Ariadne's Thread:

A Letter to Descartes

by

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I hereby declare that I am the sole author of this thesis.

This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

As Galileo peered through a lens to see the twinkle of the Jovian moons, and Antonie Van Leeuwenhoek did the same to study the tremulous basis of all life, so the fabric of threads we weave across time and space – the vast net of relations that bind and separate us – is visible only through a lens.

Footprints in the snow and the weathered stone steps of buildings hint at the shape of these threads, but the coming of spring and the hardness of stone limit our observations. The Global Positioning System (GPS) now provides us a lens to see the path that individuals, families, and communities take in space-time -- their worldlines. When millions of GPS signatures are collected from hundreds of individuals, heritable patterns emerge that embody particular individual's ideas and practices, as well as those of the society and the environment in which they operate.

Besides providing a tool to test assumptions about how space is used, I argue in this thesis that by allowing us to glimpse a *terra incognita*, mapping worldlines also provides a unique perspective on our spatial relationship to one another.

It was an inspiration to have so many people to discuss ideas with, share doubts, ask questions, and speculate. My friends' contributions are throughout this work as they themselves are throughout the world, though special consideration must be given to my brother Alex Christou, Andrew Azzopardi, Mark Zupan, Renee Keuhnle, Anna-Joy Veenstra, Henry Murdock, Shamir Panchal, Saeran Vasanthakumar, and Matt Compeau who helped immensely in the formulation of this thesis. I would also like to thank my thesis supervisor, Associate Professor Donald McKay, and committee members O'Donovan Director and Associate Professor Rick Haldenby, and Associate Professor Anne Bordeleau for their guidance and wisdom over the course of my undergraduate and graduate studies at the School, Andrew Levitt for his insight and example, and Bud Walker for his indefatigable support and trust.

It is the role of the library and librarians to keep the knowledge gained at great cost and travail so future generations may build upon it. As we put more and more knowledge into the cloud we increasingly place ourselves at the mercy of things beyond our control – floods, coronal mass ejections, electromagnetic pulses, plagues, cyber warfare – and risk a great loss of knowledge. The info-terminal, the window into all knowledge, which Jean-François Lyotard so presciently foresaw, can just as easily be rendered a mirror. It is clear that the role of the librarian as a willful selector and preservator of knowledge has never been more important. Special acknowledgement must therefore go to the librarians of Musagetes Library in Cambridge, Ontario.

This thesis is dedicated to my family,
without whom nothing is possible.

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For the individual, the ‘single man’, as people and philosophers have hitherto understood him, is an error: he does not constitute a separate entity, an atom, a “link in the chain”, something merely inherited from the past – he constitutes the entire single line ‘man’ up to and including himself.

-Nietzsche, 1888.

Into the Abyss

For when I sey derknes, I mene a lackyng of knowyng; as alle that thing that thou knowest not, or elles that thou hast forgetyn, it is derk to thee, for thou seest it not with thi goostly ighe.

- Author Unkown, ~1400

April 21, 2776 AUC (2013 CE)

Dear René Descartes,

We have not yet met, or been introduced, and we live in different countries and eras, but I'd like to propose we go on a walk sometime soon. Where we start, end, or get to isn't that important.... Only thing is, I'd like to propose that we go at night, during a raging blizzard, in the coldest, darkest depths of winter. If it is a middling storm or merely a freezing cold winter night with no snow, then it won't be worth it, so we will have to schedule this provisionally. Don't worry about clothes or gear; I'll bring a goretex shell, a goose down liner, a fleece sweater, a merino wool undershirt, a pair of long-johns, winter pants, boots, two pairs of wool socks, two pairs of mitts, a balaclava, a toque, a scarf, and goggles for you.

At first, the frigid air will sting and bite. Our limbs will shiver and shake and feel like they are being crushed in vices. Our minds will come up with every excuse to turn back. If we pause, we will get hypothermia within minutes and die within the hour. Yet, bent double against the violent wind, crushing cold and white-out snow, we'll soon be warm from the sheer labour involved in moving forward. The cold will fall from our minds and bodies; through our exertion we will be like furnaces in the abyss. Between the violent squalls which envelop us, we will catch glimpses of a desolated, colourless terrain, walled in on all sides by crazed snow that knows no gravity and falls in all directions.

