MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

COMPUTAÇÃO APLICADA

Catalog of the Graduate Program in Applied Computing

Contents

Faculty 2
Courses 3
Courses by Term 5
Course Descriptions 7

Coordenação do Programa de Pós-Graduação em Computação Aplicada – PGCAP
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2025

Faculty

Alan James Peixoto Calheiros, Dr., INPE, 2013.
Celso Luiz Mendes, Dr., University of Illinois, 1997.
Elbert Einstein Nehrer Macau, Dr., ITA, 1993.
Elcio Hideiti Shiguemori, Dr., INPE, 2007.
Gilberto Câmara, Dr., INPE, 1995.
Gilberto Ribeiro Queiroz, Dr., INPE, 2012.
Haroldo Fraga de Campos Velho, Dr., UFRGS, 1992.
Karine Reis Ferreira, Dra., INPE, 2012.
Lamartine Nogueira Frutuoso Guimarães, Ph.D., University of Tennesse, 1992.
Leonardo Bacelar Lima Santos, Dr., INPE, 2014.
Lúbia Vinhas, Dra., INPE, 2006.
Marcos Gonçalves Quiles, Dr., USP, 2009.
Nandamudi Lankalapalli Vijaykumar, Dr., ITA, 1999.
Pedro Ribeiro de Andrade Neto, Dr., INPE, 2010.
Rafael Duarte Coelho dos Santos, Dr., Kyushu Institute of Technology, 1998.
Reinaldo Roberto Rosa, Dr., INPE, 1995.
Stephan Stephany, Dr., INPE, 1997.
Thales Sehn Körting, Dr., INPE, 2012.
Valdivino Alexandre de Santiago Júnior, Dr., INPE, 2011.

Academic Coordination

Rafael Duarte Coelho dos Santos, Dr., Kyushu Institute of Technology, 1998.

Courses

- CAP-237-3 - Chaotic Systems
- CAP-242-1 - Scientific Methodology in Applied Computing
- CAP-335-3 - Computational Learning and Pattern Recognition
- CAP-340-3 - Inverse Problems
- CAP-349-3 - Geographic Databases
- CAP-351-3 - Neurocomputing
- CAP-354-3 - Artificial Intelligence
- CAP-368-3 - Introduction to Dynamic Systems Theory
- CAP-370-3 - Applied Computing for Environmental Physics
- CAP-372-3 - High-Performance Computing
- CAP-381-3 - Complex Networks, Dynamics, and Applications
- CAP-394-3 - Introduction to Data Science
- CAP-395-3 - Geoinformatics
- CAP-398-3 - Modeling and Applications of Complex Reactive Systems
- CAP-399-3 - Programming of Massively Parallel Systems
- CAP-408-3 - Applied Computing for Atmospheric Sciences
- CAP-417-3 - Computational Statistics
- CAP-418-4 - Numerical Methods I
- CAP-419-3 - Introduction to Programming with Geospatial Data
- CAP-420-3 - Numerical Methods II
- CAP-421-3 - Deep Learning
- CAP-422-3 - Computational Mathematical Physics
- CAP-423-4 - Geospatial Data Science
- CAP-424-3 - Fuzzy Logic
- CAP-425-3 - Advanced Topics in Environmental Modeling
- CAP-465-4 - Modeling and Simulation of Earth Systems
- CAP-501-0 - Seminars in Applied Computing I
- CAP-502-0 - Seminars in Applied Computing II
- CAP-730-0 - Master's Research in Applied Computing
- CAP-750-12 - Master's Dissertation in Applied Computing
- CAP-780-0 - Doctoral Research in Applied Computing
- CAP-800-36 - Doctoral Thesis in Applied Computing

Track **Geospatial Data Science**

First Term	Second Term	Third Term
CAP-395-3 - Geoinformatics	CAP-349-3 - Geographic Databases	CAP-423-4 - Geospatial Data Science
CAP-419-3 - Introduction to Programming with Geospatial Data		

Track **Mathematical and Computational Modeling of Natural Phenomena**

First Term	Second Term	Third Term
CAP-368-3 - Introduction to Dynamic Systems Theory	CAP-381-3 - Complex Networks, Dynamics, and Applications	CAP-422-3 - Computational Mathematical Physics
CAP-417-3 - Computational Statistics	CAP-465-4 - Modeling and Simulation of Earth Systems	CAP-425-3 - Advanced Topics in Environmental Modeling

Track **Applied Artificial Intelligence**

First Term	Second Term	Third Term
CAP-354-3 - Artificial Intelligence	CAP-335-3 - Computational Learning and Pattern Recognition	CAP-421-3 - Deep Learning
	CAP-351-3 - Neurocomputing	CAP-424-3 - Fuzzy Logic

Courses by Term

First Term
CAP-242-1 - Scientific Methodology in Applied Computing
CAP-354-3 - Artificial Intelligence
CAP-368-3 - Introduction to Dynamic Systems Theory
CAP-395-3 - Geoinformatics
CAP-417-3 - Computational Statistics
CAP-418-4 - Numerical Methods I
CAP-419-3 - Introduction to Programming with Geospatial Data

Second Term
CAP-335-3 - Computational Learning and Pattern Recognition
CAP-349-3 - Geographic Databases
CAP-351-3 - Neurocomputing
CAP-370-3 - Applied Computing for Environmental Physics
CAP-372-3 - High-Performance Computing
CAP-381-3 - Complex Networks, Dynamics, and Applications
CAP-394-3 - Introduction to Data Science
CAP-398-3 - Modeling and Applications of Complex Reactive Systems
CAP-420-3 - Numerical Methods II
CAP-465-4 - Modeling and Simulation of Earth Systems

Third Term
CAP-237-3 - Chaotic Systems
CAP-340-3 - Inverse Problems
CAP-399-3 - Programming of Massively Parallel Systems
CAP-408-3 - Applied Computing for Atmospheric Sciences
CAP-421-3 - Deep Learning
CAP-422-3 - Computational Mathematical Physics
CAP-423-4 - Geospatial Data Science
CAP-424-3 - Fuzzy Logic
CAP-425-3 - Advanced Topics in Environmental Modeling

General Requirements

All master's students must complete the mandatory courses determined in the study plan, participate in the **Seminars in Applied Computing I** with at least 20 attendances, and attend mandatory program events as directed by the Course Coordination. In addition, they must fulfill all other requirements listed in the program and general regulations.

