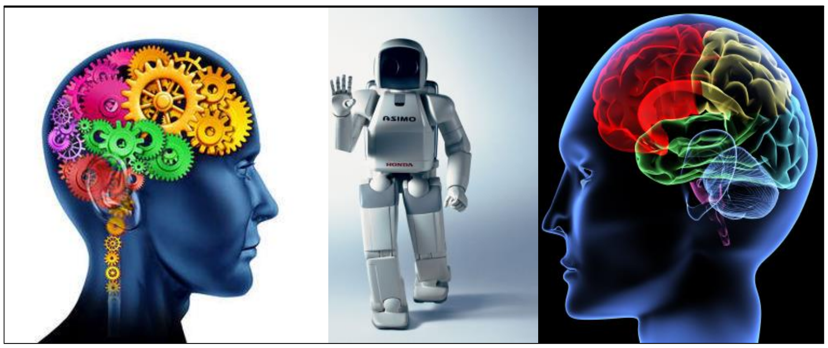
Artificial Intelligence – SCI2036

Course Manual

– Course Edition 2017, version 1.0 –



UCM
University College Maastricht

1. An Introductory Word about Artificial Intelligence

The term "Artificial Intelligence" dates back to the 1950s when John McCarthy defined it as "the science and engineering of intelligent systems". Today Artificial Intelligence is a well established, very active and flourishing field and technology which is widely recognized in academia and industry. It has achieved, for instance, to build computer programs and robots that learn automatically from experience, that reason strategically in complex decision making situations, and that coordinate efficiently to jointly solve some given problem. Artificial Intelligence is already present in our daily lives to an extent which most people are not aware of, and therefore it important to understand what Artificial Intelligence is about. The core concept of Artificial Intelligence is that of an intelligent agent, that is, an entity capable of acting and interacting flexibly and autonomously. Artificial Intelligence is a multidisciplinary field where computer science, mathematics, psychology, sociology, neuroscience, economics and philosophy meet.

2. Course Coordinator

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3. Prerequisites

The course is intended to give an introduction to Artificial Intelligence. It assumes no background in computer science or programming. Secondary school mathematics is sufficient.

4. Main Objectives

- To be able to understand
  - What Artificial Intelligence is and isn't.
  - Why Artificial Intelligence is an important subject nowadays.

- The concept of an “intelligent agent”.
- Elementary principles of building systems (software and robots) that show intelligent behavior.

- Familiarity with basic and advanced (i) search and problem solving methods, (ii) coordination and cooperation schemes, and (iii) architectures for intelligent systems available in the field of Artificial Intelligence.

- Please note: Computer programming skills are neither required nor taught in this course.

5. Course Contents and Planning

The course starts with an analysis of the question "Can machines think", and the (philosophical) preconceptions usually encountered in discussions about that idea. Next the metaphor of an “intelligent agent” is introduced, that is, of an entity that pursues goals by perceiving and acting flexibly and autonomously in a possibly very complex environment. The main part of the course explores the metaphor of an intelligent agent by introducing a number of state-of-the-art concepts, algorithms, and methods from the field of Artificial Intelligence.

Main topical areas covered in this course are (but may be not limited to):

- AI search techniques (they are the main focus of this course)
- Constraint satisfaction
- Coordination and cooperation among intelligent agents
- Architectures for intelligent systems.

All key AI concepts and methods covered in this course are to be applied by the students (in teamwork) through specific tasks and exercises. Examples of such tasks/exercises are given below.

6. Literature

The course primarily follows selected chapters of the following standard AI book:

- Russell, S., & Norvig, P. (2009, Third Edition). Artificial Intelligence. A modern approach. Prentice-Hall.

Motivated students interested in a complementary AI textbook may find this book useful:

- Wooldridge, M. (2009, Second Edition). An introduction to multi-agent systems. John Wiley & Sons.

7. Course Material

- Lecture slides.
- Selected supplementary material.

