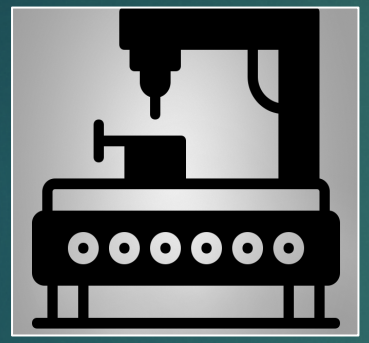
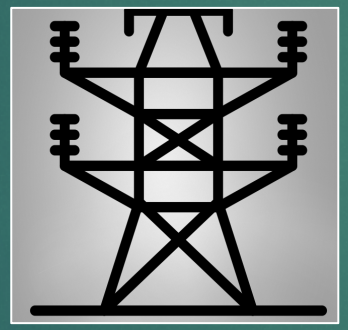
CULTURE OF INDUSTRIAL SOCIETY

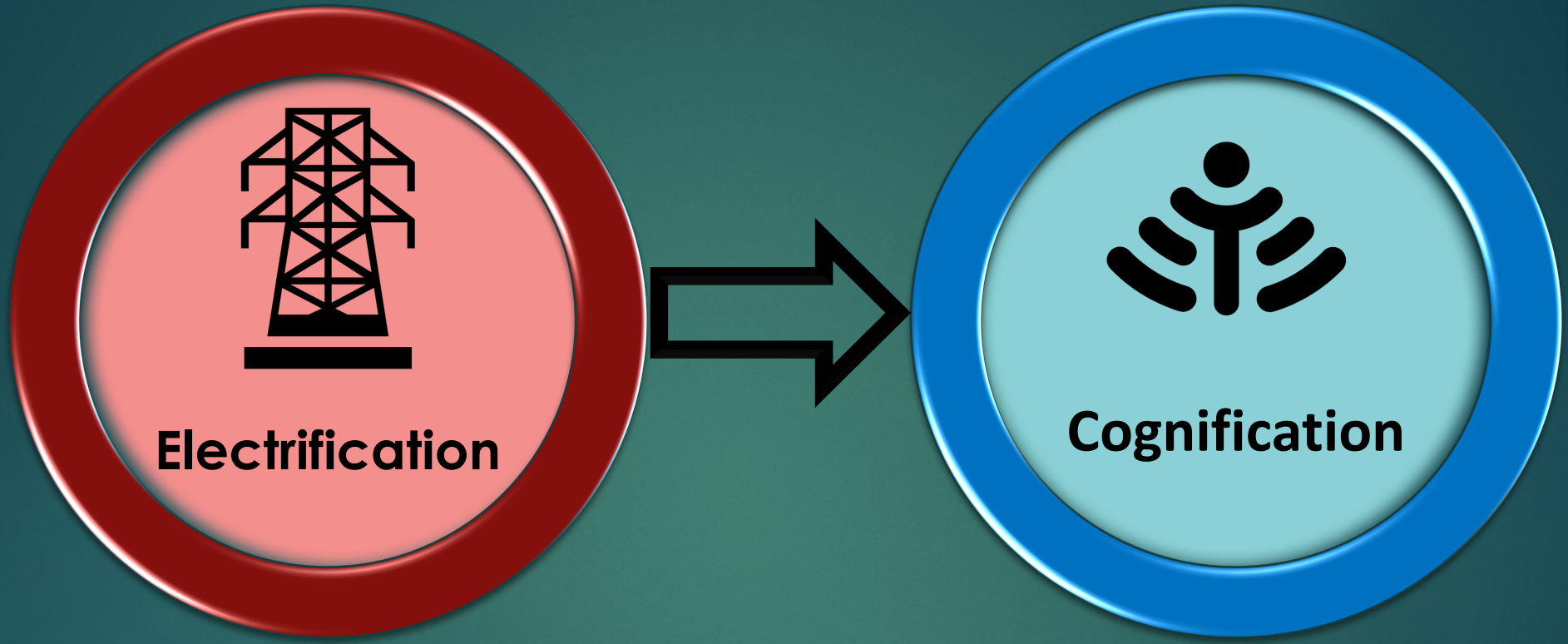


FROM INDUSTRIAL TO DIGITAL SOCIETY



Four industrial revolutions

1-st industrial revolution	2-st industrial revolution	3-st industrial revolution	4-st industrial revolution
MECHANIZATION	ELECTRIFICATION	DIGITALISATION	COGNIFICATION
around 1750	around 1900	around 1970	around 2010
			
