# CONNECTIONS AND INTERFACES OF MECHATRONIC COMPONENTS ON DIGITAL FACTORY

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**Rezumat.** *În ultimii ani, componentele mecatronice ale fabricii digitale manifestă un interes din ce în ce mai mare. Astfel, au apărut noi oportunități în acest domeniu. Componentele fabricii digitale, cum ar fi mecanica, electronica și software-ul, trebuie dezvoltate independent, astfel încât să formeze la final un sistem. Drept urmare, fabrica digitală este un astfel de sistem. Mecanica evoluează practic spre informatică și, prin urmare, avem un produs finit cu o precizie mai mare, funcționând mai repede și mai fiabil. Fabrica digitală oferă o gamă completă de hardware, software și servicii încorporate bazate pe tehnologie. În această lucrare ne vom referi la componentele mecatronice, precum și modul în care sunt utilizate în fabrica digitală.*

**Abstract.** *In recent years, the mechatronic components of the digital factory are showing increasing interest. Thus, new opportunities have emerged in this area. Components of the digital factory, such as mechanical, electronics and software, need to be developed independently so that they finally form a system. As a result, the digital factory is such a system. Mechanics evolves practically towards computer science, and as a result we have a finite product with greater accuracy, working faster and more reliable. The digital factory offers a full range of embedded hardware, software and services based on technology. In this paper we will refer to the mechatronic components, as well as how they are used in the digital factory.*

**Keywords:** Mechatronics, Control interface/ computing hardware, Digital factory

## 1. Introduction

Mechatronics is a multi-disciplinary approach to product and manufacturing system design. Mechatronics, the mechatronic engineering, is a synergic and systematic combination of mechanics, electric/electronics and real-time computing, with `mecha` from the word mechanism and `tronics` from the word electronics (Fig. 1).

The interest of this interdisciplinary engineering area is to design powerful automated systems and allow for the control of complex systems.

The term "mechatronics" was introduced by an engineer from the Japanese company "Yaskawa Electric Corporation" in 1969. The term mechatronic appeared officially in France in Larousse 2005.

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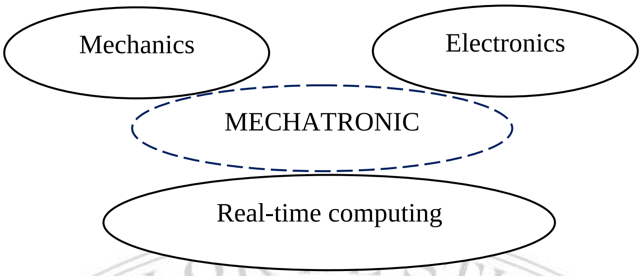


**Fig. 1.** The approach of the mechatronic discipline

The NF Standard E 01-010 (2008) defines mechatronics as an "approach to synergistic integration of mechanics, electronics, automation, and informatics into designing and manufacturing a product to increase and / or optimize its functionality". [8]

The term mechatronics is used to denote a rapidly developing, interdisciplinary field of engineering dealing with the design of products whose function relies on the integration of mechanical and electronic components coordinated by control architecture.

The primary disciplines important in the design of mechatronic systems include mechanics, electronics, controls, and computer engineering. A mechatronic system engineer must be able to design and select analog and digital circuits, microprocessor-based components, mechanical devices, sensors and actuators, and controls so that the final product achieves a desired goal.

The development of mechatronic systems involves the use of multiple disciplines, from mechanical engineering to electronics engineering and computer science. Every discipline was developed independently and then integrated to generate the final system. But the high-quality designs cannot be achieved without simultaneously considering all the engineering disciplines. The mechatronic carries intrinsic complexity into system design process and a lot of researches are developed to find out the optimal methods.

The engineering of such mechatronic systems requires the simultaneous and multidisciplinary design of several subsystems:

- Operative part (predominantly mechanical and electromechanical skeleton and muscle system);
- Part of the command (the built-in intelligence of the system, mainly Electronic and Real-Time Computers);
- Part of the machine / machine interface (data exchange between two separate systems, in particular IT and networks);
- Part of the human / machine interface (geometric shape and dialogue of the predominantly ergonomic and aesthetic system).

