Introducing Simulation Tools early in Engineering Course

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Brasil

Summary

- Brief facts about São Paulo, USP, and *Escola Politécnica*
- Course Structure
- Simulation Classes
- Pros and Contras
- Conclusions

Abstract

Recently the Mechanical Engineering Course of the Escola Politecnica da Universidade de Sao Paulo –Brazil has been updated. The goal was to turn the program more flexible and to introduce engineering lectures earlier in order to make the course more attractive to young students. The updated program is now reaching the final years of the course, and we are getting a first glance of the pros and contras of the new program structure.

Modeling was always a common task in many disciplines in mechanical engineering, e.g., classical mechanics, instrumentation, mechanical vibration, dynamic systems modeling, fluid and thermodynamics, analog and digital control, biomechanics, etc. But, in the old program we have experienced that in all classes that use modeling and simulation, students spend more time trying to get their models running than actually analyzing the phenomena. Therefore we decided to anticipate a class in system modeling to an earlier stage in the mechanical course with the goal of introducing simulation tools as soon as possible. The purpose was to make simulation tools available for the students along the rest of the course. So a new class on simulation was created, where the students are exposed to simulation concepts and have the opportunity to practice with simulations tools.

The scope of this discipline is introducing numerical integration of systems of algebraic and ordinary differential equations, show some representation options, like, algebraic-numerical model, state-space representation, block diagram, equation and component representation.

We present typical simple dynamic problems in many domains as class and homework examples, like simple and double pendulum, spherical pendulum, sphere moving in a fluid with viscose and drag forces, mass-spring-damper system, electrical first and second order systems, hydraulic and thermal systems and the serial and parallel association of them.

In a view to making this tools available for students, at all times, we use only free available computing software like Scilab, Xcos, and OpenModelica. This paper presents the structure of the curricula, strategies, and exercises of the simulation class, and discuss our experience, their pros and contras.

Brief facts about São Paulo

São Paulo is the industrial and financial center of Brazil

Brazil

- Summary
- Olympics Data
- Economy
- Social indicators
- Environment
- Population
- Networks

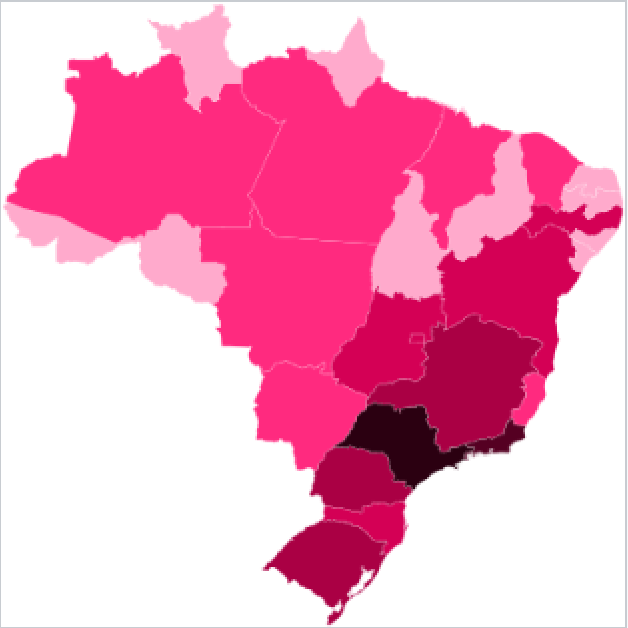
Economy

Economically-active population 15 years of age or over	69.7 %
Economically-active women 15 years of age or over	60.03 %
GDP per capita	8,528 US$
Investment in research and development	1.15 % of GDP
Overall GDP	1,772,591 million US$
Public expenditure on education	5.8 % of GDP
Public expenditure on health services	9.7 % of GDP
Total exports	225,098.41 million US$
Total imports	229,060.06 million US$
Tourist arrivals	6,430,000 tourists

Some facts about São Paulo State

MHDI 2010	MHDI range	Population (2010 Census)	Area	Demographic density
0,783	High (MHDI between 0,700 and 0,799)	41.262.199 Inhabitants	248222,36 km²	166,23 hab/km²

Federative unit	population in millions †	#	GDP in BRL million	GDP in USD million	Share
São Paulo	44.0	1	1,408,904	721,036	32.1%



Mapa dos estados brasileiros segundo o PIB em 2014. Em reais:

- + 1,2 trilhão
- + 600 bilhões
- + 300 bilhões
- + 150 bilhões
- + 75 bilhões
- até 75 bilhões

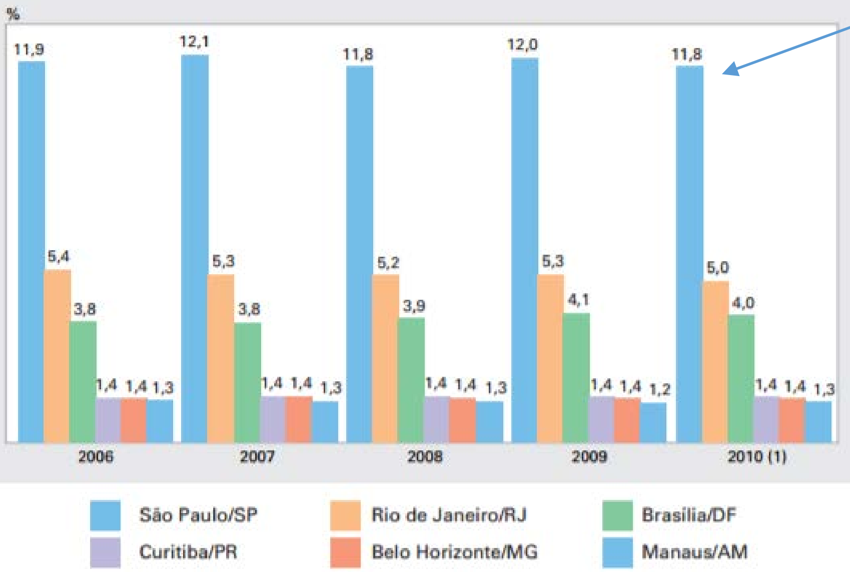
Population estimated - 2016 [1]	12.038.175
Population - 2010	11.253.503
Area of the territorial unit - 2015 (km²)	1.521,110
Population density - 2010 (inhab/km²)	7.398,26

City of São Paulo

Gross Domestic Product of Municipalities - 2014		
Gross value added of agriculture	39.801	thousand reais
Gross value added of industry	66.843.382	thousand reais
Gross value added of services (*)	410.722.122	thousand reais

About US$ 150 billion

Gráfico 4 - Participação percentual do Produto Interno Bruto dos seis maiores municípios, por municípios e respectivas Unidades da Federação - 2006-2010

