
Cybernetics

Cybernetics

- It deals with general principles of regulatory systems and information transfer in machines, living organisms and communities
- Based on the observation that some of the processes in living organisms can be described by the same mathematical equations as similar processes in technical installations, but also in the social systems
- Widely interdisciplinary field

Cybernetics

- Theoretical Cybernetics - a general description of information and control processes, mainly uses mathematical description of the studied processes
- Experimental Cybernetics - examines the information and control mechanisms in specific cases using simulation or modeling methods

Cybernetics

- Applied Cybernetics - uses cybernetic approach to the design and analysis in these specialized fields and sectors
  - Technical Cybernetics
  - Biocybernetics
  - Social Cybernetics

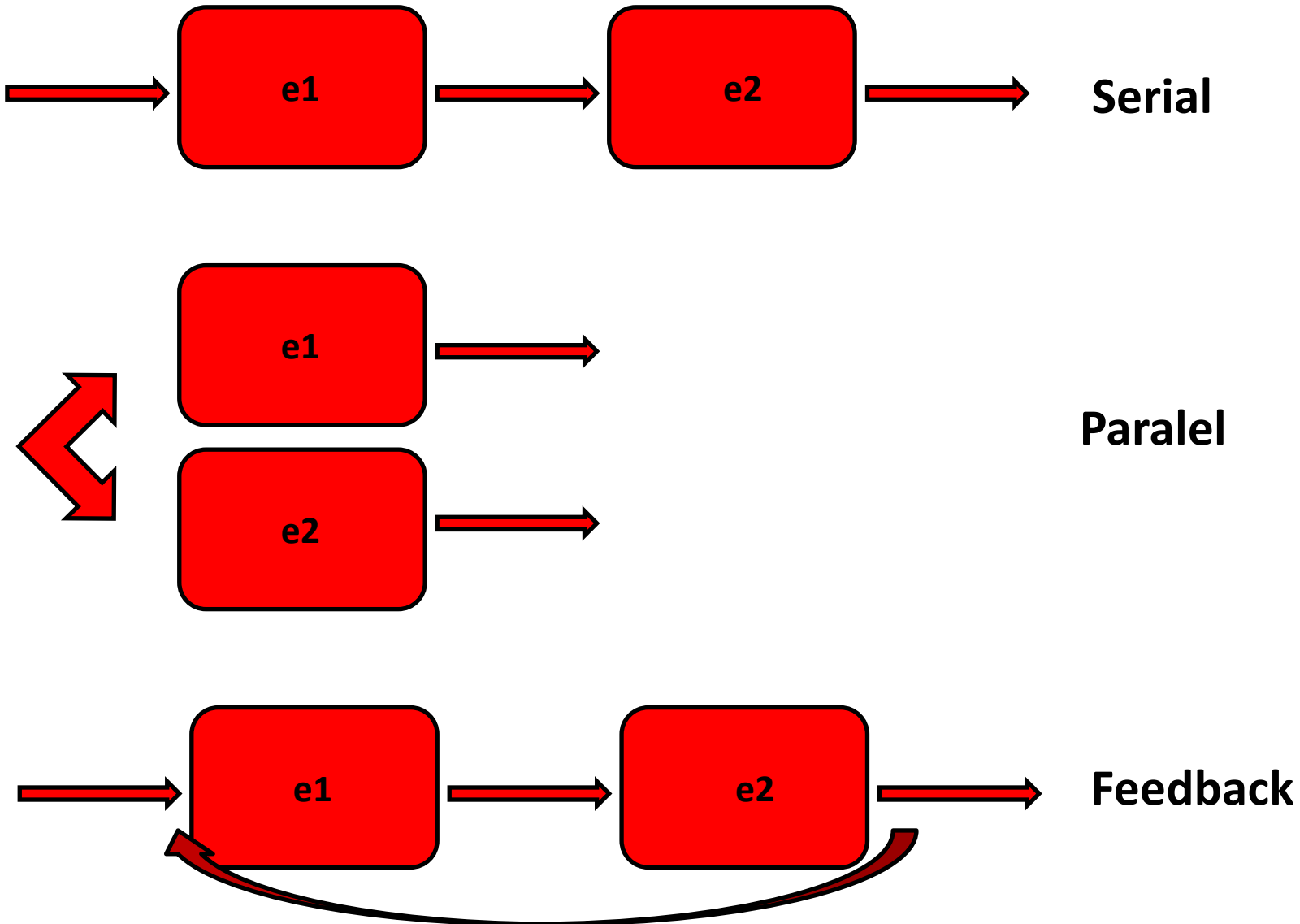
Biocybernetics

- Biocybernetics - uses cybernetics to study living systems
- Analysis and modeling of regulation and control systems of living organisms under physiological and pathological conditions
- Pathological process - violation of the regulatory mechanisms of living system
- Therapy = compensation of regulatory mechanisms disruption

Basic concepts

- Cybernetic systems - a set of elements, among which there are some relationships
- Cybernetic system is a simplified expression of objective reality
- Systems can be divided into:
  - Static - includes passive elements that do not influence each other
  - Dynamic - contains active elements (they have an input and output) that are in mutual functional relations

Basic concepts - linkage



Basic concepts

- Cybernetic systems
  - Totally enclosed - interaction with the environment does not exist
  - Relatively closed - have limited interaction with the environment
  - Open systems - unlimited interaction with the environment
- Environmental influences acting on the system = input values; the impact of the system on the environment = outputs

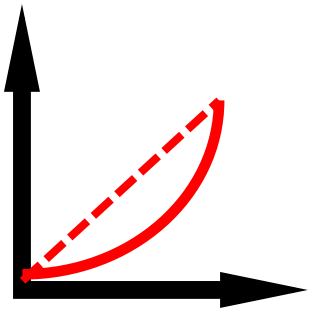
Basic concepts

- The dependence of variables output on changes in the values of the input variables = system static characteristics
  - Linear systems - static characteristic is a straight line
  - Nonlinear systems - static characteristic curve or a broken line

