Why the Future of Geography is Cheap

Royal Geographical Society with IBG

Advancing geography and geographical learning

Jon Reades, Department of Geography, King's College London

Summary

We live in a world transformed by big (geo)data: from Facebook likes and satellites, to Oyster cards and drones, the process of collecting and analysing data about the world around us is becoming very, very *cheap*. Twenty years ago, gathering data about the human and physical environment was expensive, but now a lot of it is generated as the 'exhaust' of day-to-day activity: tapping on to the bus or train, taking photos (whether from a satellite, drone, or disposable camera), making phone calls, using our credit cards, and surfing the web. As the costs of capturing, curating, and processing these data sets falls, the discipline of geography is changing; so in this short, deliberately provocative, piece I hope to get you thinking about how the rise of 'cheap' creates opportunities that geography students are uniquely positioned to observe, but perhaps poorly trained to exploit.

Introduction

Today's students face a world in which many of the defining career options for geographers with *basic* quantitative skills will either no longer exist, or will have been seriously de-skilled. Indeed, so much can now be done through a web browser (*e.g.* CartoDB) that specifying 'Knowledge of ArcGIS' is increasingly superfluous for a new hire; not because geo-analysis jobs are no longer in demand or no longer done – in fact, they are more vital than ever – but because the market for these skills has split in two: expensive, specialist software is being superseded by simple, non-specialist web-based tools on the 'basic' side, and by customised code on the 'advanced' side. The logic behind resources such as ArcGIS Online and Google's Fusion Tables is that *making maps* should be possible for anyone, regardless of background or training. At the same time, *geodata analysis*, which calls for the ability to pull in and manipulate real-time data on river-flow or air quality, may become the preserve of 'data scientists' and engineers.

In short, because of the way that the discipline has been studied and taught in Britain, geography practitioners are at risk of being side-lined at the very moment that our understanding of the complexity of (spatial) relationships between subjects and objects in real and virtual worlds becomes critically important. We are witnessing the triumph of 'cheap' and a resulting change in the mix of skills that are in demand by employers in the public, private, and third sectors. So a reluctance to engage with quantitative and computational methods – to engage, in other words, with data – puts geographers, and their hard-won understanding of the balance and appropriateness of methodological approaches, at risk. To meet this challenge, the A-level syllabus is changing and the way that Geography is taught in secondary schools will need to change as well if it's not to end up being seen as a 'cheap' backup instead of what it actually is: a valuable contribution to critical engagement with the world.

As I indicated above, the title of this short paper is intended as a *deliberate* provocation: I wouldn't have become a geographer if I thought that our discipline had no *value*. Instead, I hope to get you thinking about how the rise of 'cheap' creates opportunities that geography students are uniquely positioned to observe, but may be poorly trained to exploit. My argument is not new: this short paper should be read together with the RGS-IGB's *A Short Introduction to Quantitative Geography* (Harris, 2012), which is just one of a number of recent publications to detail the importance of quantitative skills in geography and other disciplines (see also: *Society Counts* [British Academy, 2012], *Geographers Count…* [Harris *et al.*, 2013], and *Learning to code* [Singleton 2014] amongst others), and which highlight a relative weakness in these skills amongst British students.

Figure 1. Tools of the Trade?
Sources & Attributions: Arduino Uno (Derivative Work by JotaCartas, CC BY 2.0); Oyster Card (Own Work by Frank Murmann, CC BY 3.0); Xbox Kinect (Own Work by Evan-Amos, Public Domain); iPhones (Apple.com); DJI Phantom (DJI.com).

However, in this piece I'd like to distinguish here between quantitative geography as commonly taught and the emergence of what we might call computational geography, or *geocomputation* for short. Even though these two dimensions of our discipline are inseparable, computational approaches differ in important ways from the quantitative skills commonly taught in 'methods' classes: computational geography is underpinned by algorithms that employ concepts such as iteration and recursion tackling everything from a data processing problem to an entire research question. For example, Alex Singleton's OpenAtlas (available for free from the Consumer Data Research Centre) contains 134,567 maps. Alex designed and wrote a script able to *iterate* over the Census areas (*i.e.* to 'visit' each area in turn when creating a map), and to *recurse* into smaller sub-regions from larger regions in order to generate maps at, literally, every conceivable scale; and then he let the computer do the 'boring bit' of actually creating each and every map.

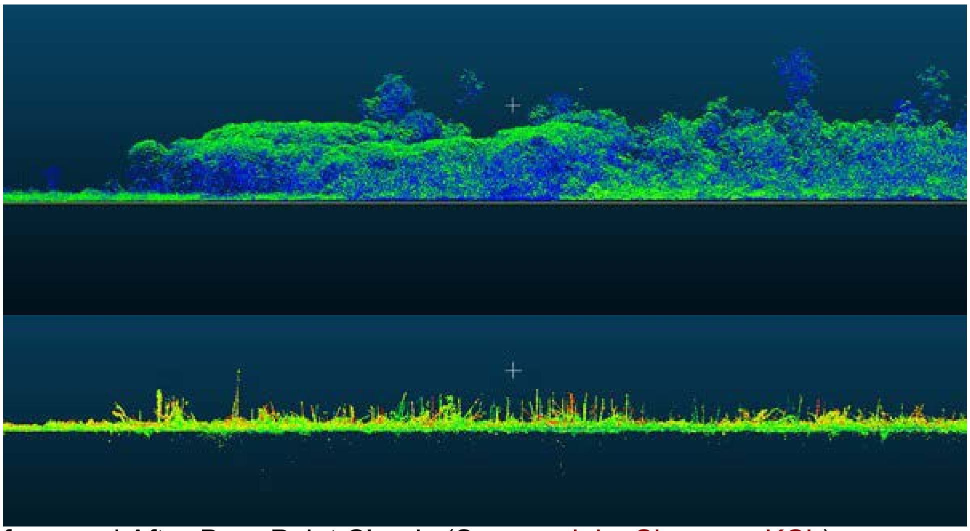


Figure 2. Before- and After-Burn Point Clouds (Source: Jake Simpson, KCL)