8. Instructional Format

The course is based on two instructional formats: *lectures* in which AI concepts and methods are introduced, and *practicals* in which the students apply and explore (usually in small teams) the introduced AI concepts and methods.

Examples of the type of tasks treated in this course are shown below.

9. Attendance, Examination, Assessment, Grading, Resit

Attendance, examination, assessment and resit is handled in accordance with the standard UCM regulations.

Attendance. Regular classroom attendence and active participation is essential. Students who have not met the standard attendance requirements are not eligible for the final exam.

Examination. Examination consists of two assessment moments:

1. A *written midterm exam*, usually in week 4 on the material covered in weeks 1-3.
2. A written final exam, in week 7 on the contents covered in weeks 4-6.

Assessment and Grading. The maximum number of points achievable in the midterm and the final exam are 10 points each. If *M* is the number of points a student achieved in the midterm exam and *F* is the number of points this student achieved in the final exam, then the overall final grade achieved by the student is calculated as follows:

Final Grade = 0.5 x *M* + 0.5 x *F*

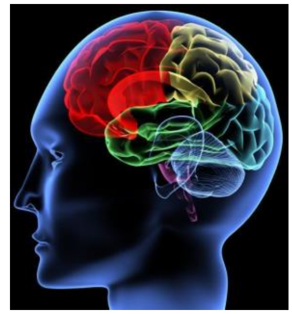
(Example: If *M* = 5 and *P* = 7, then *Final Grade* = 0.5x5 + 0.5x7 = 6.)

Resit. The resit is in written form on the entire contents of the course. In very exceptional cases (e.g., proven illness or other serious reasons) the resit may be in oral form or in form of an individual student assignment. A student who passes a course (i.e., grade ≥ 5.5) will NOT be allowed to take a resit to improve his or her grade. Moreover, in order to be eligible for a resit examination, students must have met the UCM attendance requirements.

10. Tasks / Exercises

On the following pages, you see sample tasks and exercises (with acronyms “RefAI”, “RefAgent”, “UIS”, “InfS”, etc.) discussed in this course. Note that not all shown examples may be covered and that not all tasks and exercises covered during the course may be listed below.

RefAI – Reflecting on (Artificial) Intelligence, I



RefAI1 - Thinking

Many people who have a pet sometimes wonder what is going on in the animal's head. However, we cannot just ask an animal to find out. Can we? Actually, it turns out that there are ways of doing so. The following is an excerpt from a conversation between Irene Pepperberg and her pet, Alex the Parrot:

"*IRENE PEPPERBERG*: I've got to go eat dinner. Gonna put you in, okay? You be good.
ALEX: You be good.
IRENE PEPPERBERG: Okay. I'll see you tomorrow. I'll see you then.
ALEX: Bye.
IRENE PEPPERBERG: Bye.
NARRATION: Irene Pepperberg is a professor at the University of Arizona.
ALEX: I love you.
IRENE PEPPERBERG: I love you, too. Bye.
NARRATION: And one of her top students is an African grey parrot named Alex. Like many parrots, Alex is a virtuoso mimic.
ALEX: I'm sorry. You're a good boy. I love you.
NARRATION: He doesn't understand what he's saying, he's just parroting. Or is he?
MAN: Come on, what is it?
ALEX: Key chain.
IRENE PEPPERBERG: Good birdie. Good parrot.
NARRATION: The extraordinary thing about Alex is that very often, he does understand what he's saying.
IRENE PEPPERBERG: What is it?
ALEX: Rock.
MAN: Good boy.
IRENE PEPPERBERG: Yeah, good birdie. Alex, what toy?
ALEX: Nail.
[…]".

Possible discussion points:

1. Are these good questions to find out whether Alex understands what he is saying? Why or why not?
2. Does Alex really think? Why or why not?
3. What would you ask Alex? (Take into account his limited experience with the world. You should ask about something of which he has previous experience/knowledge).
4. Can Alex understand what he is saying?
5. Does Alex think? Why or why not?
6. Is Alex intelligent? Why or why not?
7. Would you ask a machine the same things? Why or why not?
8. What would you ask a machine to find out whether it really thinks?
9. Can a machine think? Why or why not?
10. What would you ask a human being to find out what he/she is thinking?
11. Can a human being think?

