

# hendrik baier

artificial intelligence researcher

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## research interests

I am fascinated by *artificial intelligence* and *games*.

Decision making is a basic activity in our lives, and an essential feature of intelligent autonomous agents. I am interested in creating agents that are able to succeed in a wide range of complex decision-making tasks, in order to help human users solve real-world problems. To achieve this, my research focuses on *planning*, required for acting towards long-term goals; on *learning*, required for acting in unknown environments; and on the *explainability* of planning and learning, required for successful human-AI collaboration.

In order to tackle these challenges, I use the unifying framework of reinforcement learning - of learning by trial and error - and aim at pushing its boundaries in a variety of traditional and digital games as testbeds. I then transfer game AI technology to non-game domains in collaborative projects with industry, in sectors such as logistics and transportation, smart manufacturing, and sustainable energy.

## research experience

- |                                   |  |                             |
|-----------------------------------|--|-----------------------------|
| 2022 – present                    | <b>Eindhoven University of Technology</b><br><i>Assistant Professor</i><br>Information Systems Group<br>Developing learning, planning, and explainable AI techniques in collaboration with industry partners from sectors such as logistics, energy, and manufacturing   | Eindhoven, The Netherlands  |
| 2018 – 2021<br>and 2023 – present | <b>Centrum Wiskunde &amp; Informatica</b><br><i>Researcher</i><br>Intelligent and Autonomous Systems Group<br>In collaboration with industry, took a leading role in applying AI and machine learning to the optimal management of energy producers and consumers on future energy markets with an increasing share of renewable energy; developed a related research vision for explainable search-based AI | Amsterdam, The Netherlands  |
| 2016 – 2018                       | <b>University of York</b><br><i>Research associate in artificial intelligence and data analytics</i><br>Digital Creativity Labs<br>Explored the integration of search algorithms and machine learning in increasingly complex commercial video games; explored ethical and societal issues around AI in interdisciplinary workshops  | York, United Kingdom        |
| 2015 – 2016                       | <b>European Space Agency</b><br><i>Research fellow in artificial intelligence</i><br>Advanced Concepts Team<br>Worked on “blue sky” research with potential future impact for the space sector, as well as serving as an internal science consultant for the European Space Research and Technology Centre   | Noordwijk, The Netherlands  |
| 2010 – 2015                       | <b>Maastricht University</b><br><i>PhD researcher</i><br>Department of Knowledge Engineering<br>Improved sequential decision making based on Monte Carlo Tree Search both in adversarial as well as single-agent environments  | Maastricht, The Netherlands |

## education

|             |   |   |
|-------------|---|---|
| 2007 – 2010 | <b>M.Sc. Cognitive Science</b><br>Grade: “excellent with distinction”<br>Specialization: artificial intelligence and linguistics<br>Thesis title: “Adaptive Payout Policies for Monte-Carlo Go” | Universität Osnabrück, Germany            |
| 2006 – 2007 | <b>Linguistics</b>  | Universität Leipzig, Germany              |
| 2001 – 2006 | <b>B.Sc. Computer Science</b><br>Grade: “very good”, ranked top 2%<br>Thesis title: “Der Alpha-Beta-Algorithmus und Erweiterungen bei Vier Gewinnt”   | Technische Universität Darmstadt, Germany |