All doctoral students must complete the mandatory courses determined in the study plan, participate in the **Seminars in Applied Computing II** with at least 40 attendances, and attend mandatory program events as directed by the Course Coordination. In addition, they must fulfill all other requirements listed in the program and general regulations.

Specific Requirements

Students who wish to choose one of the concentration areas (**Geoinformatics and Geospatial Data Science**, **Artificial Intelligence for Space Applications**, or **Mathematical and Computational Modeling of Natural Phenomena**) **must** enroll and be approved at least three courses from the respective tracks. The selection of a concentration area must be made by the time the proposal is submitted.

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Code	Title	Credits
CAP-237-3	Chaotic Systems	3

Scheduled for the Third Term
Prerequisites: CAP-368 - Introduction to Dynamic Systems
Course Lecturer(s): Elbert Einstein Nehrer Macau ✉

Course Description

Dynamic Systems. Orbits in Phase Space. Fixed and Periodic Points. Bifurcation. One- and Two-Dimensional Maps. Fractals. Chaos in Maps and Flows. Chaotic Attractor. Manifolds and Crises. Chaos in Non-Attractive Sets. Space Reconstruction. Chaos in Conservative Systems. Chaos Control. Applications.

Bibliography

- Alligood, K. T.; Sauer, T. D.; Yorke, J. A. *Chaos: An Introduction to Dynamical Systems*, Springer, 1997.
- Hirsch, M. W.; Smale, S.; Devaney, R. L. *Differential Equations, Dynamical Systems & An Introduction to Chaos*, Elsevier, 2004.
- Ott, E. *Chaos in Dynamical Systems, 2nd ed.*, Cambridge, 2002.
- Tel, T.; Gruiz, M. *Chaotic Dynamics: An Introduction Based on Classic Mechanics*. Cambridge, 2006.
- Wiggins, S. *Introduction to Applied Nonlinear Dynamical Systems and Chaos, 2nd ed.*, Springer-Verlag, 2003.

Code	Title	Credits
CAP-242-1	Scientific Methodology in Applied Computing	1

Scheduled for the First Term
Course Lecturer(s): Gilberto Câmara ✉

Course Description

Introduction to the scientific method. Research process. How to search for and organize references. Scientific contribution versus technological contribution. Experiments in computing and reproducibility. How to write and review a scientific paper. Theses and Dissertations in Applied Computing. How to present research results.

Bibliography

- Booth, Wayne; Colomb, Gregory; William, Joseph, The Craft of Research. University of Chicago Press, 1995
- Grinnel, Frederick. A atitude científica, 1992 (tradução).
- Popper, Karl. Science: Conjectures and refutations. In: Karl Popper, Conjectures and refutations: The growth of scientific knowledge. Basic Books, 1962.
- Strunk, William. The elements of style. Penguin, 2007.
- Zobel, Justin. Writing for Computer Science. Springer-Verlag, 1997.

Code	Title	Credits
CAP-335-3	Computational Learning and Pattern Recognition	3

Track **Applied Artificial Intelligence**
Scheduled for the Second Term
Course Lecturer(s): *A CONFIRMAR*

Course Description

Introduction; typical sequence of a computational learning system; types of classifiers - statistical, deterministic, hierarchical; point-based and region-based classification; support vector machines; the use of context in point-based classification - iterative Markovian models: ICM, MPM, Potts-Strauss model, composite decision theory; methods for feature extraction and selection; segmentation of multi-spectral images; segment classification; classification evaluation; concordance indices.

Bibliography

- Bishop, C.M. *Pattern Recognition and Machine Learning. 1st ed.* Springer, 2006.
- Duda, R.O.; Hart, P.E.; Stork, D.G. *Pattern Classification. 2nd Ed.* John Wiley & Sons, New York, NY, 2001.
- Everitt, B.S.; Landau, S.; Leese, M.*Cluster Analysis. 4th ed.* Eduard Arnold, Ltd., London, UK, 2001
- Fukunaga, K. *Introduction to Statistical Pattern Recognition. 2nd Ed.* Academic Press, Boston, 1990.
- Heijden, F. *Image Based Measurement Systems.* John Wiley & Sons, New York, NY,1994.
- Kuncheva, L.I. *Combining Pattern Classifiers: Methods and Algorithms.* Wiley, June, 2004.
- Mitchell, T. *Machine Learning*, McGraw Hill, 1997.
- Theodoridis, S.; Koutroumbas, K. *Pattern Recognition, 3nd ed.*, Academic Press,2006.
- Webb, A.R. *Statistical Pattern Recognition, John Wiley & Sons; 2nd edition*, 2002.

Code	Title	Credits
CAP-340-3	Inverse Problems	3

Scheduled for the Third Term
Course Lecturer(s): Haroldo Fraga de Campos Velho ✉

Course Description

Fundamental concepts in inverse problems. Definition of ill-posed problems. Explicit and implicit solution methods. Classical optimization methods. Stochastic optimization techniques. Neural networks in inverse problems. Tikhonov-Twomey-Philips regularization. Entropic regularization. Selection of the regularization parameter. Applications.

Bibliography

- Beck J.V.; Blackwell B.; St-Clair, Jr., C.R. Inverse Heat Conduction: Ill-Posed Problems, John Wiley, New York, 1985.
- Tarantola A. Inverse Problem Theory: Methods for Data Fitting and Model Parameter Estimation, Elsevier, Amsterdam, 1987.
- Tikhonov A. N.; Arsenin V. Y. Solutions of Ill-Posed Problems, John Wiley, New York, 1977.