RefAI2 - Acting vs Thinking, Humanly vs Rationally

Look at the following table and explain the difference between the four definitions of systems.

Systems that think like humans	Systems that think rationally
Systems that act like humans	Systems that act rationally

From: Russell and Norvig

1. Where would you classify a machine that passes the Turing test? Why?
2. Is the Turing Test a good tool to define whether a machine can think? Why or why not?
3. Is the Turing Test suited as an intelligence test? Why or why not?

Literature:

- Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 1. → Literature and Readings, REF_01
- Alan Turing, *Computing machinery and intelligence*, 1950. →Literature and Readings, REF_02
- Alex the Parrot: see Wikipedia, https://en.wikipedia.org/wiki/Alex_%28parrot%29

RefAI – Reflecting on (Artificial) Intelligence, II

Artificial Intelligence (AI) is one of the most recent fields of science. One of the many objectives of AI is to create systems that behave intelligently, and this requires an understanding of what intelligence is and how it works. Intelligence is a topic that has always intrigued mankind, and many different explanations of the way it works, and how the human brain is constituted, have been developed during History. AI can be considered to have been born in the second half of the last century, but we can track many ideas, viewpoints and techniques from other disciplines back in past. Interestingly, on its way towards a science AI has always been criticized as a "mission impossible".

RefAI3 - Roots and Foundations of AI

- What are the scientific roots of AI?
- Are there any scientific disciplines you are missing among these roots?
- Why are we humans interested at all in creating artificial intelligent systems? What is the underlying motivation and intention?

RefAI4 - Potential Limitations and Risks

- [Russell&Norvig] In Turing's original paper, he discusses several potential objections to his proposed enterprise and his test for intelligence. Which objectives still carry some weight? Are his refutations valid? Can you think of new objections? In the paper, he predicts that, by the year 2000, a computer will have a 30% chance of passing a five-minute Turing Test with an unskilled interrogator. What chance do you think would a computer have today? In another 50 years?
- [Russell&Norvig] Every year the Loebner prize is awarded to the program that comes closest to passing a version of the Turing Test. Read about the latest winners (search the Internet for "Loebner prize") and try to find out what techniques they use.
- What tasks are intrinsically difficult for computers, and what tasks are easy to solve?
- What is your opinion about Searle's "Chinese room" argument? (For instance, see http://en.wikipedia.org/wiki/Chinese_room)
- What is your opinion about the AI criticism raised by Hubert Dreyfus (For instance, use Wikipedia as an entry point: http://en.wikipedia.org/wiki/Hubert_Dreyfus)
- For further inspiration, you may also look into the Exercises 1.7 to 1.13 at the end of Chapter 1 of the Russell&Norvig book.
- What is your opinion about the "risk of singularity", that is, the risk that somewhere in the (near) future intelligent machines "take over control"?

Literature:

- Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 1. → Literature and Readings, REF_01
- Alan Turing, *Computing machinery and intelligence*, 1950. →Literature and Readings, REF_02
- Search the Internet for "Searle Chinese room" and "Dreyfus criticism AI".

RefAgent – Reflecting on the Concept of an Intelligent Agent

RefAgent1 - Game of Life

Consider the famous “Game of Life” (see, e.g., https://www.youtube.com/watch?v=C2vgICfQawE or https://www.youtube.com/watch?v=Su1Uu4_wIak).

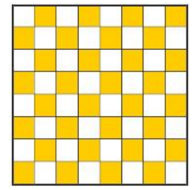
Think about these questions (and related questions that come into your mind):

- Do you see any intelligence in Game of Life?
- How do see any “intelligent agency” in the Game of Life? What are the characteristics of this agent?
- Which of the concepts of “coordination”, “collaboration” or “interaction” can you see in Game of Life?