## teaching experience

|                |   |                             |
|----------------|---|-----------------------------|
| 2022 – present | <b>Eindhoven University of Technology</b><br><i>Lecturer</i><br>MSc course “Decision making with artificial and computational intelligence”<br>My course redesign in 2023, part of my Dutch University Teaching Qualification, led to an increase of my average student evaluation from 3.9/5 to 4.7/5. | Eindhoven, The Netherlands  |
| 2022 – present | <b>Jheronimus Academy of Data Science</b><br><i>Lecturer</i><br>MSc course “Prescriptive Algorithms”  | Tilburg, The Netherlands    |
| 2021           | <b>Utrecht University</b><br><i>Guest lecturer</i><br>Introductory class on reinforcement learning in games   | Utrecht, The Netherlands    |
| 2013 – 2014    | <b>Maastricht University</b><br><i>Teaching assistant in computer science</i><br>Taught “skills class LaTeX” for undergraduates   | Maastricht, The Netherlands |
| 2011 – 2013    | <b>Maastricht University</b><br><i>Teaching assistant in computer science</i><br>Introduction to data structures and algorithms for undergraduates  | Maastricht, The Netherlands |
| 2009 – 2010    | <b>IDF Language School</b><br><i>English teacher</i><br>Grammar and conversational courses for individuals and groups   | Osnabrück, Germany          |
| 2004 – 2005    | <b>Technische Universität Darmstadt</b><br><i>Teaching assistant in mathematics and computer science</i><br>Introduction to logic for second-year students, and programming for first-year students   | Darmstadt, Germany          |

## project management

|                |   |  |
|----------------|---|--|
| 2023 – present | <b>Project “PEER”</b><br>Work package leader of WP3: “Human-AI collaboration on sequential decision-making tasks” (229 person-months total)           | Horizon Europe project no. 101120406                   |
| 2022 – present | <b>Project “ALIGN4Energy”</b><br>Work package co-leader of WP3: “Aligning human preferences, choices and technical systems” (132 person-months total) | Dutch Research Agenda, NWO-ORC project NWA.1389.20.251 |

## supervision experience

### phd students

|                |   |                                    |
|----------------|---|------------------------------------|
| 2023 – present | <b>Bart von Meijenfeldt</b><br>“Human-centric, collaborative sequential decision-making”; role: <i>supervisor</i>   | Eindhoven University of Technology |
| 2023 – present | <b>Gao Peng</b><br>“Sequential Decision-making for Multi-Agent Interest Alignment in Sustainable Energy Investments”; role: <i>co-supervisor</i>              | Centrum Wiskunde & Informatica     |
| 2022 – present | <b>Tim de Boer</b><br>“Preference Elicitation for Multi-Agent Interest Alignment in Sustainable Energy Investments”; role: <i>co-supervisor</i>               | Centrum Wiskunde & Informatica     |
| 2022 – present | <b>Luca Begnardi</b><br>“Integration of Planning and Learning: from Online Combinatorial Optimization to Real-World Applications”; role: <i>co-supervisor</i> | Eindhoven University of Technology |
| 2017 – 2018    | <b>Daniel Hernandez</b><br>“Multi-Agent Reinforcement Learning for Game AI and Robotic Control”; role: <i>supervision team member</i>                         | University of York                 |
| 2017 – 2018    | <b>Peter York</b><br>“Applying Tree Search and Reinforcement Learning to Competitive and Human-Like MOBA AI”; role: <i>supervision team member</i>            | University of York                 |
| 2016 – 2018    | <b>Adam Sattaur</b><br>“The Use of Gameplay Data to Inform High-level AI Decision Making”; role: <i>supervision team member</i>                               | University of York                 |

### engd and msc students

|             |   |                                    |
|-------------|---|------------------------------------|
| 2022 – 2023 | <b>Ambika Moothedath, EngD</b><br><i>1st supervisor</i> | Eindhoven University of Technology |
| 2023        | <b>Willem Roodenburg, MSc</b><br><i>2nd supervisor</i>  | Eindhoven University of Technology |
| 2022        | <b>Rob Claassen, MSc</b><br><i>1st supervisor</i>       | Eindhoven University of Technology |
| 2022        | <b>Niek van Bavel, MSc</b><br><i>3rd supervisor</i>     | Eindhoven University of Technology |
| 2022        | <b>Erwin Martens, MSc</b><br><i>3rd supervisor</i>      | Eindhoven University of Technology |
| 2021        | <b>Obada Aljabasini, MSc</b><br><i>co-supervisor</i>    | Centrum Wiskunde & Informatica     |
| 2021        | <b>Bart van Laatum, MSc</b><br><i>2nd supervisor</i>    | Centrum Wiskunde & Informatica     |
| 2020        | <b>Sorin Dragan, MSc</b><br><i>co-supervisor</i>        | Centrum Wiskunde & Informatica     |