Thinking algorithmically requires students – and professionals – to deal with abstraction: we don't want to define how *each* analysis should work, or how *each* map should look; rather, we want to specify a set of rules around how to go about selecting and displaying data on a map *generically*, and then let the computer make them for us. In this way of working, it's not really any more work to create 500 maps than it is to create 5 because we've been able to describe to the computer how maps are made in terms of code that it can 'understand' or, more accurately, apply. And when we combine computational approaches with rich data from, for instance, a drone then we can convert a set of digital photos into a 'point cloud' that allows us to estimate the damage caused by peat fires with unprecedented detail (see Figure 2).

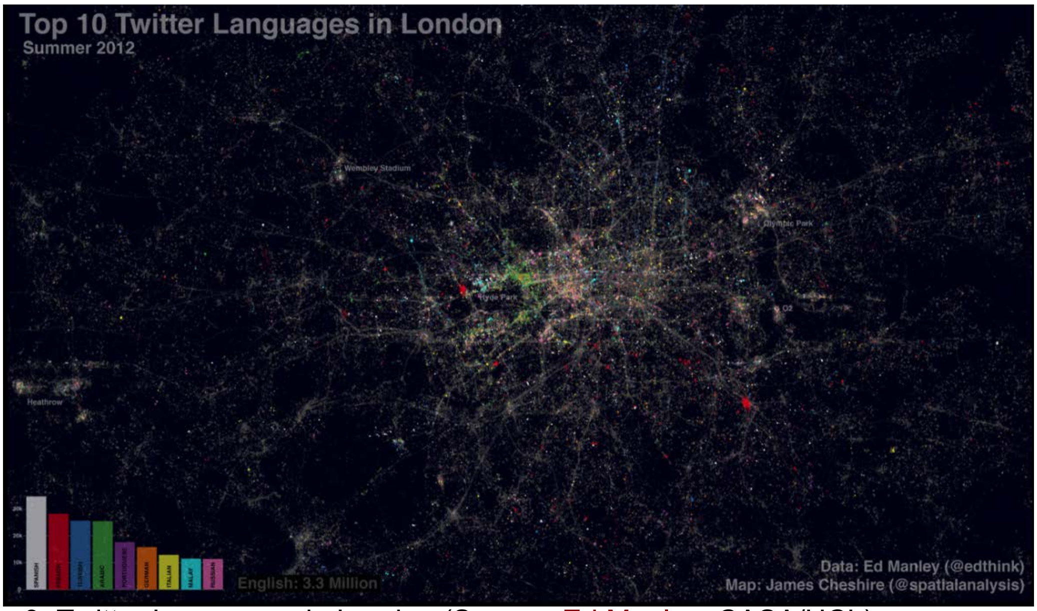


Figure 3. Twitter Languages in London (Source: Ed Manley, CASA/UCL)

Of course, not all computational geographers work with numerical data: they have used text scraped from social networking sites to look at topics ranging from language use in London (see Figure 3) to gentrification. And at other times, they create and populate virtual worlds within which they can run hundreds or thousands of simulations in order to better understand the parameters affecting how wildfires spread, how cities grow, and how neighbourhood segregation can emerge even in tolerant communities. By manipulating the initial conditions of these simulations, geocomputation enables us to explore the 'space' of the inputs: we can test out different forestry management practices in a virtual forest, start silicon wildfires, and see what happens! We can do this for different types of trees, terrains, climates, and practices, searching for the combinations that reduce the risk of a massive, uncontrollable conflagration such as happened recently in Indonesia.

Geocomputation is therefore more properly understood as a way of thinking about a problem rather than being a new branch of geography, and at its heart it remains the analysis of information in a spatial context. Until recently, students could expect to encounter these methods and ideas only at the postgraduate level, with UCL's Centre for Advanced Spatial Analysis being the best-known training ground for Masters and PhD students. The landscape is changing rapidly, however, with a number of universities, including King's College London and the University of Liverpool, having recently introduced optional, programming-oriented modules to 2nd and 3rd year undergraduates on topics such as 'geocomputation' and 'geographic data science'. Geographers with the requisite skills find themselves with the opportunity to collaborate with Computer Scientists, Electrical Engineers, Anthropologists, Digital Humanities Scholars, as well as with organisations ranging from BT Research to Transport for London, from the Treasury to Local Authorities, from the Defence Science and Technology Laboratory to the Humanitarian OpenStreetMap Team.

Why Now?