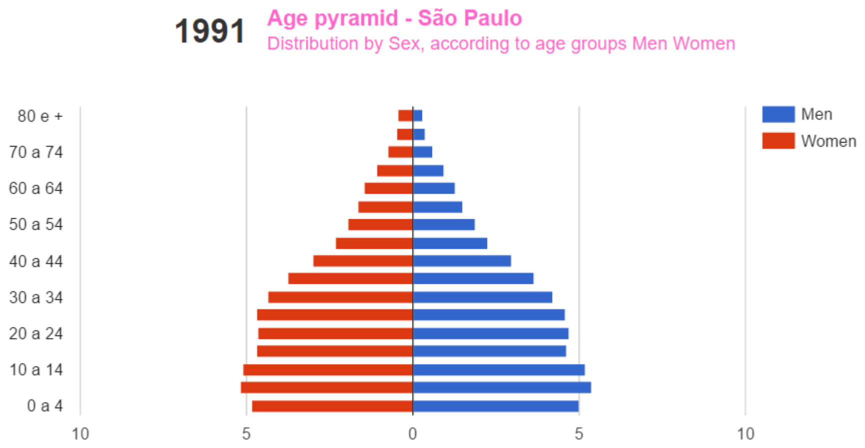


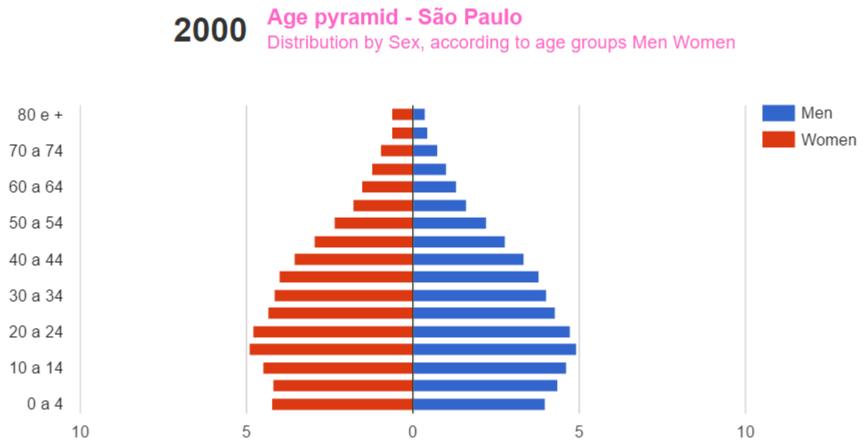
~12%

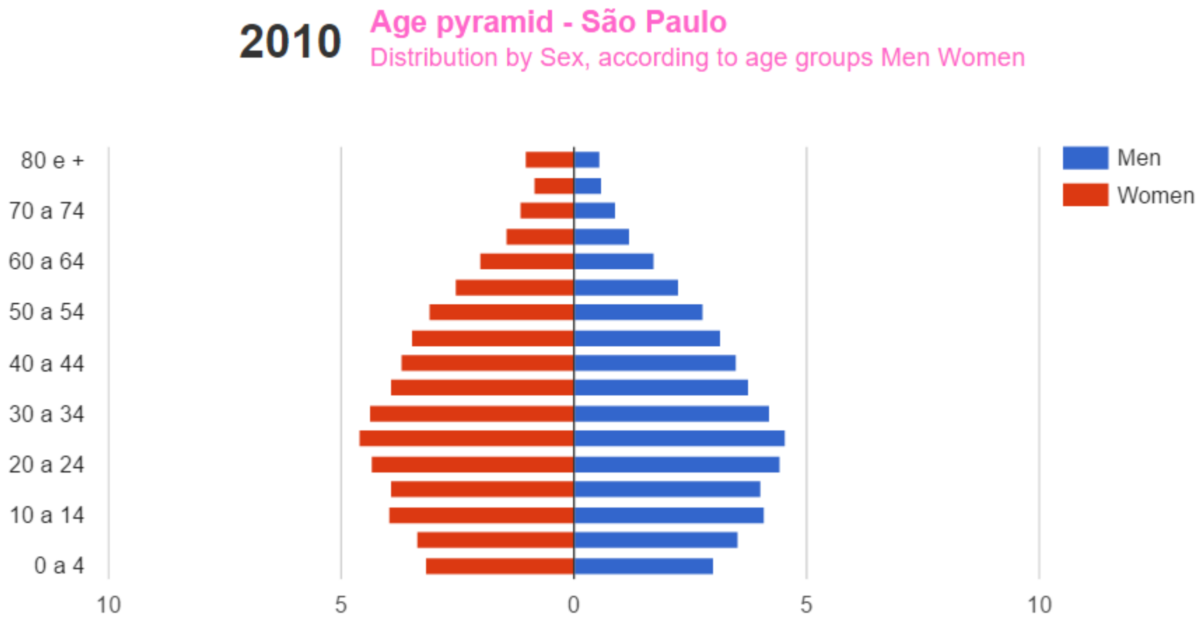
Fonte: IBGE, em parceria com os Órgãos Estaduais de Estatística, Secretarias Estaduais de Governo e Superintendência da Zona Franca de Manaus - SUFRAMA.
(1) Dados sujeitos a revisão.

Kingdom of Sweden
Konungariket Sverige[a]

Area	
• Total	450,295 km² (173,860 sq mi) (55th)
• Water (%)	8.7
Population	
• 31 January 2017 estimate	10,005,600[3] (89th)
• 30 November 2016 census	9,981,799[4]
• Density	23.1/km² (59.8/sq mi) (196th)
GDP (PPP)	2016 estimate
• Total	$498.130 billion[5] (34th)
• Per capita	$49,678[5] (17th)
GDP (nominal)	2016 estimate
• Total	$517.440 billion[5] (21st)
• Per capita	$51,603[5] (11th)
Gini (2015)	▲ 25.4[6] low
HDI (2014)	▲ 0.907[7] very high · 14th