A global approach also reduces costs, increases reliability and modularity.

The advantages of mechatronics:
- Cost effective and good quality products;
- High degree of flexibility to modify or redesign;
- Very good performance characteristics;
- Wide are of application;
- Greater productivity in case of manufacturing organization;
- Greater extend of machine utilization.

As every system, some disadvantages exist:
- High initial cost;
- Multi-disciplinary engineering background required to design and implementation;
- Need of highly trained workers;
- Complexity in identification and correction of problems in the system.

## 2. The constitutive elements of the mechatronic components

The mechanical elements that make up the mechanical structure, the mechanism, the thermo-fluid, as well as the hydraulic aspects, form a mechatronic system. Mechanical elements may include static / dynamic mechanical characteristics and interact properly in the environment. The mechanical elements of mechatronic systems require physical power to produce motion, force, heat, etc.

Electromechanical elements refer to sensors and actuators. An actuator is something that converts energy into motion. It also can be used to apply a force (Fig. 2). An actuator converts the corrected signal into an input signal (moment, force, speed) according to the requirements process. Typically, is a mechanical device that takes energy - usually energy that is created by air, electricity or liquid - and converts it into some kind of motion. That motion can be in virtually any form, such as blocking, clamping or ejecting. Actuators typically are used in manufacturing or industrial applications and might be used in devices such as motors, pumps, switches and valves.

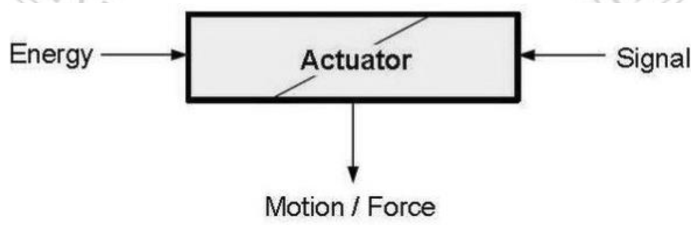


**Fig. 2.** The actuator

Most mechatronic systems involve motion or action of some sort. This motion or action can be applied to anything from a single atom to a large articulated structure. It is created by a force or torque that results in acceleration and displacement. Actuators are the devices used to produce this motion or action.

A sensor is a device, module, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics (Fig. 3).

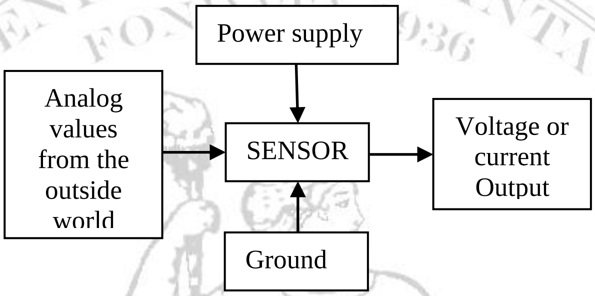


**Fig. 3.** The sensor

Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, besides innumerable applications of which most people are never aware. With advances in micro machinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, pressure or flow measurement, for example into MARG sensors. Moreover, analog sensors such as potentiometers and force-sensing resistors are still widely used. Applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics and many other aspects of our day-to-day life.

A variety of physical variables can be measured using sensors, e.g., light using photo-resistor, level and displacement using potentiometer, direction/tilt using magnetic sensor, sound using microphone, stress and pressure using strain gauge; touch using micro-switch; temperature using thermistor and humidity using conductivity sensor. Actuators such as light emitting diode (LED), DC servomotor, stepper motor, relay, solenoid, speaker, shape memory alloy, electromagnet, and pump apply commanded action on the physical process. In recent years, IC-based sensing and actuation solutions have also become ubiquitous (e.g., digital-compass, -potentiometer, etc.). The actuator is used in automatic systems for executing commands.

Electrical elements refer to electrical components (e.g. resistor (R), capacitor (C), inductor (L), transformer, etc.), circuits, and analog signals. Electronic elements refer to analog/digital electronics, transistors, thyristors, opto-isolators, operational amplifiers, power electronics, and signal conditioning. The electrical/electronic elements are used to interface electro-mechanical sensors and actuators to the control interface hardware elements.