Mechanical production, using the power of water and steam	Centralized electric power infrastructure	Digital technology, enhancing systems' functioning	Everybody and everything is networked, "huge brain", AI everywhere



The 2nd industrial revolution networked the resources of power
In the 4th industrial revolution will network the resources of intelligence

COGNIFIED WASHING MACHINE

Clothes tell the washing machines how they want to be washed

COGNIFIED TOYS

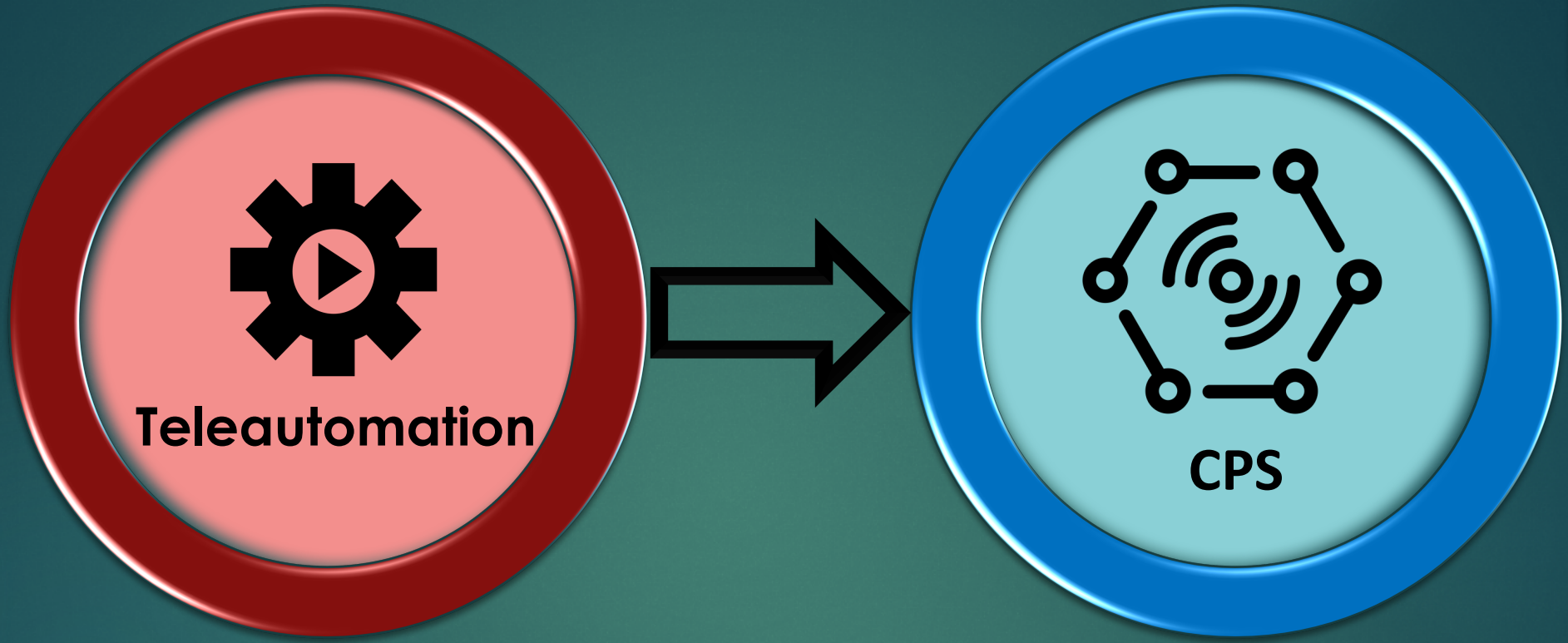
Toys more like pets

COGNIFIED NURSING

Patients with sensors that track their bio markers can generate personalized treatments

COGNIFIED REAL ESTATE

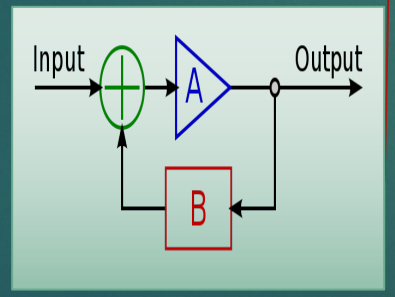
Matching buyers and sellers via AI



From teleautomation (1898) to CPS (2010)