Literature:

- Search the Internet for “Game of Life”

UIS – Uninformed Search



UIS1 - 8-Queens Problem

Consider the famous *8-queens problem*. Solving this problem means to place eight queens on an (8x8) chessboard in such a way that no queen attacks any other queen.

- **(a)** Represent this problem as a search problem by specifying (i) the initial/goal state (based on some appropriate - programmable - state representation), (ii) a goal test, (iii) a successor function, and (iv) the path costs.

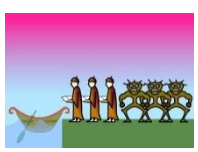
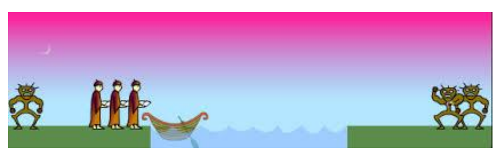
- **(b)** Solve this problem with the depth-first algorithm and the breadth-first algorithm. Which one do you think is more adequate (given your search problem representation), and why?

UIS2 - Missionaries-and-Cannibals Problem

Another very well-known problem is the *missionaries-and-cannibals problem*:

"*Three missionaries and three cannibals are on one side of a river, along with a boat that can hold one or two people. Find a way to carry everybody to the other side, without ever leaving a group of missionaries in one place outnumbered by the cannibals in that place*."

Thereby "place" means (a) left side of the river (including bank and – if on the left side – boat) and (b) right side (bank and – if on the right side – boat).

 **…**  **… ?**

- **(a)** Represent this problem as a search problem by specifying (i) the initial/goal state (based on some appropriate - programmable - state representation), (ii) a goal test, (iii) a successor function, and (iv) the path costs.

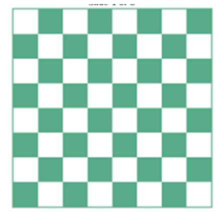
- **(b)** Solve this problem with the depth-first algorithm and the breadth-first algorithm. Which one do you think is more adequate (given your search problem representation), and why?

Literature:

- Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 3. → Literature and Readings, REF_04

InfS – Informed Search

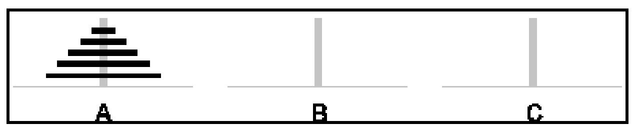
InfS1 - n-Queens Problem



Consider the n-queens problem (i.e., the problem of placing n queens on a nxn chessboard so that no queen attacks any other). Assume we want to solve this with an informed tree search, that is, with a search algorithm that employs a heuristic that estimates the value of any possible board state.

- **(i)** Propose such a heuristic and briefly explain the underlying idea.
- **(ii)** Discuss your heuristic in terms of admissibility, if possible. (Recall: A heuristic is said to be admissible if it never overestimate the remaining number of necessary moves.)
- **(iii)** Does your heuristic have any shortcomings? Justify your answer.

InfS2 - Towers-of-Hanoi Problem



Consider the Towers of Hanoi problem. The Tower of Hanoi problem is to move a set of n disks of different sizes from a start peg to a goal peg, using a third peg for temporary storage; disks are moved one at a time, and a larger disk cannot rest on a smaller one. (See http://en.wikipedia.org/wiki/File:Tower_of_Hanoi_4.gif for an animated solution for n = 4. The figure illustrates this problem for n = 5; "A" is the start peg and "B" and "C" are the temporary-storage peg and the goal peg.)

- **(i)** To get familiar with the Towers of Hanoi problem, draw the complete search space for n = 3.
- **(ii)** Propose a heuristic for this problem and briefly explain the underlying idea.
- **(iii)** How good is your heuristics, what are its shortcomings (if any)?

Literature:

Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 4. → Literature and Readings, REF_05

LOCS – Local Search

LOCS1 - Genetic Algorithm and Queens Problem

Assume the Genetic Algorithm shall be used to solve the 8-queens problem. Specify a representation scheme, genetic operators and a fitness function. Discuss pros and cons of your scheme and operators.