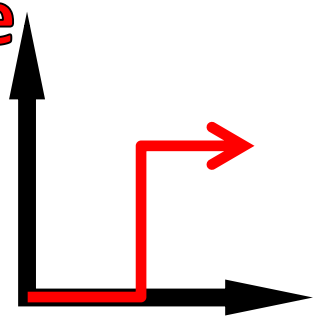
Basic concepts

The time course of changes in the output variable determines the behavior of the system

- **Continuous - continuous change in time**



- **Discontinuous - change is not smooth, eg. Step change**

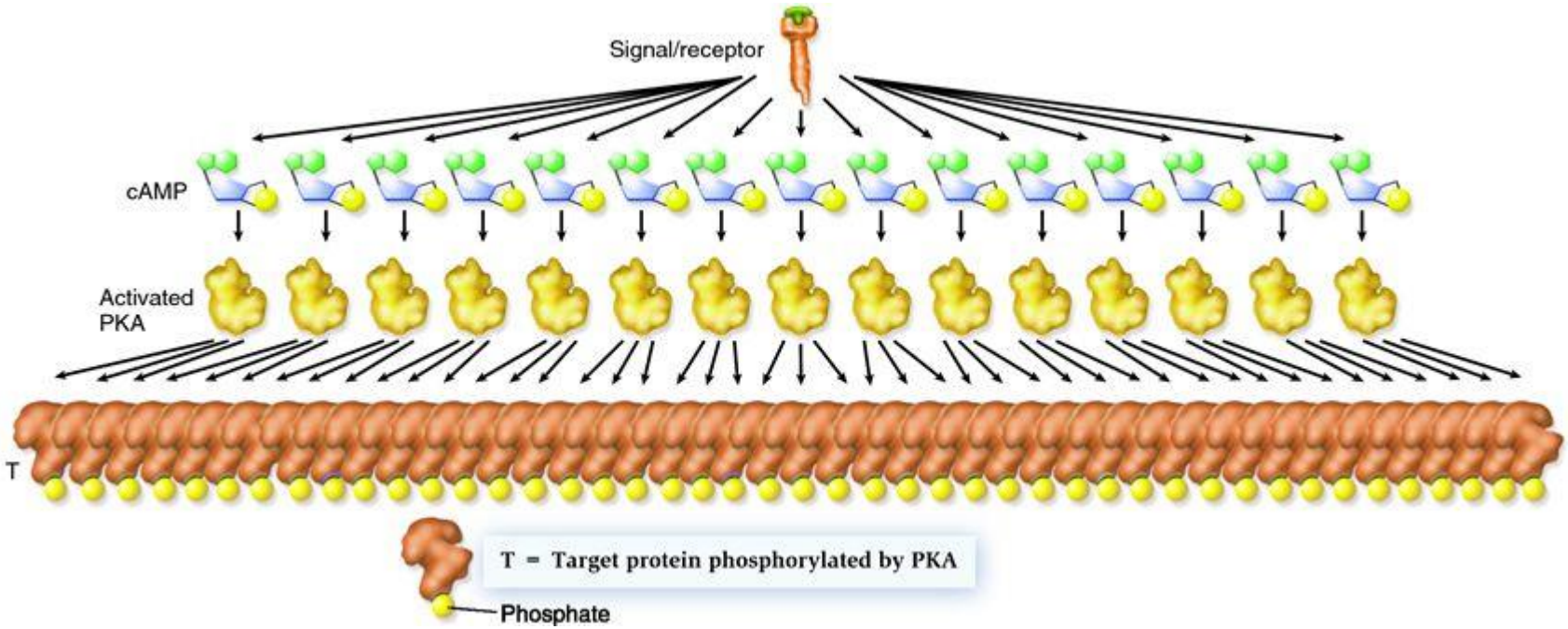


Dynamic systems

- Multiple interactions with the environment
- Transformation - state transition of input variables into state of output values
  - Unequivocal: one input, one output
  - Ambiguous: at least one input, multiple outputs
    - Random
    - Determined

Dynamic systems

- **Transformation - basic type is the increase or decrease of input values; as well as the delay of course, throughput, deformations ...**



Dynamic systems

Transformation in biological systems

- Increasing the signal is an important type of transformation, especially in sensory perception
- Decreasing the signal - homeostasis

- Progress of output values is generally delayed compared to the input quantities - in a biological system, caused by e.g. due to transport of signal molecules

- Relations between the input and output variables do not have to remain rigid - adaptation and learning; in biological systems affected by growth, development and aging

Information

- Information Theory - C. E. Shannon, W. Weaver
- Information = data about the processes occurring in the system and its surroundings
- Information is an indication of relations between systems and between parts of the same system

Information

Information entropy

- **We have a phenomenon which may result in A1 ... An of the results with the same probability of occurrence**
- **With the growing number of result options of this phenomenon, degree of uncertainty around the phenomenon is also growing**
- **The degree of uncertainty is given by the number of partial uncertainties of the individual results; degree of uncertainty = information entropy**

Information

- Information theory uses the principles of probability theory
- Probability theory is the study of random phenomena = phenomena, which may or may not occur in certain conditions
- The frequency of the phenomenon is given by the percentage of cases where the phenomenon actually occurred in the total number of options which could occur

$$F_A = \frac{n}{N}$$

Information

- With a sufficiently large number of experiments we obtain the mean value of the frequency of the observed phenomenon, and this expresses the probability P(A)
- The more observations of this phenomenon we perform, probability is then more accurate
- Probability ranges from 0-1
- If the probability is zero, monitored phenomenon is impossible
- If the probability is equal to one, it is given as a certain event

