# PAUL LINTON, PhD

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## INTRODUCTION

My PhD challenges fundamental assumptions about the mechanisms of 3D vision that date back to Kepler and Descartes. In their place, I develop new theories of visual scale (perception of size and distance) and visual shape (perception of 3D geometry). My book *The Perception and Cognition of Visual Space* (Palgrave Macmillan, 2017) argues that we often overlook an important distinction between our *inferences* (judgements) about a scene and our *visual experience*, and I develop this insight into an account of the primary visual cortex and visual consciousness. My work has significant implications for Artificial Intelligence, where my Royal Society meeting *New Approaches to 3D Vision* was supported by Meta Reality Labs, Google DeepMind, Google AI, and Microsoft.

## POSITIONS

**Columbia University, Presidential Scholar in Society and Neuroscience**　　2022 – 2025
　Independent Fellowship in Neuroscience, Philosophy, and AI　　New York, NY
　Mentors: Prof. Nikolaus Kriegeskorte and Prof. Christopher Peacocke

**Columbia University, Italian Academy for Advanced Studies**　　2022 – 2024
　Fellow in Art, Humanities, and Neuroscience　　New York, NY

## EDUCATION

**PhD, Vision Science, City, University of London**　　2016 – 2021
　Supervisors: Prof. Christopher Tyler* and Dr. Simon Grant　　London, UK
　　*Head of Brain Imaging, Smith-Kettlewell Eye Research Institute

**Graduate Courses in Philosophy NYU (Cross-registered Harvard)**　　2008 – 2011
　Supervisor: Prof. Amartya Sen (Harvard)　　New York, NY

**BA, Law with European Law, University of Oxford**　　2004 – 2008
　Gluckstein Scholar, Hanbury Scholar, Exhibitioner　　Oxford, UK

## PREVIOUS POSITIONS

**City, University of London, Centre for Applied Vision Research**　　2021 – 2022
　Research Fellow in Visual Neuroscience　　London, UK

**University College London, Department of Psychology**　　Jan 2021
　Visiting Lecturer on 3D Vision　　London, UK

**Meta (Facebook) Reality Labs, Display Systems Research**　　Sept – Dec 2018
　Part of the "DeepFocus Team" [press release] as a PhD Research Intern　　Redmond, WA

**University of Oxford, Faculty of Law**　　2011 – 2015
　Non-Stipendiary Lecturer in Moral and Political Philosophy　　Oxford, UK

**University College London, Department of Philosophy**　　Jan – Aug 2014
　Teaching Fellow (Associate Lecturer) in Early Modern Philosophy　　London, UK

**University of Oxford, St Hilda's College**　　2012 – 2013
　Stipendiary Lecturer (+ College Tutor) in Law and Legal Philosophy　　Oxford, UK

## BOOK

Linton, P. (2017). *The Perception and Cognition of Visual Space* (Palgrave Macmillan) [Link to full text]
Single authored 176-page book developing a new interpretation of the 'Perception' / 'Cognition' distinction, and applying it to develop a new two-stage theory of 3D spatial perception

Reviewed in *Perception* [Link]. Serialised on the *Brains Blog*, the leading online forum for cognitive science:
Post One / Post Two / Post Three / Post Four / Post Five

## EDITED VOLUME

Linton, P., Morgan, M., Read, R., Vishwanath, D., Creem-Regehr, S., Domini, F. (eds.) (2022). 'New Approaches to 3D Vision', *Philosophical Transactions of the Royal Society B* [Link]

## PAPERS

Golan et al. (forthcoming), 'Deep neural networks are not a single hypothesis but a language for expressing computational hypotheses', forthcoming commentary in *Behavioral and Brain Sciences* [Link]

Competitively selected response to Bowers et al. (2022), 'Deep Problems with Neural Network Models of Human Vision' [Link], explaining how AI can contribute to our understanding of human vision

Linton, P., Morgan, M., Read, J., Vishwanath, D., Creem-Regehr, S., Domini, F. (2023), 'New Approaches to 3D Vision', in Linton, Morgan, Read, Vishwanath, Creem-Regehr, Domini (eds.), 'New Approaches to 3D Vision', *Philosophical Transactions of the Royal Society B* [Link]

Explores how AI + Computer Vision, Animal Navigation, and Human Vision, are all grappling with the very same problem: what is the most appropriate representation for 3D vision and action?