LOCS2 - Hill-Climbing and TSP

Devise a hill-climbing approach to solve the traveling salesperson problem (TSP): *Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once?* (There are several variants of the TSP; perhaps the most famous version of the TSP is that the route has to return to the origin city. TSP is a so-called NP-hard problem, that is, there is no fast solution known and its complexity grows superpolynomially with the number of cities.)

LOCS3 - Genetic Algorithm and TSP

Think about solving the TSP with a Genetic Algorithm. How could a representation and the basic operators (mutation and recombination) look like? Compare the Genetic-Algorithm-based search with the Hill-Climbing-based search, what are main differences?

Literature:

Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 4. → Literature and Readings, REF_05

AdS – Adversarial Search

AdS1 - Game Tree

Adversarial search problems (also called games) are problems in which two or more opponents play against each other. Well known examples are tic-tac-toe, chess and Go. Characteristic to this kind of search is that each player needs to take her opponent(s)’ possible next moves into account in order to maximize her own profit.

Consider the following game (taken from Russell&Norvig)

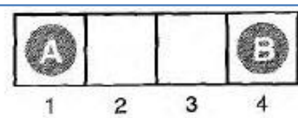


Figure 6.14 The starting position of a simple game. Player A moves first. The two players take turns moving, and each player must move his token to an open adjacent space in either direction. If the opponent occupies an adjacent space, then a player may jump over the opponent to the next open space if any. (For example, if A is on 3 and B is on 2, then A may move back to 1.) The game ends when one player reaches the opposite end of the board. If player A reaches space 4 first, then the value of the game to A is $+1$; if player B reaches space 1 first, then the value of the game to A is -1.

and address these subtasks:

(i) Draw the complete game tree. Use these conventions:
- Put each terminal state in a box and put loop states (i.e., states that already appear on the path to the root) in double square boxes.
- For each terminal state write its game value in a circle. Since it is not clear how to assign values to loop states, declare its game value as “?”.

(ii) Mark each node with its backed-up minimax value (also in a circle). Explain how you handled the “?” values and why.

(iii) Is the standard minimax procedure suited for this game?

Literature:

Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 6. → Literature and Readings, REF_07

ConS – Constraint Satisfaction

(Note: Some of the tasks are from Russell&Norvig)

ConS1 - Cryptarithmetics

Solve the cryptarithmetic problem you know from the lecture (i.e., “TWO + TWO = FOUR”) by hand. First formulate all constraints and then apply backtracking, forward checking, and the “minimum remaining value” and “least constraining value” heuristics.

ConS2 - Constraints for ToH and n-Queens

Consider *(i)* the Towers of Hanoi problem and *(ii)* the n-queens problem. Formulate the constraints for this problem as detailed as possible (so that they can be “directly implemented” in a software program).

ConS3 - Ternary Constraints

Show how a single ternary constraint such as “A + B = C” can be turned into three binary constraints by using an auxiliary variable.

ConS4 - Einstein’s Puzzle

Consider the following puzzle, which is also known as Einstein’s Puzzle: *There are five houses of different colors next to each other on the same road, in each house lives a man of a different nationality, and every man has his favorite drink, his favorite brand of cigarettes, and keeps pets of a particular kind. Some hints:*

1. *The Englishman lives in the red house.*
2. *The Swede keeps dogs.*
3. *The Dane drinks tea.*
4. *The green house is just to the left of the white one.*
5. *The owner of the green house drinks coffee.*
6. *The Pall Mall smoker keeps birds.*
7. *The owner of the yellow house smokes Dunhills.*
8. *The man in the center house drinks milk.*
9. *The Norwegian lives in the first house.*
10. *The Blend smoker has a neighbor who keeps cats.*
11. *The man who smokes Blue Masters drinks bier.*
12. *The man who keeps horses lives next to the Dunhill smoker.*
13. *The German smokes Prince.*
14. *The Norwegian lives next to the blue house.*
15. *The Blend smoker has a neighbor who drinks water.*

Question: Who keeps fish?