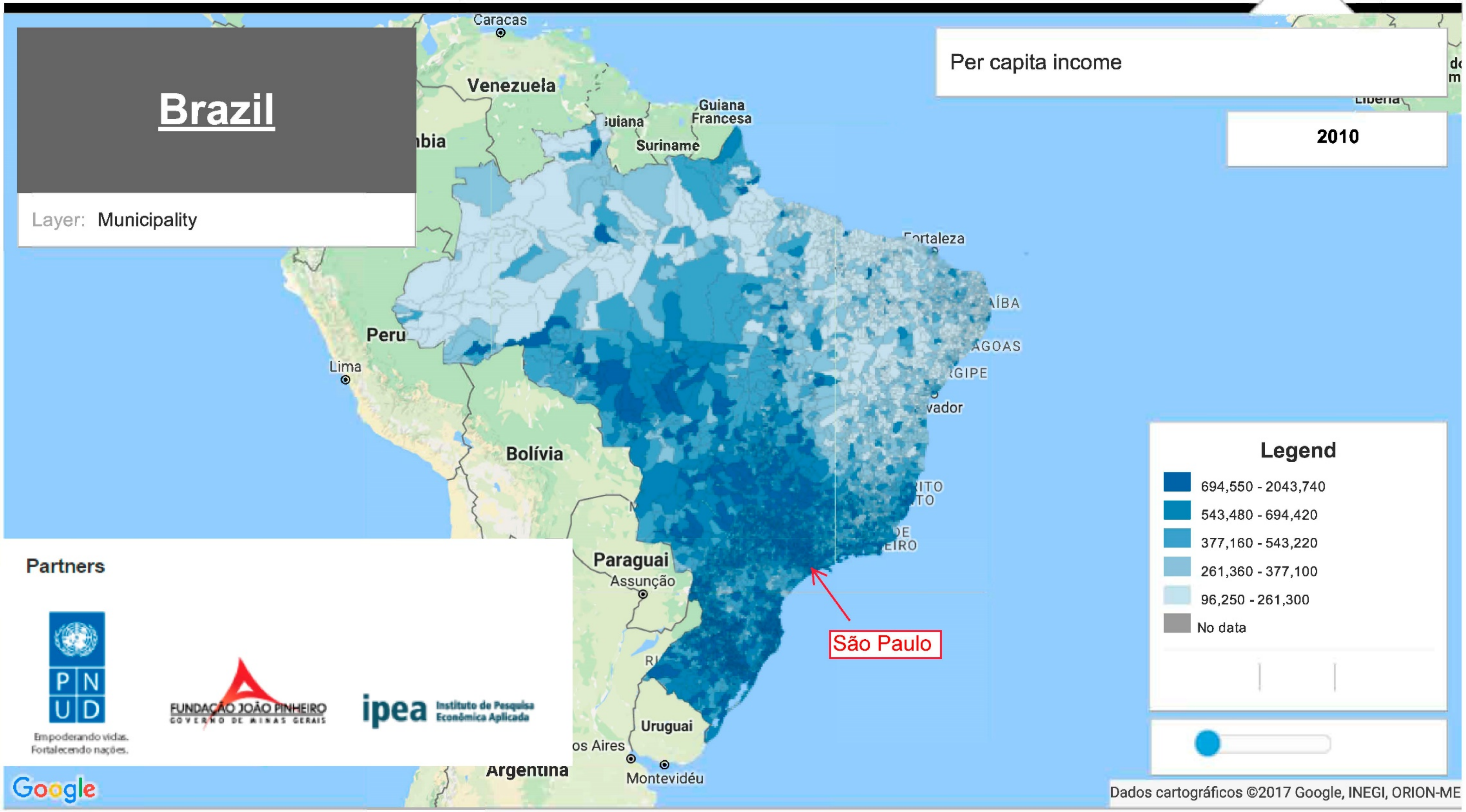




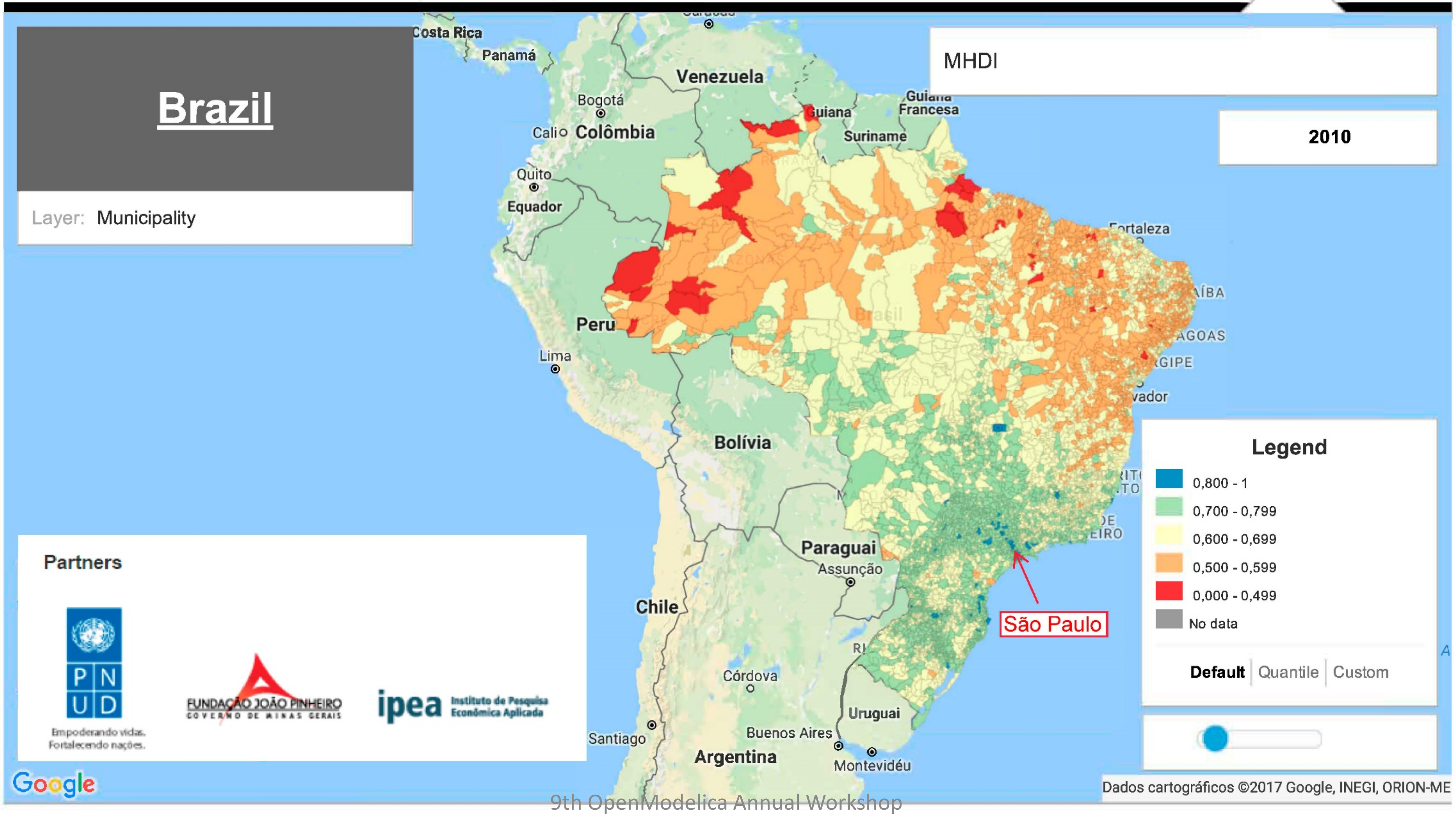


Brazilian population is aging – demographic transition

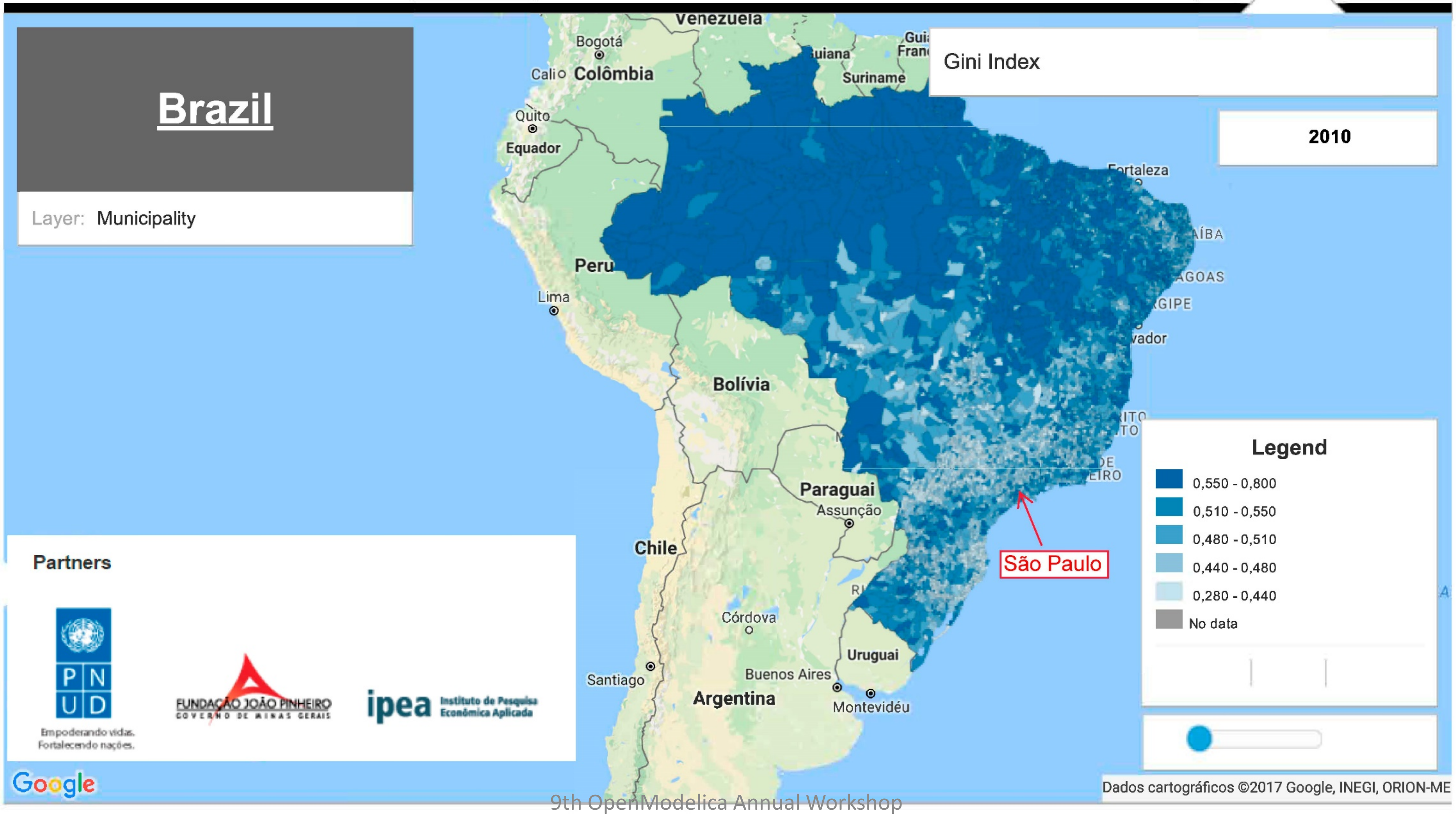
Atlas do Desenvolvimento Humano no Brasil



Atlas do Desenvolvimento Humano no Brasil



Atlas do Desenvolvimento Humano no Brasil



University of São Paulo – USP and Escola Politécnica

Escola Politécnica is the Engineering School of USP

University of São Paulo

Public university established in 1934

Advanced center for education, research and extension services to the community

- 247 undergraduate courses
- 239 graduate programs
- 5,940 professors
- 58,000 students

Escola Politécnica

Escola Politécnica

- Since 1893
- Incorporated to University of São Paulo - USP in 1934

Total Area

- ≈152.525 m²

Faculty and Staff

- 466 lectures and professors (about 20% full professors)
- 466 staff

Students

- 4.964 undergraduate students
- 1.830 graduate students
- Master Degree 705
- Doctor Degree 694
- Special enrollment 431

http://www.poli.usp.br/

Departments - 15

- Civil Engineering
- Structures and Geotechnics
- Environment and Hydraulics
- Transportation