We will be the only two living things in this environment. Everyone and everything that has a heart and mind is warmly, safely ensconced in front of a crackling fire, drinking tea and brandy, under deep blankets. Most birds will be in Florida; most squirrels in their nest; most deer huddled beneath the pine boughs.

What leads us then, so knowingly into privation?

It takes a lot to see nothing. I would hazard that it is perhaps the most difficult thing in the world to go out and see not a single thing. Usually we are surrounded by something, some sign, some sound, some indication of life or the world at-large. We go out in the midst of this raging blizzard, in this deepest darkest coldest hour because it represents an exception. When all that is familiar to us is still we are faced with only the unfamiliar and the unintelligible. We are presented with a world insensate, without evidence of creation or actuality.

Everyone's instincts have instructed them to turn inwards in this inhospitable hour and find comfort in their homes, books, dreams, spouses. Yet it is in our nature, as Nietzsche says, 'to walk alone along a lonely street' and so we seek an understanding of that senseless and inhospitable exterior, the tumultuous maelstrom, which unites us all by its immanence and daunts us all by its immensity. We move through an occluded landscape, which might as well be the surface of the moon, so unfamiliar, monochromatic, lifeless.

If someone by chance peers out through their frosted window into our abyss, they will see nothing. We are hidden by the squall and the dark. We are, in a real way, invisible. No one will know that we passed. No trace will prove that we existed. Our footprints will be immediately wiped away by the wind and snow. We will move, perhaps for the only

time in our lives, without leaving a single sign, or indication that we ever were. We will be like ghosts or gods or god-knows-what, because we will travel pathlessly and without impression.

Those who come after us, in the morning – once the blizzard has subsided – will look on a pristine environment, blanketed in snow. The early risers and dog walkers will break trail. We will follow in their footsteps.

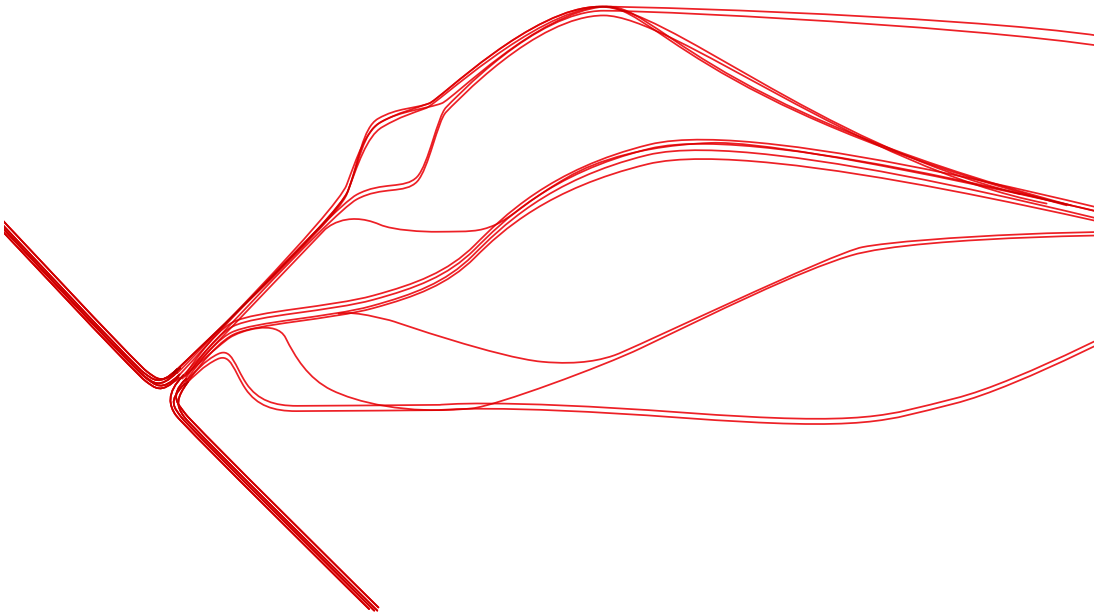
A Sign in the Plane

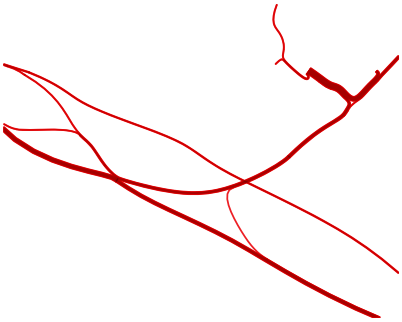
Those who have gone before have not preempted what can be said, rather they have shown us the way.