Code	Title	Credits
CAP-349-3	Geographic Databases	3

Track **Geospatial Data Science**
Scheduled for the Second Term
Course Lecturer(s): Gilberto Queiroz ✉ Karine Reis Ferreira ✉ Lúbia Vinhas ✉

Course Description

In the last decade, the use of geospatial data has become increasingly common in everyday applications as well as in various fields of knowledge. This data is fundamental for decision-making in environmental and socio-economic problems. Additionally, there has been greater availability of geospatial data due to the adoption of open data policies by numerous space agencies, research institutions, and initiatives based on collaborative systems (VGI, Crowdsourcing, Citizen Science). As a result, a wide range of technologies is now available for storing, analyzing, visualizing, and disseminating this type of data. Thus, the effective use of geospatial data and technologies has been a decisive factor in the success of businesses, government agencies, and the development of innovative research. This course will provide theoretical and practical foundations for the computational representation of geographic space, manipulation, modeling, and visualization of geographic data. The main topics of the course are:

- Introduction to Database Systems: concepts, architectures, data modeling, relational data model, query languages, and SQL.
- Introduction to big data, NoSQL, and NewSQL.
- Introduction to Geographic Information Systems: computational representation of geographic space, layer organization, spatial reference systems, and visualization of geographic data.
- Geospatial Database Systems: types of data and spatial operators, spatial queries, geospatial extensions for database management systems.
- Spatial data structures and geometric algorithms.
- Geographic data modeling.
- Interoperability in geospatial database systems.

Bibliography

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- Date, C. J. Introduction to Database Systems. 8th Edition. Addison-Wesley, 2003.
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- Shekkar, S.;Chawla, S. Spatial databases - a tour. Upper Saddle River, NJ, USA, Prentice-Hall. 2003.

Code	Title	Credits
CAP-351-3	Neurocomputing	3

Track **Applied Artificial Intelligence**
Scheduled for the Second Term

Course Lecturer(s): Marcos Gonçalves Quiles

Course Description

Introduction to neural networks, history, concepts, and definitions. Paradigms and learning rules. Perceptrons. Multi-layer Perceptrons (MLP). The Backpropagation Algorithm and its variations. Techniques for topology configuration. Regularizations. Autoencoders. Competitive neural networks: SOM, GNG. PCA. Hopfield Networks. Boltzmann Machines and Restricted Boltzmann Machines. Introduction to deep architectures: DNN, CNN, RNN. Software and applications.

Bibliography

- Rumelhart, David E.; McClelland, James L., Parallel Distributed Processing, Vol. 1: Foundations, A Bradford Book, 1994.
- Haykin S., Neural Networks: A comprehensive Foundation, 2rd Edition Prentice Hall, 1998.
- Haykin S., Neural Networks and Learning Machines, 3rd Edition, Pearson India, 2008.
- Yoshua Bengio and Ian J. Goodfellow and Aaron Courville, Deep Learning, MIT Press, 2016.
- LeCun, Y., Bengio, Y. and Hinton, G. E., Deep Learning, Nature, Vol. 521, pp 436-444.

Code	Title	Credits
CAP-354-3	Artificial Intelligence	3

Track **Applied Artificial Intelligence**
Scheduled for the First Term
Course Lecturer(s): Lamartine Nogueira Frutuoso Guimarães   Elcio Hideiti Shiguemori

Course Description

History of Artificial Intelligence. Pre-history prior to 1956. The role of Alan Turing in the development of today's AI. History after 1956. The Turing Test over the decades. Introduction to the main AI paradigms: 1. Production Systems. Expert systems. Logic and PROLOG. Automated theorem proving. LISP and CLIPS. Symbolic manipulation. Representation and problem-solving in state spaces. Search methods. Heuristics. 2. Concept of Fuzzy Logic (referencing track courses). Introduction to non-conventional logics. 3. Neural Networks. Perceptron and SOM. The 10-year gap. 4. Case-Based Reasoning. 5. Genetic Algorithms. 6. Agents. 7. Deep Learning. Knowledge representation for the paradigms covered. Introduction to natural language processing. Learning and knowledge acquisition for the paradigms covered. Examples of general applications and space-focused activities for the paradigms covered.

Bibliography

- Barr, A.; Feigenbaum, E.A. ed. *The Handbook of Artificial Intelligence. vol.1.* Stanford, CA, Heuristech Press, 1981.
- Bittencourt, G., *Inteligência Artificial Ferramentas e Teorias*, Ed. DAUFSC, 1998.
- Charniak, E.; McDermott, D. *Introduction to Artificial Intelligence*. Reading, MA, Addison, 1985.
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Code	Title	Credits
CAP-368-3	Introduction to Dynamic Systems Theory	3

Scheduled for the First Term
Course Lecturer(s): Elbert Einstein Nehrer Macau

Course Description

Nonlinear differential equations. Phase plane, eigenvalues and eigenvectors, phase plane classification. Linear algebra in high-dimensional systems. Nonlinear systems and equilibrium points. Bifurcations. Global analysis techniques. Limit cycles. Closed orbits and limit sets.

Bibliography

- Hirsh, M.W.; S. Smale, S., R. L.; Devaney, R.L., *Differential Equations, Dynamical Systems & an Introduction to Chaos*, Elsevier, 2003.
- Monteiro, L.H.A., *Sistemas Dinâmicos*, Livraria da Física, São Paulo, 2002.
- Strogatz, S.H., *Nonlinear Dynamics and Chaos*, Perseus, Cambridge, 2000.

Code	Title	Credits
CAP-370-3	Applied Computing for Environmental Physics	3

Scheduled for the Second Term
Course Lecturer(s): Reinaldo Roberto Rosa

Course Description

What is Environmental Physics? Sun-Earth relationships, space weather, and the terrestrial environment. Characterization of systems and physical processes in the terrestrial environment. Observation and representation of physical processes in geological, meteorological, oceanographic, and limnological systems. Thermodynamics, gradients, and physical instabilities. Generation of digital data for physical processes observed in the terrestrial environment: basic instrumentation, data collection, transmission, and organization. Period and frequency. Resolution and noise. Measurements of air and water temperature. Gradient measurements: pressure, air and water displacement, vortices, and other coherent structures. Computational analysis of deterministic and stochastic regimes. Aspects of computational statistical physics. Spectral analysis and pattern-gradient analysis. Computational handling of short series: techniques and algorithms for interpolation, smoothing, characterization, and prediction. Data assimilation in climate models. Computational analysis and modeling of nonlinear physical processes: case studies involving (a) pattern formation in miscible fluid systems in the ocean; (b) greenhouse gas emissions in reservoirs; (c) wind and temperature turbulence in forest systems; (d) flow and flooding in limnological systems. Data representation and mining systems. Model validation with case studies in environmental physics: Generalized numerical grids for data from the Amazon, Pantanal, and Guanabara Bay. Compatibility with geographic information systems and similar platforms. Computational applications for new technologies: Energy and sustainability.

