Lliçó de graduació
"De l'electrònica a la intel·ligència artificial: el meu fascinant viatge per la recerca", a càrrec de Ramon López de Mántaras Badia, professor i director de l'Institut de Recerca d'Intel·ligència Artificial del CSIC

Good evening. It is an honour for me to be here with you today for this graduation ceremony.

Let me begin by congratulating the graduates and thanking the university's authorities for their very kind invitation.

Today I would like to tell you about a personal journey: a real journey, through space and time, that began more than 40 years ago, but also a metaphorical journey, through the fascinating world of science and technology.

Before I begin, however, let me briefly switch to my mother tongue, Catalan, so as to express feelings that I cannot properly give voice to in another language:

> *Ni la vessant real ni la metafòrica del viatge de la meva vida personal i professional haurien estat possibles sense l'amor i el suport incondicional, durant més de 38 anys, de la que fou la meva esposa i professora del Departament de Traducció i Ciències del Llenguatge d'aquesta universitat, la Dra. Joëlle Rey, recentment traspassada. Permetin, doncs, que dediqui aquesta lliçó a la seva memòria.*

I began my fascinating journey through the world of science and technology in September 1969, departing from a small village in the province of Barcelona. I was just 17 years old, but I was already carrying a suitcase full of dreams thanks to the unconditional support of my parents, a wonderful working-class couple. My first destination was Mondragon University in the Basque Country. Earlier that same year, on 20 July, the astronauts Armstrong, Aldrin and Collins had completed another journey of much greater importance to mankind: they landed the Eagle lunar module on the moon, in the southern Sea of Tranquillity. This 'small step for man, yet giant leap for mankind', to paraphrase Armstrong, was broadcast live on TV, and I was lucky enough to see it. I was so deeply impressed by the exploit that I decided to undertake my own personal journey through the study of science and technology and, in particular, electronics and automatic control, because I had been told that these were the technologies that had allowed mankind to achieve its age-old dream of reaching the moon. Indeed, both the launch and trajectory of the Saturn rocket that powered the Apollo 11 mission and the landing of the lunar module were controlled by software running on on-board computers. Back then, however, hardly anyone talked about concepts such as computing or computers. On the contrary, the media referred to computers as ‘electronic brains’.

And electronics certainly was the technology that revolutionized the twentieth century. It all started in 1904, when John Fleming, a professor at the University of London, using the so-called ‘Edison effect’ (that is, the flow of a current between an incandescent filament and a nearby metal electrode), built a thermionic valve known as a vacuum tube rectifier, or diode. This diode acted analogously to a tap controlling the flow of water: when the electrode was given a more positive voltage than that of the filament, the current flowed between them. It ceased to flow when the voltage was reversed. Thanks to this ‘rectification effect’, these diodes were used to improve the crystal radios of the time. Those of us who are not so young may recall with some nostalgia the valve radios that our mothers and grandmothers used to listen to radio shows. A bit later, the American engineer Lee de Forest added a third electrode to the diode. By applying a low voltage to this third electrode, it was possible to regulate the amount of flowing current.

Thus was born the triode, which, in addition to rectifying, could be used to amplify weak electrical signals and was therefore instrumental to the development of the radio and the phone. Vacuum tubes dominated the first 50 years of electronics and telecommunication, including television and the first digital computers; however, in the late 1930s, some visionaries felt the need to replace them with other much smaller, faster, less fragile and more durable devices. The solution was the transistor, invented in 1947 at Bell Labs by Bardeen, Brattain and Shockley, who were awarded the Nobel Prize in Physics for their work in 1956. The first transistors, based on a semiconductor material called germanium, were difficult to control, suffered from erratic performance, and were about ten times more expensive than vacuum triodes. However, thanks to advances in basic research in the field of semiconductor physics, scientists discovered the advantages of silicon over germanium, especially its ability to oxidize. This property turned out to be crucial to enabling the integration of multiple transistors on a single substrate, thereby reducing manufacturing costs, lowering power consumption and increasing switching speed. The great electronics revolution had begun: the first transistor-based radios appeared in 1954; in 1957, IBM introduced the first transistorized computer; and in 1971, Intel Corporation unveiled the first commercial microprocessor, which contained about a thousand transistors, each one tenth the thickness of a hair. Since then, the progressive miniaturization of these chips has followed what is known as Moore’s law, which holds that the number of transistors on a chip will double every 18 months. Today’s chips contain over one billion transistors.

This miniaturization process has been such that we will soon run up against insurmountable physical limitations. Indeed, when the dimensions reach only a few tens of nanometres, the electrons become governed by the still poorly understood laws of quantum mechanics, and conventional transistors stop working. Anticipating this problem, physicists are looking into possible solutions to replace conventional transistors, including, among others, the use of new materials such as graphene or organic molecules or very thin carbon-based wires called nanotubes. As with silicon, the answer once again lies with basic research, the only way to advance technology.