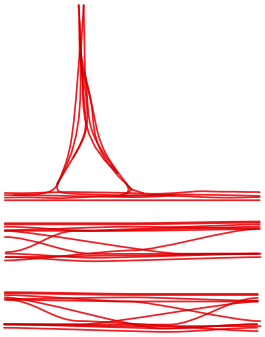
- Blaise Pascal, 1662.

Figure 1: Footprints in the Snow. Mississauga, Ontario. December 21, 2011.

Figure 2 (following): More Footprints in the Snow. Mississauga, Ontario. December 21, 2011.







> I stood like one Thunder-struck, or as if I had seen an Apparition; I listen'd, I look'd round me, I could hear nothing, nor see any Thing; I went up to a rising Ground to look farther; I went up the Shore and down the Shore, but it was all one, I could see no other Impression but that one, I went to it again to see if there were any more, and to observe if it might not be my Fancy; but there was no Room for that, for there was exactly the very Print of a Foot, Toes, Heel, and every Part of a Foot; how it came thither, I knew not, nor could in the least imagine. (Defoe. 1719)

Journal Entry from December 21, 2011:

> *Boot prints are visible as dark smudges in the snow covered field. I see where my neighbours feet have trodden, picked out against the white-blue snow. Four or five people's footsteps in this area form a sparse system of dark smudges. Footsteps are followed by others... a walking path is forming in the snow. Looking more closely, the shape of the footsteps are like a river's course. I see Tiber Island and Île de la Cité picked out in the snow... while some paths are spindly and narrow, where only one person has walked, others are wide, heavily trodden, a dozen people have walked this path.*

In the snow-covered field, a few hours since the blizzard subsided, a set of footprints is visible. The snow is deep and there is no "path" merely the discrete footprints from whoever it was that trekked across the field. With the dawning of day and the warmth of the sun, more people are out and the snow is packed down along the line of travel which was only a few hours ago a single set of footprints, and a few hours before that an empty field. Individual prints are still visible, although it has become harder to differentiate them amidst the mass. After a few days

Figure 3: Traces derived from connecting footprints in the snow. Mississauga, Ontario. December 2011.

the path is wide enough for two people to pass side-by-side. This one path participates in a hierarchal network of paths which show the routes that exist constantly across the landscape yet are invisible without the snows receptive surface.

Footprints in the snow, even though they will melt with the spring, are fossils – technically, ichnofossils – which show the behaviour of the owner of the feet. Taken together, footprints in the snow form a network of larger and smaller paths in which it is possible to determine the behaviour of a group of individuals. The American paleoanthropologist Mary Leakey, in looking at a series of 3.6 million year old hominid footprints in Tanzania known as the Laeotoli Footprints, concluded that these hominids,

> ... followed the same line or pathway but it is possible that they did not pass at the same time...at one point the smaller individual appears to have paused and made a half-turn to the left before continuing in a northerly direction.

From trace fossils and footprints we can tell a story about what happened in a specific place at a specific time, even though we were not there to witness what happened when it happened.

Figure 4: *A Dance to the Music of Time,* by Nicolas Poussin. 1636. For Giulio Rospigliosi the future Pope Clement IX. Now at the Wallace Collection, London.

"... stepping slowly, methodically sometimes a trifle awkwardly, in evolutions that take recognisable shape: or breaking into seemingly meaningless gyrations, while partners disappear only to reappear again, once more giving pattern to the spectacle: unable to control the melody, unable, perhaps, to control the steps of the dance." via Anthony Powell, in: *A Question of Upbringing. p2. 1951.*

A Line in the Plane

By Ariadne's aid was found, the thread that traced the way rewound.

- Ovid

The Labyrinth is home and prison to the Minotaur, the monstrous half human, half bull – dread product of the bestial union of King Minos' wife and the god Poseidon. Fourteen victims, children from the city of Athens, are sent into the labyrinth every seven years to die at the hands of the Minotaur in retribution for a crime committed against the king. On the third such payment, the hero Theseus takes the place of an Athenian youth, planning to slay the Minotaur and save the children. Ariadne, a priestess of the Labyrinth and a daughter of King Minos, falls in love with Theseus, and conspires to help him in his quest. At first she is completely lost, gripped by fear, immobile. She does not know how Theseus can escape the intractable maze or the Minotaur's violence. "I've killed bigger and scarier things, the Minotaur is no problem," Theseus says, laughing. But secretly, he is terrified that he will lose his way in the Labyrinth, starving in its dark winding ways as everyone who has gone before him. In desperation, and at the last possible moment, Ariadne goes to Daedalus, the architect who built the Labyrinth (as well as the device which allowed for the Minotaurs conception) and asks for its secret.