Linton, P. (2023). 'Minimal Theory of 3D Vision: New Approach to Visual Scale and Visual Shape', in Linton, Morgan, Read, Vishwanath, Creem-Regehr, Domini (eds.), 'New Approaches to 3D Vision', *Philosophical Transactions of the Royal Society B* [Link]

Argues for a new account of visual scale (perceived size and distance) and visual shape (perceived 3D geometry) based on my experimental findings (below) that the visual system does not use 'vergence' (the angular rotation of the eyes) to triangulate distance. Also argues that the same approach should be applied to AI, which has traditionally struggled with biologically plausible models of 3D vision

Linton, P. (2021). 'V1 as an Egocentric Cognitive Map', *Neuroscience of Consciousness*, 7(2), 1–19 [Link]

Argues that the processing of 3D depth in V1 appears to operate at two distinct levels: our visual experience and post-perceptual cognition. Hypothesises that these two levels of processing can be differentiated in the different layers of V1. Uses this insight to argue for a low-level (feedforward V1) account of visual consciousness in contrast mid-level theories (recurrent processing theory; integrated information theory) and higher-level theories (higher-order thought; global workspace theory). *Special Issue on Consciousness Science*

Linton, P. (2021). 'Does Vergence Affect Perceived Size?', *Vision*, 5(3), 33 [Link]

Demonstrates that 'vergence' (the angular rotation of the eyes) does not contribute to our perception of size, with a discussion of the implications for size constancy. Invited for publication by Prof. Mel Goodale FRS and Dr. Robert Whitwell for their special issue on 'Size Constancy for Perception and Action'

Linton, P., (2021). 'Conflicting shape percepts explained by perception cognition distinction', *Proceedings of the National Academy of Sciences*, 118 (10) e2024195118 [Link]

Letter to the Editor in response to Morales et al. (2020). 'Sustained representation of perspectival shape', *PNAS*, 117(26), 14873-82 [Link]. Provided inspiration for new experiments in Morales et al. (2021). 'Reply to Linton: Perspectival interference up close', *PNAS*, 118 (28) e2025440118 [Link]

Linton, P. (2020). 'Does Vision Extract Absolute Distance from Vergence?', *Attention, Perception, & Psychophysics*, 82, 3176–95 [Link]

> Demonstrates that 'vergence' (the angular rotation of the eyes) does not provide absolute distance information to the visual system, with discussion of implications for distance perception
> Featured on the Psychonomic Society's "All Things Cognition" podcast [Link]
> Cited with approval in the *Annual Review of Vision Science* [Link]

## PREPRINT

Linton, P. (2019). 'Would Gaze-Contingent Rendering Improve Depth Perception in Virtual and Augmented Reality?', *ArXiv*, 1905.10366 [cs.HC][Link]

> First person to propose updating the camera frustum in virtual reality with eye movements to account for differences between centre of rotation and nodal point of the eye. I show this is important because failure to account for these small differences can lead to distortions in virtual reality

## CONFERENCE

"New Approaches to 3D Vision", Royal Society Discussion Meeting (Nov 2021) [Link]
> Royal Society's most prestigious, and most competitive, scientific meeting format

> Co-organised with Prof. Michael Morgan FRS, Prof. Jenny Read, Dr. Dhanraj Vishwanath, Prof. Sarah Creem-Regehr, and Prof. Fulvio Domini. I initiated the proposal, drafted the proposal, invited the speakers, organised the meeting, gave opening remarks, and gave a talk