- Computation and Digital Systems
- Automation and Energy
- Electronic Systems
- Telecommunication and Control
- **Mechanics**
- Mechatronics
- Naval and Offshore
- Production
- Chemistry
- Metallurgical and Materials
- Mining, Oil, and Gas

International Relations

Offers 3 types of student exchange program:

- Open
- Credit transfer
- Double diploma

Polytechnic School has exchange agreements with dozens of education and research institutions abroad, as England, France, Germany, Italy, Korea, Portugal, Spain and USA.

International Agreements and Student Exchange

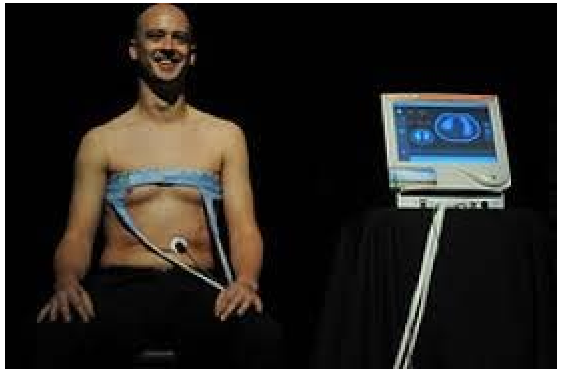
- 31 agreements for Double Diploma (Germany, Spain, France, Italy, Peru e Portugal)
- 160 agreements for student exchange (credit transfer) with
  36 countries from America, Europe, and Asia
- 39 agreement for Double Degree at graduation level
- 02 graduation agreements
- 01 agreement for Technological and Scientific Cooperation

- 915 Total of students abroad
  - 513 at study exchange
  - 402 at study exchange for Double Diploma
- 192 Total of foreigners students
  - 157 foreigners students at the exchange program
  - 45 foreigners students for double diploma

