Asymptopia

CENTRE FOR MATHEMATICAL SCIENCES NEWSLETTER

UNIVERSITY OF CAMBRIDGE

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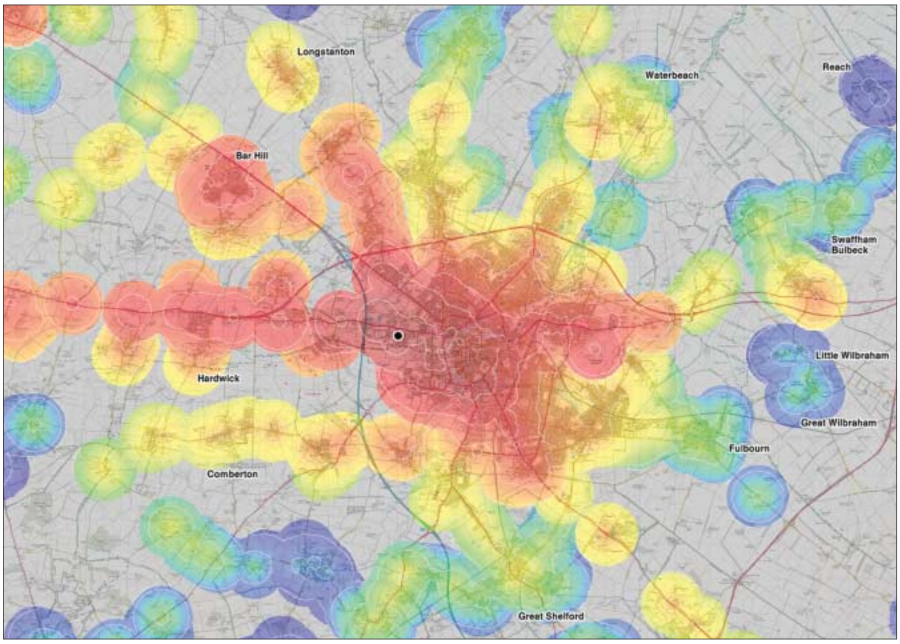
Travel-time maps – transforming our view of transport

Just arrived in Cambridge and wondering where to live? Then take a look at this map of Cambridge and its surrounds – the transition of colours from warm red to cool violet indicate how long it will take you to get to the CMS, situated in West Cambridge, by 9am using public transport.



At a glance you can see the well connected areas bathed in red, and the uncoloured areas from which you won't be able to make the journey on public transport at all.

This is an example of the influential travel-time maps produced by mySociety, in work funded by the Department for Transport. The maps show how the data put together for TransportDirect, a real-time information service, can be used for other purposes, for example to help employers site a new facility, or individuals choose where to live, or to inform the planning of transport and land use.

Clearly the travel-time for a particular journey is a function of the origin and destination points, the time of travel, the modes used, and of decisions made by the traveller (for instance whether to prefer faster or cheaper journeys). Our travel-time maps can only conveniently display a function of one point (the origin or destination point), so we need to fix the other arguments so that it describes journey times which are useful to users in some context, and is practical to compute.

TransportDirect has a set of databases of timetable information and how public transport services connect up. We feed very large numbers of queries into the journey planner at TransportDirect (approximately 30,000) and use these to form an estimate of the travel time. For maps such as the one above, we fix the destination and arrival deadline and iterate over all the transport interchanges in the region of interest to compute the latest departure necessary to arrive before the deadline.

Now we have enough information to draw the map. We iterate over a grid of points in the region of interest (choosing the spacing by the resolution of the map to be drawn); at each point we search for transport interchanges within 15 minutes' walking distance of that point, and choose the one which gives the shortest overall journey time, if any. This generates a grid of points at which we know the journey time, or know that no journey is possible. From this it is trivial to draw a map where each point is coloured according to journey time, or uncoloured if no journey is possible. We choose the colours according to a standard scale, but adjust them using histogram equalisation so that each colour covers approximately the same area of map.