Control interface/ computing hardware elements refer to analog-to-digital (A2D) converter, digital-to-analog (D2A) converter, digital input/output (I/O), counters, timers, microprocessor, microcontroller, data acquisition and control (DAC) board, and digital signal processing (DSP) board. The control interface hardware allows analog/digital interfacing, i.e., communication of sensor signal to the control computer and communication of control signal from the control computer to the actuator. The control computing hardware implements a control algorithm, which uses sensor measurements, to compute control actions to be applied by the actuator.

Computer elements refer to the hardware and software used to perform computer-aided dynamic system analysis, optimization, design, and simulation; virtual instrumentation; rapid control prototyping; hardware-in-the-loop simulation; and PC-based data acquisition and control.

## 3. The evolution of Mechatronics

The technology is growing in design, manufacturing, and operation of engineered products or devices or processes and those could be traced through:

- Industrial revolution;
- Semiconductor revolution;
- Information revolution.

Industrially, the semiconductor and information revolutions have led to major technological advances in designing and exploiting engineering products. [1]

Mechanical engineering, as a widespread professional practice, experienced a surge of growth during the early 19th century because it provided a necessary foundation for the rapid and successful development of the industrial revolution. At that time, mines needed large pumps never before seen to keep their shafts dry, iron and steel mills required pressures and temperatures beyond levels used commercially until then, transportation systems needed more than real horse power to move goods; structures began to stretch across ever wider abysses and to climb to dizzying heights, manufacturing moved from the shop bench to large factories; and to support these technical feats, people began to specialize and build bodies of knowledge that formed the beginnings of the engineering disciplines.

The primary engineering disciplines of the 20th century -mechanical, electrical, civil, and chemical- retained their individual bodies of knowledge, textbooks, and professional journals because the disciplines were viewed as having mutually exclusive intellectual and professional territory. Entering students could assess their individual intellectual talents and choose one of the fields as a profession. We are now witnessing a new scientific and social revolution known as the information revolution, where engineering specialization ironically seems to be simultaneously focusing and diversifying. This contemporary revolution was spawned by the engineering development of semiconductor electronics, which has driven an information and communications explosion that is transforming human life.

The **industrial revolution** has allowed the design of products and processes to convert and transmit more and more energy to industrial activities (Fig. 4). The design projects of this period carried out motion, detection, actuation and computation operations using mechanical components, such as cams, tools, levers, links, etc. Unfortunately, purely mechanical systems suffer from power amplification and power loss due to tolerances, inertia and friction. [2]

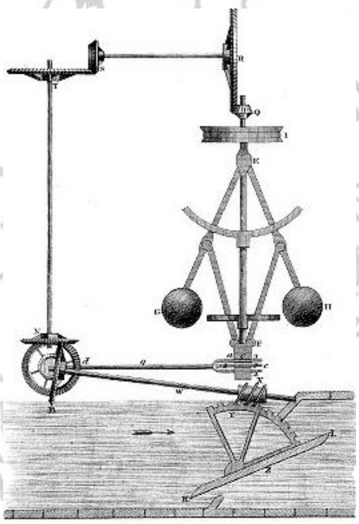

**Fig. 4.** The industrial revolution

The **semiconductor revolution** that led to the development of Integrated Circuit Technology (IC) has created the next key impact on designing engineering products (Fig. 5). This contemporary revolution was spawned by the engineering development of semiconductor electronics, which has driven an information and communications explosion that is transforming human life.

These days, we need to understand new ways to process information and be able to utilize semiconductor electronics within our products, no matter what label we put on ourselves as practitioners. Mechatronics is one of the new and exciting fields on the engineering landscape, subsuming parts of traditional engineering fields and requiring a broader approach to the design of systems that we can formally call mechatronic systems.