## bsc students

|      |   |                                    |
|------|---|------------------------------------|
| 2023 | <b>Alex Hermans, BSc</b><br><i>1st supervisor</i>         | Eindhoven University of Technology |
| 2023 | <b>Sicco Lammers, BSc</b><br><i>2nd supervisor</i>        | Eindhoven University of Technology |
| 2023 | <b>Kasper Knuijt, BSc</b><br><i>2nd supervisor</i>        | Eindhoven University of Technology |
| 2023 | <b>Jorrit van Iersel, BSc</b><br><i>2nd supervisor</i>    | Eindhoven University of Technology |
| 2023 | <b>Anne van den Eijnden, BSc</b><br><i>2nd supervisor</i> | Eindhoven University of Technology |
| 2022 | <b>Annika Spijker, BSc</b><br><i>2nd supervisor</i>       | Eindhoven University of Technology |
| 2022 | <b>Daan Oomen, BSc</b><br><i>2nd supervisor</i>           | Eindhoven University of Technology |
| 2013 | <b>Jonathan Brouwers, BSc</b><br><i>1st supervisor</i>    | Maastricht University              |

## interns

|      |  |                                |
|------|--|--------------------------------|
| 2020 | <b>Daniel Hernandez</b><br><i>PhD internship supervisor</i>  | Centrum Wiskunde & Informatica |
| 2019 | <b>Daniel Willemsen</b><br><i>MSc internship supervisor</i>  | Centrum Wiskunde & Informatica |
| 2021 | <b>Sanjukta Bhattacharya</b><br><i>Internship supervisor</i>   | Centrum Wiskunde & Informatica |
| 2021 | <b>Daniele Foffano</b><br><i>MSc internship supervisor</i>   | Centrum Wiskunde & Informatica |
| 2017 | <b>Joseph Hesketh, Jonathan Levinkind, David Vaughan-Jackson</b><br><i>Digital Creativity Labs Summer School co-supervisor</i> | University of York             |

## admin experience

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|-------------|--|-----------------------------|
| 2013 – 2015 | <b>Department of Knowledge Engineering</b><br><i>PhD coordinator</i><br>Supported and represented PhD students at the department level   | Maastricht, The Netherlands |
| 2011 – 2015 | <b>PhD Academy of Maastricht University</b><br><i>Member, from 2013 board member, in 2014 chair of PhD Academy</i><br>Organized social, cultural and academic events for PhD students; funded by Maastricht University | Maastricht, The Netherlands |
| 2013 – 2014 | <b>University Council</b><br><i>Co-founder of a group representing PhD researchers</i><br>Elected as one of six representatives of scientific staff in the University Council of Maastricht University                 | Maastricht, The Netherlands |

## invited talks and research visits

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|------|---|----------------------------|
| 2023 | <b>University of Alberta</b><br>Talk at the Workshop on Neurosymbolic Programming   | Edmonton, Canada           |
| 2022 | <b>Leiden University</b><br>Talk at the Belgium-Netherlands workshop on Reinforcement Learning (BeNeRL)   | Leiden, The Netherlands    |
| 2022 | <b>Dutch Institute for Emergent Phenomena (DIEP)</b><br>Talk at the DIEP seminar  | Amsterdam, The Netherlands |
| 2019 | <b>Queen Mary University of London</b><br>Talk at the game AI group seminar   | London, United Kingdom     |
| 2017 | <b>Lancaster University</b><br>Talk at the PACTMAN workshop on Trust, Identity, Privacy and Security in the Digital Economy   | Lancaster, United Kingdom  |
| 2017 | <b>University of York</b><br>Talk at the GamesLab Emerging Tech workshop (industry audience)  | York, United Kingdom       |
| 2017 | <b>University of York</b><br>Talk at the AI group seminar   | York, United Kingdom       |
| 2017 | <b>University of Essex</b><br>Talk at the School of Computer Science and Electronic Engineering seminar   | Colchester, United Kingdom |
| 2016 | <b>New York University Tandon School of Engineering</b><br>Talk at the NYU Game Innovation Lab seminar  | New York City, NY, USA     |
| 2013 | <b>University of Alberta</b><br>Talk at the AI group seminar  | Edmonton, Canada           |
| 2012 | <b>Reykjavik University</b><br>Research visit to the Center for Analysis and Design of Intelligent Agents; funded by the Netherlands Organisation for Scientific Research (NWO) | Reykjavik, Iceland         |