The contours, or *isochrones*, are essential to making the map comprehensible. Drawing these is slightly more subtle, because the function to contour (the travel-time) is not actually defined everywhere in the region of interest. We fix this up by extrapolating the values of the travel time outside the domain of the function, contouring the extrapolated function, and then clipping the contours against the domain of the function. Our extrapolation is a solution to Laplace's equation, fixing its value to the value of the travel-time on the boundary of its domain, and fixing the normal derivative at zero on the boundary of the region of interest. Though there is no real justification for this approach it produces acceptable results.

The map above shows the travel-time from locations in Cambridge and the surrounding villages to reach West Cambridge (the small black circle near the centre) by 9am. The contour lines are drawn at intervals of 10 minutes, so that the innermost contour around the destination corresponds to a start time of about ten to nine.

Cambridge is a small city with a lot of bus services, so it is not very surprising that the whole of the city centre and much of the suburbs are within twenty to thirty minutes' travel of the destination, even including waiting and walking time. Moving further out, though, the picture changes. Areas connected to Cambridge by fast roads such as the A14 fare much better than those villages off the beaten track. For some habitations it is not possible to reach the West Cambridge Site for 9 o'clock purely by public transport without a long walk or an overnight journey.

The hope is that the travel-time maps can offer people an easy way to make decisions about where to live, and work, and travel to, that may encourage the use of the public transport system. Other travel-time maps also compare travel by car to public transport, and future work may link transport to house prices and to indicators of social deprivation.

Isochrones were first calculated by Francis Galton in the 19th century, in an early application of dynamic programming to the determination of routes for sailing boats. The major issues in more recent years have concerned the organisation of, and access to, data of fine granularity in space and time. An underlying purpose of the work described here is to tackle the question of access to data. The maps produced by mySociety were produced under the auspices of the Department for Transport, so they did not have to pay for the use of expensive datasets such as postcodes and the Ordnance Survey maps. The work has raised questions about who owns the data, who can access it and how easily it can be interchanged and the maps reproduced.

The travel-time maps are more than just pretty to look at: they also demonstrate an innovative way to use and present existing data. We are entering a world where we have access to vast quantities of data, and ways of turning that data into information, often involving clever ideas about visualisation, are becoming more and more important in science, government and our daily lives.

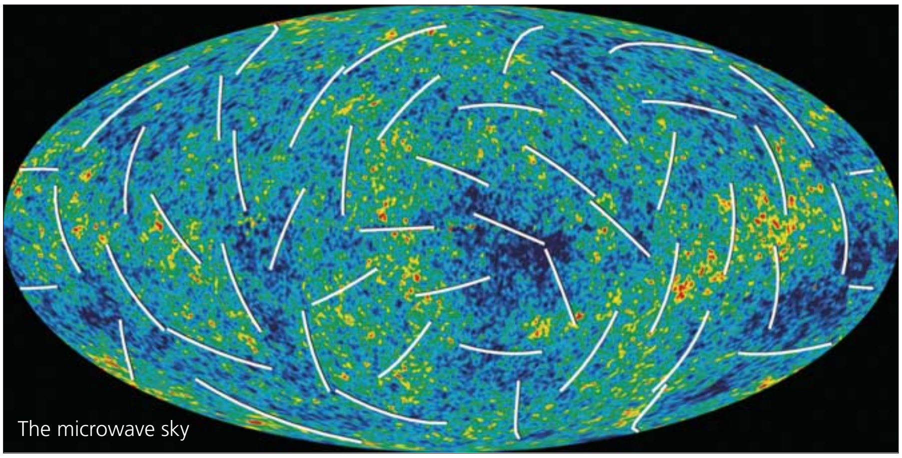
Authors

Chris Lightfoot is a core developer at mySociety, (www.mysociety.org) – a charitable project that builds websites that help people to get involved in civic and community activities. The page (www.mysociety.org/2006/ travel-time-maps) gives more examples, and a description of methods.

Frank Kelly is in the Statistical Laboratory in DPMMS, and has just finished a three year term as Chief Scientific Adviser to the Department for Transport. Some wider issues of transport data and innovation are addressed in a recent article (www.foundation.org.uk/pdf18/ fst 19_2.pdf).

