System modelling and simulation

Course description sheet

Basic information

Field of study Computer Science and Data Science	**Didactic cycle** 2025/2026
Major All	**Course code** WIIDSS.IIi1.02895.25
Organisational unit Faculty of Computer Science	**Lecture languages** Polish
Study level Second-cycle (engineer) programme	**Mandatoriness** Elective
Form of study Full-time studies	**Block** Core Modules
Profile General academic	**Course related to scientific research** Yes

Course coordinator	Rafał Dreżewski
Lecturer	Rafał Dreżewski, Wojciech Turek

Period Semester 1	**Method of verification of the learning outcomes** Completing the classes **Activities and hours** Lectures: 14 Laboratory classes: 28	**Number of ECTS credits** 3

Goals

C1	Providing students with knowledge of modern approaches and algorithms used in modeling and simulation, with particular emphasis on the agent-based approach.
C2	To acquaint students with the consecutive stages of developing the agent-based model and simulation of a selected real-world phenomenon.
C3	To acquaint students with the methods of conducting simulation experiments and developing and presenting their results.

Course's learning outcomes

Code	Outcomes in terms of	Learning outcomes prescribed to a field of study	Methods of verification
Knowledge – Student knows and understands:			
W1	basic types of models and simulation systems.	INFDS2A_W01, INFDS2A_W02, INFDS2A_W04	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
W2	basic simulation control mechanisms.	INFDS2A_W01, INFDS2A_W02	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
W3	the concepts of agent-based modeling and simulation as well as the principles of creating agent-based models of selected real-world phenomena.	INFDS2A_W01, INFDS2A_W02, INFDS2A_W04	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
W4	techniques and algorithms used in the implementation of agent-based simulation systems.	INFDS2A_W01, INFDS2A_W02, INFDS2A_W03	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
Skills – Student can:			
U1	conduct simulation experiments using the implemented software and develop, interpret and describe the results of experiments.	INFDS2A_U01, INFDS2A_U03, INFDS2A_U04, INFDS2A_U05, INFDS2A_U06, INFDS2A_U07	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
U2	develop an agent-based model of the chosen phenomenon.	INFDS2A_U02, INFDS2A_U04, INFDS2A_U05, INFDS2A_U06, INFDS2A_U07	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
U3	implement a developed agent-based simulation model using selected tools and programming libraries.	INFDS2A_U01, INFDS2A_U02, INFDS2A_U03, INFDS2A_U04, INFDS2A_U06, INFDS2A_U07	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research
Social competences – Student is ready to:			
K1	analyse and critically evaluate non-technical aspects of the application of modeling and simulation techniques.	INFDS2A_K01, INFDS2A_K02	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research

Program content ensuring the achievement of the learning outcomes prescribed to the module

As part of the course, the student acquaints with the basic mechanisms, techniques, and approaches to modeling and simulation with particular emphasis on the agent-based approach.

Student workload

Activity form	**Average amount of hours* needed to complete each activity form**
Lectures	14
Laboratory classes	28
Realization of independently performed tasks	14
Preparation of project, presentation, essay, report	28
Contact hours	5
Student workload	**Hours** 89
Workload involving teacher	**Hours** 42