In 1999, Rita Gardner, Director of the RGS-IBG, observed that 80% of information is spatially referenced in some way (*Geographical*, Vol.71, No.8). We have no real idea what that figure might be today, but thanks to the growth of a data-driven economy – what NESTA has called the *Rise of the Datavores* – in industry and academia it's now nearly impossible to avoid discussions of 'big data' and 'data science'. You've probably come across the term in the news as well: the controversy surrounding Edward Snowden (who is thought to have download more than 1.7 million secret documents on mass surveillance by the security services) is rooted in the ability of governments today to capture and analyse *everything*: who we call, what we buy, what we say to one another. But 'big data' is also changing how organisations in sectors from software to steel, and from teaching to transport, think about their operations. Crucially, nearly all of this data is geographical in some way because social and economic activity is inherently geographical: even for Internet businesses human and physical geography matter, which is why Google and Facebook are building their data centres in Finland (low temperatures and skilled workers).

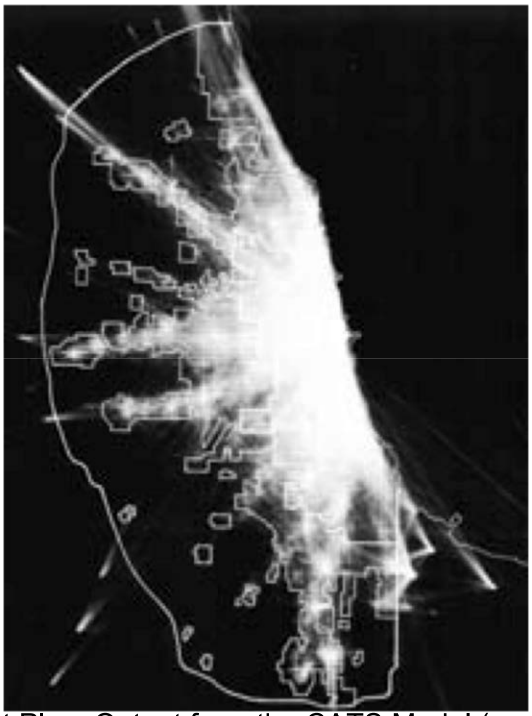
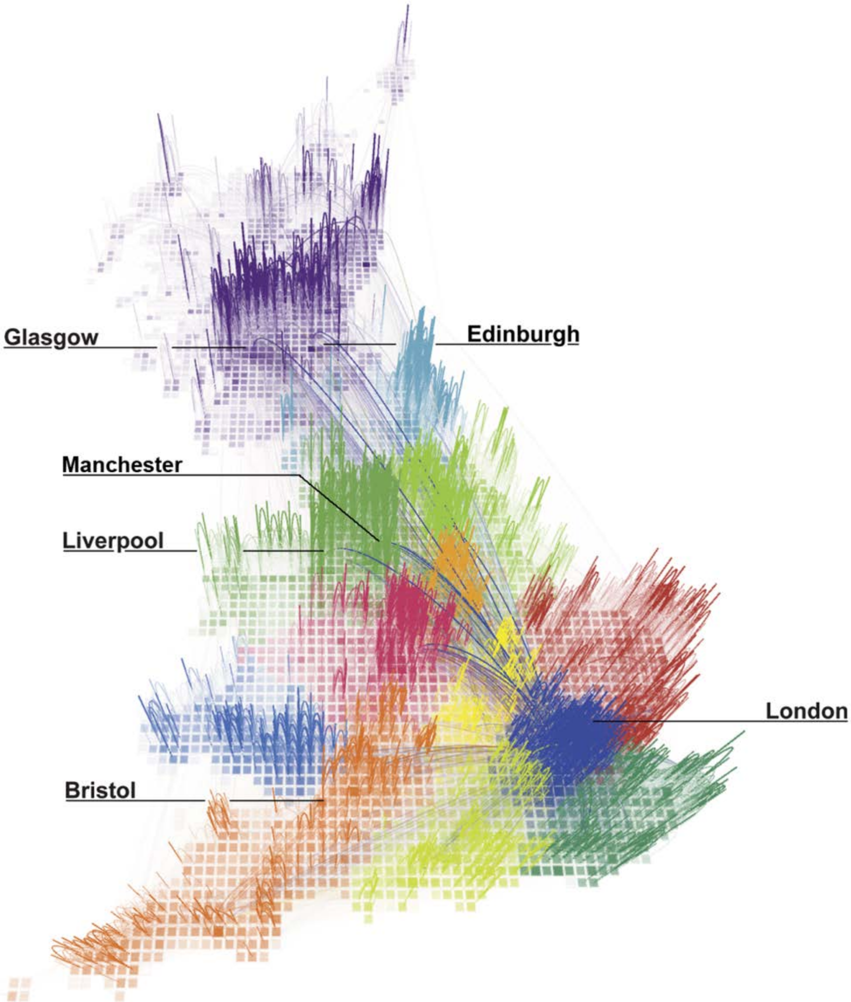


Figure 4. Chicago's Transport Plan: Output from the CATS Model (ca. 1955)

Of course, we've been stretching computers to their limits ever since the first room-sized machines were installed on campuses fifty years ago and maps were created by a 'Cartographatron' (see Figure 4). Back then, geographers and geographic analysis needs were often in the vanguard of computational research: one of the first big applications of the computer in Britain during the 1950s was to work out the supply chain for distributing tea made in London to the rest of the UK, and British Rail then got the Lyons Tea Company's programmers to work out the shortest routes between every rail station – over 5,000 in all – in Britain (Graham-Cumming, "The Great Railway Caper").