Information

Information entropy

- In n mutually exclusive phenomenon results with probabilities P (A1), P (A2) ... P (An), degree of uncertainty Ni of one possible outcome is a product of the probability and the logarithm of the probability:

$$N_i = -P(A_i).\log_2 P(A_i)$$

  - Information entropy of the whole system is the sum of the partial uncertainties:

$$H = \sum_{i=1}^{n} -P(A_i).\log_2 P(A_i)$$

Information

- Imagine two machines that generate symbol letters A B C D
- The first machine generates random letters, ie. with equal probability, i.e. 25% for each character

A	B	C	D
25%	25%	25%	25%

Information

- Imagine two machines that generate symbol letters A B C D
- The second machine generates letters with the following probabilities:

A	B	C	D
50%	12,5%	12,5%	25%

Information

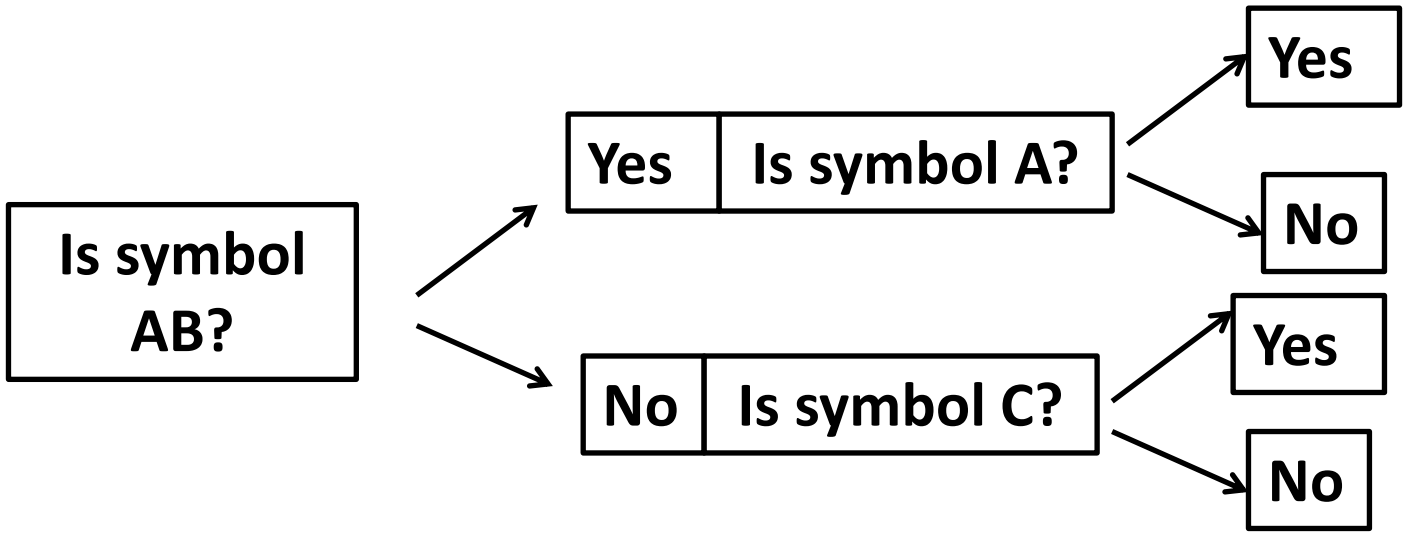
Which machine produces more information entropy?

- **C. E. Shannon: If you have to guess the next symbol, what is the minimum number of questions that you must ask to know that symbol?**
- **The most effective way is to ask the question, which divides probability in half**

Information

- **First machine:**

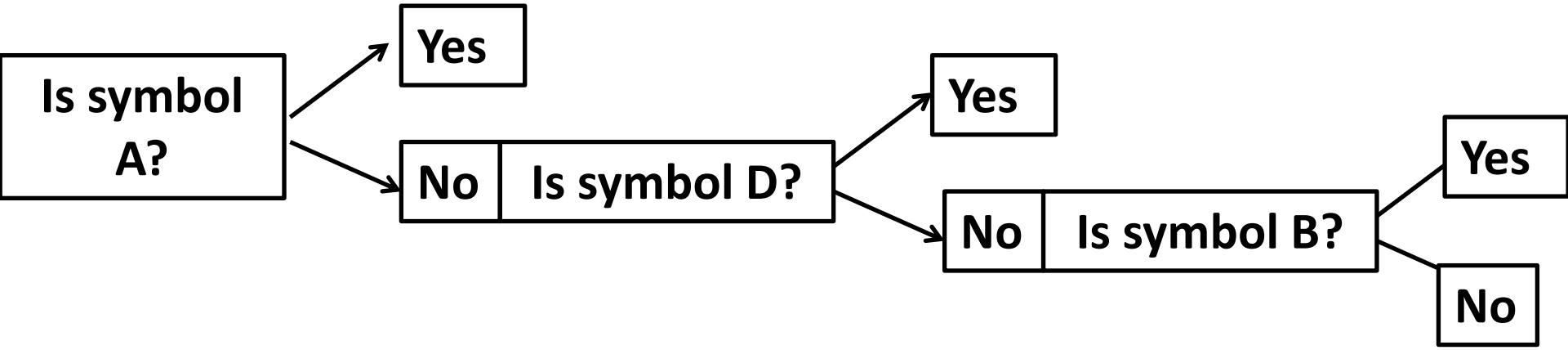
A	B	C	D
25%	25%	25%	25%



Information

- **Second options:**

A	B	C	D
50%	12,5%	12,5%	25%



Information

- **Entropy is the sum of the probabilities of each character multiplied by the number of questions to get this character**

$$H = \sum_{i=1}^{n} p_i . \#questions_i$$

$$\#questions_i = \log_2 \#results_i$$

$$\#results_i = \frac{1}{p}$$

$$H = \sum_{i=1}^{n} - p_i . \log_2 p_i$$

Information

- Number of questions:
  - First machine= pA*2 + pB*2 + pC*2 + pD*2 = 2
  - Second machine = pA*1 + pB*3 + pC*3 + pD*2 = 1,75