> Great Daedalus of Athens was the man
> That made the draught, and form'd the wondrous plan;
> Where rooms within themselves encircled lye,
> With various windings, to deceive the eye...
> Such was the work, so intricate the place,
> That scarce the workman all its turns cou'd trace;
> And Daedalus was puzzled how to find
> The secret ways of what himself design'd. (Ovid)

> ...and yet Daedalus himself, pitying the noble princess Ariadne's love, unravelled the deceptive tangle of corridors, guiding Theseus's blind footsteps with the clue of thread. (Homer)

> Theseus fastened it to the door, and, drawing it after him, entered in. And having found the Minotaur in the last part of the labyrinth, he killed him by smiting him with his fists; and drawing the clue after him made his way out again. (Apollodorus)

Successful in his quest, Theseus escapes from Crete with Ariadne. Soon after, a god snatches Ariadne away from Theseus who returns home dejected and bemused by the caprice of the gods. Daedalus, meanwhile, to avoid the vengeance of King Minos, flees from the island with his son Icarus upon waxen wings.

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Worldlines and Spacetime

The path that an object takes through space-time was outlined in a geometric way by the Austrian physicist and mathematician Hermann Minkowski, a professor of the young Albert Einstein, in a speech he gave in 1908 to natural philosophers:

> Let x, y, z be the rectangular coordinates of space, and t denote the time. Subjects of our perception are always places and times connected. No one has observed a place except at a particular time, or has observed a time except at a particular place. Yet I still respect the dogma that time and space have independent existences each. I will call a space-point at a time-point, i.e., a system of values x, y,

> z, t, as a world-point. The manifold of all possible value systems of x, y, z, t, shall be denoted as the world.... We direct our attention to the substantial point located at world-point x, y, z, t, and suppose that we are in a position to recognize this substantial point at any other time. Let dt be the time element corresponding to the changes dx, dy, dz of space coordinates of this substantial point. Then we obtain (as a picture, so to speak, of the perennial life-career of the substantial point), a curve in the world, the world-line, whose points can unambiguously be connected to the parameter 't' from positive to negative infinity. The whole world appears to be resolved in such world-lines, and I may just anticipate, that according to my opinion the physical laws would find their most perfect expression as mutual relations among these world-lines.

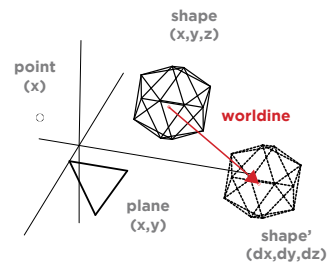

Figure 5: Diagram illustrating geometric space in which worldlines occur.

About the time of Minkowski's speech, the British physicist Alfred A. Robb, in his book *A Theory of Space and Time* (1914), elaborates a four-dimensional geometry (see Figure 5) and points out how the elements of time follow an ordered progression:

> The system of geometry thus built up will ultimately assume a sort of four dimensional character, or rather, we should say, any element of it is determined by four coordinates... It thus appears that the theory of space becomes absorbed in the theory of time, spacial [sic] relations being regarded as the manifestation of the fact that the elements of time form a system in conical order: a conception which may be analysed in terms of the relations of after and before.

By applying this four-dimensional geometric formulation to the paths of individuals, i.e., their 'worldlines', we can visualize people over four dimensions. As numbers can be viewed on a complex plane,

so individuals can be viewed in the three perceivable dimensions of space, which we call length, height, and width, but also in the fourth, time. By using a lens composed from a set of tools which include 24 geostationary satellites orbiting 20,000km above the surface of the earth, atomic clocks, and computers, we are afforded a vantage point into a previously occluded terrain, a *terra incognita*, which exists, and has existed forever, around us: the paths of individuals, their worldlines.