Figure 5. The Regions of Britain, as Seen Through Phone Usage (Source: Ratti *et al.*)



So even if it seems like the ground is shifting beneath the feet of many Geography teachers, this change has actually been a long time coming: back in 1965, Gordon Moore – co-founder of the chip-maker Intel – observed that the performance of computers was doubling roughly every two years. That may not sound like much, but over 40 years exponential growth adds up: a computer chip in the early 1970s might have had 2,000 transistors, by the early 2010s they had 2,500,000,000. In the early 2000s, one of the challenges faced by the Ordnance Survey was getting maps on to phones, now phones have both more power and a higher resolution displays than the desktops of the time! Regardless of whether 'Moore's Law' holds for another 5, or 25 years, this change has radically altered how data are created and consumed by society.

Dimensions of Cheap

It is this breathtaking technological transformation that helps us to understand why we're now debating the onset of a 2nd quantitative revolution in geography (see the special issue of *Dialogues in Human Geography*). If the first 'revolution' in the 60s and 70s was about the availability of computing *at all*, then this one is about the availability of computers *everywhere*. Chips are now so cheap that we can literally throw them away in the name of research (*e.g.* TrashTrack – which attached stripped-down mobile phone hardware to rubbish in order to track the 'removal chain') and, with a bit of patience, a desktop computer can now process, analyse, and map ten billion phone calls (see Figure 5 and free content from PLoS One). But if you are thinking that 'cheap' is just about money, then you are missing out on how a confluence of technological and social trends is radically transforming how we work with geo-data and democratising – for both good and ill – our access to GIS:

Cheap sensors: miniaturisation has affected not just the things we see as computers, but many of the tools we use in research. The fact that computers are embedded in everything means that *anything* is a potential sensor: our mobile phones can help to monitor crowding or congestion, and our WiFi usage can help researchers to understand who goes where, when, and even why. We can now attach a set of air quality sensors to a bicycle wheel (*e.g.* the Copenhagen Wheel) and power it by pedalling around the city. Add a GPS module and now the sensors can also record their location anywhere on the planet. Edina's free FieldTripGB application allows students to collect and share GPS trails from their smartphones while taking geo-tagged photos and observations along the way; all of this can then be pulled together by the teacher for in-class analysis (see RGS-IBG Fieldwork).

For fun, one of my colleagues attached a small 'Arduino' (a computer costing less than £40) to the plant in his office; it now tweets when it gets thirsty. More seriously, Arduinos and their siblings – the Raspberry Pi and less-known LillyPads, which are designed to be sewn into clothing – are being used in a range of contexts, including flood and drought reporting (such as Gaugemap, with its tweeting river sensors), and cheap drones are now being used for crop monitoring and disaster relief. Physical geography has always made use of cutting-edge technology, but the use of drones takes the study of stratovolcanos to a whole new level (see video linked from Figure 6).

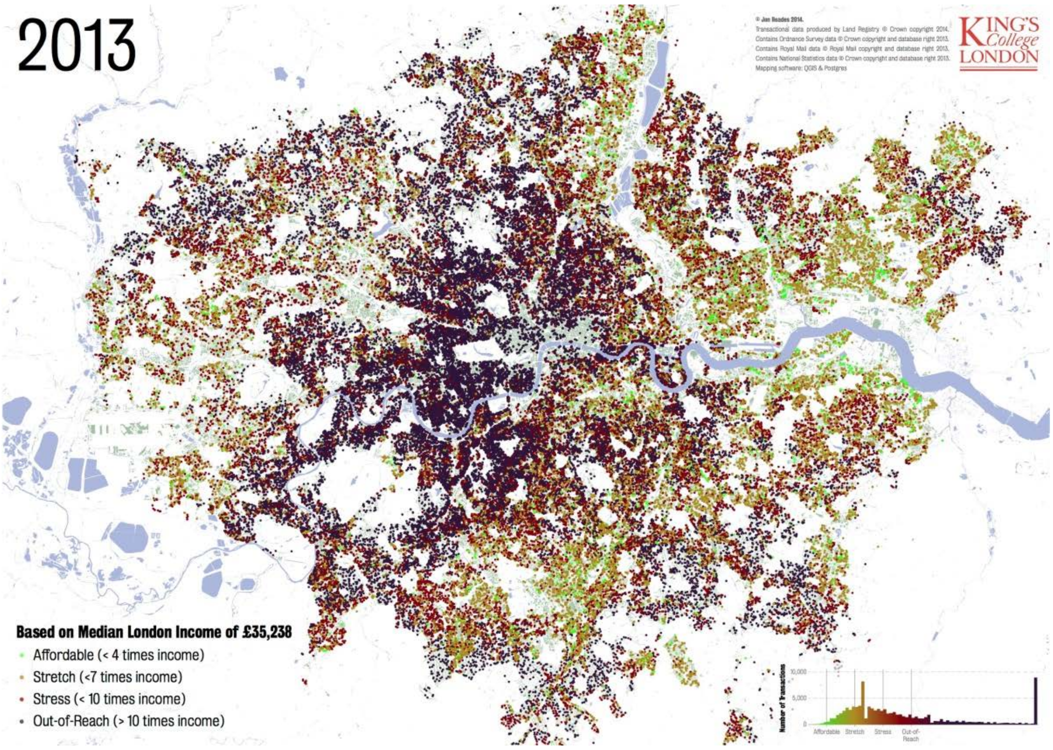
Figure 6. Flying a Drone Over Bárðarbunga Volcano (Source: DJI)

Cheap data: the pervasiveness of computers means that we are now looking at a very different scale of data collection; we used to have to do a lot of legwork for each data point, but now we can get billions of them in a matter of minutes. However, cheap data is also about a philosophy of access to data: the UK government has, on the whole, been a world-leader in making data *open*. The open data movement – represented here in the UK by the efforts of the Open Data Institute, which runs a variety of training and outreach activities – believes that the more governments and other organisations make their data available, the more innovation and creativity we will see.