Department of Mechanical Engineering

- 51 professors
- 350 undergraduate students
- 223 graduate students
- 2,000 students from others courses at Poli

http://www.poli.usp.br/



Course Structure

Simulation

Semester	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Calculus 1						Linear Algebra 1				Descritive Geometry			Experimental Physics			Chemistry				Computation				Introduction to Engineering			
2	Calculus 2				Physics 1		Linear Algebra 2				Classical Mechanics						Mechanical Design				Workshop		Environment		Economy & Administration			
3	Calculus 3				Physics 2				Physics Lab 1		Analytic Mechanics				Solid Mechanics 1				Manufacturing				Probability		Materials 1			
4	Calculus 4				Physics 3				Physics Lab 2		Fluid dynamics 1				Solid Mechanics 2				Simulation Lab		Statistics				freely electable disciplines			
5	Electricity				Thermodynamics 1						Fluid dynamics 2				Mechine Design 1				Methodology 1		Numerical Methods							
6	Thermodynamics 2				Heat and Mass Transfer						Electronics				Modeling				Electronics Lab		Machine Desing 2							
7	Materials 2			Thermodynamics 3		Hydralic Machines					Vibrations				Control				Vib & Control Lab		Methodology 2		Design					
8	Materials 3			Engines		Thermal Machines							Instrumentation		Instr. Lab		Discrete Control		Quality		Manifacturing							
9	aplied electalbe disciplines																											
10																												

260 class credits

Simulation Classes

PME 3201

Lab class offered in the 4th semester

of the 10 semester mechanical engineering course

Simulation Lab

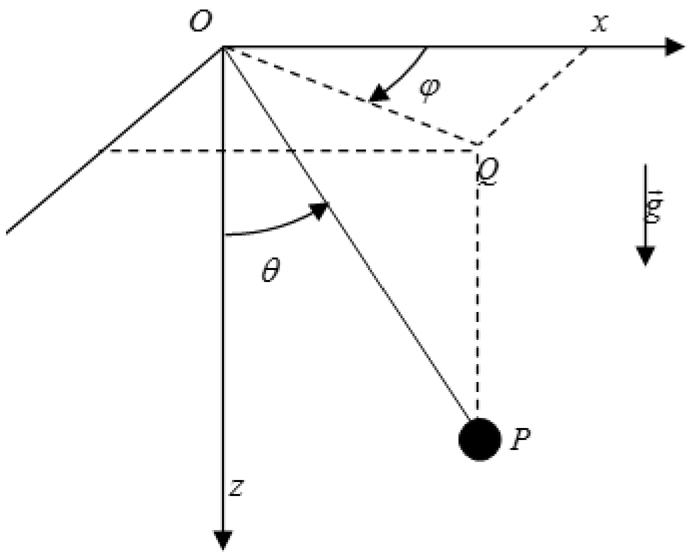
- 24 hours of lab activity
- 6 classes of 4 hours + examination
- 24 students per class
- hands-on class activity and home assignments
- Three main blocks:
  - Numerical Integration – command line programing in Scilab
  - Modeling and Analysis of mechanical systems – direct programing in Scilab
  - Modeling techniques with MODELICA – modeling in OpenModelica

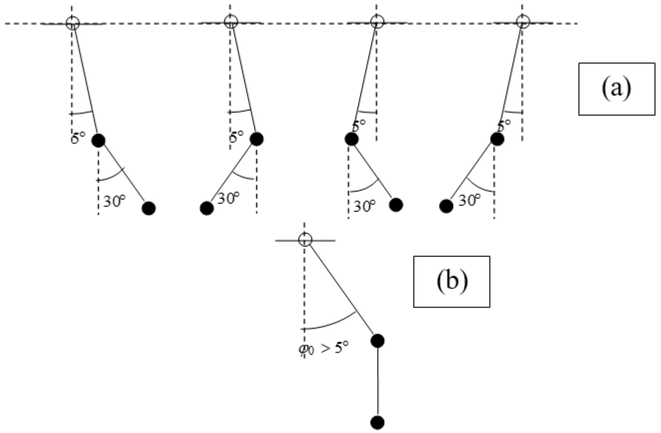
Numerical Integration

- implicit and explicit Euler, Runge-Kutta, Adams
- Integration and interpretation of differential equations and system of differential equations
- State space formulation
- Programming of numerical integration algorithm in Scilab

Modeling of Mechanical Systems

- Application to Mechanical Systems
- Write the differential equations by hand
- Integration of differential equations with Scilab functions
- Solution of linear and non-linear dynamics
- Emphasis on interpretation of the solution and on model verification
- Block diagram representation





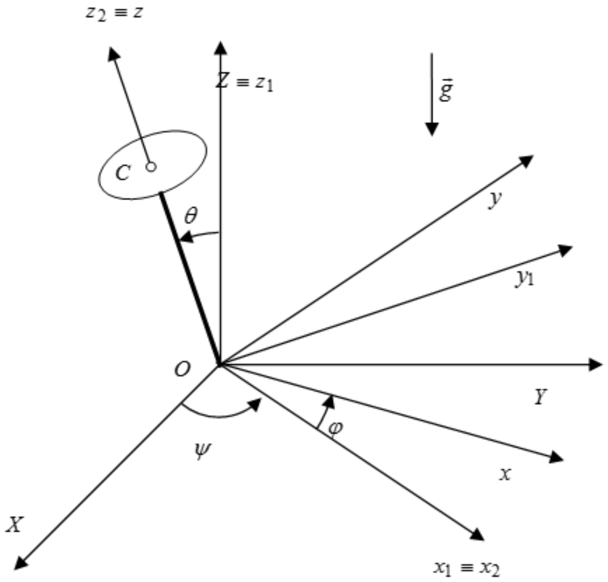
$$\frac{\partial L}{\partial \dot{\varphi}} = (m_1 + m_2)\dot{\varphi}.l_1^2 + m_2.l_1.l_2.\cos(\varphi - \theta)\dot{\theta}$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) = (m_1 + m_2)l_1^2\ddot{\varphi}. + m_2.l_1.l_2.\cos(\varphi - \theta)\ddot{\theta} - m_2.l_1.l_2.\sin(\varphi - \theta)(\dot{\varphi} - \dot{\theta})\dot{\theta}$$

$$\frac{\partial L}{\partial \varphi} = -m_2.l_1.l_2.\sin(\varphi - \theta)\dot{\varphi}.\dot{\theta} - (m_1 + m_2)g.l_1.\sin\varphi$$

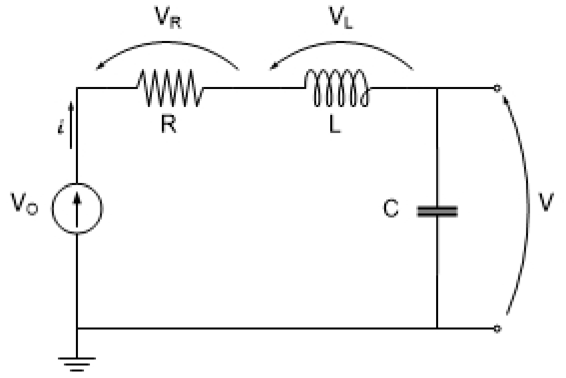
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) - \frac{\partial L}{\partial \varphi} = 0$$

$$\Rightarrow (m_1 + m_2)l_1\ddot{\varphi}. + m_2.l_2.\cos(\varphi - \theta)\ddot{\theta} + m_2.l_2.\sin(\varphi - \theta)\dot{\theta}^2 + (m_1 + m_2)g.\sin\varphi = 0$$