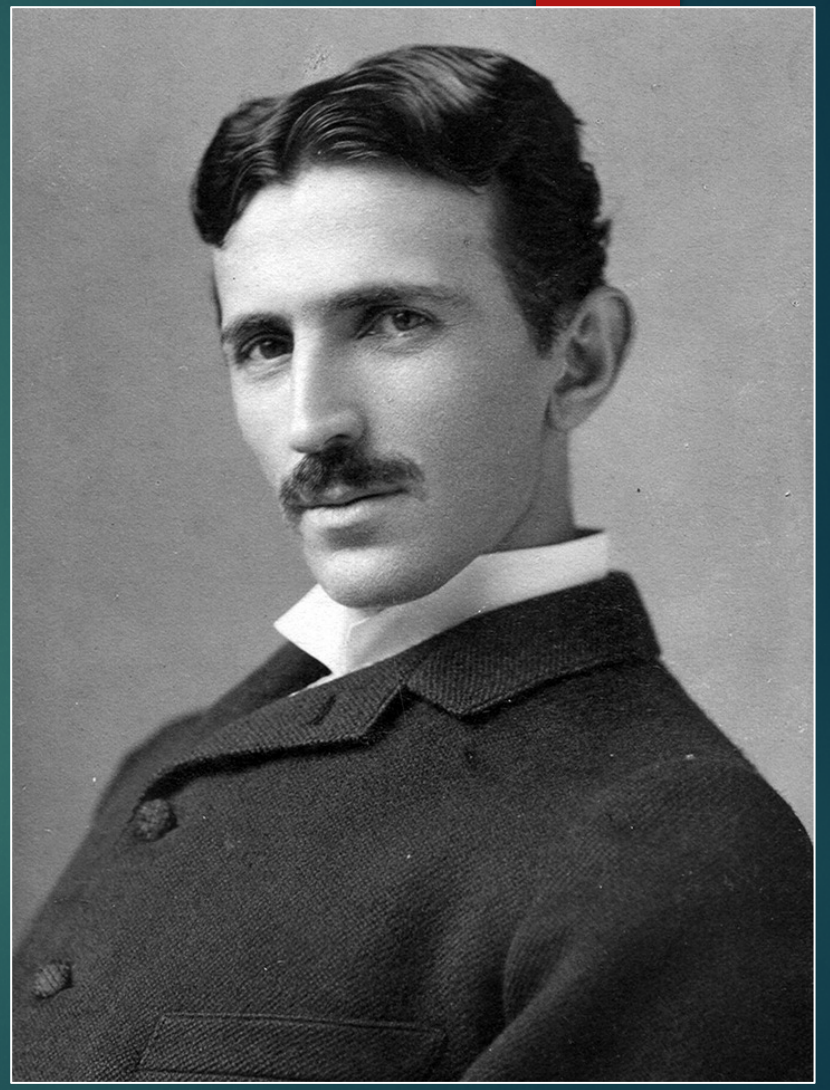
CPS Predecessors

Nikola Tesla	Norbert Wiener	Charles Draper	Mark Weiser	Kevin Ashton	Helen Gill
Teleautomatics	**Cybernetics**	**Embedded**	**Ubiquitous**	**IoT**	**CPS**
1898	**1948**	**1961**	**1988**	**1999**	**2010**



Teleautomation

When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance. Not only this, but through television and telephony we shall see and hear one another as perfectly as though we were face to face, despite intervening distances of thousands of miles; and the instruments through which we shall be able to do this will be amazingly simple compared with our present telephone. A man will be able to carry one in his vest pocket.



Nikola Tesla, 1898

Cyber Physical Systems

CPS are hybrid physical-engineered systems where:

1. Operations are integrated, monitored, and/or controlled by a computational core
2. Components are networked at every scale
3. Computing is embedded into every physical component, possibly even into materials
4. The computational core is an embedded system, demanding real-time response, and is often distributed

Two Worlds coming together

Physical World

- Natural
- Physical changes
- Real time
- Continuous
- Math: Calculus
- Closed system
- Controllable
- Predictable

Cyber-Physical World

Hyperconnected World of:
Hybrid Systems
Embedded Systems

Digital World

- Artificial
- Computations
- Computational time
- Discrete
- Math: State machine
- Open system
- Uncontrollable
- Unpredictable

Natural

Artificial

Cyber-physical systems

… and related terms: Internet of Things & Industry 4.0

Cyber-physical systems **OR** Internet of things **?**

Shared

Vision	• large-scale distributed computing systems of systems • Computation and "intelligence" is not decoupled from environment
Core Technology	• Internet as large-scale network • embedded systems (= intelligent components)