## impact and engagement

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|------|---|----------------------------|
| 2023 | <b>Vanderlande Tech Day</b><br>Guest talk for industry audience about human-centered, collaborative learning and planning   | Veghel, The Netherlands    |
| 2018 | <b>Pint of Science Festival</b><br>Talk about artificial intelligence and games at the “To the future... and beyond” session  | York, United Kingdom       |
| 2017 | <b>Yorkshire Games Festival</b><br>Talk about artificial intelligence and games at the “Lates: Gaming” session at the National Science and Media Museum                                 | Bradford, United Kingdom   |
| 2017 | <b>Science out of the Lab</b><br>Organized the activities of the Digital Creativity Labs at a science outreach event as part of the “York Festival of Ideas”; reached about 2000 people | York, United Kingdom       |
| 2016 | <b>ESTEC Open Day</b><br>Co-organized the activities of the Advanced Concepts Team at the open day of the European Space Research and Technology Centre; reached about 9000 people      | Noordwijk, The Netherlands |

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|------|---|-----------------------------|
| 2013 | <b>Career Day</b><br>Informed students on academic careers at the Department of Knowledge Engineering's career information day, Maastricht University | Maastricht, The Netherlands |
| 2012 | <b>DKE Open Day</b><br>Represented the game AI group at the Department of Knowledge Engineering's open day, Maastricht University                     | Maastricht, The Netherlands |

## other activities

|                |  |  |
|----------------|--|--|
| 2023           | <b>32nd International Joint Conference on Artificial Intelligence (IJCAI)</b><br><i>Co-Chair</i> of Explainable AI Workshop  | Macao, S.A.R.                            |
| 2023           | <b>17th Learning and Intelligent Optimization conference (LION)</b><br><i>Co-Organizer</i> of Special Session "Responsible AI in Practice"   | Nice, France                             |
| 2017-2018      | <b>IEEE Conference on Computational Intelligence in Games 2017 and 2018</b><br>NY, USA / Maastricht, The Netherlands<br><i>Co-Organizer</i> of Text-Based Adventure AI Competition   | New York,                                |
| 2017           | <b>CHERISH-DE initiative of the EPSRC</b><br><i>Participant</i> of Digital Economy Crucible, a seven-day development program for young academics   | Swansea/Edinburgh/London, United Kingdom |
| 2013           | <b>Artificial Intelligence and Interactive Digital Entertainment Conference 2012</b><br><i>Participant</i> of AIIDE Doctoral Consortium  | Stanford, CA, USA                        |
| 2011 – present | <b>Professional Service</b><br><i>Program committee member</i> and <i>reviewer</i> for conferences and workshops in the fields of game AI, general AI and related fields, such as the International Joint Conference on Artificial Intelligence, the European Conference on Artificial Intelligence, the IEEE Conference on Computational Intelligence and Games, the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment, the International Conference on the Foundations of Digital Games, and the International Conference on Advances in Computer Games; as well as for journals such as the Journal of Autonomous Agents and Multi-Agent Systems, Theoretical Computer Science, Engineering Optimization, the IEEE Transactions on Games, and the ICGA Journal. <i>Senior program committee member</i> for the International Conference on Autonomous Agents and Multiagent Systems. |  |