The future of observational cosmology – made in Cambridge

Since its discovery in 1965, the cosmic microwave background (CMB) has been an essential tool in cosmologists' quest to understand the large-scale properties of the universe.



The microwave sky

NASA/WMAP Science Team

This radiation has a remarkably uniform temperature across the sky and is believed to be the thermal relic radiation from the hot, dense conditions that prevailed as the universe emerged from the Big Bang. The discovery of the CMB convinced many of the reality of the Big Bang. Explanations of the puzzling uniformity of its temperature led, in part, to the theory of inflation, describing a brief period of accelerated expansion in the early universe.

But although the CMB temperature is uniform on the whole, it cannot be *completely* uniform. The primordial universe must have contained small irregularities in the density of matter that grew under the influence of gravity into the concentrations (e.g. the galaxies and their clusters) that we observe today. The origin of these primordial perturbations is uncertain, but they are believed to have been generated by quantum effects in the early universe. As Stephen Hawking and others showed in the early 1980s, the quantum generation of fluctuations is a compelling by-product of inflation. As well as shaping the distribution of galaxies, the primordial fluctuations should be reflected in small variations in the CMB temperature across the sky. The statistics of the observed temperature irregularities – called anisotropies – contain a wealth of information about the nature of the primordial perturbations, as well as the matter composition and geometry of the universe. By mapping the microwave sky, cosmologists thus hope to answer some of the biggest questions in physics.

It is now 15 years since fluctuations in the CMB temperature were discovered by an instrument on-board the COBE satellite. Since then, many instruments (including Cambridge's CAT and VSA experiments) have mapped the anisotropies using a range of technologies deployed on the ground, from the stratosphere with balloons, and from space. The goal has been to improve sensitivity and accuracy of instruments to uncover more of the encoded information. More accurate measurements can give vital information on the densities of baryonic matter (the ordinary matter from which we are made) and cold dark matter (a exotic form of matter required to fit astronomical observations), as well as the spatial geometry of the universe and the amplitude and scale-dependence of the primordial density fluctuations.

The current state-of-the-art dataset is provided by COBE's successor, the WMAP satellite, which released its three-year results earlier this year. The WMAP observations strongly support a simple cosmological model which assumes that space is flat or uncurved, and the data require that 4% of the total energy density is made up of baryons, 20% of cold dark matter and the remaining 76% of mysterious 'dark energy'. Moreover, the primordial density perturbations were found to have an almost, but not quite, scale-invariant spectrum. The accuracy of the WMAP's measurements is impressive – the baryon density, for example, is measured to 4% precision and the flatness of space to better than 1%. This is unprecedented in cosmology.

The theory of inflation, with its typical predictions of a flat universe and almost scale-invariant primordial density perturbations, continues to stand up to exacting comparison with observations. Theorists had proposed a plethora of different inflation models, but the quality of the data is now so good that several popular ones are ruled out.

The community now eagerly awaits the launch of the Planck satellite in early 2008. Forecasts indicate that Planck should measure several important parameters to better than 1%, and place tight constraints on inflation models. Cambridge researchers are actively involved in preparing for the data analysis, and will also take a leading role in the scientific interpretation of Planck data.

Temperature fluctuations are not the only CMB observable; the CMB is also polarised (like light reflected from glass). Polarisation observations nicely complement those of the temperature as they encode new information on the epoch of reionization – when atoms were dissociated by the ultraviolet light from the first stars – and on primordial gravitational waves. The latter is particularly interesting for fundamental physics since a detection would provide strong support for inflation, and rule out some alternatives such as the cyclic model co-developed by Neil Turok of DAMTP.

Although direct detection of primordial gravitational waves may be possible with futuristic space-based interferometers, CMB polarisation provides the only viable route in the near future. Since Planck may not have the sensitivity to make a definitive test, a new generation of ambitious ground-based instruments that will deploy thousands of superconducting detectors are already under construction. One such instrument with significant Cambridge involvement is Clover, planned to be fully operational in Chile by 2009. Looking further ahead, a post-Planck satellite, dedicated to measuring large-angle polarisation with exquisite accuracy, is likely to be put forward early next year in response to ESA's call for proposals under their Cosmic Vision programme. Plans are already afoot to ensure that the Cambridge community will take a major role should such a mission be approved.