Distinct

Scientific Community	• **Internet of Things** driven from computer sciences, Internet technologies driven by EC • **Cyber-physical system** driven from engineering aspects driven by the NSF
Philosophy, focus	• **Internet of Things** focusing on **openness** and on the **network** - virtuality • **Cyber-physical system** focusing on the **physical system** behind, often a **closed-loop system**

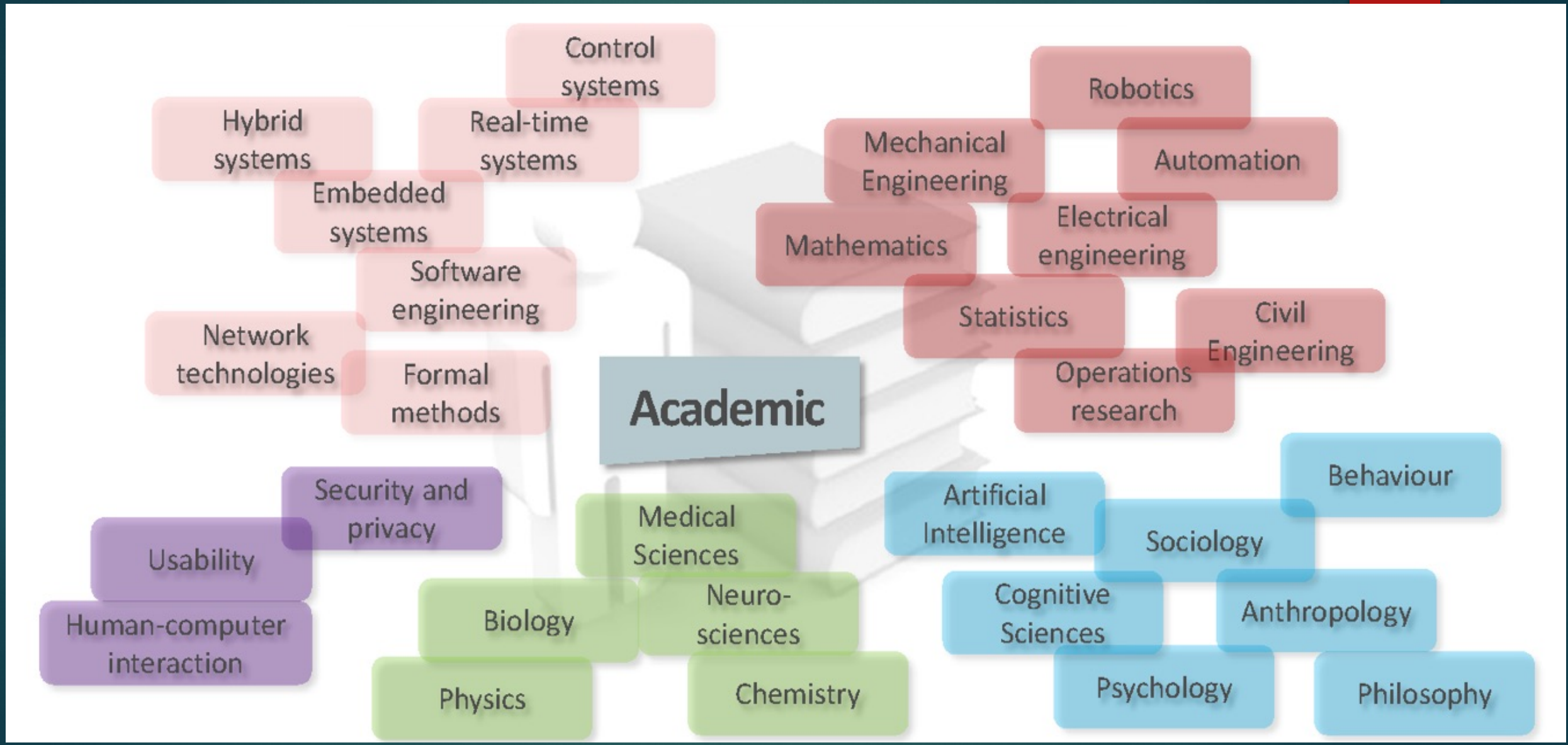
For all practical purposes:

- Today: more or less synonym
- Industry 4.0 as a special field of application

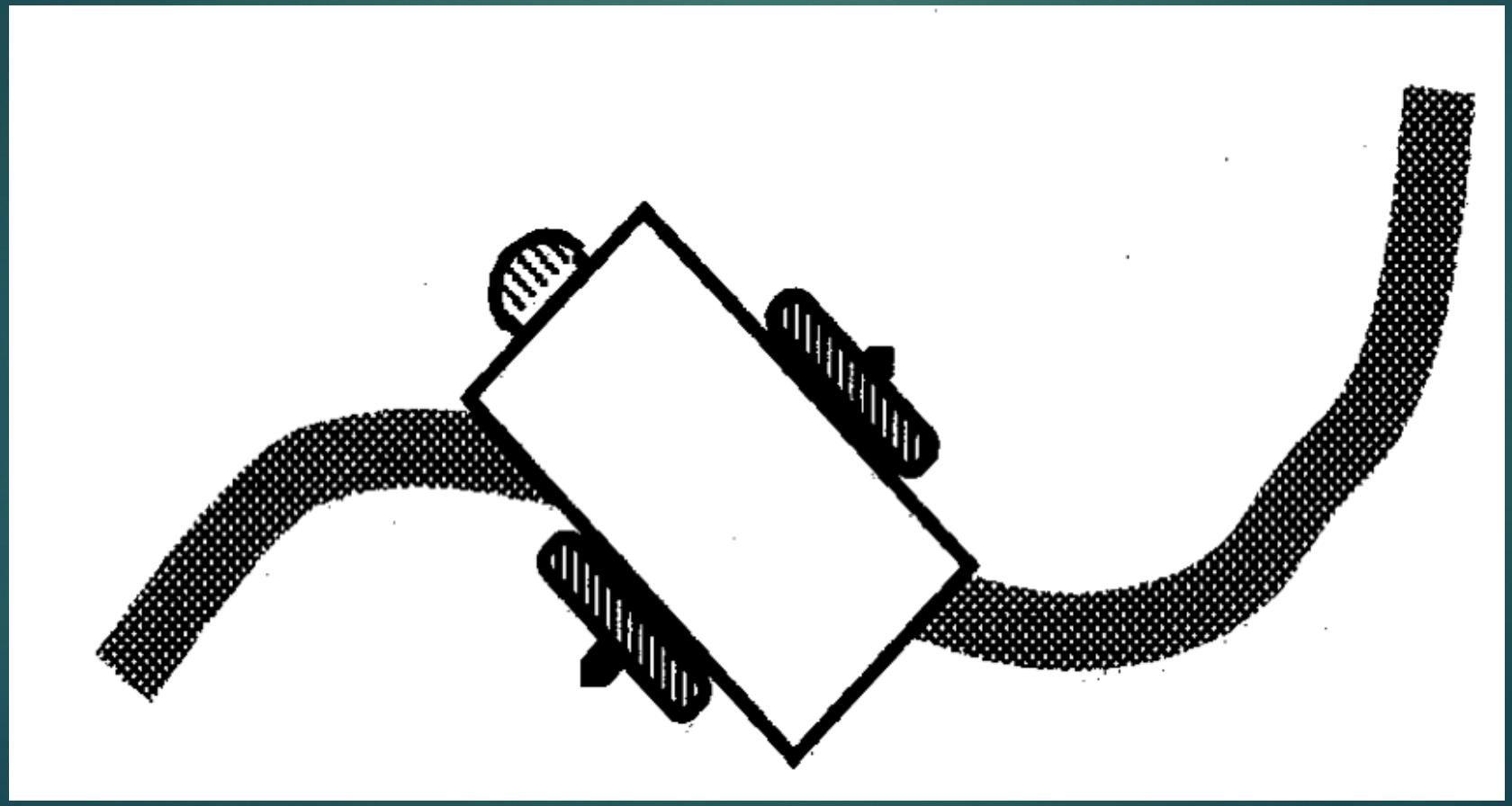
“The innovation and development of Cyber-Physical Systems will require computer scientists and network professionals to work with experts in various ...disciplines .... This, will revolutionize how universities educate engineers and scientists.”