  - = In first machine for 100 symbols we have to ask for 200 questions, in the second only 175 questions
  - Second machine produces less entropy, because there is less uncertainty on output = lower entropy

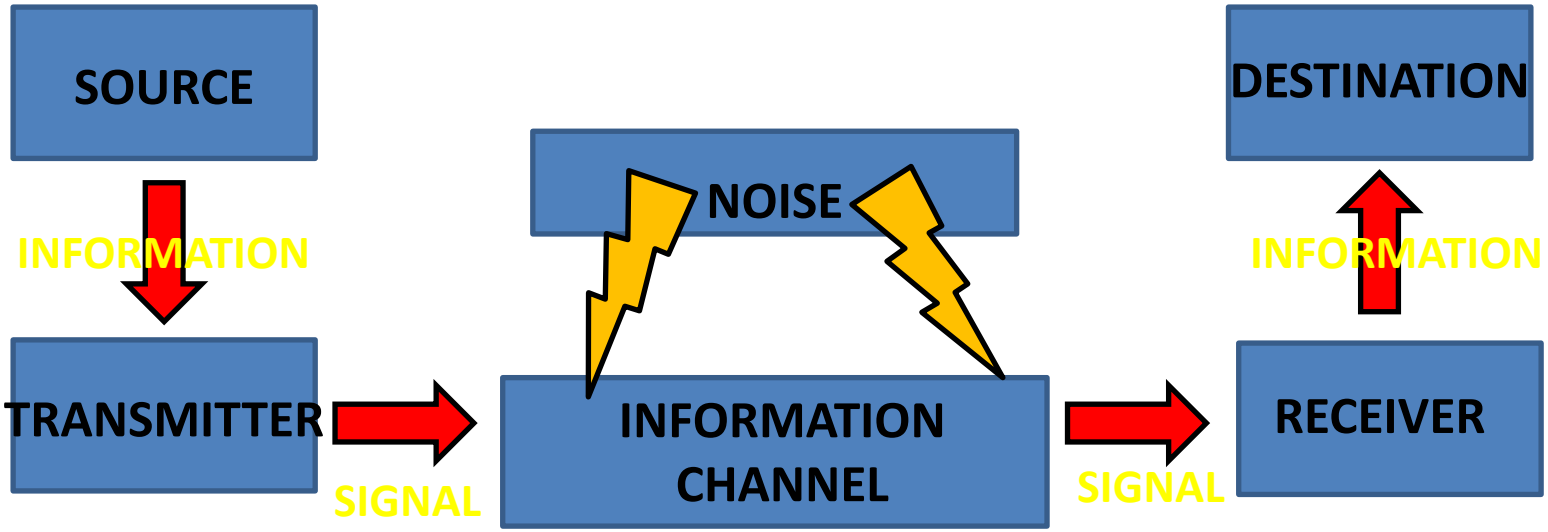
Information

- Entropy is at its maximum when all the results are just as likely, if you deviate from the equally likely outcomes or there is predictability, entropy decreases
- The entropy = 1 bit (0/1; yes / no; +/- ...)

Information system

- The simplest system - the source of information - information channel - receiver of information
- It is usually necessary to convert the signal by a transmitter (physical media) - Coding
- Signal changes in the receiver back on the information - decoding

Information system



Information system

- Elemental signal = carries one bit of information
- Information channel capacity - the maximum amount of information transmitted per unit of time
- Factors reduce the amount of original information = noise
- To increase reliability, it is necessary to transmit a certain amount of extra information = redundant information

Information system

- In the human body - the transfer of information is nervous and humoral
- Three basic level assessment of the transmission and processing of information:

1. Management of basic biochemical reactions (humoral)
2. Autonomous systems (humoral and neural mechanisms)
3. Central nervous system

Control and regulation

- Function: to achieve the desired state
- Control - changes in the system behavior, which is based on information received from the control section
  - Controlled systems
  - regulated (feedback) systems

Control and regulation

- Regulation - a phenomenon that minimizes the difference between the actual values of controlled variables and their desired value
- Automatic regulation - a special case, the three main properties:
  - Direct connection between procedure and control
  - Feedback (~~positive~~ / negative)
  - Conversion of information from feedback channel to control command

Control and regulation

- Control forms:
- Direct control - direct transfer control of commands
- Control with autonomic response - control commands are merely a mechanism moving the controlled system from one equilibrium to another (hormonal control)
- Differentiated complex procedure - a combination of the two previous cases - the central nervous system

Principles of modeling

- Modeling - a theoretical cognitive processes; objective is based on the master view knowledge of their properties
- Abstraction of identification - taking into account only those properties that are similar to the original model, and; if the model adequately displays the properties of the original, it can be used as a source of information about it
- Analogy - structural or functional similarity between objects, processes and phenomena
- Isomorphism: two analogue systems conforming a mathematical description

Principles of modeling

- Models - formally
  - Real (physical, chemical)
  - Abstract (mathematical)
- Models – according to creation
  - Inductive (formation based on empirical experience)
  - Deductive (based on projected relations)
- Models - according to purpose
  - Descriptive (characterization of the original)
  - Explanatory (test hypotheses)

Principles of modeling

System simulation

- **Replacement of the original system simulation model**
- **The verification of the findings obtained through a simulation model to the original system**