> Meeting covered Computer Vision + AI, Animal Navigation, and Human Vision, with representatives from Google DeepMind, Google Robotics, Meta (Facebook) Reality Labs, and Microsoft Research
> Over 800 attendees; full schedule at end of CV

## AWARDS

Presidential Scholarship in Neuroscience and Society, Columbia University (2022-2025)     [Undisclosed]
> 3-year independent fellowship with research funding to conduct research at the intersection of Philosophy, Neuroscience, and Artificial Intelligence

Fellowship of the Italian Academy for Advanced Studies, Columbia University (2022-2024)     [Undisclosed]
> Fellowship in Art, Humanities, and Neuroscience
> Contribution towards Presidential Scholar funding (joint appointment)

Royal Society Scientific Meeting Award for "New Approaches to 3D Vision" (2021)     ≈ $52,000
> Funding to host major international conference at Royal Society

Elsevier / Vision Research Travel Award for Vision Sciences Society Meeting (2020)     $280

Grindley Grant, Experimental Psychology Society for Researchers in Touch Meeting (2019)     $160

Worshipful Company of Saddlers for European Conference on Visual Perception (2018)     $800

Gluckstein Scholarship, Lincoln College, University of Oxford (2008)     $920
> College's highest scholarship for "demonstrated academic excellence"

## INVITED TALKS

Minimal Theory of 3D Vision: New Approach to Visual Scale and Visual Shape     Oct 2023
     NYU Philosophy of Mind (invited by Prof. David Chalmers and Prof. Ned Block)     New York, NY

Visual Scale and Visual Shape at 'Art and Science of Seeing' (Royal Society of Arts)     May 2023
     (invited by Dr. Aaron Hertzmann, Adobe and Prof. Robert Pepperell, Cardiff)     London, UK

Minimal Theory of 3D Vision: New Approach to Visual Scale and Visual Shape     April 2023
     Perception & Action Seminar, Brown University (invited by Prof. Fulvio Domini)     Providence, RI

Four Challenges for Human 3D Vision     Jan 2022
     Cognitive & Neural Computation Lab, Yale (invited by Prof. I. Yildirim)     New Haven, CT
     and Computational Vision Lab, Yale (invited by Prof. S. Zucker)

Four Challenges for Human 3D Vision     Jan 2022
     Visual Inference Lab, Columbia (invited by Prof. Nikolaus Kriegeskorte)     New York, NY

Four Challenges for Human 3D Vision     Nov 2021
     Computational Cognitive Science Lab, MIT (invited by Prof. Josh Tenenbaum)     Cambridge, MA

New Approaches to Visual Scale and Visual Shape [Talk]     Nov 2021
     Royal Society Meeting "New Approaches to 3D Vision"     Online

[Title Redacted]     Aug 2021
     Meta (Facebook) Reality Labs     Online

Size and Distance Perception in Virtual and Augmented Reality [Talk]     June 2021
     Optical Society (OSA), Technical Group on Display Technology     Online

Size and Distance Perception in Virtual and Augmented Reality     June 2021
     Virtual Environments and Computer Graphics Group, UCL     Online

The Perception and Cognition of Visual Space     Feb 2021
     Institute of Philosophy (invited by Prof. Chris Frith FRS FBA)     London, UK

The Paradox of Visual Scale [Cancelled due to pandemic] [Advert]     April 2020
     Center for Cognitive Science, Rutgers (invited by Prof. Thomas Papathomas)     New Brunswick, NJ

[Title Redacted]     Dec 2018
     Meta (Facebook) Reality Labs     Redmond, WA

## PEER REVIEWED CONFERENCE PRESENTATIONS

Linton, P., 'Consciousness: How Low Can You Go?' [Poster][Twitter Thread]     June 2023
     Poster at Association for the Scientific Study of Consciousness     New York, NY