Many governments now actively support this opening up of data – again, nearly all of it implicitly or explicitly geographical – through the creation of web portals and two of the best-known can be found in the UK: the London Data Store and Data.gov.uk. Academic initiatives are also trying to make this data more accessible to teachers: the DataShine web site allows you to view much of the Census as an interactive web map and even to save your results as a PDF map; and the CDRC provides access to even more types of data by geographical location. The 'best' open data can be used by anyone, at any time, for any reason at all, and many commercial 'apps' use this as a foundation for their business. Companies can make money by adding value to existing data (*e.g.* making it searchable, making it 'smarter', tying in other data…); the CityMapper app, on which many urbanites depend for travel information, is dependent in turn on free access to data from transport authorities, mapping agencies, and the like.

Cheap software: in many ways, the growth of open data was presaged by the growth of open software, of which the Linux operating system remains the most famous. Often referred to by the acronym FOSS (Free Open Source Software), our discipline is not immune to this change and the majority of geocomputational researchers work with Python, R and QGIS. All of these are free: free to download; free to install; free to use… and they'll run on a Mac as well! By making the underlying code accessible to everyone, FOSS tools make it possible for contributors to add new features at a rapid clip. Alasdair Rae's elegant maps of commuting in Britain were generated via *programmed iteration* in QGIS! Nor were my maps of London's housing crisis (see Figure 7) created by hand: the 100,000 transactions shown on each map were processed entirely in code.

Figure 7. Affordability of Property Transactions in London (Source: Jon Reades, KCL)



Switching to FOSS isn't always painless since it requires teaching materials to be redeveloped – sometimes quite frequently because of the rapid rate of progress – and installation isn't always seamless, but the budget and flexibility benefits are enormous. Of course, even free software isn't very powerful if it only does the *one* specific thing its creator intended; QGIS by itself is useful, but it's the open plugin model – which gives users new abilities such as making time-based animations, or embedding Google's StreetView, amongst thousands of others – that makes QGIS shine. Got a complex, annoying, but common task to accomplish? Chances are someone has already written a plugin for it! Best of all, the plugins are all written in a language – Python – that students are already encountering in their Computer Science classes at GCSE and A-level.

Cheap interaction: a final area in which the spread of cheap hardware is having an impact is user interaction. This might sound a bit abstract, but if you think about the pervasiveness of touch screens and X-Box Kinects then the implications are rather more exciting. Researchers at UCL's

Centre for Advanced Spatial Analysis demonstrated with 'Roving Eye' that they could allow users to manipulate a sophisticated pedestrian flow model by moving physical blocks representing buildings around a table; the Kinect allowed the computer to 'see' the change to the street layout and update pedestrian behaviour accordingly. This kind of play can also be deadly serious: SimTable uses a sandbox, Kinect-type sensor, and a projector to allow firefighters to explore different ways of fighting wildfires! And if you want to build your own with your students, there's always the Augmented Reality Sandbox (see

Figure 8): watching the video on YouTube you aren't thinking "What a fantastic physics simulation", you're wondering "How do I get me one of these?" Well, since the underlying code is free and open source, you can (ucdavis.edu/~okreylos). And then you can start to understand how the model was put together.

Figure 8. Augmented Reality Sandbox Video (Source: UC Davis/YouTube)

The Challenge

The confluence of all of these different types of 'cheap' means that Geography teachers face a real hurdle: somehow finding the time to re-learn technical skills that may have been only poorly or partially taught in the first place. But, to put it bluntly, the new A-level syllabus leaves you little choice: it will be testing the students' capacity to *understand* quantitative and, increasingly, computational concepts, not just to replicate a 'set piece' analysis. Worse, many of the statistics that were traditionally taught to geographers are also beginning to look rather 'tired': the chi-square test may be 'taught once and misunderstood thereafter', but it's not even on the table when looking at GPS traces or at data sets representing the activities of millions of users! A lot of the tasks in which computational geographers engage apply concepts that are rarely, or weakly, taught in secondary schools.

Moreover, the ‘big data’ streaming in from sensors and systems across the planet are not ‘given’ to us in the way that data often were in undergraduate degree or PGCE programmes: some of you may recall being given an SPSS file and told to perform a set of seemingly arbitrary tasks in order to obtain ‘a result’ with some level of statistical significance. Real-world and real-time data doesn’t look anything like this: it is messy, incomplete, undocumented, and almost always biased. Why might Twitter data be a bad way to understand deprivation, but a good way to understand gentrification? Why might mobile phone data be useful for exploring working-age commuting patterns, but miss out the most vulnerable members of society?