**Fig. 5.** The semiconductor revolution: an integrated circuit

On the drive side, through cost-miniaturized power electronics, for efficient power amplification, semiconductor technology has provided a practical means of delivering the power levels required for mechanical devices by electrical means. Similarly, on the sensor side, semiconductor technology has provided an ability to condition and encode physical measurements as analog / digital signals. In addition, on-board analog / digital electronic systems on board have provided computational skills to rudimentary mechanical devices. The rapid advances in mechanical detection and drive hardware that began in a previous era have further fueled the adoption of semiconductor technology in the design and operation of mechanical devices. [3]

The information revolution involves the development of VLSI technology led to the introduction of microprocessor, microcomputer, and microcontroller. Now computing hardware is everywhere, cheap, and small. As computing hardware can be effortlessly interfaced with real world electromechanical systems, it is now routinely embedded in engineered products/processes for decision making. [5]

The microcontrollers are replacing precision mechanical components, e.g., precision machined camshaft that in many applications functions as a timing device.

Programmability of microcontrollers is providing a versatile and flexible alternative to the hard-wired analog/digital computational hardware. [10]

Integrated computer-electrical-mechanical devices are now capable of converting, transmitting, and processing both the physical energy and the virtual energy (information). [6]

As a result, we have the highly efficient products and processes, which are now being developed by judicious selection and integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software.

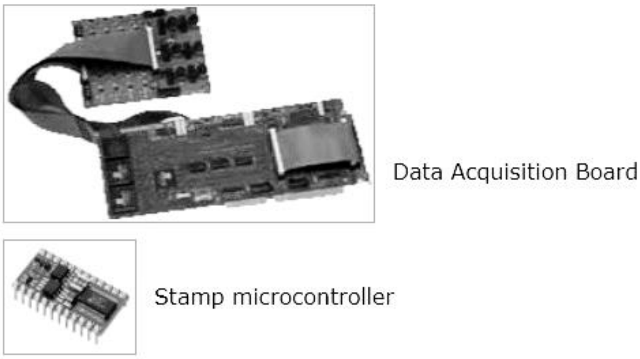


**Fig. 6.** The revolution of the information

In the late 20th century decades, as the semiconductor and information technology industry experienced explosive growth, computing hardware has become omnipresent and cheap. An important transformation in the design and operation of mechanical devices and systems has begun to take place, information technology becoming a stimulus factor for technology that brings intelligence to many products, processes and machines (Fig. 6). Microprocessors have begun to replace precision mechanical components, for example, the precision camshaft, which in many applications functions as a distribution device. In addition, microprocessor programmability has provided a versatile and flexible alternative to analog / digital computing hardware. Integrated electrical-mechanical computerized devices now have become capable of converting, transmitting and processing both physical energy and virtual energy (information). In recent years, engineers have begun to develop highly efficient products and processes by judiciously selecting and integrating sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software. [7]

## 4. Mechatronics stages

• Primary Level Mechatronics: Integrates electrical signaling with mechanical action at the basic control level for e.g. fluid valves and relay switches;

• Secondary Level Mechatronics: Integrates microelectronics into electrically controlled devices for e.g. cassette tape player;

• Tertiary Level Mechatronics: Incorporates advanced control strategy using microelectronics, microprocessors and other application specific integrated circuits for e.g. microprocessor based electrical motor used for actuation purpose in robots;

• Quaternary Level Mechatronics: This level attempts to improve smartness a step ahead by introducing intelligence (artificial neutral network and fuzzy logic) and fault detection and isolation capability into the system. [11]

## 5. Conclusions

The mechatronics applications refer to:

- Smart consumer products: home security, camera, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, Automatic Digital Camera, etc.
- Computer disk VCR/DVD drives, ATM, etc.
- Medical: implant-devices, assisted surgery, etc.
- Defense: unmanned air, ground, and underwater vehicles, smart weapons, jet engines, etc.
- Manufacturing: NC & CNC machine tools, Rapid Prototyping, robotics, etc.
- Automotive: climate control, antilock brake, active suspension, cruise control, air bags, engine management, safety, etc.
- Network-centric, distributed systems: distributed robotics, intelligent highways, etc.

The mechatronic systems are sometimes referred to as smart devices. While the term smart is elusive in precise definition, in the engineering sense we mean the inclusion of elements such as logic, feedback, and computation that in a complex design may appear to simulate human thinking processes. It is not easy to compartmentalize mechatronic system design within a traditional field of engineering because such design draws from knowledge across many fields.