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GPS

The Global Positioning System (GPS) is a method of locating points via latitude, longitude, altitude, and time (x,y,z,t) implemented 19 years ago by the US Department of Defense. It consists of a network of 24 geostationary satellites, each of which beams a unique radio signal towards earth containing an identification code and a time stamp indicating when the radiowave was emitted. Radiowaves from the GPS satellites fill the air around us: those with a GPS receiver can hear them and use these to locate themselves. For every satellite that a GPS receiver (a device containing an antenna, battery, memory, clock, and microprocessor) hears, it draws an imaginary sphere. The center of each sphere is the location of the satellite in orbit around the earth (based of the name of the satellites encoded in the radiowaves), and the radius of which is the time difference between the receivers clock and the timestamp in the radiowave multiplied by the speed of light (299,792,458 m/s). From four or more satellites the receiver calculates its location as the intersection of the imaginary sphere's surfaces (see Figure 6). This location is stored in the memory of the GPS Receiver as a data entry recording the time, latitude, longitude, and altitude of

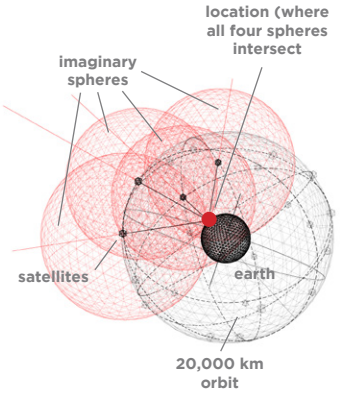

Figure 6: Diagram illustrating how Global Positioning System (GPS) works.

the event (similar to a single footprint in the snow, which also may be said to have these coordinates). The accuracy of the location can be in the range of one to five metres or more depending on the environment in which the receiver is located, the number of satellites being 'heard', and the accuracy of the receiver's clock.

The possibilities that GPS brings to mapping worldlines is illustrated in a study conducted by the French sociologist Paul Henry Chombart de Lauwe, in *Paris: essais de sociologie* (1952-1964). In this study a university student tracked her location in the city of Paris for a year, recording the shape of her worldline. What emerges is a structure that stretches across the city of Paris. The method available to de Lauwe to record worldlines was the same method available to researchers for all of human history. He instructed the student to mark down in a notebook where she went. If the student forgot or for some reason was prevented from logging her location, then there would be no record for that time. Further, for a fine-grain resolution record she would need to record her route at frequent intervals, the execution of which would soon impede on her life. In *On Exactitude in Science* (1946), Jorge Luis Borges, describes this situation by analogy when a map grows to the size of the terrain it represents:

> ... In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that vast Map was Useless, and

not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.

The degree of interference caused by the students meticulous recording of her own path would heavily limit the student actually taking her path. Therefore, in the past only a low-grain resolution of worldlines was possible (see Figure 7) without limiting the person and receiving a skewed map. However, it is not only accuracy that was denied to previous researchers: it was also the quantity of data and the scope of such data. If de Lauwe wished to map the paths of more than just one student, the time spent organizing and correlating the data in order to produce the map would increase by many factors, quickly making the endeavour impossible.

With the advent of small, portable GPS receivers it is possible to record an individual's worldlines simply, with high accuracy, and minimal disturbance of the participant's life. The frequency and ease with which millions of GPS points can now be logged from hundreds of people simultaneously means that there is also a need for an efficient method for organizing and mapping this data (or else we run into the same hurdles that de Lauwe faced).