Linton, P., 'No Vergence Size Constancy'                                                    June 2020
    Poster at Vision Sciences Society [Poster][Poster Walkthrough]                           Online

Linton, P., 'Does Human Vision Triangulate Absolute Distance?' [Talk]                       Jan 2020
    Talk at '3D Worlds from 2D Images', British Machine Vision Association                   London, UK

Linton, P., 'Does Vergence Explain the Taylor Illusion?'                                    Dec 2019
    Talk at Applied Vision Association [Abstract]                                            Cardiff, UK

Linton, P., 'Do We See Scale?' [Poster]                                                     July 2019
    Poster at Association for the Scientific Study of Consciousness                          Ontario, Canada

Linton, P., 'Re-Evaluating Vergence as a Distance Cue'                                      Aug 2018
    Talk at European Conference on Visual Perception [Abstract]                             Trieste, Italy

Linton, P., 'How Do We See Distance in VR' [Abstract]                                       June 2018
    Poster at 'Frontiers in Virtual Reality', University of Rochester                        Rochester, NY

Linton, P., 'Are Vergence and Accommodation Effective Cues to Distance?'                    March 2018
    Talk at Scottish Vision Group                                                            Glencoe, UK

## PUBLIC EVENTS

Organiser and speaker at public event on *Designing Space*, with talks by Steven Holl       Sept 2023
    (Architect, Steven Holl Associates), Prof. Anjan Chatterjee (Neuroscientist, UPenn),     New York, NY
    and Nitzan Bartov (Research Designer, CTRL Labs, Meta Reality Labs) [Link][Talks]

Panellist discussing the film *Blind Eye Artist* (2023) after its premiere at the           May 2023
    Harlem International Film Festival (representing Columbia's Zuckerman Institute)          New York, NY

Organiser and speaker at public event on Royal Society volume *New Approaches to*           Feb 2023
    *3D Vision* with talks by Prof. Fulvio Domini (Brown), Prof. Kate Jeffery (Glasgow),     New York, NY
    and Dr. Ida Momennejad (Microsoft Research) [Link][Talks]

## EDITOR

Lead Editor, Philosophical Transactions of the Royal Society B (Volume: "New Approaches to 3D Vision")

## REVIEWER

Psychological Review / Journal of Vision ("Exceptional Reviewer") / Vision Research / Vision /
Philosophical Transactions of the Royal Society B / British Journal for the Philosophy of Science

## TEACHING EXPERIENCE – COURSE LECTURER

**Oxford University, Faculty of Law, Lecturer in Moral and Political Philosophy**      2011 – 2015

Responsible for co-developing and teaching 3rd year BA Moral & Political Philosophy course

Developed my own course for visiting postgraduate (JD) students from NYU Law

Evaluated as "outstanding in both preparation and delivery" by the Oxford Law Faculty

**University College London, Teaching Fellow (Associate Lecturer) in Philosophy**      Spring 2014

Responsible for development for 2 undergraduate philosophy courses at University College London:

Early Modern Philosophy (1st Year course with 100+ students), and

Empiricism (advanced course with 30+ 2nd and 3rd Year students)

I created the syllabuses, gave lectures and seminars, and supervised seminars and marking by three TAs

Evaluation by Prof. Paul Snowdon, late Grote Professor of Mind and Logic and Head of Department:

Paul's "contribution to the teaching in our department was unsurpassed … it was first rate – original but also clear and suitable for undergraduates. I was especially impressed by the way he made his lectures intelligible for undergraduates, but also comprehensive and wide-ranging, covering as well as philosophy, both the science of the time and relevant cultural developments. I know from student feedback that the course was a great success."