Formulate this puzzle as a constraint satisfaction problem and try to solve it.

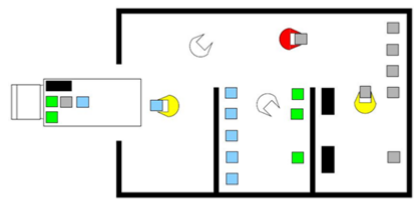
Literature:

Russell and Norvig, *Artificial intelligence. A modern approach*, 2nd edition, 2005, Chapter 5. → Literature and Readings, REF_06

CC – Components of Coordination

To build an intelligent cooperative system requires, in particular, to identify the involved agents and the interdependencies among their activities. This identification, which is to be done during the so called "systems analysis and design" phase of systems engineering, is highly crucial for effective and efficient cooperation.

CC1 - Analysis of an IS Application



Consider the Docking Station application from an engineering perspective.

a) Identify and specify (in a precise/formal style)

(i) main goal(s) to be achieved,
(ii) main activities needed for achievement,
(iii) actors (= agents), and
(iv) interdependencies among the activities.

b) Reflect on the assignment of the identified activities to actors by addressing these questions

(i) Why is this assignment in general non-trivial?
(ii) How can this assignment be done in principle?

c) What coordination mechanisms would you choose for this application?

Background material: Lecture slides on „Coordination“, esp. see slides 6f.

Voting – A Closer Look into Voting Procedures

Voting1 - Iterated Borda”

Problem: Standard Borda violates Independence of Irrelevant Alternatives (IIA). An interesting question thus is whether Borda voting can be modified so that IIA is not longer violated by the modified variant.

Idea: Iterated version of Borda voting (i.e., run multiple rounds of standard Borda and remove the least popular option in each round).

Question: Does iterated Borda solve the IIA issue? Justify your answer.

Voting2 - Strategic (Tactical, insincere) Voting

Strategic voting = A voter supports an option other than their sincere (true) preference in order to prevent an undesirable outcome.

Scenario: Assume that a “society” consisting of five agents (A1, …, A5) uses Borda voting to come to an agreement on four options (A, B, C and D), where the true preferences of the agents are as follows:

	A1	A2	A3	A4	A5
4	C	B	C	B	B
3	A	D	D	D	C
2	D	C	A	C	D
1	B	A	B	A	A

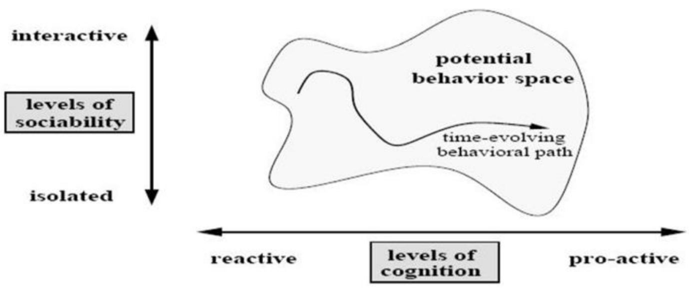
Question: Are there possibilities for strategic voting? (Hint: also think about “strategic voting in response to strategic voting”.)

Basic background material: Lecture slides.

AA – Agent Architectures

AA1 - “Behavioral Space of Agent Architectures

Qualitatively characterize the potential behavioral space of PRS, IRMA, GRATE*, INTERRAP in terms of the „levels-of-sociability – levels-of-cognition coordinate system“.



AA2 - Application → Architecture

Consider the three application domains

1) **Chess**,
2) **Mars exploration**, and
3) **Robot soccer**.

Are the architectures discussed in the course suited for any of these applications? Briefly indicate the main reason(s) for your answer.

AA3 - Architecture → Application

Now take the „reverse“ engineering perspective:

(i) briefly characterize for the treated architectures the type of applications they are suited for and

(ii) give a representative example for each application type.

Basic background material: Lecture slides.