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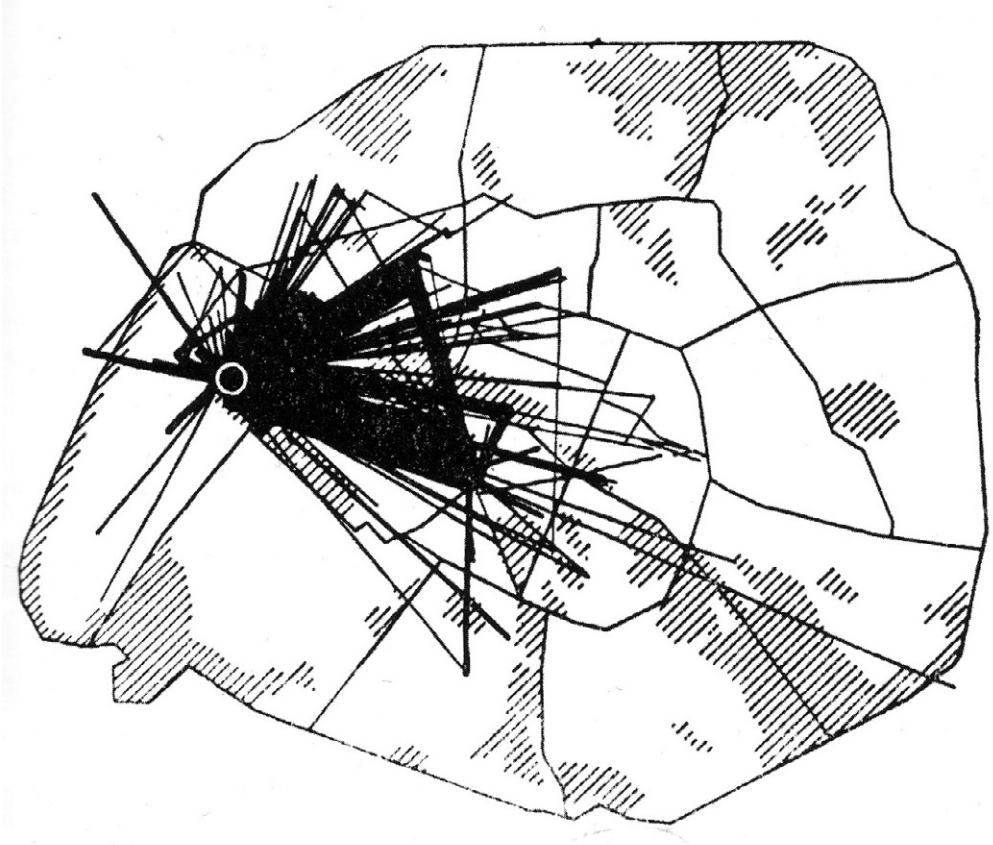
Computer Language

The emergence, in the last decades, of personal computers and computer languages has enabled us to deal with large, complicated data sets, by organizing and manipulating them with computational algorithms. Benjamin Fry, an American designer, highlights the power

Figure 7: Map from Paul Henry Chombart de Lauwe, in *Paris: essais de sociologie, 1952-1964*

The map showing the places that a young student went in Paris.

Historically, it was difficult to map the four dimensional shape of an individual or society, however due to the technological innovations, such as GPS and smartphones, of the last decade this has changed. For instance, in April 2013 researchers at the University of California, San Francisco launched a decade long study named Health eHeart, which will have over 1,000,000 participants



of this approach in his dissertation, *Computational Information Design* (2000):

> For instance, a color change can be automatically applied to the thousands of elements that require it, rather than requiring the designer to painstakingly make such a tedious modification. This is the strength of a computational approach, where tedious processes are minimized through automation.

By organizing and mapping the millions of GPS data points, a computer program allows us to sort, scale, plot, and analyze the GPS data single-handedly and in a relatively short amount of time. Combining this with the accuracy and simplicity of GPS, it is now possible to map in fine resolution the worldlines of many individuals over the course of many millions of instants of time. With these tools we can create a lens to see the causal structures which were previously beyond our sight. Footprints in the snow only hint at the scope, scale, and beauty of these structures.

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Figure 8: My paths in a park in Applewood Acres, Mississauga, Ontario, Canada, from GPS data collected December 26, 2011 to February 13, 2012.

Over the almost two decades I have lived near this park I have walked its paths and fields thousands of times. Most of the content of this letter had its birth in the night time meanderings I made in this park.

Figure 9 (following): My paths in a park in Applewood Acres, Mississauga, Ontario, Canada.

Meaningful Aggregations

Thus, if later people begin at the point that their predecessors had reached and thereby join together the lives and labours of many, we would make much more progress together than each person could ever make on their own.

- Descartes,1637

Thought experiment:

> *Walking through the door of my office, I sit at my desk. Turning around, looking back, imagining the route I traced from the door across the room. If I imagine this route as a thread, it makes an "L" shape on the floor... this is a small segment of my worldine. If I keep imagining farther back, it snakes out of the office into the hallway I have passed 75,000 times, down the foyer, past the doors, and into the snow-covered field. Considering my family's worldlines, I see a series of labyrinthine structures traced out across the city. The worldlines pulse and seethe, changing hour-to-hour, day-to-day, year-by-year, as the family goes about moves in it's rhythms... in the morning and evening, after classes or work... the home is a complex orchestration of paths. A family uses many rooms throughout the week, throughout the day: a network of routes and flows.*

Over the course of two years, in Rome, Mississauga, and Waterloo, I worked with 374 volunteers to collect over 2,500,000 GPS data points. What emerges shows that our worldlines are informed by a combination of laws, property divisions, cultural practices, infrastructure, as well as our own particular ideas and beliefs. The maps reveal that we are in a particular space at a particular time because of the decisions we make, as well as decisions we do not make and cannot control, such as the place, time, and culture into which we are born.