The mechatronic system designer must be a generalist, willing to seek and apply knowledge from a broad range of sources. This may intimidate the student at first, but it offers great benefits for individuality and continued learning during one's career. The next figure illustrates all the components in a typical mechatronic system, an office copy machine.

The actuators produce motion or cause some action; the sensors detect the state of the system parameters, inputs, and outputs; digital devices control the system; conditioning and interfacing circuits provide connections between the control circuits and the input/output devices; and graphical displays provide visual feedback to users.

All the components from Figure 7 can be found in this common piece of office equipment. It includes analog and digital circuits, sensors, actuators, and microprocessors. The copying process works as follows: the user places an original in a loading bin and pushes a button to start the process; the original is transported to the platen glass; and a high intensity light source scans the original and transfers the corresponding image as a charge distribution to a drum. Next, a blank piece of paper is retrieved from a loading cartridge, and the image is transferred onto the paper with an electrostatic deposition of ink toner powder that is heated to bond to the paper. A sorting mechanism then optionally delivers the copy to an appropriate bin. [9]

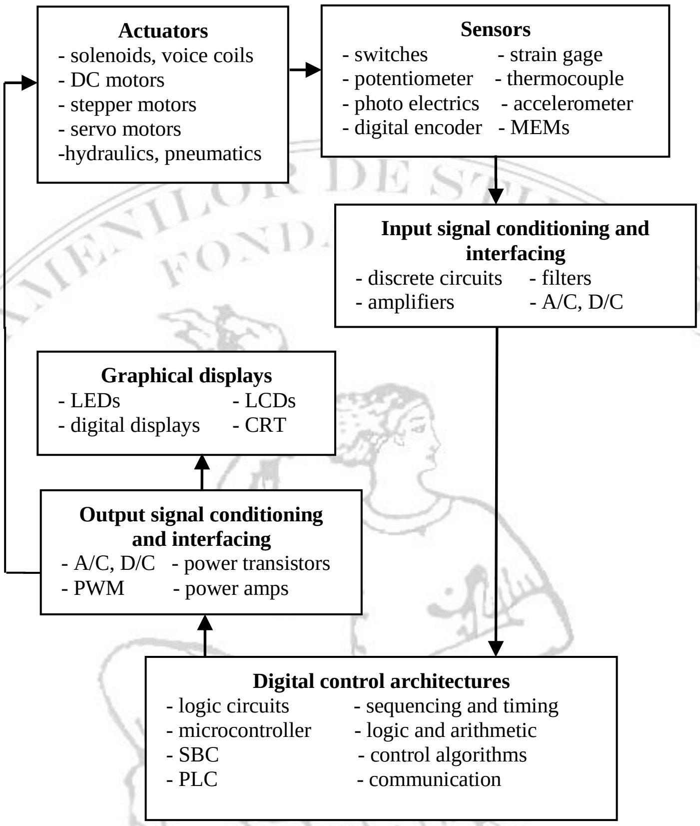


**Fig. 7.** Mechatronic system components

Analog circuits control the lamp, heater, and other power circuits in the machine. Digital circuits control the digital displays, indicator lights, buttons, and switches forming the user interface. Other digital circuits include logic circuits and microprocessors that coordinate all of the functions in the machine. Optical sensors and microswitches detect the presence or absence of paper, its proper positioning, and whether or not doors and latches are in their correct positions. Other sensors include encoders used to track motor rotation. Actuators include servo and stepper motors that load and transport the paper, turn the drum, and index the sorter. These days, practically all mechanical devices include electronic components and some type of computer monitoring or control. Increasingly, microcontrollers are embedded in electromechanical devices, creating much more flexibility and control possibilities in system design.

Examples of mechatronic systems include an aircraft flight control and navigation system, automobile air bag safety system and antilock brake systems, automated manufacturing equipment such as robots and numerically controlled (NC) machine tools, smart kitchen and home appliances such as bread machines and clothes washing machines, and even toys. Some big companies are developing special programs with Digital Factories. Here, proven and tested components and technologies are used.

The feasibility can be shown and tested directly in the learning factory environment. In addition, there is the possibility to qualify employees at the existing facility with regard to practical and theoretical knowledge and to prepare them for the future challenges in the digital factory. In the digital factory area, Siemens has developed a digital factory (DF) program.