Digital Health

- Digital Health addresses the development of interconnected health systems to improve the use of computing technologies, smart devices, computer analytical techniques and communication media to help healthcare professionals and patients to manage disease and health risks.
  - Hardware and software
  - Telemedicine
  - Internet
  - E-mail
  - Mobile Phones & Apps (Smartphones)
  - monitoring devices (clinical and personal)

Digital Health

- Supporting technologies and rehabilitation robotics for people with disabilities (independence of patients)
- monitoring sensors and wearables
- Virtual reality, rehabilitation video games and serious games providing social and interactive experiences for student and patient education
- Speech and auditory systems for natural communication processing, speech recognition techniques and medical devices (eg cochlear implants)
- Telehealth, telemedicine, telecare, telecoaching and telerehabilitation - remote support of classical therapy

Monitoring devices

Blood glucose monitoring apparatus

- Using continuous glucose monitoring, glucose levels can be monitored throughout the day. In conjunction with the transmitter and glucose sensor, glucose data is transmitted wirelessly to the insulin pump

e-Health

The term may include a range of services or systems:

- Electronic Health Record: sharing patient data between different healthcare professionals (doctors, specialists, pharmacists, etc.); Complications: controversy over the confidentiality of private data
- ePrescribing
- Cybermedicine - use of the Internet for therapy (replacement of teletherapy)
- Medical research
- Health informatics / health information systems
- mHealth: use of mobile devices to collect overall health data, monitor patient vital signs in real time, and direct care delivery (via mobile telemedicine)

Pharmaco-cybernetics

- is a new direction that aims to promote the right use of medicines and the right medication through the application of information and internet technologies to improve pharmaceutical care for patients

Pharmaco-cybernetics

Four basic recommendations for developers of pharmaco-information tools and applications:

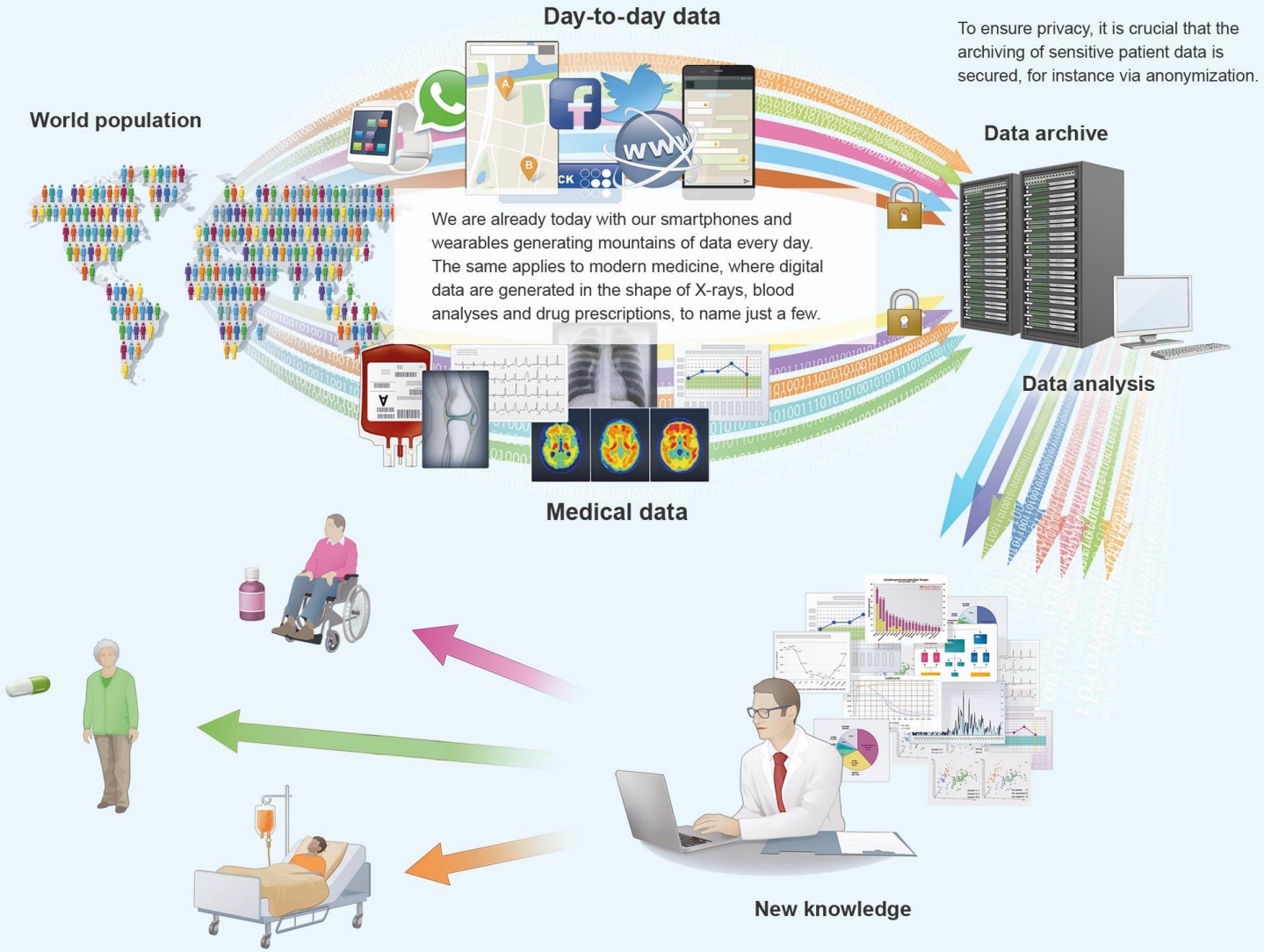
- Quality of information: The quality of information should be as accurate as possible, based on solid knowledge, obtained from relevant sources (scientific publications, established drug databases, SPCs)
- Amount of information: The tool / application should provide an adequate amount of information regarding drugs or pharmacotherapy so that the users have sufficient knowledge to minimize complications associated with drug use.
- Relationship to the target audience: The content should be relevant to the target audience and should provide maximum clarity.
- Method of data presentation: The presentation of information must be absolutely clear so as not to give contradictory information or misinterpretation

Pharmaco-cybernetics

It brings new problems related to drug use:

- Dehumanizing the patient - caregiving relationship
- Virtual conflicts of therapeutic recommendations
- Online self-medication

Big data in medicine



To ensure privacy, it is crucial that the archiving of sensitive patient data is secured, for instance via anonymization.