Bibliography

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- Artaxo, P . Física do Meio Ambiente: Entendendo o Funcionamento do Planeta Terra. In: Gil da Costa Marques. (Org.). Física: Tendências e Perspectivas. São Paulo: Editora Livraria da Física, 2005, p. 235-240.
- Boeker, E.: Van Grondelle, R. Environmental Physics, Wiley, 1999.
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- Hanslmeier, A The Sun and the Space Weather, Springer, 2006.
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- Pelletier, J.D. Quantitative Modeling of Earth Surface Processes, Cambridge, 2008.
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- Sethna, J., Entropy, Order Parameters and Complexity, Oxford, 2006.

Code	Title	Credits
CAP-372-3	High-Performance Computing	3

Scheduled for the Second Term
Course Lecturer(s): Celso Luiz Mendes ✉ Stephan Stephany ✉

Course Description

This course aims to provide fundamental knowledge for parallel programming, covering parallel computer architectures, parallel programming techniques, performance evaluation tools, and parallel programming libraries. Topics include code optimization, a review of vector processor architectures and their programming, parallel programming using the Message Passing Interface (MPI) library and the OpenMP API. Practical programming exercises using a supercomputer are also included.

Bibliography

- Dowd, K.; Severance, C. High Performance Computing, Second Edition, O'Reilly,1998.
- Foster, I. Designing and Building Parallel Programs, Addison-Wesley, 1995.
- Hennessy, J. L, Patterson, D. A. Computer Architecture: A Quantitative Approach (3a. edição), Morgan Kaufmann Publishers, 2003.
- Modi, J. J. Parallel Algorithms and Matrix Computation, Oxford University Press, 1988.
- Pacheco, P. Parallel Programming with MPI, Morgan Kaufmann Publishers, 1997.
- Pacheco, P. An Introduction to Parallel Programming, Morgan Kaufmann Publishers, 2011.

Code	Title	Credits
CAP-381-3	Complex Networks, Dynamics, and Applications	3

Scheduled for the Second Term
Prerequisites: CAP-368-3 - Introduction to Dynamic Systems Theory
Course Lecturer(s): Elbert Einstein Nehrer Macau ✉ Leonardo Bacelar Lima Santos ✉

Course Description

Synchronization in dynamic systems. Graphs. Networks and complexity. Structure and topology of complex networks. Complex network models. Information propagation analysis. Robustness. Synchronization and collective dynamic effects. Control in complex networks. Applications.

Bibliography

- Alex, A; Díaz-Guikera, A.; Kurths J., Moreno, Y., Zhou C. Synchronization in complex networks. Physics Reports, 469. 93-153. 2008.
- Barrat, A.; Barthélemy, M.; Vespignani, A. Dynamical Processes on Complex Networks, Cambridge, 2008.
- Boccaletti, S.; Latora, V.; Moreno, Y.; Chavez, M.; Hwang, D. –U. Complex networks: Structure and dynamics. Physics Reports 424. 175-308. 2006.
- Cohen, R.; Havlin, S. Complex Networks: Structure, Robusteness and Function, Cambridge, 2010.
- Newman, M. E. J. Networks: An Introduction, Oxford. 2010.

Code	Title	Credits
CAP-394-3	Introduction to Data Science	3

Scheduled for the Second Term
Course Lecturer(s): Gilberto Queiroz ✉ Rafael Santos ✉

Course Description

What is Data Science? Why does Data Science exist as a discipline? The role of a Data Scientist. Other roles and responsibilities in Data Science. Data Collection and Discovery. Data Provenance and Annotation. Data Federation and Distribution. Tools for Data Science: Databases, Artificial Intelligence, and Machine Learning, Visualization. Implementation of algorithms in R and Python. Analytics and Exploratory Data Analysis. Reproducible Research. Data-driven products. Examples of applications, case studies, and project development.

Bibliography

- Roger D. Peng, Elizabeth Matsui, *The Art of Data Science: A Guide for Anyone who works with Data*, Leanpub, 2016.
- Rachel Schutt, Cathy O'Neill, *Doing Data Science: Straight Talk from the Frontline*, O'Reilly, 2014.
- Sebastian Gutierrez, *Data Scientists at Work*, APress, 2014.
- Harlan D. Harris, Sean Patrick Murphy, Marck Vaisman, *Analyzing the Analyzers: An Introspective Survey of Data Scientists and Their Work*, O'Reilly, 2013.

Code	Title	Credits
CAP-395-3	Geoinformatics	3

Track **Geospatial Data Science**
Scheduled for the First Term
Course Lecturer(s): Gilberto Queiroz ✉ Karine Reis Ferreira ✉ Lúbia Vinhas ✉

Course Description

This course aims to present concepts, methodologies, and tools in the field of Geoinformatics. This area deals with the application of computational methods to solve problems involving phenomena on the Earth's surface, which are dynamic over time. To this end, the course provides students with an understanding of concepts related to the representation of spatiotemporal data obtained from various sources, such as time series of satellite images or geographic data from voluntary collaboration (Volunteered Geographic Information – VGI). Technologies for storing and processing spatiotemporal data, with an emphasis on big data, and platforms for processing such data will be studied. Methods and technologies for sharing and interoperability of geographic and spatiotemporal data through web-based geographic services will also be examined. The course will be based on in-person classes, group discussions of classic and recent literature articles that present the state-of-the-art on related topics, as well as practical exercise labs. The main topics of the course are:

- Representation, storage, and analysis of spatiotemporal data;
- Web services for geographic data;
- Interoperability and standards for geospatial web services;
- Spatial Data Infrastructures (SDI), addressing examples of existing SDIs, such as INDE - Spatial Data Infrastructure of Brazil and INSPIRE of the European Community;
- Volunteered Geographical Information (VGI) and citizen science;
- Concepts and tools for processing and analyzing large volumes of spatiotemporal data;
- Earth Observation Data Cubes;
- Platforms for managing and storing large volumes of geospatial data;
- Open science concepts and reproducibility in the geospatial field.