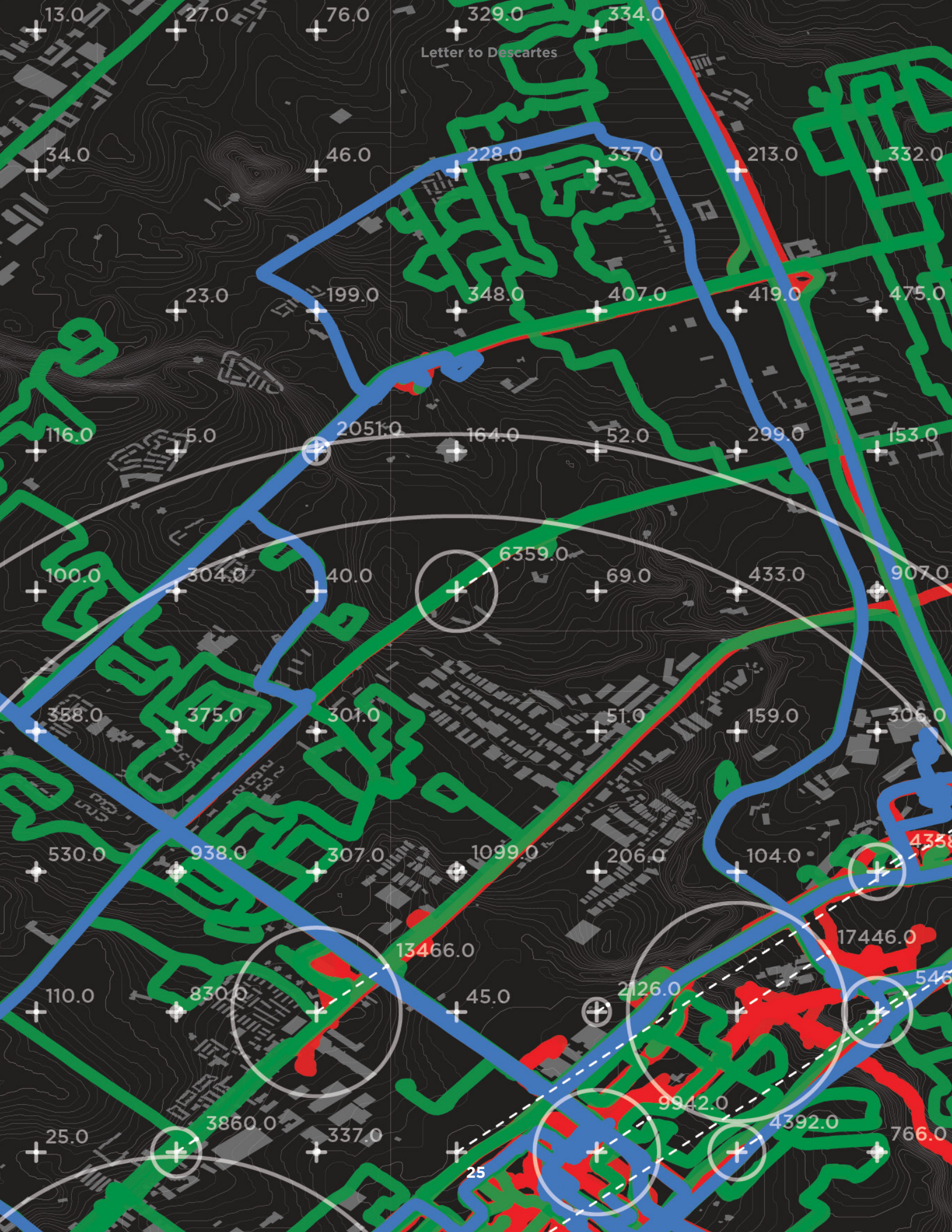
In the worldlines of a family in Mississauga, a group of students in Rome, 367 students at the University of Waterloo, and in four Catholic liturgies, we see how, in various places and contexts, people appear in spacetime. Similarities emerge in the shape of the worldlines of individuals, along with differences that trace the history of their decisions, beliefs, and motivations.