## awards and funding

|      |  |   |
|------|--|---|
| 2023 | <b>Horizon Europe call HORIZON-CL4-2022-HUMAN-02-01 — "AI for human empowerment (AI, Data and Robotics Partnership)"</b><br><i>Co-Investigator and work package leader</i><br>Project title: "PEER – hyPER ExpeRt" | total €7,737,900; work package €637,450 |
| 2023 | <b>EWUU Alliance call "AI for Preventive Health and a Circular Society"</b><br><i>Co-Investigator</i><br>Project title: "TakePart: An AI-driven Game in Digital Twin Platforms for Circular Green"                 | €40,000                                 |
| 2017 | <b>Digital Economy Crucible "Research Priming" Award</b><br><i>Co-Investigator and workshop organizer</i><br>Project title: "Building Trust in AI – Designing for Consent"   | €5000                                   |

# publications

## journal articles

### Value Targets in Off-policy AlphaZero: A New Greedy Backup

D. Willemsen, H. Baier, M. Kaisers  
*Neural Computing and Applications* 34.3. Pp. 1801–1814. 2022

### The Text-Based Adventure AI Competition

T. Atkinson, H. Baier, T. Copplesone, S. Devlin, J. Swan  
*IEEE Transactions on Games* 11.3. Pp. 260–266. 2019

### Emulating Human Play in a Leading Mobile Card Game

H. Baier, A. Sattaur, E. J. Powley, S. Devlin, P. I. Cowling, J. Rollason  
*IEEE Transactions on Games* 11.4. Pp. 386–395. 2019

### MCTS-Minimax Hybrids with State Evaluations

H. Baier, M. H. M. Winands  
*Journal of Artificial Intelligence Research* 62. Pp. 193–231. 2018

### Time Management for Monte Carlo Tree Search

H. Baier, M. H. M. Winands  
*IEEE Transactions on Computational Intelligence and AI in Games* 8.3. Pp. 301–314. 2016

### MCTS-Minimax Hybrids

H. Baier, M. H. M. Winands  
*IEEE Transactions on Computational Intelligence and AI in Games* 7.2. Pp. 167–179. 2015

### The Power of Forgetting: Improving the Last-Good-Reply Policy in Monte Carlo Go

H. Baier, P. Drake  
*IEEE Transactions on Computational Intelligence and AI in Games* 2.4. Pp. 303–309. 2010

## conference articles

### Deep Reinforcement Learning for Two-sided Online Bipartite Matching in Collaborative Order Picking

L. Bagnardi, H. Baier, W. Jaarsveld, Y. Zhang  
*Asian Conference on Machine Learning 2023 (ACML 2023)*. Accepted.

### BRExit: On Opponent Modelling in Expert Iteration

D. Hernandez, H. Baier, M. Kaisers  
*32th International Joint Conference on Artificial Intelligence (IJCAI 2023)*, pp. 3795–3802. 2023

### Online Planning in POMDPs with Self-Improving Simulators

J. He, M. Suau, H. Baier, M. Kaisers, F. A. Oliehoek  
*31st International Joint Conference on Artificial Intelligence (IJCAI 2022)*, pp. 4628–4634. 2022

### ME-MCTS: Online Generalization by Combining Multiple Value Estimators

H. Baier, M. Kaisers  
*30th International Joint Conference on Artificial Intelligence (IJCAI 2021)*, pp. 4032–4038. 2021

### Guiding Multiplayer MCTS by Focusing on Yourself [nominated for best paper]

H. Baier, M. Kaisers  
*2020 IEEE Conference on Games (CoG 2020)*, pp. 550–557. 2020

### Opponent-Pruning Paranoid Search [exceptional paper award]

H. Baier, M. Kaisers  
*2020 International Conference on the Foundations of Digital Games (FDG 2020)*, 10:1–10:7. 2020

### Evolutionary MCTS for Multi-Action Adversarial Games [nominated for best paper]

H. Baier, P. I. Cowling  
*2018 IEEE Conference on Computational Intelligence and Games (CIG 2018)*, pp. 1–8. 2018

### Evolutionary MCTS with Flexible Search Horizon

H. Baier, P. I. Cowling

*14th AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment (AIIDE 2018)*, pp. 2–8. 2018