Bibliography

- Ferreira, K. R., et al. "Earth Observation Data Cubes for Brazil: Requirements, Methodology and Products". Remote Sens. 2020, 12, 4033.
- Gomes, V. C. F.; Queiroz, G. R.; Ferreira, K. R. "An Overview of Platforms for Big Earth Observation Data Management and Analysis". Remote Sens. 2020, 12, 1253.
- Vinhas, Lubia, et al. "Web Services for Big Earth Observation data". GeoInfo. (2016).
- Güting, R. H.; Schneider, M. "Moving Objects Databases". Morgan Kaufmann, 2005.
- Baumann, Peter. "The OGC web coverage processing service (WCPS) standard". Geoinformática 14.4 (2010): 447-479.
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- Lewis, Adam, et al. "The Australian Geoscience Data Cube—Foundations and lessons learned". Remote Sensing of Environment (2017).
- Mooney, Peter, et al. "Towards a Protocol for the Collection of VGI Vector Data". ISPRS International Journal of Geo-Information 5.11 (2016): 217.
- See, Linda, et al. "Crowdsourcing, citizen science or volunteered geographic information? The current state of crowdsourced geographic information". ISPRS International Journal of Geo-Information 5.5 (2016): 55.
- Siabato, Willington, et al. "A Survey of Modelling Trends in Temporal GIS."ACM Computing Surveys (CSUR) 51.2 (2018): 30.
- Stonebraker, M.; et al. "The architecture of SciDB". In Proceedings of the 23rd international conference on Scientific and statistical database management (SSDBM'11). Springer-Verlag, Berlin, Heidelberg, 2011, 1–16.

Code	Title	Credits
CAP-398-3	Modeling and Applications of Complex Reactive Systems	3

Scheduled for the Second Term
Prerequisites: Programming Knowledge
Course Lecturer(s): Nandamudi Lankalapalli Vijaykumar ✉

Course Description

Concepts of Complex Systems and Reactive Systems. The need for modeling such systems. Representation of Encapsulation and Concurrent Activities. Techniques for representing Reactive Systems. State and Transition Diagrams. Finite State Machines, Queueing Networks, Petri Nets, and Statecharts. Concepts of Performance Evaluation. Basic concepts of Markov Chains. Simulation Concepts. Software Testing Concepts. Graph Concepts. Black-Box and White-Box Testing. Criteria and Methods for Test Generation. Why model a Software Specification or Code?

Bibliography

- Beizer, B. Black-box Testing Techniques for Functional Testing of Software and Systems. John Wiley & Sons, 1995.
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- Delamaro, M.; Jino, M.; Maldonado J. Introdução ao Teste de Software. 2a Ed. Elsevier, 2016.
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- Murata, T. Petri Nets: Properties, Analysis and Applications. Proceedings of the IEEE. Vol. 77(4). April 1989.
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Code	Title	Credits
CAP-399-3	Programming of Massively Parallel Systems	3

Scheduled for the Third Term
Prerequisites: CAP-372 - High-Performance Processing or an equivalent course from another institution. Experience in C, C++, Fortran in a Linux environment. Basic knowledge of Computer Architecture.
Course Lecturer(s): Celso Luiz Mendes ✉ Stephan Stephany ✉

Course Description

Performance Models and Measurement. Current Massively Parallel Architectures. Memory Hierarchies, Caches, and Relative Performance. Pipelining, Vectorization, Moore's Law. Speedup, Amdahl's Law, and n1/2. Advanced Programming in Shared Memory. Interconnections and Performance Aspects. Advanced Programming in Distributed Memory. Message Passing, Point-to-Point Operations, and Synchronization. Topologies, Collective Operations, and Optimizations. Parallel I/O. Fault Tolerance Techniques.

Bibliography

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- Pacheco, P. An Introduction to Parallel Programming. Morgan Kaufmann, 2011.

Code	Title	Credits
CAP-408-3	Applied Computing for Atmospheric Sciences	3

Scheduled for the Third Term
Course Lecturer(s): Alan Calheiros ✉

Course Description

Current applications of Scientific Computing and Data Science in meteorology and climatology; Exploration of large volumes of meteorological data from remote sensors, numerical models, and observation networks; Evaluation of uncertainties in meteorological estimates and forecasts; Integration of FAIR principles (Findable, Accessible, Interoperable, Reusable) to optimize curation, management, and analysis of atmospheric data; Development of practical projects and case studies using modern tools for meteorological analysis and forecasting.

Bibliography

- Holton, J.R. An introduction to Dynamic Meteorology. New York, Academic Press, Inc., 4ª ed., 2004, 511 p.
- Peixoto, J. P.; Oort, A. R. Physics of Climate. New York, American Institute of Physics, 1992.
- Petty, G. W. A first course in atmospheric radiation. Sundog Pub, 2006.
- Rinehart, Ronald E. Radar for meteorologists. Fifth edition. 2010.
- Wallace, J. M.; Hobbs, P. V. Atmospheric Science: an Introductory Survey. Academic Press, 2a ed., 2006, 504p.
- Wilks D.S. Statistical Methods in the Atmospheric Sciences. 2nd Edition. Academic Press, 2006. 627p.
- Haykin, S. Redes neurais: princípios e prática. Bookman Editora, 2001.
- Lakshmanan, V., Gilleland, E., McGovern, A., & Tingley, M. Machine learning and data mining approaches to climate science. In Proceedings of the 4th International Workshop on Climate Informatics (pp. 3-246). Basel, Switzerland: Springer International Publishing. 2015.
- Wilkinson, M. D. e. a. The fair guiding principles for scientific data management and stewardship. Scientific Data, v. 3, 3 2016.

- Specialized articles in international scientific journals and educational materials developed by centers of excellence in meteorology, computing, and related fields.

Code	Title	Credits
CAP-417-3	Computational Statistics	3

Track **Mathematical and Computational Modeling of Natural Phenomena**
Scheduled for the First Term
Course Lecturer(s): Leonardo Bacelar Lima Santos ✉ Reinaldo Roberto Rosa ✉ Valdivino Alexandre de Santiago Junior ✉

Course Description

Descriptive statistics, regression, and hypothesis testing. Introduction to Random Walks and Monte Carlo Methods. Probability. Discrete and Continuous Random Variables. Discrete and Continuous Probability Distributions. Kernel Density Estimation. Frequency domain, Series, and Fourier Transform. Introduction to Computational Analysis of Time Series. Applications in Engineering and Computer Science for Aerospace and Environmental fields.