Rajkumar, Cyber-Physical Systems: the next computing revolution, 2010

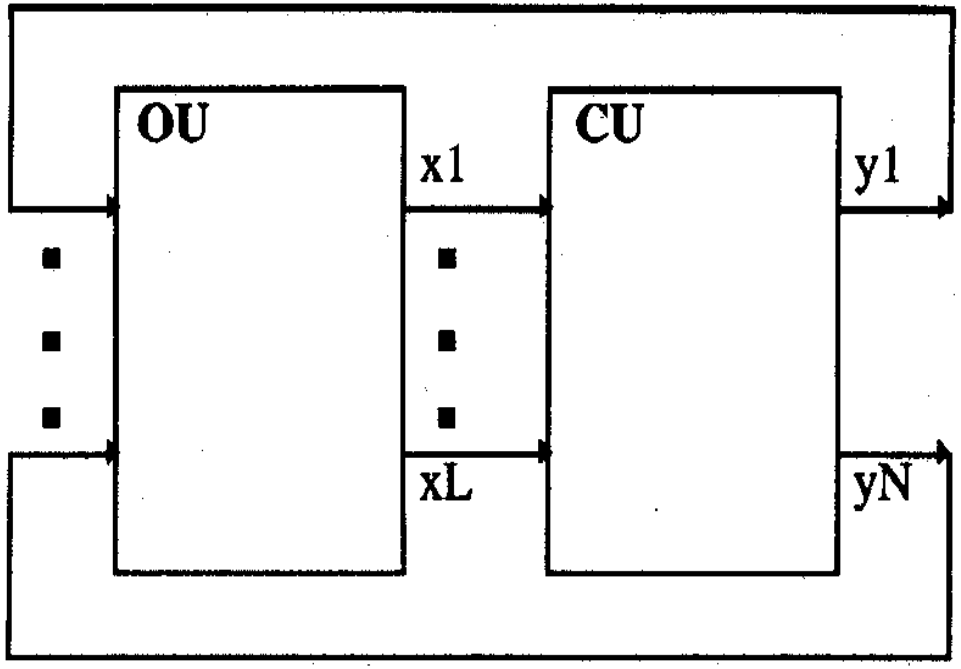
Leading to interdisciplinary science and education



TWO EXAMPLES:
Line Seeker-1997 vs. Line Seeker-2017



Line Seeker -1997



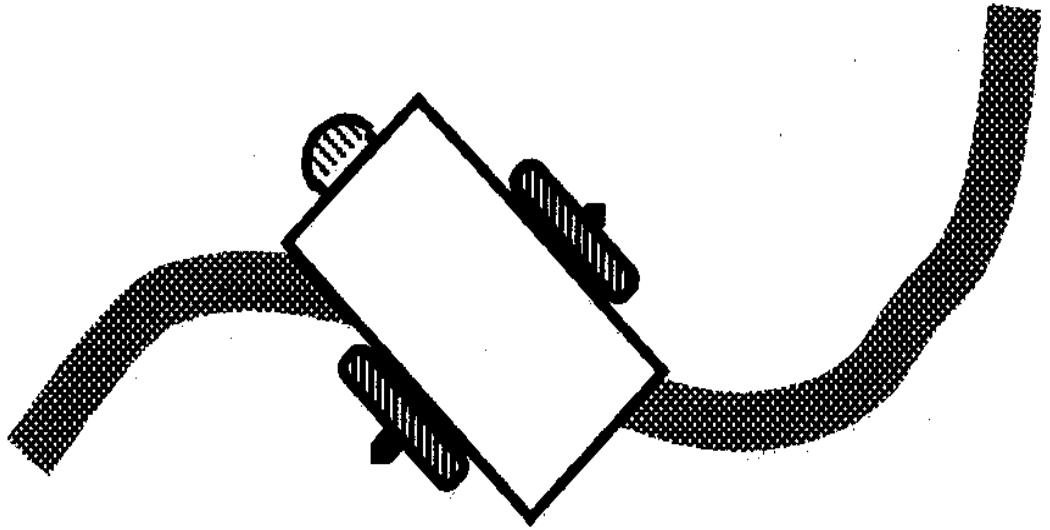
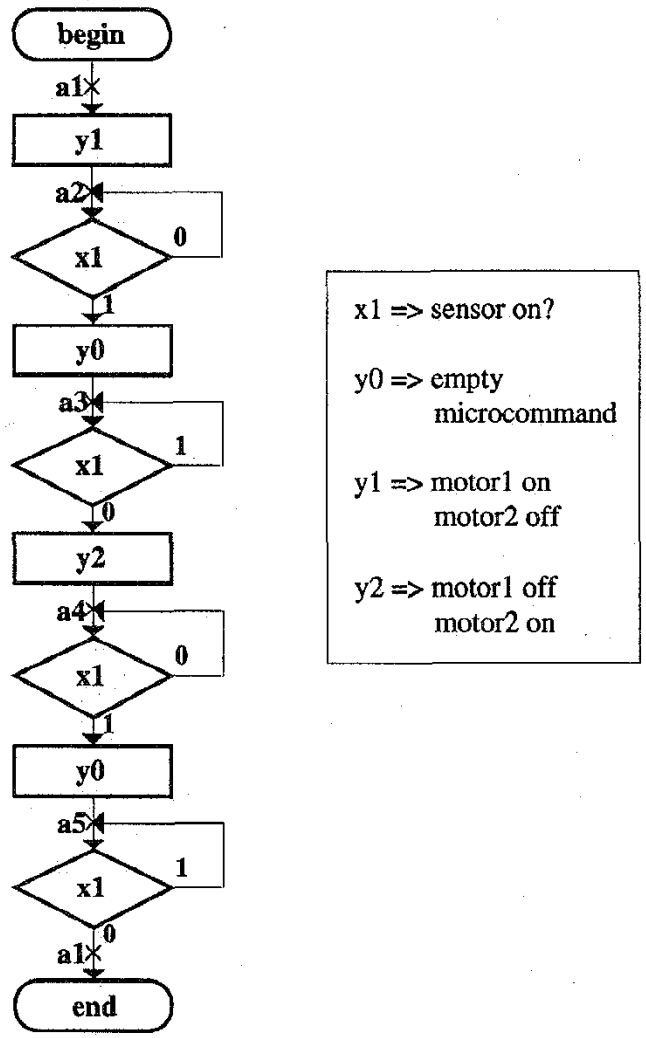