### Decentralized Online Planning for Multi-Robot Warehouse Commissioning [nominated for best paper]

D. Claes, F. Oliehoek, H. Baier, K. Tuyls

*16th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2017)*, pp. 492–500. 2017

### Monte-Carlo Tree Search and Minimax Hybrids

H. Baier, M. H. M. Winands

*2013 IEEE Conference on Computational Intelligence and Games (CIG 2013)*, pp. 129–136. 2013

### Beam Monte-Carlo Tree Search

H. Baier, M. H. M. Winands

*2012 IEEE Conference on Computational Intelligence and Games (CIG 2012)*, pp. 227–233. 2012

### Nested Monte-Carlo Tree Search for Online Planning in Large MDPs

H. Baier, M. H. M. Winands

*20th European Conference on Artificial Intelligence (ECAI 2012)*, pp. 109–114. 2012

### Time Management for Monte-Carlo Tree Search in Go

H. Baier, M. H. M. Winands

*13th International Conference on Advances in Computer Games (ACG 2011)*, pp. 39–51. 2012

### Active Opening Book Application for Monte-Carlo Tree Search in 19x19 Go

H. Baier, M. H. M. Winands

*23rd Benelux Conference on Artificial Intelligence (BNAIC 2011)*, pp. 3–10. 2011

## workshop articles and extended abstracts

### Novelty and MCTS

H. Baier, M. Kaisers

*1st Evolutionary Reinforcement Learning Workshop at GECCO (EVORL 2021)*, pp. 1483–1487. 2021

### Towards Explainable MCTS

H. Baier, M. Kaisers

*AAAI 2021 Workshop on Explainable Agency in AI*. 2021

### Explainable Search

H. Baier, M. Kaisers

*2020 IJCAI-PRICAI Workshop on Explainable Artificial Intelligence*. 2020

### Value Targets in Off-policy AlphaZero: A New Greedy Backup

D. Willemsen, H. Baier, M. Kaisers

*2020 Adaptive and Learning Agents Workshop at AAMAS (ALA 2020)*. 2020

### MCTS-Minimax Hybrids with State Evaluations (Extended Abstract)

H. Baier, M. H. M. Winands

*27th International Joint Conference on Artificial Intelligence (IJCAI 2018)*, pp. 5548–5552. 2018

### A Rollout-Based Hybrid Unifying MCTS and Alpha-Beta

H. Baier

*Computer Games: Fifth Workshop on Computer Games (CGW 2016)*, pp. 57–70. 2017

### Monte-Carlo Tree Search and Minimax Hybrids with Heuristic Evaluation Functions

H. Baier, M. H. M. Winands

*Computer Games: Third Workshop on Computer Games (CGW 2014)*, pp. 45–63. 2014

### Nested Monte-Carlo Tree Search for Online Planning in Large MDPs (Extended Abstract)

H. Baier, M. H. M. Winands

*24th Benelux Conference on Artificial Intelligence (BNAIC 2012)*, pp. 273–274. 2012



## theses

### Monte-Carlo Tree Search Enhancements for One-Player and Two-Player Domains

H. Baier

*Ph.D. thesis. Department of Knowledge Engineering, Maastricht University, Maastricht, The Netherlands. 2015*

### Adaptive Payout Policies for Monte Carlo Go

H. Baier

*Master's thesis. Institute of Cognitive Science, Osnabrück University, Osnabrück, Germany. 2010*

### Der Alpha-Beta-Algorithmus und Erweiterungen bei Vier Gewinn

H. Baier

*Bachelor's thesis. Department of Computer Science, Technische Universität Darmstadt, Darmstadt, Germany. 2006*