The efforts of theorists will be critical for the scientific interpretation of these future CMB measurements. The Centre for Theoretical Cosmology, which is currently being set up here at the CMS, endeavours to predict the cosmological consequences of modern theories of high-energy physics. Its work will help to set the agenda for the next 20 years of observation.

Author Anthony Challinor is a University Lecturer jointly at DAMTP and the Institute of Astronomy.

The Centre for Theoretical Cosmology (CTC)

The Centre for Theoretical Cosmology (CTC) is now being created at the CMS under the guidance of co-directors Neil Turok and Malcolm Perry. By attracting bright young researchers and exposing them to the high-quality research at the CMS, the centre's aim is to develop models of the beginning of the universe that can drive the observational cosmology of the future.

The CTC was made possible by an initial endowment of £2 million, given by Denis Avery, and is now seeking additional donors and partnerships to grow this endowment to £20 million. It will provide a combination of new funding for PhD students and longer-term postdoctoral fellowships, an expanded programme of lectures in Part III of the Mathematical Tripos and a programme of distinguished visitors.

At the heart of the CTC lies the idea that the best research is done in an enthusiastic and rewarding environment which allows researchers the freedom to engage in wide-ranging research without having to specify their outcomes in advance. Cambridge, with its impressive scientific legacy, is uniquely placed to provide such a stimulating environment. Stephen Hawking and other distinguished scientists are involved in the CTC and will provide inspiration and guidance for young researchers. While the first three postdoctoral researchers start this term, it is hoped that in five years' time the CTC will comprise up to 50 members providing ambitious, original and cutting edge research.

Under one roof

Professors Geoffrey Grimmett, Head of DPMMS, and Peter Haynes, Head of DAMTP

The Centre for Mathematical Sciences is complete, but what are we now doing with it? A transformation of Cambridge Mathematics is well underway, although, since so much hinges on the appointment of outstanding individuals, this is a matter not to be rushed. The physical change has been dramatic; the intellectual development relies on *community* and *visibility*.

Shared accommodation fosters the sense of community, and links across the CMS are stronger than ever before. The CMS Colloquium series attracts large non-denominational audiences, and the opportunity for partying has not been overlooked.

We are now the envy of mathematicians worldwide for our accommodation, and a large number want to spend time here, either permanently or for visits. The international visibility of CMS comes hand in hand with the progressive globalisation of Cambridge Mathematics. Our vacant posts attract many distinguished applicants from around the globe, and we have made outstanding appointments. For example, in 2005/6, in DPMMS Ben Green was elected as the first Herchel Smith Professor of Pure Mathematics, and in DAMTP Ray Goldstein was elected as the second Schlumberger Professor of Complex Physical Systems. Ben is a leading individual in analytic number theory, and has just been awarded the Ostrowski Prize for his work on long arithmetic sequences; Ray is a leading biological physicist who will maintain the strong DAMTP tradition of combining theoretical and experimental work.

The fabric is now in place, but there is much work still to be done. This is a time when new connections are being made within mathematics and between mathematics and other scientific disciplines. Many of our appointments reflect this. For example, we are currently filling a new Professorship of Statistics, and, funded by a generous donation from the Winton Charitable Foundation, we will soon be electing the first Winton Professor of the Public Understanding of Risk. A series of recent appointments, including the Schlumberger Professorship, have significantly strengthened mathematical biology, and the creation of a new Chair of Applied Mathematics gives us the further opportunity to broaden our activity through appointment of another outstanding individual.

People at the CMS
Professor Michael Proctor

Michael Proctor is Professor of Astrophysical Fluid Dynamics in DAMTP, and was recently elected to the Royal Society.