The only way to even *begin* to work with this kind of data is via the ‘magic’ of code and by developing a much deeper appreciation of what data actually *is*. Students who have been spoon-fed pre-digested data sets will naturally be less resilient when encountering real-world data for the first time because the careful scrubbing by instructors that gives nice, clear ‘teachable’ answers has not happened, and the data set contains everything from missing and incomplete ones, to readings that are materially incorrect because of a sensor malfunction or influenced by something beyond our control. However, without this exposure to *real* data, students end up with a Magic 8-Ball mentality of ‘try again later’ or ‘computer says no’. In this kind of environment it’s impossible for learners to have the depth of background and experience to ask ‘what if’ questions and to deploy the real-world modeller’s toolkit of standardisation, normalisation, cleaning and transformation.

The Value of Computational Thinking

Exposure to real-world geo-data can also deepen student understanding of the mathematics and statistics. You will rarely encounter a normal distribution working with Census data! Some of the most difficult spatial statistics in common use – Getis Ord General G/Gi*, and Moran’s I, for instance – can be much more readily grasped as examples of recursion and iteration than they can as mathematical formulae. And a more abstract conception of spatial data supports a deeper understanding of techniques, such as Geographically Weighted Regression, that remain cutting edge to this day. The two most popular languages amongst computational geographers – Python and R – are widely used in other disciplines as well: Python is frequently used in the Computer Science A-level and underlies both ESRI’s ArcGIS model builder and the entire QGIS application. Moreover, both languages are amongst the most popular for data scientists, so it's good for employability too.

Programming skills are highly transferable in the same way that wider quantitative skills are transferable, but it also reinforces one of the most visibly lacking skills in undergraduates: the ability to think abstractly and adaptively. Working with data via code is very different from working with data via a graphical user interface in a GIS or spreadsheet application: you develop a deeper understanding of the essential fungibility of all types of data, as well as a more profound comprehension of how geo-data works and can be manipulated to serve an analytical end. Place names in a historical text can be translated into coordinate pairs using a dictionary derived from Wikipedia, and observations from moisture sensors can be interpolated on to a raster surface to enable us to look at the intensity of rainfall. 'Space archaeology', in which people search for evidence of ancient settlements by the traces they leave in satellite photographs, is being augmented by code that trains computers to 'see' straight lines where none should exist, and LiDAR is being used to peer beneath the jungle canopy for lost cities in South America and Cambodia.

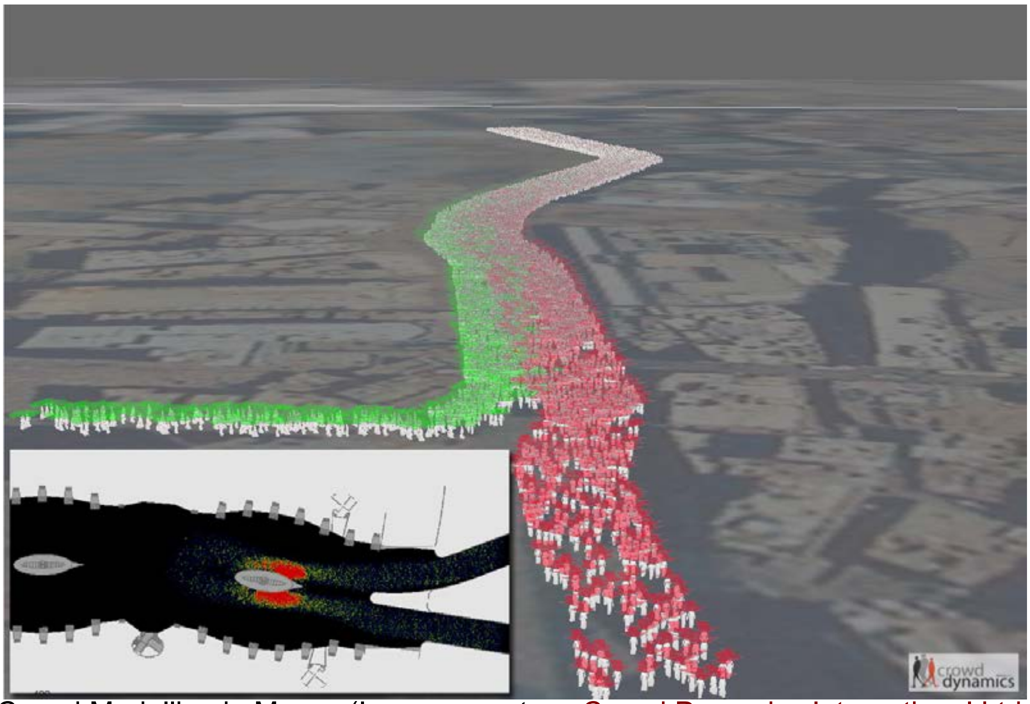


Figure 9. Crowd Modelling in Mecca (Images courtesy Crowd Dynamics International Ltd.)