Introduction to MODELICA

- Solution of simple first and second order dynamic systems
- Mechanical, electrical, thermal and fluid examples
- Modeling with OpenModelica
- Solution with:
  - Graphical approach
  - Flat text solution – acausal equation approach
  - Construction of component library
  - Connecting of physical components
  - Hierarchical class structure
- Exploring of modeling and simulation resources of OpenModelica
- Numeric experiments to explore the response of dynamic systems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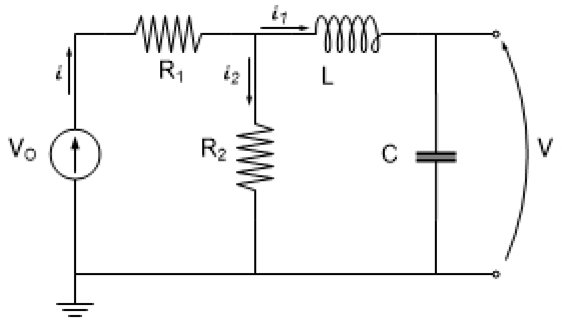
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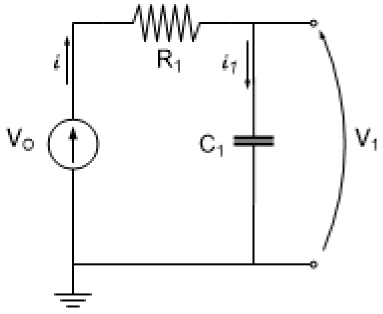
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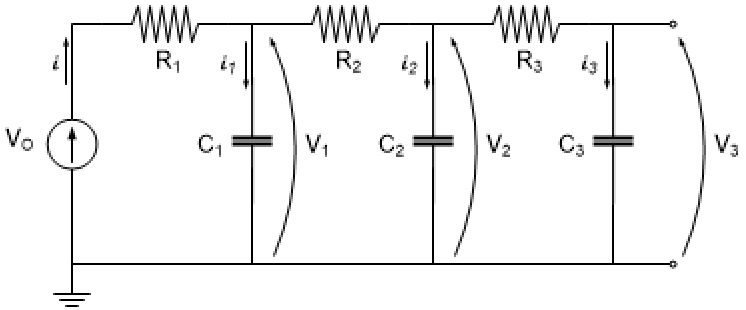