During my studies in electronic engineering, I discovered my own vocation for research, and, after graduating in 1973, I decided to continue my journey through science and technology working towards a PhD. Fortunately, the best students in each class at Mondragon University were able to continue their studies at Paul Sabatier University in Toulouse, enrolling directly in the final year of the *maîtrise* in physics, specializing in electronics and automation, the completion of which granted access to doctoral studies. Along with six other students, in autumn 1973, I went to Paul Sabatier University, where I earned my PhD in 1977, the same year I married, Joëlle, the amazing French woman I had met and fallen in love with just three years earlier. For my dissertation, I developed algorithms that enabled a robot to learn to recognize solid objects through the sense of touch using an anthropomorphic artificial hand.

Over the course of my PhD, I discovered that learning algorithms were related to a new field of research called 'artificial intelligence', which might be defined as the science and engineering required to design and program machines able to perform tasks requiring intelligence. I also learnt that postgraduate programmes in artificial intelligence were already being offered at several top universities in the United States. So I decided to continue my personal journey in the US and study artificial intelligence there. Thanks to a fellowship from the Basque industrial cooperative movement's League of Education and Culture, in Autumn 1977, I left, with my wife Joëlle, to pursue a master's degree in artificial intelligence at the University of California, Berkeley. On our return to the Basque Country, I started teaching computer science at Mondragon University and worked in the Department of Computer Technology at the IKERLAN technology centre. There, in 1980, I developed an expert system to assist in the design of high-power electrical transformers for a Basque electrical manufacturing company, which, incidentally, was one of the first such systems developed in Europe. Thus began my journey in the fascinating field of artificial intelligence research.

The rapid progress in the miniaturization of chips I alluded to earlier enabled the likewise rapid development of complex software and, in particular, of artificial intelligence. This is the main reason why artificial intelligence 'took off', allowing research laboratories to break into the business world in the 1980s on the back of the success of their expert systems. These expert systems are the paradigm of what is known as 'weak AI', whose goal is to develop systems with very specialized intelligence, i.e. that are very competent in a very specific and limited aspect of human knowledge.

Weak AI has had spectacular results. Here are just a few examples of what has been achieved so far: computer programs able to play chess at the grand master level; high-performance speech recognition systems; unmanned cars; robots able to explore the surface of Mars; hundreds of thousands of household robots; automatic music composition and performance; the proving of complex mathematical theorems, such as the Robbins conjecture; automatic fraud detection; creative industrial design systems; sophisticated computer games in which the non-player characters are driven

by intelligent software agents; teams of robots able to solve problems cooperatively; and many more things too numerous to mention!

After a time in the Basque Country, I returned to Catalonia, where I was born, to join the newly founded Barcelona School of Informatics (FIB) at UPC-Barcelona Tech as an assistant professor. In 1985, the then president of the Spanish National Research Council (CSIC) asked me to set up an Artificial Intelligence Department at the Centre for Advance Studies in Blanes. It would be the embryo of the current Artificial Intelligence Research Institute (IIIA), located on the Autonomous University of Barcelona (UAB) campus. I currently head a group of about 80 people at that institute conducting AI research in the following areas: logic, reasoning and searches (that is, mathematical models to represent knowledge and algorithms to conduct automated reasoning, with applications for decision-support systems in medicine, design and logistics, among others); machine-learning systems (that is, systems enabling machines to acquire new knowledge from examples, observation and experience in order to improve their problem-solving capabilities, with applications in the fields of medicine, robotics, music, data privacy and the automatic generation of visual narratives, among others); and multi-agent systems (or how to make programs that are reactive, proactive, autonomous and able to interact with other programs and their environment in order to solve problems requiring several agents working cooperatively, with applications ranging in areas from e-commerce and conflict resolution to sales management and the simulation of societies, among others). Twenty years later, the IIIA can objectively be said to be one of the leading European research centres in artificial intelligence. By the end of 2012, more than 70 doctoral theses had been completed, over 1600 scientific papers had been published, we had won more than 20 international awards, we had completed over 150 projects and research contracts, and, critically, we had spun off three companies, creating more than 120 high-skilled jobs. As for our scientific output, it spans areas ranging from human-like music synthesis (in collaboration with the UPF's own Music Technology Group), automated medical diagnostic systems, robots that play soccer cooperatively, the automatic generation of visual narratives, electronic institutions, privacy-preserving data mining, computational models of trust and reputation, automatic trading systems, formal mathematical and logical reasoning models, new heuristic search algorithms, etc.

I would now like to say a few words about the future of artificial intelligence. In my opinion, the state of the art in AI is such that we should now be able to turn our attention to the design of systems able to integrate the sophisticated computational components of artificial intelligence that have so far been developed independently. That is, it is time to design systems that integrate perception, learning, reasoning, communication and action, thereby covering the entire spectrum present in intelligent behaviour, from perception to action. I believe this integration is an essential stepping stone towards achieving general AI systems rather than the highly specialized types of artificial intelligence that exist today.

I would like to conclude by telling the graduating students that you have acquired a background at UPF that is, without a doubt, an excellent starting point for your own professional journey. I should like to express my hope that your journey will be as fascinating as mine. Despite the terrible economic climate, be sure to love whatever you do wherever you do it, and follow your fascination! Remember, if you are fascinated by what you do, you will enjoy it that much more and are thus certain to be more successful.

Thank you all and... congratulations!