* hour means 45 minutes

Program content

No.	Program content	Course's learning outcomes	Activities
1.	1. Basic concepts and issues: system, system versus environment, model, agent, object, attributes, system state, event, action, process. Discrete systems. Continuous systems. Simulation models. Experiments with an existing system or system model. The physical model and the mathematical model. Analytical solution and simulation. (2 hours) 2. Static and dynamic simulation models. Deterministic and stochastic simulation models. Simulation models with continuous and discrete time. Models with discrete events. Stages of modeling and simulation. Controlling the simulation. Time-driven simulation. Event-driven simulation. (2 hours) 3. Artificial life. Cellular automata. Flocking behavior. Ant systems. Introduction to agent-based modeling and simulation. The concept of an agent and a multi-agent system (environment, agents, objects, relations, agents' actions, operators representing "laws of nature"). Characteristic features of agent-based modeling. Agent-based modeling and simulation versus other approaches to modeling and simulation. (2 hours) 4. When should the agent-based modeling and simulation be used? Stages of creating an agent model. Model verification. Model validation. The issue of time in the agent model. (2 hours) 5. Design and implementation of the agent-based simulation model. Discussion of examples of programming tools, libraries, simulation environments, and frameworks. (2 hours) 6. Discussion of exemplary agent-based simulations: simulation of crowd behavior, traffic simulation, biological and social simulations. (2 hours) 7. Perspectives of the agent-based approach to modeling and simulation. Possibilities of using machine learning techniques as well as biologically and socially inspired algorithms in the agent-based modeling and simulation. (2 hours)	W1, W2, W3, W4, K1	Lectures
2.	1. Development of an agent-based model of a selected biological, social, economic or other phenomenon (4 hours). 2. Implementation of the developed agent-based simulation model using selected tools and programming libraries (12 hours). 3. Conducting preliminary simulation experiments using the implemented agent-based simulation model. Verification of the correctness of the simulation model based on the results of simulation experiments. Possible modification of the simulation model or its implementation (4 hours). 4. Conducting appropriate simulation experiments using the implemented agent-based simulation system. Elaboration, interpretation, and presentation of the results of simulation experiments (8 hours).	W1, W2, W3, W4, U1, U2, U3, K1	Laboratory classes

Extended information/Additional elements

Teaching methods and techniques :

Lectures will be conducted remotely using the MS Teams platform. Other classes will be held in classrooms., Discussion, Group work, E-learning, Project Based Learning, Mentoring, Tutoring, Inquiry Based Learning, Lecture

Activities	Methods of verification	Credit conditions
Lectures	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research	Completing a project on a topic agreed with the teacher.
Lab. classes	Activity during classes, Project, Report, Presentation, Completion of laboratory classes, Preparation and conduct of scientific research	Completing a project on a topic agreed with the teacher.

Additional info

Lectures on the subject will be conducted remotely using the MS Teams platform.
Other classes will be held in classrooms. This also applies to credits and exams taking place during examination sessions.

Conditions and the manner of completing each form of classes, including the rules of making retakes, as well as the conditions for admission to the exam

Lectures: completing a project on a topic agreed with the teacher.
Laboratory classes: completing a project on a topic agreed with the teacher.
Re-takes: completing a project on a topic agreed with the teacher.

Method of determining the final grade

The final grade is identical to the grade from the laboratory classes: 0.25 * development of the simulation model + 0.25 * implementation of the simulation model + 0.25 * conducting simulation experiments + 0.25 * development, interpretation, and presentation of results.

Manner and mode of making up for the backlog caused by a student justified absence from classes

Completing a project on a topic agreed with the teacher.

Prerequisites and additional requirements

Ability to program in Java/Scala/Python/C++ or another language in which it is possible to implement a selected simulation system.

Rules of participation in given classes, indicating whether student presence at the lecture is obligatory

Lectures: Students participate in classes learning the teaching content in accordance with the subjects from the syllabus. Students should keep asking questions and clarifying doubts. Audiovisual registration of the lecture requires the teacher's consent.
Laboratory classes: Students carry out practical work aimed at obtaining competences assumed by the syllabus. The method of project implementation and the final result are assessed.

Literature

Obligatory

1. Grimm V., Railsback S.F., _Agent-Based and Individual-Based Modeling: A Practical Introduction_, Princeton University Press, 2011.
2. Epstein J.M., _Generative Social Science: Studies in Agent-Based Computational Modeling_, Princeton University Press, 2007
3. Uhrmacher A.M., Weyns, D. (red.), _Multi-Agent Systems. Simulation and Applications_, CRC Press, 2009
4. Gilbert N., _Agent-based models_, SAGE Publications, 2008.
5. Hamill L., Gilbert N., _Agent-Based Modelling in Economics_, Wiley, 2016.
6. North M.J., Macal, C.M., _Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation_, Oxford University Press, 2007.
7. Wilensky U., Rand, W., _An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with NetLogo_, The MIT Press, 2015.