Bibliography

- BUSSAB, W. O.; MORETTIN, P. A. Estatística básica. 6ª ed. São Paulo: Saraiva, 2010
- PROAKIS, J. G. Digital Signal Processing: Principles, Algorithms and Applications, 2000.
- BAIER, C.; KATOEN, J. P. Principles of model checking. Cambridge, MA, USA: The MIT Press, 2008.
- ROSS, S. M. Introduction to Probability Models. 9th ed. Boston: Academic Press, 2006
- ROSA, R.R., Análise Estatística e Espectral de Processos Não-Lineares: uma abordagem computacional em Python, KNOBOOK, 2021.
- WALPOLE, R. E.; MYERS, R. H.; MYERS, S. L.; YE, K. Probability & Statistics for Engineers & Scientists. Boston, MA, USA: Pearson Education, Inc., 2012

Code	Title	Credits
CAP-418-4	Numerical Methods I	4

Scheduled for the First Term
Course Lecturer(s): Leonardo Bacelar Lima Santos ✉ Reinaldo Roberto Rosa ✉

Course Description

Electronic-digital computer; Representation of numerical systems and error; Polynomial Interpolation; Solution of linear equations (scalar); Matrices and Systems of Linear Equations; Zeros of nonlinear functions; Numerical Differentiation and Integration; Numerical solution of differential equations and systems of differential equations; Fourier Series and Transform; Introduction to Stochastic Differential Equations.

Bibliography

- Ruggiero, M. A. R.; Lopes, V. L. R. Cálculo numérico aspectos teóricos e computacionais. Editora Pearson Education, 2a edição, 1996.
- Hoffman, J. D. Numerical Methods for Engineers and Scientists. McGraw-Hill. 1993.

- Conte, S. D.; de Boor, C. Elementary Numerical Analysis: an algorithm approach 3rd Ed. McGraw-Hill. 1987.
- Proakis, John G.; Manolakis, Dimitris K. Digital Signal Processing, 4ed.

Code	Title	Credits
CAP-419-3	Introduction to Programming with Geospatial Data	3

Scheduled for the First Term
Course Lecturer(s): Gilberto Queiroz ✉ Thales Sehn Körting ✉

Course Description

In the era of big data, professionals increasingly require programming skills to perform data analysis quickly and efficiently. This course focuses on teaching the art of computer programming through practical problems using geospatial data. No prior programming experience is required. The course will introduce concepts, techniques, and computational tools to support the research cycle in Geospatial Data Science, including data acquisition, organization and integration, analysis, and visualization. Students will gain a general understanding of how to create small programs in Python to automate routine or repetitive tasks capable of extracting, transforming, and analyzing geospatial data. The main topics covered in the course are:

- Introduction to Programming Logic: The Python Programming Language; Data Types; Variables and Assignment; Data Reading; Control Structures; Sequences; Functions.
- Manipulation and Analysis of Raster Data: Layer stack; Transformation between Spatial Reference Systems; Cropping and Mosaics; Basic Image Statistics; Band Arithmetic; Visualization.
- Manipulation and Analysis of Vector Data: Spatial Operations (metrics, buffers, union, topology); Manipulation of vector file formats (Shapefile, KML, GeoJSON); Transformation between Spatial Reference Systems; Visualization.
- Integrated Analysis of Raster and Vector Data: Integrated Analysis with geometries (points, lines, and polygons).
- Literate Computing: Interactive Computing Environments; The Jupyter Project; Creating Jupyter Notebooks; Sharing Jupyter Notebooks.

Bibliography

- John V. Guttag. Introduction to Computation and Programming Using Python - With Application to Understanding Data. The MIT Press, Cambridge, Massachusetts, USA, 2nd edition, 2016.
- Mark Lutz. Learning Python. O'RELLY, CA, USA, 5th edition, 2013.
- Kluyver, Thomas, et al. "Jupyter Notebooks – a publishing format for reproducible computational workflows". Loizides, Fernando and Scmidt, Birgit (eds.). In Positioning and Power in Academic Publishing: Players, Agents and Agendas. IOS Press, 2016. pp. 87-90.
- Adam Rule, Aurélien Tabard, and James D. Hollan. 2018. Exploration and Explanation in Computational Notebooks. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). Association for Computing Machinery, New York, NY, USA, Paper 32, 1–12.
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- Jensen, J. R. Sensoriamento Remoto do Ambiente: Uma Perspectiva em Recursos Terrestres. Tradução da 2a. edição. J. C. N. EPIPHANIO (org.). São José dos Campos: Parêntese Editora. 672 p.

Code	Title	Credits
CAP-420-3	Numerical Methods II	3

Scheduled for the Second Term
Course Lecturer(s): Haroldo Fraga de Campos Velho ✉

Course Description

Solution of partial differential equations using finite difference methods: convection equation, convection-diffusion equation, wave equation. Topics include consistency, order, and convergence of finite difference approximations, ADI method, explicit and implicit Euler methods, Crank-Nicholson, Lax-Wendroff, Richardson, MacCormack methods, and the method of characteristics.

Bibliography

- Carnahan, B.; Luther, A.H.; Wilkes, J.O. Applied Numerical Methods, John Wiley & Sons, 1969.
- Conte, S.D.; de Boor, C. Elementary Numerical Analysis, McGraw-Hill, 1965.
- Hoffman, J.D. Numerical Methods for Engineers and Scientists, McGraw-Hill (Mechanical Engineering Series), 1993.
- Smith, G.D. Numerical Solution of Partial Differential Equations: Finite Difference Methods, Oxford University Press, 3th ed, 1985.