Fig. 2. The "line-seeker" device.

Line seeker -1997

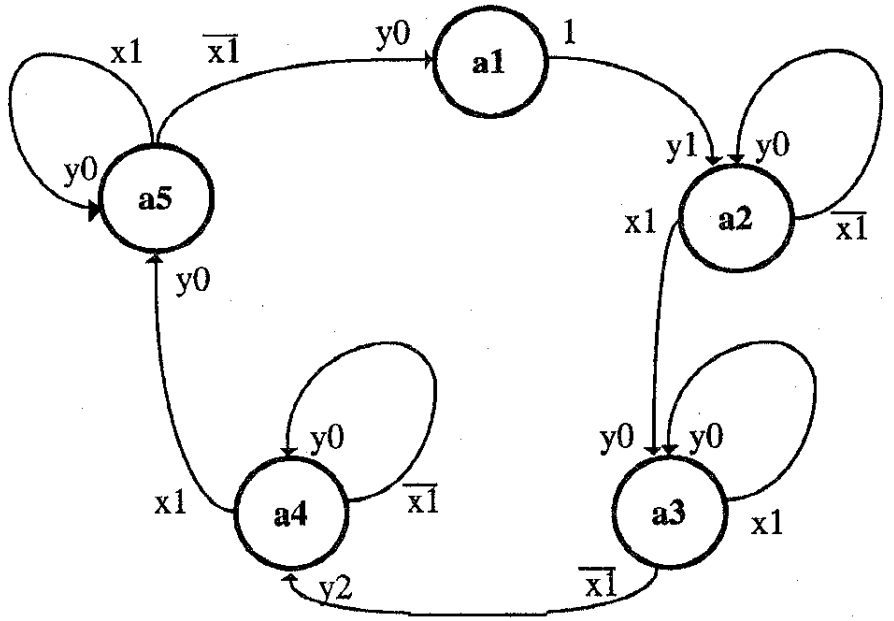


x1 => sensor on?