Optional

1. Lee R.S.T. (red.), _Computational Intelligence for Agent-based Systems_, Springer-Verlag, 2007.
2. Dorigo M., Stützle, T., _Ant Colony Optimization_, The MIT Press, 2004.
3. Engelbrecht A.P., _Fundamentals of Computational Swarm Intelligence_, Wiley, 2005.
4. Floreano D., Mattiussi C., _Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies_, The MIT Press, 2008.
5. Sarker R.A., Ray T., (red.), _Agent-Based Evolutionary Search_, Springer, 2010.
6. Grimm V., Railsback S.F., _Individual-based Modeling and Ecology_, Princeton University Press, 2005.
7. Sterling L.S., _The Art of Agent-Oriented Modeling_, The MIT Press, 2009.
8. Russell S., Norvig P., _Artificial Intelligence: A Modern Approach_, Pearson, 2010.
9. Ferber J., _Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence_, Addison-Wesley, 1999.
10. Wooldridge M., _An Introduction to MultiAgent Systems_, Wiley, 2009.
11. Gilbert N., Troitzsch K.G., _Simulation for the Social Scientist_, Open University Press, 2005
12. Epstein J.M., Axtell, R., _Growing artificial societies. Social science from bottom up_, Brookings Institution Press, The MIT Press, 1996.
13. Banks J., Carson J, Nelson B.L., Nicol D., _Discrete-Event System Simulation_, Prentice Hall, 2004
14. Zeigler B. P., Kim, T. G., Praehofer H., _Theory of Modeling and Simulation_, Academic Press, 2000
15. Severance, F. L., _System Modeling and Simulation: An Introduction_, Wiley, 2001

Scientific research and publications

Research

1. Agentowe modelowanie i symulacja zjawisk biologicznych, społecznych i ekonomicznych.

Publications

1. R. Dreżewski. The agent-based model and simulation of sexual selection and pair formation mechanisms. Entropy, 20(5):342, 2018.
2. R. Dreżewski. Agent-based modeling and simulation of speciation and ecosystem diversity. In Andri Pranolo, Adhi Prahara, Ahmad Azhari, and Agus Aktawan, editors, 2018 International Symposium on Advanced Intelligent Informatics (SAIN). Revolutionize Intelligent Informatics Spectrum for Humanity, August 29–30, 2018, Yogyakarta, Indonesia, pages 210–215. IEEE, 2019.
3. R. Dreżewski. Agent-based simulation model of sexual selection mechanism. In G. Jezic, R. J. Howlett, and L. C. Jain, editors, Agent and Multi-Agent Systems: Technologies and Applications. 9th KES International Conference, KES-AMSTA 2015 Sorrento, Italy, June 2015, Proceedings, volume 38 of Smart Innovation, Systems and Technologies, pages 155-166. Springer International Publishing, 2015.
4. A. Byrski, R. Dreżewski, L. Siwik, and M. Kisiel-Dorohinicki. Evolutionary multi-agent systems. The Knowledge Engineering Review, 30(2):171-186, 2015.
5. R. Dreżewski. Agent-based modeling and simulation of species formation processes. In F. Alkhateeb, E. Al Maghayreh, and I. Abu Doush, editors, Multi-Agent Systems – Modeling, Interactions, Simulations and Case Studies, pages 3-28. InTech, Rijeka, 2011.
6. R. Dębski and R. Dreżewski. Adaptive surrogate-assisted optimal sailboat path search using onboard computers. In Derek Groen, Clélia de Mulatier, Maciej Paszynski, Valeria V. Krzhizhanovskaya, Jack J. Dongarra, and Peter M. A.

Sloot, editors, Computational Science — ICCS 2022, pages 355–368, Cham, 2022. Springer International Publishing.
7. R. Dębski and R. Dreżewski. Surrogate-Assisted Ship Route Optimisation. In Mikyška, J., de Mulatier, C., Paszynski, M., Krzhizhanovskaya, V.V., Dongarra, J.J., Sloot, P.M., editors, Computational Science – ICCS 2023, pages 395–409, Cham, 2023. Springer International Publishing.
8. R. Dębski and R. Dreżewski. Multi-objective ship route optimisation using estimation of distribution algorithm. Applied Sciences, 14(13), 2024.