Siemens has a comprehensive portfolio of products, systems and solutions for manufacturing and process automation as well as drive technology. This spectrum is complemented by innovative services tailored to our customers' needs over the entire life cycle of a machine or plant. Automation technology from Siemens makes a decisive contribution to the continuous optimization of company-wide processes.

Totally integrated automation, the unique end-to-end product and system spectrum for automation in the manufacturing and process industry, is at the heart of the company's offering. Siemens thus offers the optimal basis for solutions that are perfectly tailored to individual requirements.

The digital factory offers a full range of embedded hardware, software and services based on technology. This range helps manufacturing companies around the world maximize the flexibility and efficiency of their processes while reducing the marketing time of their products. The perfect integration of data across industrial value chains is becoming increasingly critical for the sustainable development of manufacturing companies.

The Siemens division of digital factory strives to provide its customers with a full range of hardware and software products to fully integrate development, production and supplier data. The ultimate goal is the complete digital representation of the physical value chain as a whole. For this purpose, the Enterprise Digital solution platform has been created.

Today, the DF product line already links the essential parts of the product and production lifecycle. For example, powerful Product Lifecycle Management (PLM) software enables to develop and optimize new products on a fully virtual basis. In the real world of manufacturing, the TIA (Totally Integrated Automation) concept, which has been proven for about 20 years, ensures efficient interoperability of all automation components.

The TIA Portal offers significant time savings and considerable engineering savings. The Digital Factory division is working closely with its Siemens partners, including the Process Industries and Drives division, to offer a single and wide range of PLM software tools and automation and drive technologies that adapt to the specific needs of each customer in different industrial areas. In addition, DF is committed to encouraging the long-term development of its clients' business. Protecting our customers' investments today and in the future (an important aspect in the software industry) is one of the main pillars of Siemens business strategy. In addition, to shape the future of the sector, DF combines its dynamic and innovative capabilities with those of its partners around the world. Thus, advanced proven technologies are used to optimize productivity and protect a competitive edge. [4]

## REFERENCES


[1] Heimann B., Gerth W., Popp K: *Mechatronik (Mechatronics)* (Fachbuchverlag Leipzig, Leipzig 2001), in German, ISBN 9783446217119, pp. 13-27, 71-86;

[2] Bradley D., Dawson D., Burd D., Loader A.: *Mechatronics-electronics in Products and Processes* (Chapman Hall, London 1991), ISBN 978-0748757428, pp. 2-15, 65-74;

[3] David G. *Introduction to Mechatronics and Measurement Systems*, 4th ed. (2012), Department of Mechanical Engineering, Colorado State University, ISBN 978-0-07-338023-0; pp.1-20, 431;

[4] https://www.siemens.com/businesses/ci/fr/digital-factory.htm;

[5] Isermann, R. (2000), *Mechatronic systems: concepts and applications. Transactions of the Institute of Measurement and Control*, 22(1), 29–55, ISSN: 0142-3312, Online ISSN: 1477-0369;

[6] Isermann, R. (2009) *Mechatronic Systems*, Springer, Berlin, Heidelberg, ISBN 978-1-84628-259-1, pp. 317-328;

[7] Karnopp, Dean C., Donald L. Margolis, Ronald C. Rosenberg, *System Dynamics: Modeling and Simulation of Mechatronic Systems*, 4th Edition, Wiley, 2006. ISBN 0-471-70965-4, pp. 4-50;

[8] *NF E 01-010 2008 – AFNOR* (French standard NF E 01-010);

[9] Dolga Valer, *Proiectarea sistemelor mecatronice*, Ed. Politehnica, 2007, ISBN 978-973-625-573-1, pp. 1-60;

[10] Robert Munnig Schmidt, Georg Schitter, Adrian Rankers and Jan van Eijk, *The Design of High Performance Mechatronics – 2nd revised edition*. IOS Press, 2014, ISBN 978-1614993674, pp. 333-342;

[11] Bradley, David; Russell, David; Ferguson, Ian (March 2015). "*The Internet of Things-The future or the end of mechatronics*", Mechatronics, ISSN 1873-4006, 27: 57–74.