By taking into consideration all available information about the effects of the different drug products in real-life conditions (Real Life Evidence), the doctor can selectively prescribe the ideal treatment for each individual patient.

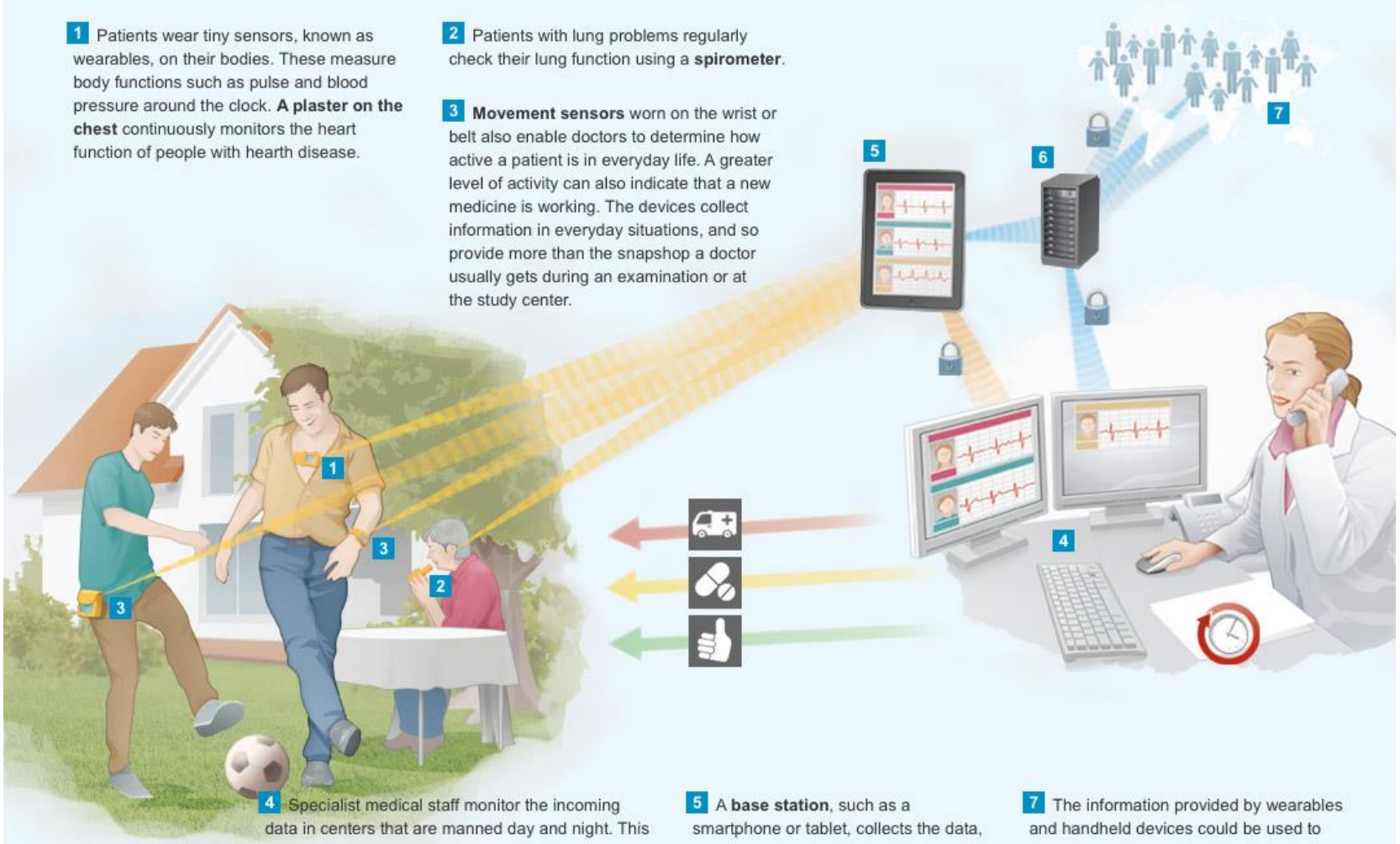
If it were possible to compile all relevant data on one central database, scientists would be able to leverage the full potential of these state-of-the-art technologies. The medical world could derive a lot of new knowledge. These data could likewise be used to optimize conventional clinical studies right from the beginning.

Mobile Sensors for Optimized Therapies

1 Patients wear tiny sensors, known as wearables, on their bodies. These measure body functions such as pulse and blood pressure around the clock. **A plaster on the chest** continuously monitors the heart function of people with hearth disease.

2 Patients with lung problems regularly check their lung function using a **spirometer**.

3 **Movement sensors** worn on the wrist or belt also enable doctors to determine how active a patient is in everyday life. A greater level of activity can also indicate that a new medicine is working. The devices collect information in everyday situations, and so provide more than the snapshop a doctor usually gets during an examination or at the study center.