I read mathematics at Cambridge as an undergraduate at Trinity. I was not the perfect student – more interested in rowing than maths – but did Part III as I had begun to be interested in fluid mechanics. There were many distractions, and that might have been the end of my academic career except that several things happened: I became fascinated by problems of hydrodynamic stability as lectured by Herbert Huppert and Nigel Weiss, who also introduced me to solar magnetism, and was inspired to study dynamo theory (the generation of magnetic fields by fluid motions) by the brilliant pedagogy of Keith Moffatt. I also crashed my car and broke both arms. That was the end of rowing, and also meant that I was unable to write for a while and so had legible notes made on carbon paper by my friend and later collaborator Dave Galloway.

Having got a Distinction (just) as a result, I went off to the Massachusetts Institute of Technology for a year on a Kennedy Scholarship to work with Willem Malkus on the nonlinear effects in models of the Earth's dynamo. An important outcome of this work is that the equilibration mechanism is independent of the fluid viscosity.

I continued to work on related problems on returning to Cambridge for my PhD with Keith Moffatt. After two years as a postdoc at MIT with Malkus, I came back to the staff of DAMTP in 1977. I then began a long collaboration with Nigel Weiss on the study of the interaction of convection with magnetic fields. This is important in understanding the structure of sunspots and other magnetic features of the solar photosphere.

The developments of these flows in space got us interested in the role of symmetry in bifurcation. Chris Jones and I considered the interactions of two different scales of convection, which lead to many interesting and complex dynamical phenomena. At the same time I was working with Edgar Knobloch and others on reduced model problems in magnetoconvection. With the assistance of many postdocs and students, including Neal Hurlburt, Alastair Rucklidge and Paul Matthews, we began more ambitious numerical simulations of compressible fluid convection, and we are now able to simulate structures very similar to those observed in the convection zone of the Sun.

At the present I am continuing my work on magnetoconvection, while gearing up for a PPARC-sponsored project on magnetic buoyancy. This is the tendency for strong magnetic field structures to be less dense than their surroundings, and thus to tend to rise through the solar atmosphere, leading eventually to sunspots and other magnetic structures at the surface. It is now believed that this mechanism plays an important role in the solar 11-year sunspot cycle, which is just the manifestation of dynamo action in the Sun. I previously worked with David Hughes and Paul Matthews on aspects of this problem, but now the aim is to show how the field structures can actually sustain themselves. Finally, I am starting an EPSRC-funded project with Knobloch and Steve Tobias on the nonlinear spatiotemporal development of instabilities in long spatial domains.

I have much enjoyed being able to work in so many different areas, and with so many able collaborators. I hope to be able to keep up with all these fields of interest for the next decade!

News at the CMS

The continuing high reputation of Cambridge mathematics has been marked by several prestigious prizes and honours. Professor Michael Proctor of the Department for Applied Mathematics and Theoretical Physics (DAMTP) and Professor Nick Shepherd-Barron of the Department of Pure Mathematics and Mathematical Statistics (DPMMS) have been elected to the Royal Society. Professor Thanasis Fokas has been jointly awarded the Excellence Prize of the Bodossaki Foundation, intended to give recognition to Greek scientists who have earned international renown. Sir Peter Swinnerton-Dyer has been awarded the Sylvester Medal of the Royal Society "for his fundamental work in arithmetic geometry and his many contributions to the theory of ordinary differential equations".

The CMS is pleased to welcome Ray Goldstein as Schlumberger Professor of Complex Physical Systems and Ben Green, who has also been awarded the prestigious Ostrowski Prize, as the first Herchel Smith Professor of Pure Mathematics. We also welcome Teruyoshi Yoshida, appointed as Lecturer in Pure Mathematics, Anthony Challinor, appointed as Lecturer on a joint post in DAMTP and the Institute of Astronomy, and Julia Gog and Matthew Wingate, both appointed to University Lectureships in DAMTP.

We would also like to congratulate Dr John Lister, Dr James Norris and Dr Ian Grojnowski on their promotion to Professor, Dr Adrian Kent, Dr Mihalis Dafermos and Dr Ivan Smith on their promotion to Reader, as well as Dr Stephen Eglen, on his promotion to Senior Lecturer. Congratulations to all!

To discuss any aspect of making a donation in support of mathematics at Cambridge, please contact Patrick Hawke-Smith (ph250@cam.ac.uk)