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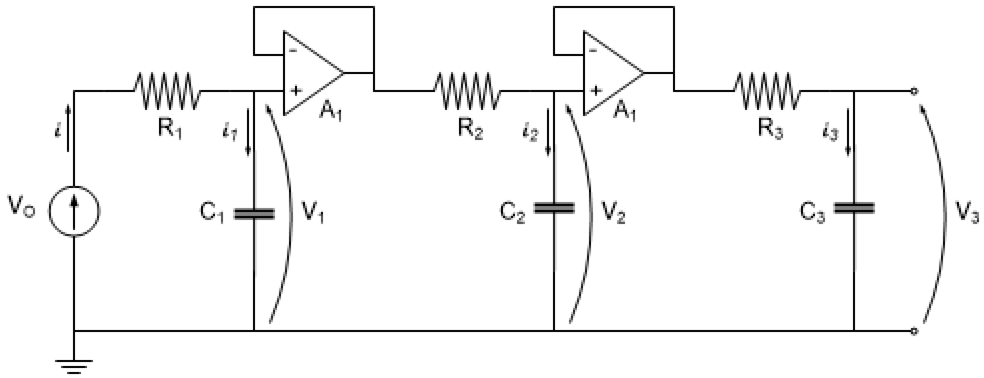
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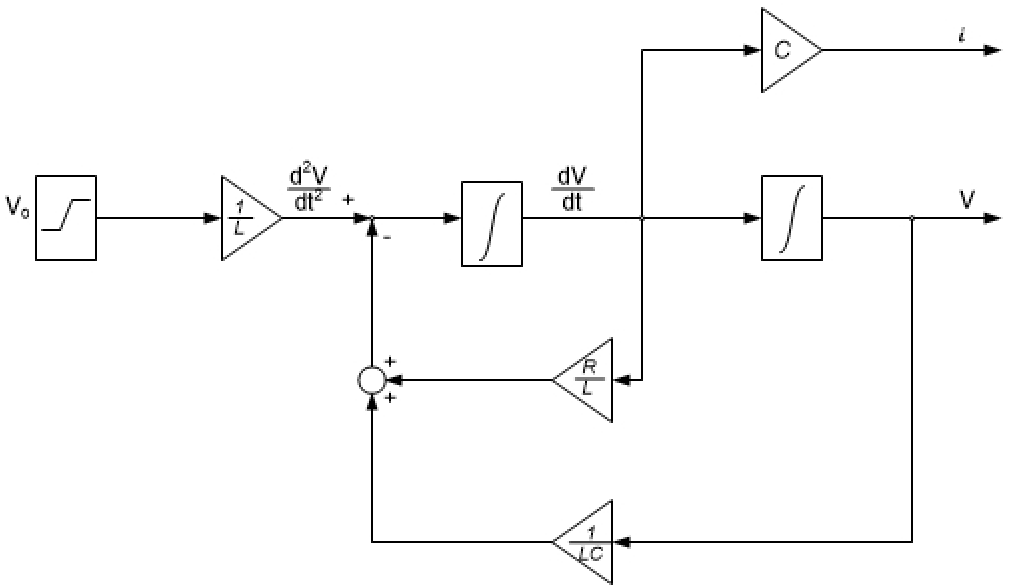
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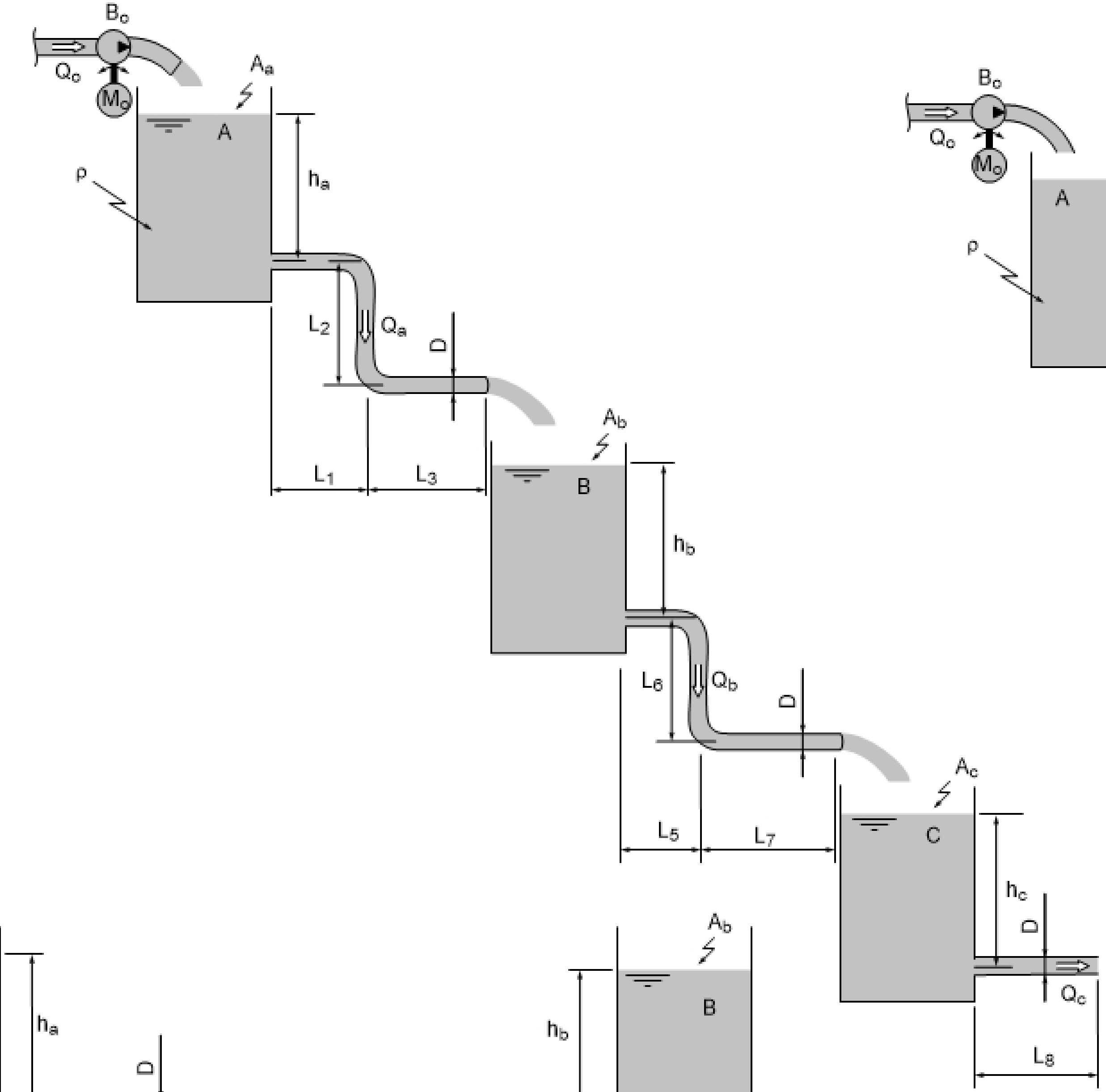
B_o
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L_5
L_7
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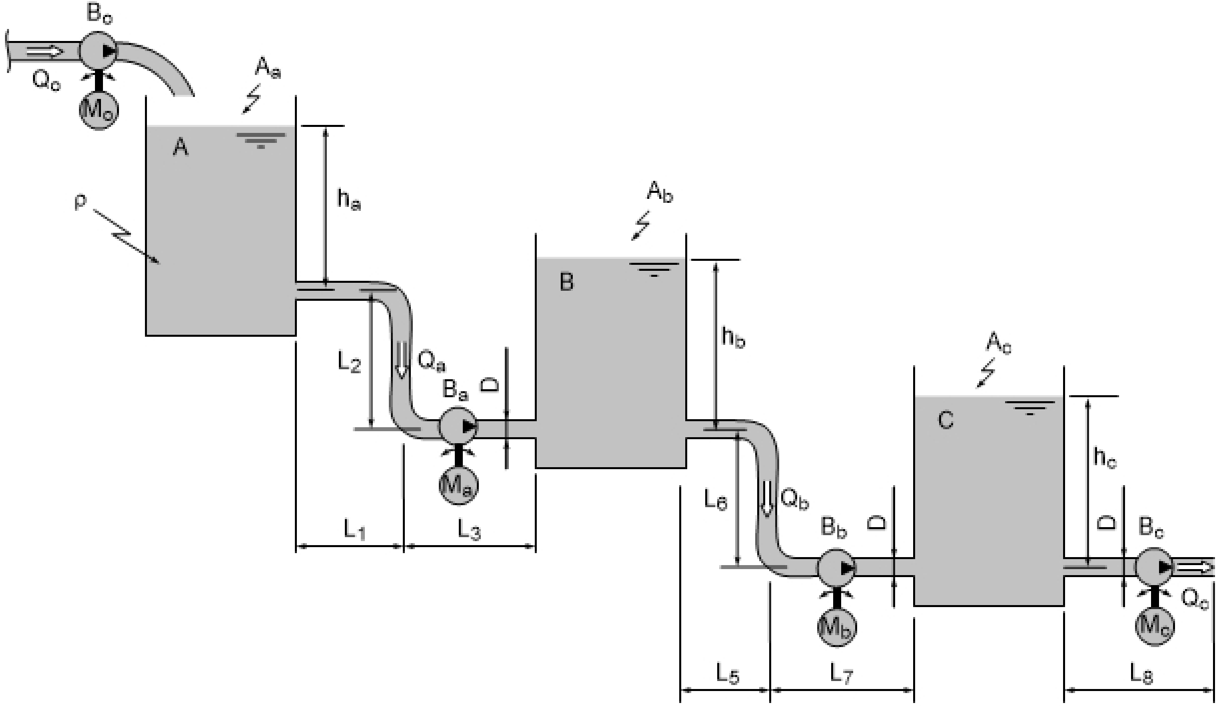
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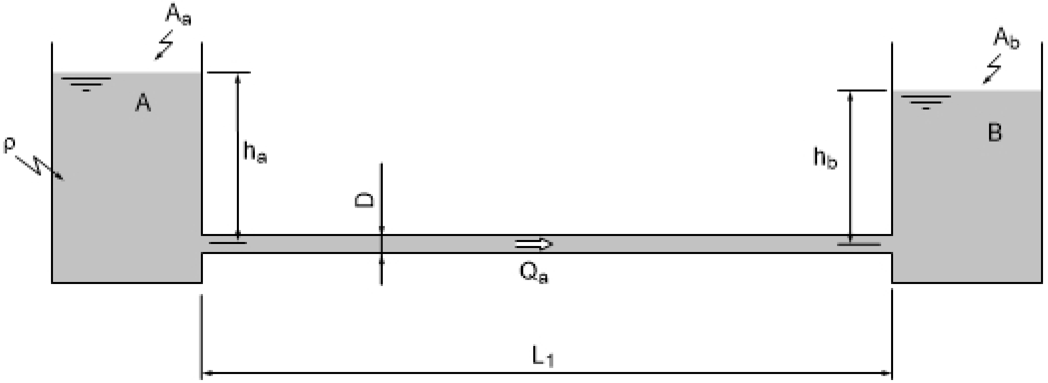
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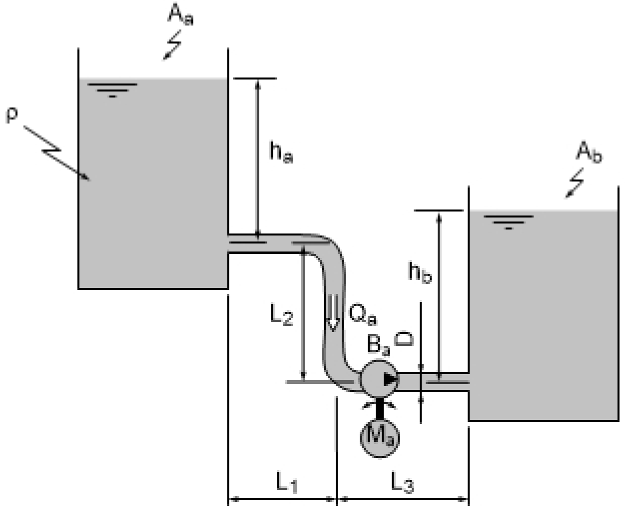
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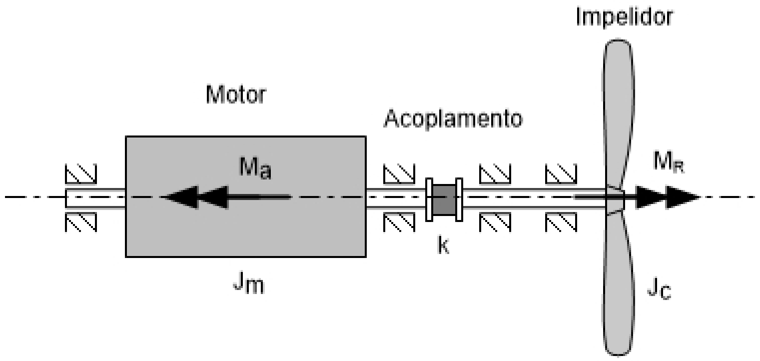