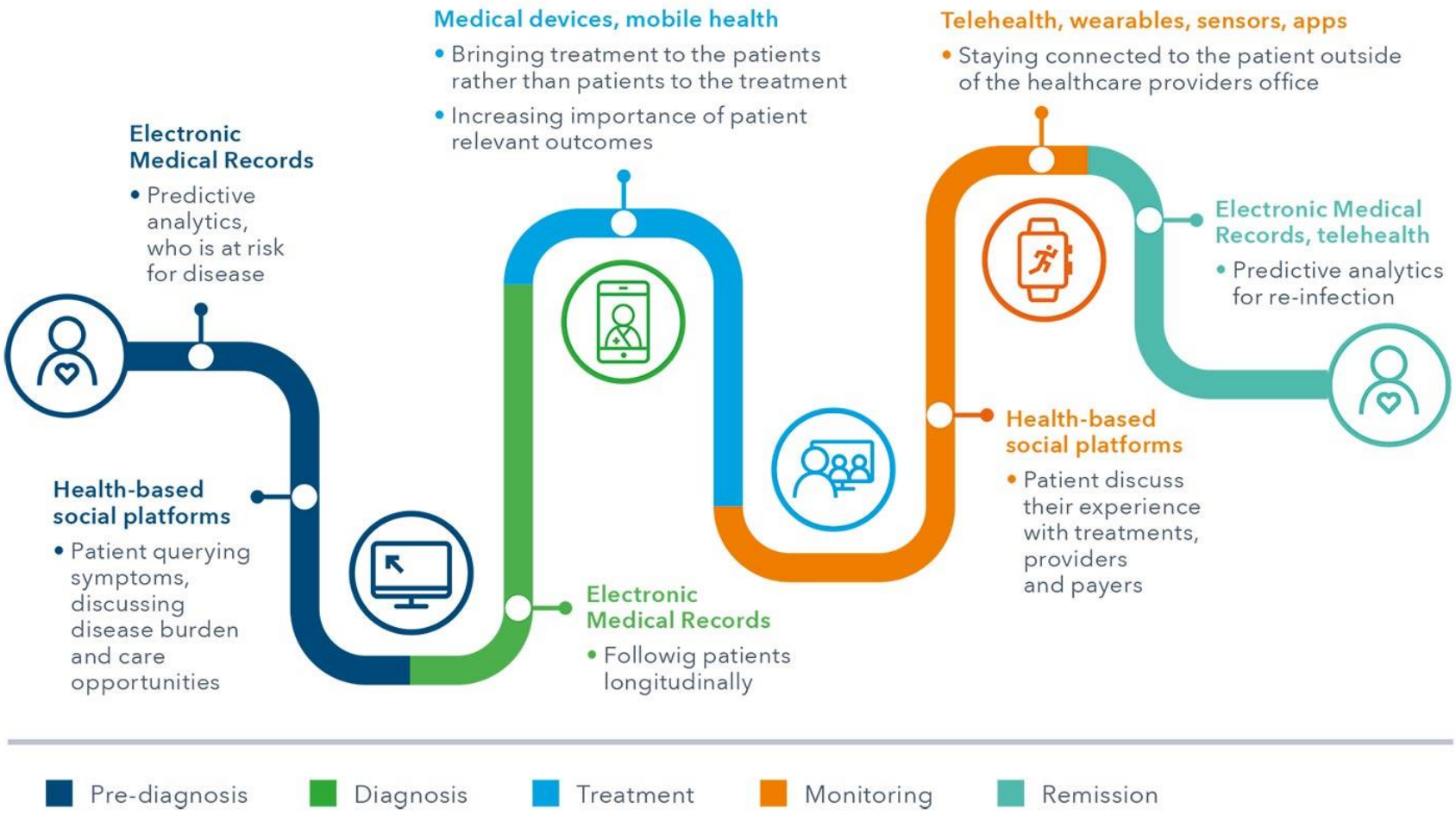


4 Specialist medical staff monitor the incoming data in centers that are manned day and night. This enables a rapid response if a patient's condition deteriorates. Depending on the situation, the **doctor** treating the patient **can be alerted**, or the patient can be requested to **modify the treatment** in consultation with the doctor. If all of the body's **functions are normal**, on the other hand, there is no need to disturb the patient's routine.

5 A **base station**, such as a smartphone or tablet, collects the data, encrypts them, and sends them to a database. During a clinical study, for example, this allows the ongoing collation of information from all study subjects.

6 **Data security** has top priority. All patient information is encrypted and stored in a certified central database.

7 The information provided by wearables and handheld devices could be used to **improve treatment**. The vast amount of data for comparison, illustrating such things as the effect of a medication on a patient group, makes it possible to tailor the treatment of individual patients even more precisely to their specific disease profile and life situation.


Electronic Medical Records
• Predictive analytics, who is at risk for disease
Health-based social platforms
• Patient querying symptoms, discussing disease burden and care opportunities
Medical devices, mobile health
• Bringing treatment to the patients rather than patients to the treatment
• Increasing importance of patient relevant outcomes
Electronic Medical Records
• Followig patients longitudinally
Telehealth, wearables, sensors, apps
• Staying connected to the patient outside of the healthcare providers office
Health-based social platforms
• Patient discuss their experience with treatments, providers and payers
Electronic Medical Records, telehealth
• Predictive analytics for re-infection
Pre-diagnosis
Diagnosis
Treatment
Monitoring
Remission

Smart Pills

Smart Pills

The oral dosage forms which contain one or more sensors, cameras or monitoring systems. The obtained information is then wirelessly sent to an external storage. The new dosage form is used as a digital drug-monitoring system or as a non-invasive GIT diagnostic method.

The goal of digital drug monitoring using smart pills is primarily to improve adherence in chronically ill patients, patients suffering from rare diseases and patients participating in clinical trials. The most common reasons for non-adherence include forgetfulness, side effects or fear of side effects, lack of motivation for treatment (the patient is not aware of the severity of the consequences of the disease and does not perceive the benefits of treatment), use of large amounts of drugs or complex treatment regimen.