Code	Title	Credits
CAP-421-3	Deep Learning	3

Track **Applied Artificial Intelligence**
Scheduled for the Third Term
Course Lecturer(s): Valdivino Alexandre de Santiago Junior ✉ Elcio Hideiti Shiguemori ✉ Thales Sehn Körting ✉

Course Description

Definitions of Artificial Intelligence, Deep Learning, and Computer Vision. Computer Vision tasks. Basic concepts of Digital Image Processing. Convolution: Padding, Filter Dimension, Stride, Dilation. Review of Multilayer Perceptron Neural Networks with Backpropagation Algorithm. Loss Functions and Optimizers. Convolutional Neural Networks (CNNs). Convolutional and Fully Connected Layers. Activation Functions. Batch Normalization. Dropout. Transfer Learning. Data Augmentation. Hyperparameter Tuning. Examples of CNN Architectures for various Computer Vision tasks. Recurrent Neural Networks (RNNs). Generative Artificial Intelligence. Generative Adversarial Networks (GANs). Visual Transformers. Diffusion Models. Deep Reinforcement Learning.

Bibliography

- I. Goodfellow, Y. Bengio and A. Courville. Deep Learning. Cambridge, MA, USA: The MIT Press, 2016. 775 p.
- F. Chollet. Deep Learning with Python. Shelter Island, NY, USA: Manning Publications, 2018. 384 p.
- J. Patterson and A. Gibson. Deep Learning: A Practitioner's Approach. Sebastopol, CA, USA: O'Reilly Media, 2017. 538 p.
- S. Raschka and V. Mirjalili. Python Machine Learning - Second Edition: Machine Learning and Deep Learning with Python, scikit-learn, and TensorFlow. Birmingham, UK: Packt Publishing, 2017. 624 p.

Code	Title	Credits
CAP-422-3	Computational Mathematical Physics	3

Scheduled for the Third Term
Course Lecturer(s): Reinaldo Roberto Rosa ✉

Course Description

Introduction to algebraic structures and symbolic mathematics in SymPy. Tensor algebra (tensors, vectors, and scalars).

Scalar and vector fields. Variational Method: Lagrangian and Hamiltonian. Functions of complex variables; Special functions; Green's functions;

Distribution Theory; Perturbation Theory; Group Theory; Algebraic and geometric models in mathematical physics.

Computational generation and characterization of processes in scalar and vector fields with examples in space physics.

Bibliography

- Anderssen, R. S.; Watts, R. O. Computational Methods in Mathematical Physics, University of Queensland Press, 1975.
- Boas, M. L. ; Mathematical Methods in the Physical Sciences, Wiley, New York, 2006.
- Butkov, E.; Física-Matemática, LTC, 1988.
- Chun, W. and Rosa, R.R., Introdução à Matemática Simbólica no SymPy. Knobook, 2021.
- Kusse, B.R., Westwig, E.A.; Mathematical Physics, Wiley-VCH, 2006.

Code	Title	Credits
CAP-423-4	Geospatial Data Science	4

Track **Geospatial Data Science**
Scheduled for the Third Term
Course Lecturer(s): Gilberto Queiroz ✉ Karine Reis Ferreira ✉ Lúbia Vinhas ✉ Rafael Santos ✉ Thales Sehn Körting ✉

Course Description

This course focuses on research and applications with geospatial data, including techniques for image manipulation, time series analysis, and machine learning methods to identify patterns and extract information from spatiotemporal data and remote sensing images. With a practical approach, the course will cover applications where preprocessing techniques, similarity measures, filters, feature extraction, segmentation, clustering, classification, and validation are employed in the production of land use and land cover maps. The course will also study different methods for analyzing remote sensing image time series, such as TWDTW, TimeSat, and BFast. It is based on theoretical and practical classes, as well as discussions and reproductions of well-known literature articles presenting the state-of-the-art in related topics. The main topics of the course are:

- Introduction to spatiotemporal data and remote sensing image time series;
- Analysis of remote sensing image time series, including the use of filters, feature extraction, similarity measures, and clustering;
- Image segmentation;

- Analysis of land use and land cover samples using neural networks;
- Land use and land cover classification using Machine Learning and Deep Learning methods;
- Analysis of land use and land cover trajectories;

Bibliography

- Adeu, R. S. S.; Ferreira, K. R.; Andrade, P. R.; Santos, L. "Assessing Satellite Image Time Series Clustering Using Growing SOM". In: Gervasi O. et al. (eds) Computational Science and Its Applications ICCSA 2020. Lecture Notes in Computer Science, vol 12253. Springer, Cham. University of Cagliari, Cagliari, Italy. July-1-4, 2020.
- Ferreira, K. R., et al. "Earth Observation Data Cubes for Brazil: Requirements, Methodology and Products". Remote Sens. 2020, 12, 4033.
- Maciel, A.; Camara, G.; Vinhas, L.; Picoli, M.; Begotti, R.; Assis, L. "Spatiotemporal interval logic for reasoning about land use change dynamics". Inter. Journal of Geographical Information Science, 33(1):176-192, 2019.
- Maciel, A.; Picoli, M..; Vinhas, L.; Camara, G. "Identifying Land Use Change Trajectories in Brazil's Agricultural Frontier"Land 9, no. 12: 506, 2020.
- Maretto, R. V.; et al. "Spatio-Temporal Deep Learning Approach to Map Deforestation in Amazon Rainforest". IEEE Geoscience and Remote Sensing Letters, v. 1, p. 1-5, 2020.
- Maus, V.; et al. "A Time-Weighted Dynamic Time Warping Method for Land-Use and Land-Cover Mapping". IEEE J-STARS, v. 9, p. 1-11, 2016.
- Monteiro, D. V.; Santos, R. D. C.; Ferreira, K. R. "Mining Partners in Trajectories". International Journal of Data Warehousing and Mining, v. 16, p. 22-38, 2020.
- Neves, A. K.; et al. "Assessment of TerraClass and MapBiomas data on legend and map agreement for the Brazilian Amazon biome". ACTA AMAZONICA, v. 50, p. 170-182, 2020.
- Picoli, M. C. A.; et al. "CBERS Data Cube: A Powerful Technology for Mapping and Monitoring Brazilian Biomes". In: XXIVth International Society for Photogrammery and Remote Sensing (ISPRS) Congress. Virtual Event. August 31 to September 2, 2020.
- Santos, L.; Ferreira, K. R.; Picoli, M.; Camara, G. "Self-Organizing Maps in Earth Observation Data Cubes Analysis". 13th International Workshop on Self-Organizing Maps and Learning Vector Quantization, Clustering and Data Visualization (WSOM+ 2019), Barcelona, Spain, June 26-28, 2019.
- A. Soares, T. Körting, L. Fonseca and H. Bendini, "Simple Nonlinear Iterative Temporal Clustering,"in IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2020.3033266.
- Simoes, R.; et al. "Land use and cover maps for Mato Grosso State in Brazil from 2001 to 2017". Scientific Data, v. 7, p. 34, 2020.