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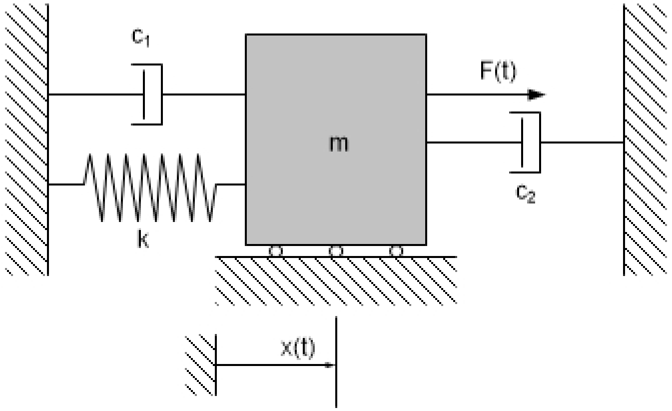

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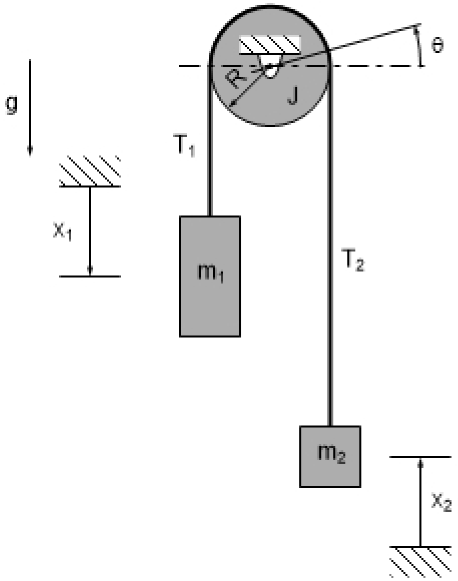

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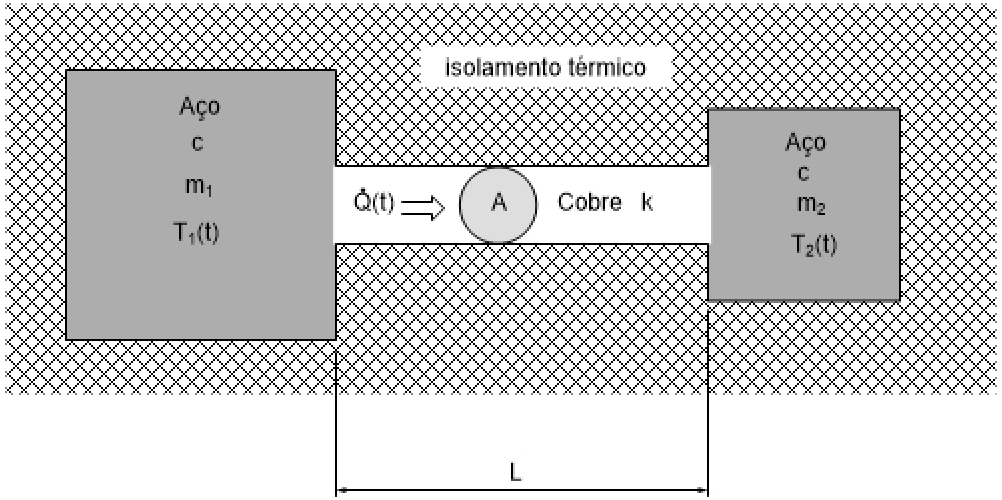

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Example of problems

- simple and double pendulum;
- spherical pendulum;
- sphere moving in a fluid with viscose and drag forces;
- mass-spring-damper system;
- electrical first and second order systems;
- hydraulic and thermal systems;
- serial and parallel association;
- Non-linear and linearized solution;
- Forced and autonomous solution.

Pros and Contras

- Pros
  - Solution of engineering applications and hand-on approach stimulates student interest
  - Permits “what's if” exploration of system dynamics
  - Acquired Simulation skills make upcoming modeling classes more productive
- Contras
  - Lack of basic knowledge in modeling and have little proficiency in analytical solution of differential equations
  - Short and intense course is not easy for some students
  - Not all Students are mature to understand dynamic solutions

Conclusions

- Earlier contact to numerical simulations motivates students and prepare for modeling classes
- Free software is a very important education resource that can be used in class and at home
- OpenModelica is very appreciate by the students and is an important tool for teaching modelling and system dynamics
- Further analysis must be done to evaluate the performance of students in modeling classes after attending simulation lab

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