It's easy to equate computational geography with 'big (geo)data' – which is already beginning to sound a bit 2012 – but it's also applied in another context: simulation. The most common form of geographical simulation is via Agent-Based Models in which you can represent everything from cars to households as independent 'snippets' of code. This kind of coding can improve our understanding of the complexity of the world around us – why do traffic jams seems to travel *backwards* even though cars are all travelling *forwards* – but it also highlights the extent to which the real world is only partially captured by data. The Roving Eye and SimTable mentioned above are examples of Agent-Based Models, and they are commonly used in situations where understanding the activities of individuals or households is important: after a series of disasters in which pilgrims were crushed to death, the Saudi government is using ABMs to try to improve the safety of the Hajj, the largest flow of people on the planet, by modelling how crowds – which can exceed a million people – behave on the Jamarat Bridge and on the streets approach the Holy Mosque!

SimCity is another modern example of an Agent-Based Model, but the best known model was created in 1971 by an American economist named Thomas Schelling: it allows students to see how even a grossly simplified representation of human behaviour – reduced to just a vague preference to be near people 'like me' – can reproduce extreme segregation at the urban scale. The Schelling Model (free downloadable version) contains two types of households – usually, and suggestively, coloured black and white – each of which has a degree of preference for households of the same colour. Students can change the strength of the preference, the number of each type of household, and the amount of space available to see what types of spatial patterns emerge. Even though it's a grossly simplified version of the real world, many geographers have never really grasped the meaning of 'all models are wrong, but some are useful' (attributed to the statistician George Box); social simulation brings this issue to the front every time and there are clearly going to be some interesting discussions after a few runs of a segregation model.

To sum up, researchers, corporations, and governments are examining human behaviour on an unprecedented scale with a view to understanding how we make decisions about where to live and who to love, selling us individually targeted products based on our browsing habits, and trying to keep us safe. For some this is the 'end of theory' because we no longer need to extrapolate, sample, or just plain guess; for others, we seem to be headed towards an Orwellian dystopia in which we are surveilled by governments and unaccountable corporations without consent and without appeal. We all have growing 'data shadows' thanks to the penetration of our physical and social worlds by network-enabled computers, but the majority of students – and their teachers – are unaware of the myriad ways in which this data can be used and abused.

Shifting Perspective

Changes to secondary education create new opportunities for Geography teachers: they do not need to master programming themselves in order to work with Computer Science teachers to develop joint exercises that teach geographers to think like programmers and programmers to think like geographers. The concepts mastered in the Computer Science A-level may seem to have little real-world relevance, so it's hard to think of a better exercise for a group of such students than to get them outside collecting geo-data that they can bring back to the lab and analyse collectively using code. On a project like this, both disciplines bring something exciting to the table since students can generate, monitor, collect, and analyse their own data. It's a full data science pipeline!

Even for the most data-phobic geographer, the use of GPS data can lead to wider discussions of topics such as surveillance and privacy. Can you find your classmate's home just by looking at his or her data? What about hidden friendships or relationships? How variable are our travel patterns? How widely do we roam? These are the kinds of questions that might well be explored in the forthcoming A-Level individual investigation. And these types of exercises and discussions also help to move us away from the 'traditional' divide between human and physical geography; algorithms don't distinguish between disciplinary boundaries, what matters is the relevance of the approach. Can river models help us to understand the flow of crowds? Can landslide models tell us something about the impact of rail closures?

Sad to say, there are still some geography teachers who do not get enough access to, or have the desire to take advantage of, the computer lab beyond a requisite 'GIS session'. To answer the inevitable question from colleagues: what do computers have to do with geography? Geography can provide the practical context – the ground – in which concepts covered in maths and computing classes are applied in practice. Not only does this kind of experiential, problem-oriented learning reinforce the formal teaching in other classes, but it is also likely to increase retention in Computer Science of students – including women and those with Black and Minority Ethnic backgrounds – for which there is evidence to suggest that they place additional value on the potential *impact* of their studies (see Raja 2014). So linking maths and computing to issues ranging from segregation to development seems to create possibilities for enhanced retention and higher achievement.

Spatial thinking now pervades social sciences with, for example, ideas of mobility and diffusion infecting public health and transportation research (Torrens 2010, p.135), but in universities it's still the case that just over half of undergraduate programmes in Geography include any discussion of spatial statistics or computer modelling (Harris *et al*., p.4). To educate the next generation of computational geographers we need to start earlier: there is an up and coming cohort of recent graduates of Masters and Doctoral programmes, but for tomorrow's A-level students to *start* to acquire computational thinking at that point in time will be too late since the most exciting and rapidly changing areas of our discipline will have been colonised, or even subsumed, by 'physicists with geography envy'.