y0 => empty microcommand

y1 => motor1 on
motor2 off

y2 => motor1 off
motor2 on



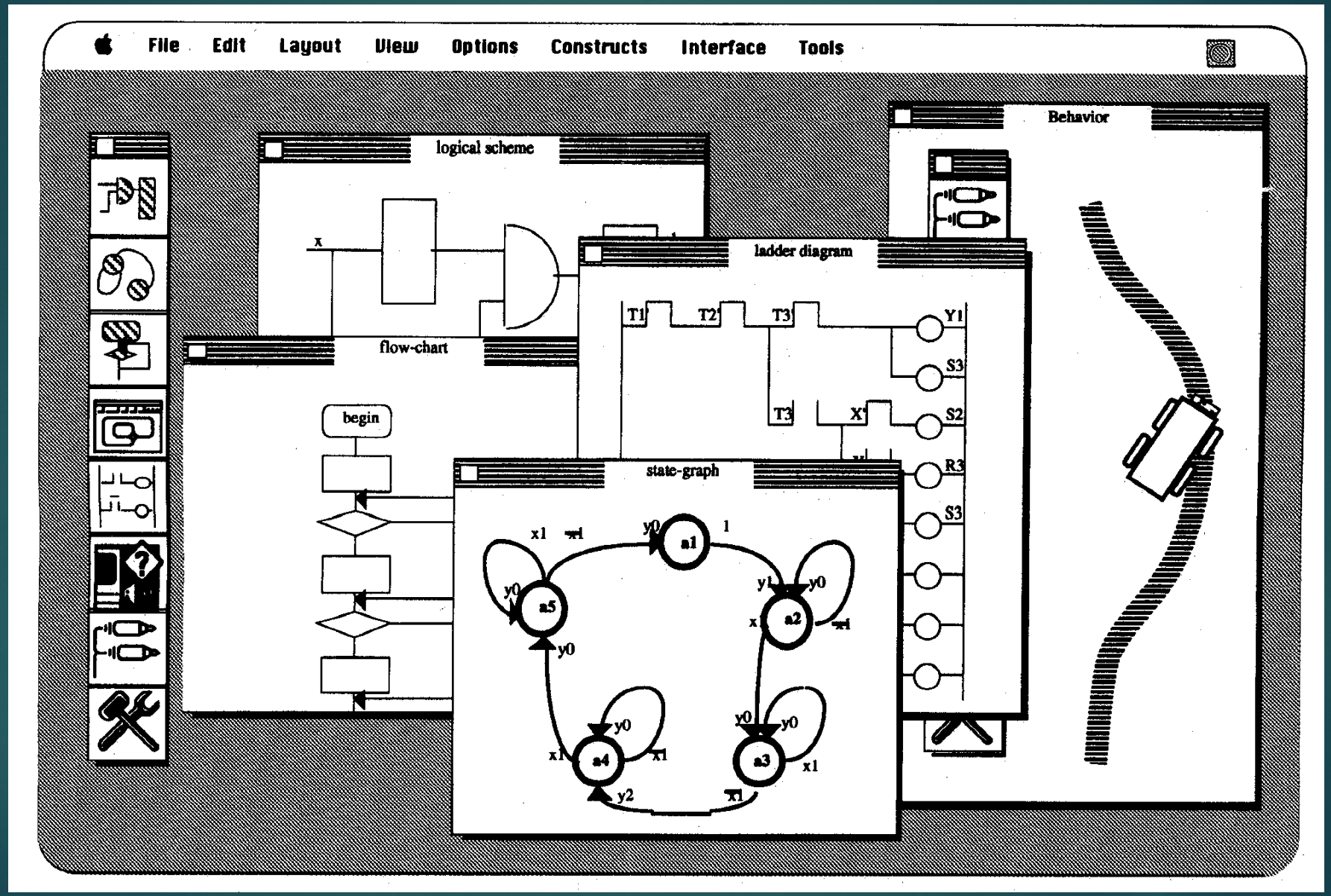
Transition table
a(t+1)= δ(a(t),x(t))

x\a	a_1	a_2	a_3	a_4	a_5
0	a_2	a_3	a_4	a_4	a_1
1	a_2	a_2	a_3	a_5	a_5

Output table
y(t)= λ(a(t),x(t))

x\a	a_1	a_2	a_3	a_4	a_5
0	y_1	y_0	y_2	y_0	y_0
1	y_1	y_0	y_0	y_0	y_0

Line Seeker -1997



Line seeker - 1997

The robot is equipped with a light sensor and motors actuators

1. The line-seeker follows the line by the sensor and a control algorithm
2. Firmware design

Line-seeker robot turns on its motor and moves from its present position to the destination according to the color under the sensor

Line seeker - 2017

The robot is equipped with GPS sensor and communicate with the cloud

1. Line-seeker robot follows the line by using it's internal GPS sensor and a line-road map
2. The line surface updates its configuration (map) to the Web
3. High level design

1. Line-seeker robot turns on its motor and moves from its present position to the destination according to the line's map.
2. The line surface sends its configuration (map) to the Web.

Line seeker - 2017

Conclusions

- CPS is the main design object of the 4-th Industrial Revolution
- CPS is the Hybrid System
- CPS is communicating system
- CPS is synonym of IoT
- Design is changing significantly
- From Firmware design to Cognified System design