Learning outcomes prescribed to a field of study

Code	Content
INFDS2A_K01	Ma świadomość odpowiedzialności za własną pracę oraz za wspólnie realizowane zadania; potrafi myśleć i działać w sposób kreatywny i przedsiębiorczy
INFDS2A_K02	Ma świadomość roli społecznej absolwenta uczelni technicznej; rozumie potrzebę formułowania i przekazywania społeczeństwu informacji i opinii dotyczących osiągnięć informatyki, w tym zwłaszcza metod eksploracji danych, uczenia maszynowego i sztucznej inteligencji; ma świadomość wagi profesjonalnego zachowania i przestrzegania zasad etyki zawodowej, prawidłowo identyfikuje i rozstrzyga dylematy związane z wykonywaniem zawodu
INFDS2A_U01	Potrafi projektować i realizować systemy informatyczne oparte na danych, a także konstruować systemy uczące się
INFDS2A_U02	Potrafi wykorzystać znane algorytmy, metody obliczeniowe i struktury danych w budowie systemu informatycznego
INFDS2A_U03	Posługuje się technikami i językami programowania stosowanymi w analizie danych, uczeniu maszynowym i systemach wykorzystujących metody sztucznej inteligencji; potrafi ocenić przydatność różnych paradygmatów i związanych z nimi środowisk programistycznych do rozwiązywania problemów analizy danych i realizacji systemów uczących się; potrafi czytać ze zrozumieniem, pisać, uruchamiać i weryfikować programy zapisane z użyciem różnych paradygmatów programowania
INFDS2A_U04	Potrafi ocenić przydatność i korzystać z dostępnych bibliotek, komponentów oprogramowania i narzędzi z uwzględnieniem wymagań systemów opartych na danych oraz systemów wykorzystujących metody uczenia maszynowego i sztucznej inteligencji; potrafi porównać istniejące rozwiązania ze względu na zadane kryteria użytkowe i ekonomiczne oraz wskazać możliwości ich ulepszenia; potrafi ocenić przydatność i możliwość wykorzystania nowych osiągnięć w zakresie informatyki
INFDS2A_U05	Potrafi formułować i testować hipotezy związane z problemami inżynierskimi i prostymi problemami badawczymi, w szczególności potrafi opracować specyfikację projektową złożonego oprogramowania, z uwzględnieniem aspektów prawnych oraz innych aspektów pozatechnicznych, z uwzględnieniem norm i standardów, zaprojektować oprogramowanie adekwatnie do specyfikacji wymagań, opracować szczegółową dokumentację wyników, a także przygotować i przedstawić prezentację oraz przeprowadzić dyskusję wyników
INFDS2A_U06	Posługuje się językiem specjalistycznym oraz językiem obcym na poziomie B2+, w stopniu wystarczającym do porozumiewania się, czytania ze zrozumieniem literatury fachowej, a także przygotowania i wygłoszenia prezentacji na temat realizacji zadania projektowego lub badawczego
INFDS2A_U07	Rozumie potrzebę i zna możliwości podnoszenia kompetencji swoich i innych osób; potrafi współdziałać i pracować w grupie, przyjmując w niej różne role
INFDS2A_W01	Ma pogłębioną wiedzę w zakresie przedmiotów ścisłych, pozwalającą na formułowanie i rozwiązywanie złożonych zadań z zakresu informatyki, analizy danych oraz metod uczenia maszynowego i sztucznej inteligencji
INFDS2A_W02	Ma pogłębioną wiedzę w zakresie rozwiązań algorytmicznych, struktur danych i metod obliczeniowych związanych z analizą danych, uczeniem maszynowym i metodami sztucznej inteligencji
INFDS2A_W03	Ma szczegółową wiedzę w zakresie wybranych języków, paradygmatów i technik programowania oraz rozwiązań systemowych w zagadnieniach analizy danych, uczenia maszynowego i metod sztucznej inteligencji
INFDS2A_W04	Orientuje się w obecnym stanie oraz najnowszych osiągnięciach i trendach rozwojowych informatyki i dziedzin pokrewnych oraz ma wiedzę niezbędną do rozumienia pozatechnicznych uwarunkowań działalności inżynierskiej