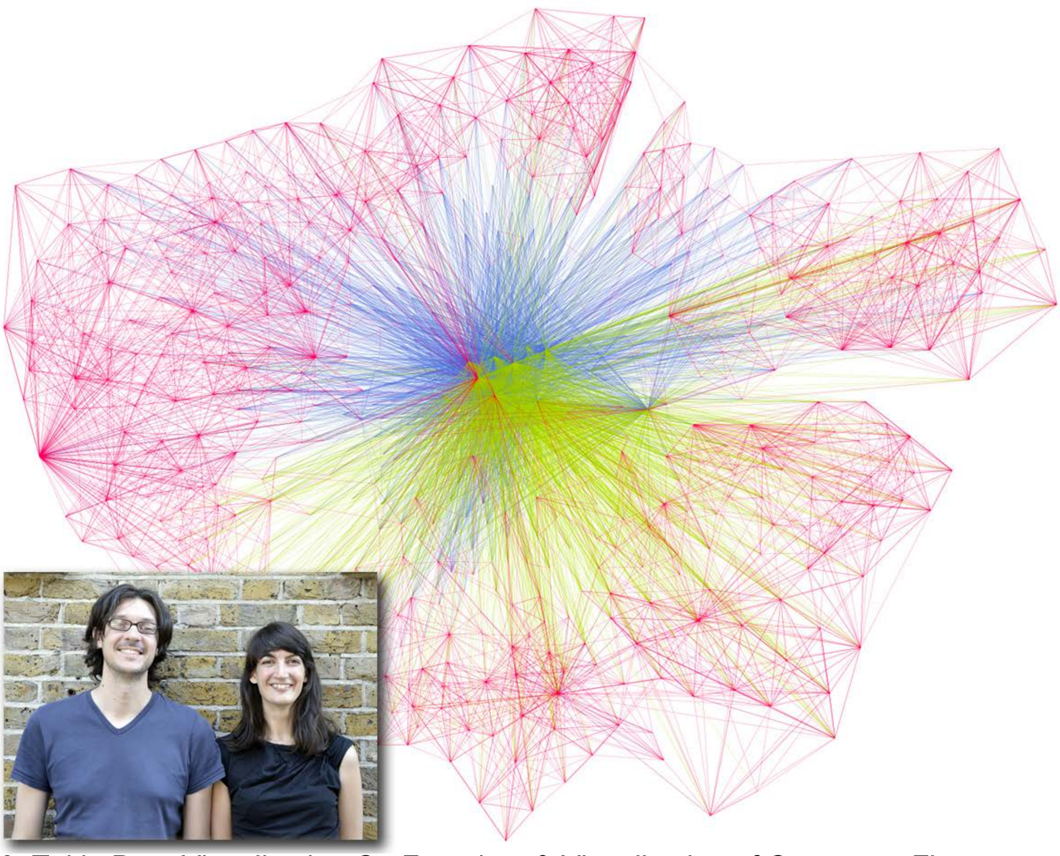


Figure 10. Tekja Data Visualisation Co-Founders & Visualisation of Commuter Flows
Sources: Jacopo Hirschstein and Amanda Taylor, Tekja Data Visualisation; London commuter map, Tekja Data Visualisation.

Not that this challenge can't be met and welcomed: while there is an obvious 'human flavour' to the examples I've used – they are the ones that I know best – in my work I regularly collaborate with physical geographers, theoretical physicists, computer scientists, transport engineers, data visualisation specialists, and sociologists amongst others. We regularly swap techniques and concepts that might be useful without much regard for disciplinary boundaries; it is what makes this field so exciting! But for completeness, and for a richer sense of how these techniques are being applied in physical geography, there are useful taster chapters in the new edition of *Key Methods in Geography* – in particular the chapters by Guth, Lane, Malanson & Heumann, and Millington – to round out the ideas presented here.

Geography is one of the only disciplines where diverse intellectual traditions are in regular, if sometimes contentious, contact. And geocomputation has the potential to be one of the main avenues for knowledge exchange between the hard sciences, the social sciences, and the humanities! Some students, and not a few parents, seem to think of geography as the 'safe' backup A-level: interesting and useful enough to continue to AS, but easy to drop once it's clear that the student is on track to master the 'hard' sciences. That view needs to change. It deserves to change. At the bleeding edge geography doesn't wear socks and sandals, it looks a lot like a tech start-up in Shoreditch or Hackney Wick (see '.

Figure 10) while remaining grounded in the discipline’s critical traditions. The future of geography may be cheap, but even so one thing will remain expensive: people with the broad-based knowledge, the specialist skills, and the passion to change it.

Acknowledgements

This work has benefited immensely from the time and generosity of colleagues and collaborators across the UK, many of who are referenced in the text. Special mention, however, should be made of the contribution made by Dr. James Millington: the ideas expressed above seek to capture our extensive and on-going discussions around the purpose, methods, and delivery of our undergraduate Geocomputation pathway at King’s College London. This piece could not have been written without his input, though any misrepresentations or omissions remains mine alone.

References

The British Academy (2012), *Society Counts*, URL: <http://www.britac.ac.uk/policy/Society_Counts.cfm>.

Harris, R. (2012), *A Short Introduction to Quantitative Geography*, Royal Geographical Society with IBG, URL: <https://www.rgs.org/NR/rdonlyres/46EB70CA-5508-4FB6-9629-ECD718CDCB83/0/AShortIntroductiontoQuantitativeGeography.pdf>.

Harris, R. and Fitzpatrick, K. and Souch, C. and Brunsdon, C. and Jarvis, C. and Keylock, C. and Orford, S. and Singleton, A. and Tate, N. (2013), *Quantitative Methods in Geography: Making the Connections between Schools, Universities and Employers*, Royal Geographical Society with IBG, URL: <https://www.researchgate.net/publication/256191493_Quantitative_Methods_in_Geography_Making_the_Connections_between_Schools_Universities_and_Employers>.

Raja, T. (2014), ‘Is coding the new literacy?’, *Mother Jones*, June 2014, URL: <http://m.motherjones.com/media/2014/06/ computer-science-programming-code-diversity-sexism-education>.

Singleton, A. (2014), “Learning to Code”, *Geographical Magazine*, January 2014, p.77.

Torrens, P.M. (2010), “Geography and computational social science”, *GeoJournal*, 75:133-148.