**Oxford University, St Hilda's College, Stipendiary Lecturer and Tutor in Law**      2012 – 2013

Responsible for teaching and curriculum development of 3 courses at St Hilda's College:
Legal Philosophy, Constitutional Law, and Administrative law

Students received a disproportionate number of 1sts, especially in my first year course

Responsible for admissions and pastoral care of 2nd year undergraduates and taught postgraduates

Performance evaluated "top 5% of Oxford Law Tutors" by Senior Law Tutor

## TEACHING EXPERIENCE – VISITING LECTURER

University College London, Perception Lecture Series, 2nd Year BSc in Psychology      Jan 2021

New York University, Prof. Wei Ji Ma's 'Psychological Science and Society'      May 2020
(Group discussion of my work on distance perception)

Cambridge University, School of Architecture, Invited Critic      2014 – 2017
Also Invited Critic at Central St Martins and University College London
Contributor to Architectural Association's *AAConversations* [Link]

## VISITING POSITIONS

University of Aberdeen, Northern Institute of Philosophy      Summer 2010
Supervisor: Crispin Wright (NYU)

Harvard University, Department of Philosophy      Spring 2010
Supervisors: Derek Parfit and Tim Scanlon

Cambridge University, Kings College, Centre for History and Economics      Spring + Summer 2009
Supervisor: Amartya Sen (Harvard)

## LEGAL EXPERIENCE

Council of Europe, Commission for Democracy through Law                    Summer 2008
    Effectiveness of constitutional safeguards in Eastern Europe                    Strasbourg, FR

University of Leiden, Faculty of Law, Meijers Institute                    Spring + Summer 2007
    European Parliament project on sexual orientation discrimination                    Leiden, NL

Research Assistant to Sir Keir Starmer KC (now Leader of Opposition in UK)                    Spring + Summer 2003
    International human rights law, death row cases in Trinidad and Tobago                    London, UK

## DAY ONE - SEEING BEYOND SLAM
Chair: Andrew Fitzgibbon (Microsoft)

**Session One**: **Neural Scene Representation**
SM Ali Eslami (DeepMind): "Neural priors, neural encoders and neural renderers"
Ida Momennejad (Microsoft Research): "Multi-scale predictive representations and human-like RL"

**Session Two**: **Perception-Action Loop**
Sergey Levine (UC Berkeley and Google): "Generalization in data-driven control"
Andrew Glennerster (University of Reading): "Understanding 3D vision as a policy network"

## DAY TWO – ANIMALS IN ACTION
Chair: Matteo Carandini (University College London)

**Session One**: **Locating Prey and Rewards**
Jenny Read (Newcastle University): "Stupid stereoscopic algorithms that still work"
Aman Saleem (University College London): "Visual processing in the brain during navigation"

**Session Two**: **Navigation in 3D Space**
Kate Jeffery (University College London): "The cognitive map of 3D space: not as metric as we thought?"
Gily Ginosar (Weizmann Institute): "Locally ordered representation of 3D space in the entorhinal cortex"

## DAY THREE - EXPERIENCING SPACE
Chair: Mar Gonzalez-Franco (Microsoft Research)

**Session One**: **Theories of Visual Space**
Dhanraj Vishwanath (University of St Andrews): "Tripartite encoding of visual 3D space"
Paul Linton (City, University of London): "New approaches to visual scale and visual shape"

**Session Two**: **Challenges for Virtual Reality**
Sarah Creem-Regehr (University of Utah): "Perception and action in virtual and augmented reality"
Douglas Lanman (Facebook Reality Labs): "Engineering challenges for realistic displays"

## DAY FOUR - GRASPING THE WORLD
Chair: Jody Culham (Western University)

**Session One**: **One Visual Stream or Two?**
Fulvio Domini (Brown University): "A novel non-probabilistic model of 3D cue integration explains both perception and action"
Irene Sperandio (Trento): "Dissociations between perception and action in size-distance scaling"

**Session Two**: **3D Space and Visual Impairment**
Ione Fine (University of Washington): "Do you hear what I see? How do early blind individuals experience object motion?"
Ewa Niechwiej-Szwedo (University of Waterloo): "The role of binocular vision in the development of visuomotor control and performance of fine motor skills"