Code	Title	Credits
CAP-424-3	Fuzzy Logic	3

Track **Applied Artificial Intelligence**
Scheduled for the Third Term
Course Lecturer(s): Lamartine Nogueira Frutuoso Guimarães ✉

Course Description

Fuzzy Concepts: fuzzy sets versus crisp sets, singleton, membership function, fuzzy variable, Universe of Discourse, Linguistic Variable and its meanings, Extension Principle, Alpha-cuts, Resolution Principle, fuzzy relations, fuzzy numbers and their operations, linguistic descriptions and their analytical forms, open-loop fuzzy control, dynamic systems without control, dynamic systems and PI/PID control, dynamic systems and fuzzy control (with feedback), and a project developing fuzzy control applied to a dynamic system chosen by the student.

Bibliography

- Tsoukalas, L. H.; Uhrig, R. E. Fuzzy and Neural Approaches in Engineering, John Wiley and Sons, Inc., New York, 1997.
- Hines, J. W.; MATLAB Supplement to Fuzzy and Neural Approaches in Engineering, John Wiley and Sons, Inc., New York, 1997.
- Shaw, I.S.; Simões, M.G. Controle e Modelagem Fuzzy, Editora Edgard Blücher,Ltda., 1999.
- Tanaka, K. An Introduction to Fuzzy Logic for Practical Applications, Springer-Verlag, 1997.

Code	Title	Credits
CAP-425-3	Advanced Topics in Environmental Modeling	3

Track **Mathematical and Computational Modeling of Natural Phenomena**
Scheduled for the Third Term
Course Lecturer(s): Leonardo Bacelar Lima Santos ✉ Stephan Stephany ✉

Course Description

Anomalies and extreme events. Statistical fundamentals. Monitoring and change detection. Examples involving Geostatistics and Machine Learning. Applications in space weather - ionospheric scintillation, and hydrology - floods and urban flooding.

Bibliography

- Albeverio, S., Jentsch, V., Kantz, H. (2006). Extreme Events in Nature and Society, Springer.
- Stephan et al. (2019) Data Mining Approaches to the Real-Time Monitoring and Early Warning of Convective Weather Using Lightning Data. Towards Mathematics, Computers and Environment: A Disasters Perspective. Editors: Santos, L. B. L., Negri, R. G., Carvalho, T. J. (Eds.), Springer.
- Santos, L. B. L. et al. (2019) About Interfaces Between Machine Learning, Complex Networks, Survivability Analysis, and Disaster Risk Reduction. Towards Mathematics, Computers and Environment: A Disasters Perspective. Editors: Santos, L. B. L., Negri, R. G., Carvalho, T. J. (Eds.), Springer.

Code	Title	Credits
CAP-465-4	Modeling and Simulation of Earth Systems	4

Track **Mathematical and Computational Modeling of Natural Phenomena**
Scheduled for the Second Term
Course Lecturer(s): Pedro Ribeiro de Andrade Neto ✉

Course Description

Earth System Science is an interdisciplinary field that addresses various aspects of the interaction between society and nature. This course covers the basic fundamentals of nature-society interactions through computational simulation models. Three modeling paradigms are presented: system dynamics, cellular automata, and agent-based modeling.

The topics covered include: (a) Renewable and non-renewable resources; (b) Epidemiology; (c) Predator-prey ecological models; (d) Hydrology; (e) Land-use change.

Bibliography

- Ford, A. Modeling the Environment (2nd edition), Island Press, 2010.
- Meadows, D. Thinking in Systems, Chelsea Publishing, 2008.
- Miller, J. H.; Page, S. Complex Adaptive Systems, Princeton University Press, 2007.
- Batty, M. Cities and Complexity. MIT Press, 2007.
- Nowak, M. A. Evolutionary Dynamics: Exploring the Equations of Life, Harvard University Press, 2006.

Code	Title	Credits
CAP-501-0	Seminars in Applied Computing I	0

Available in all terms
Course Lecturer(s): Rafael Santos ✉ Nandamudi Lankalapalli Vijaykumar ✉

Course Description

Lectures given by the faculty and external guests, covering various topics in Applied Computing and Mathematics.

Code	Title	Credits
CAP-502-0	Seminars in Applied Computing II	0

Available in all terms
Course Lecturer(s): Rafael Santos ✉ Nandamudi Lankalapalli Vijaykumar ✉

Course Description

Lectures given by the faculty and external guests, covering various topics in Applied Computing and Mathematics.

Code	Title	Credits
CAP-730-0	Master's Research in Applied Computing	0

Prerequisites: None
Course Lecturer(s): Research Advisor

Course Description

Does not count for credits. Enrollment is mandatory for all master's students in the research phase. Their Research Advisor will evaluate the student's performance in this activity. Enrollment is also mandatory for students without a formal Research Advisor and who are not enrolled in any courses. In such cases, the student's guidance and evaluation will be conducted by a faculty member approved by the Academic Coordinator.

Code	Title	Credits
CAP-750-12	Master's Dissertation in Applied Computing	12

Prerequisites: Approval of the Master's proposal
Course Lecturer(s):

Course Description

12 Credits. Final Project for the Master's Program.

Code	Title	Credits
CAP-780-0	Doctoral Research in Applied Computing	0

Prerequisites: None
Course Lecturer(s): Research Advisor

Course Description

Does not count for credits. Enrollment is mandatory for all doctoral students in the research phase. Their Research Advisor will evaluate the student's performance in this activity. Enrollment is also mandatory for students without a formal Research Advisor and who are not enrolled in any courses. In such cases, the student's guidance and evaluation will be conducted by a faculty member approved by the Academic Coordinator.

Code	Title	Credits
CAP-800-36	Doctoral Thesis in Applied Computing	36

Prerequisites: Approval of the Doctoral proposal
Course Lecturer(s):

Course Description

36 Credits. Final Project for the Doctoral Program.

Catalog approved by the Graduate Council in December 27th,