Smart Pills in treatment

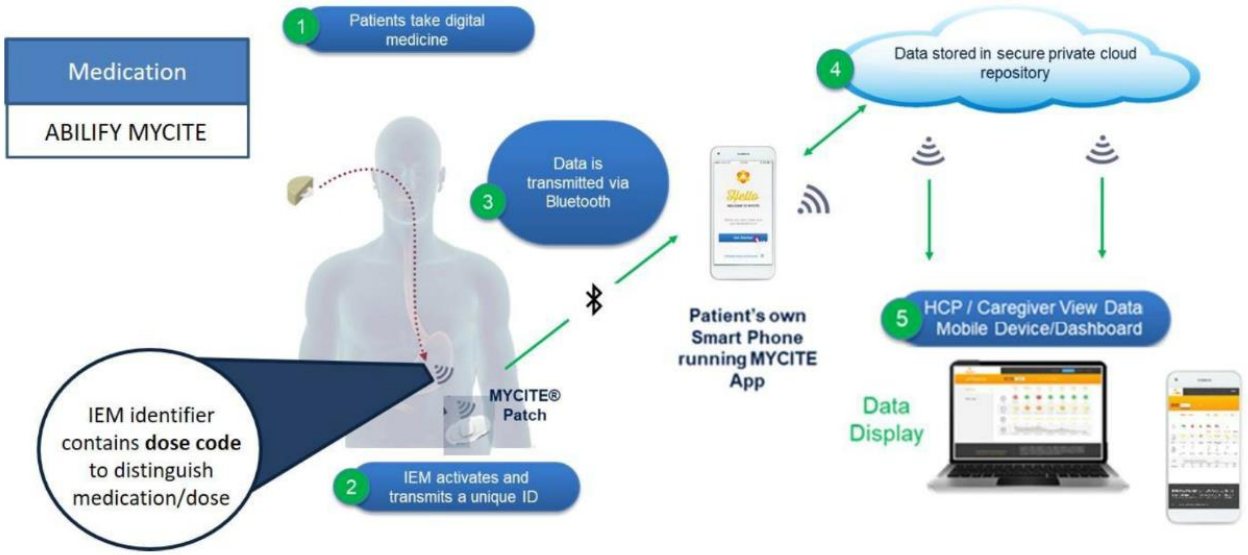
Abilify Mycite (Aripiprazol)

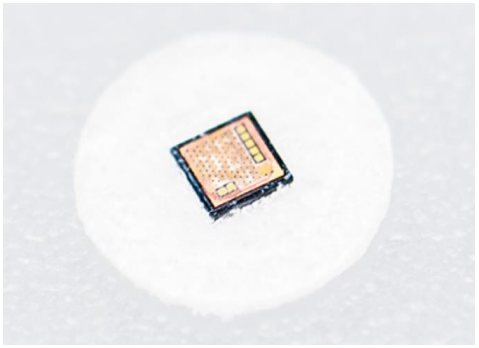
- **2017 the first smart pill approved by the FDA.**
- **2019 this pharmaceutical form has been included in the European Directorate-General for Medicinal Products' database as "tablet with sensor".**

Abilify MyCite system contains these components:

- **Tablets containing aripiprazole, an atypical antipsychotic, and an ingestible 1 mm sensor**
- **MyCite patch containing a monitor to detect the signal of the administered tablet and transfer data to the patient's mobile application**
- **Mobile application for recording acquired data**

Smart Pills in treatment



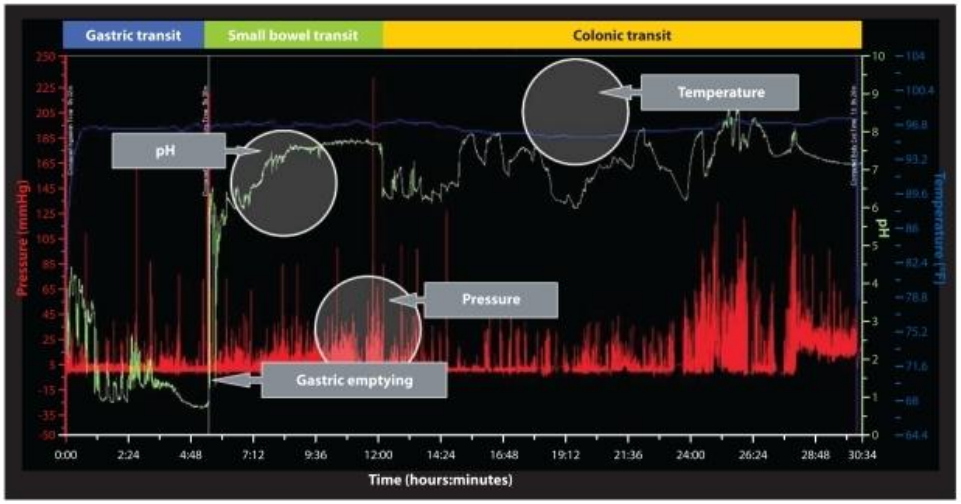


Abilify MyCite system

Smart Pills in diagnostics

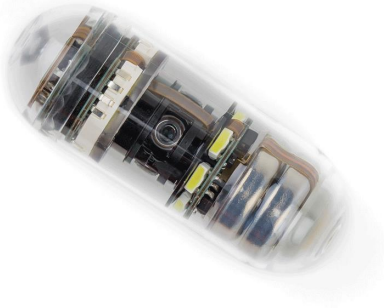
Smart pill motility testing system

- pressure, pH, temperature, transit times in GIT
- FDA approved for diagnostic purpose
- Indications: gastroparesis or chronic functional constipation



CapsoCam

- capsule for small bowel diagnosis
- mini cameras providing 360 ° image




Thanks for attention