Figure 10 (right): Detail of a map of the GPS data collected from three family members in Mississauga and Toronto.

Mississauga is a relatively new city with 713,443 people. It is composed of the amalgamation of smaller villages and farms which began to from in the middle of the 19th century. It is now Canada's sixth largest city.

Figure 11 (following): Map of Southern Ontario with GPS data collected from three family members in Mississauga and Toronto.

Figure 12 (next following): Map of the GPS data collected from three family members in Mississauga and Toronto.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-80°
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Mississauga
Cambridge
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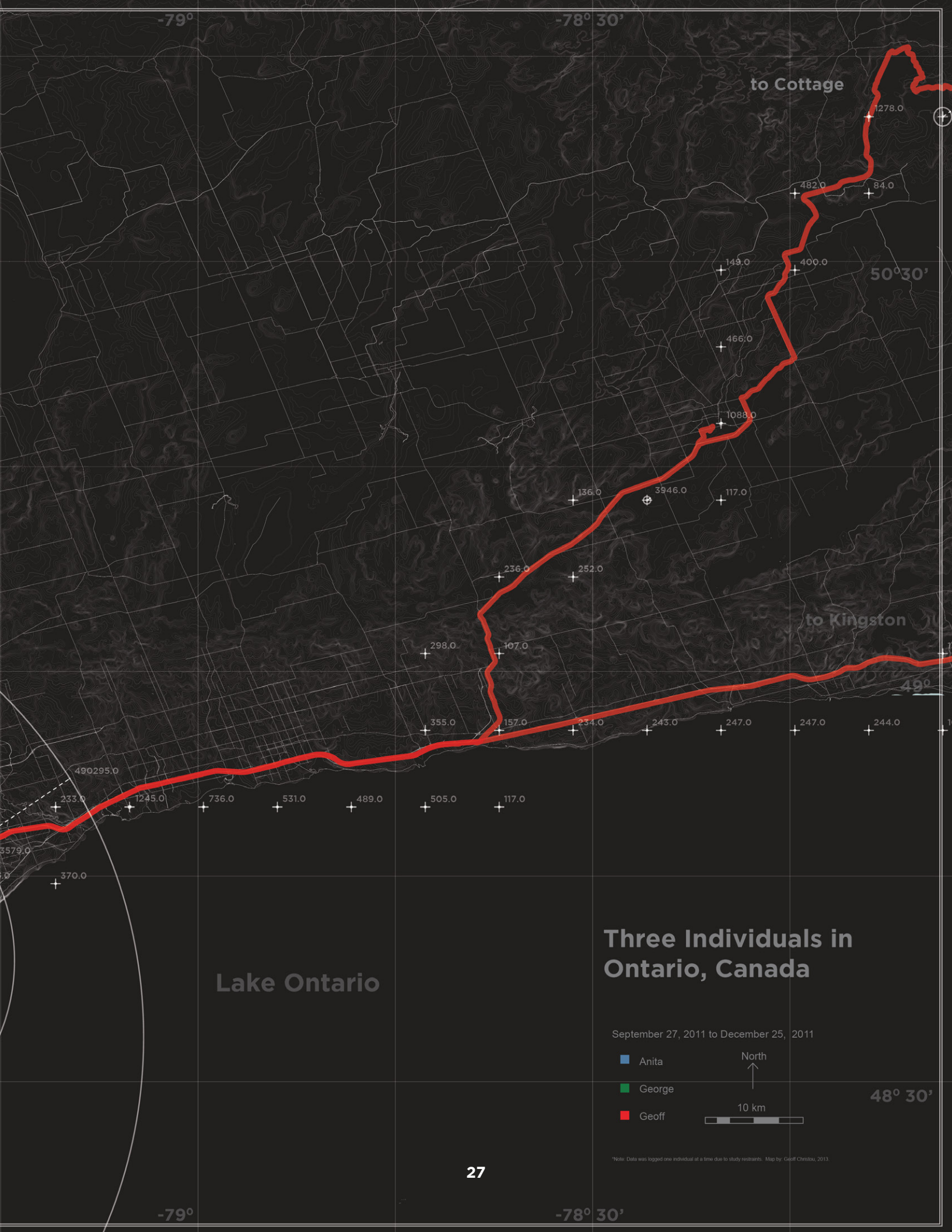
-79° 30'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to Kingston
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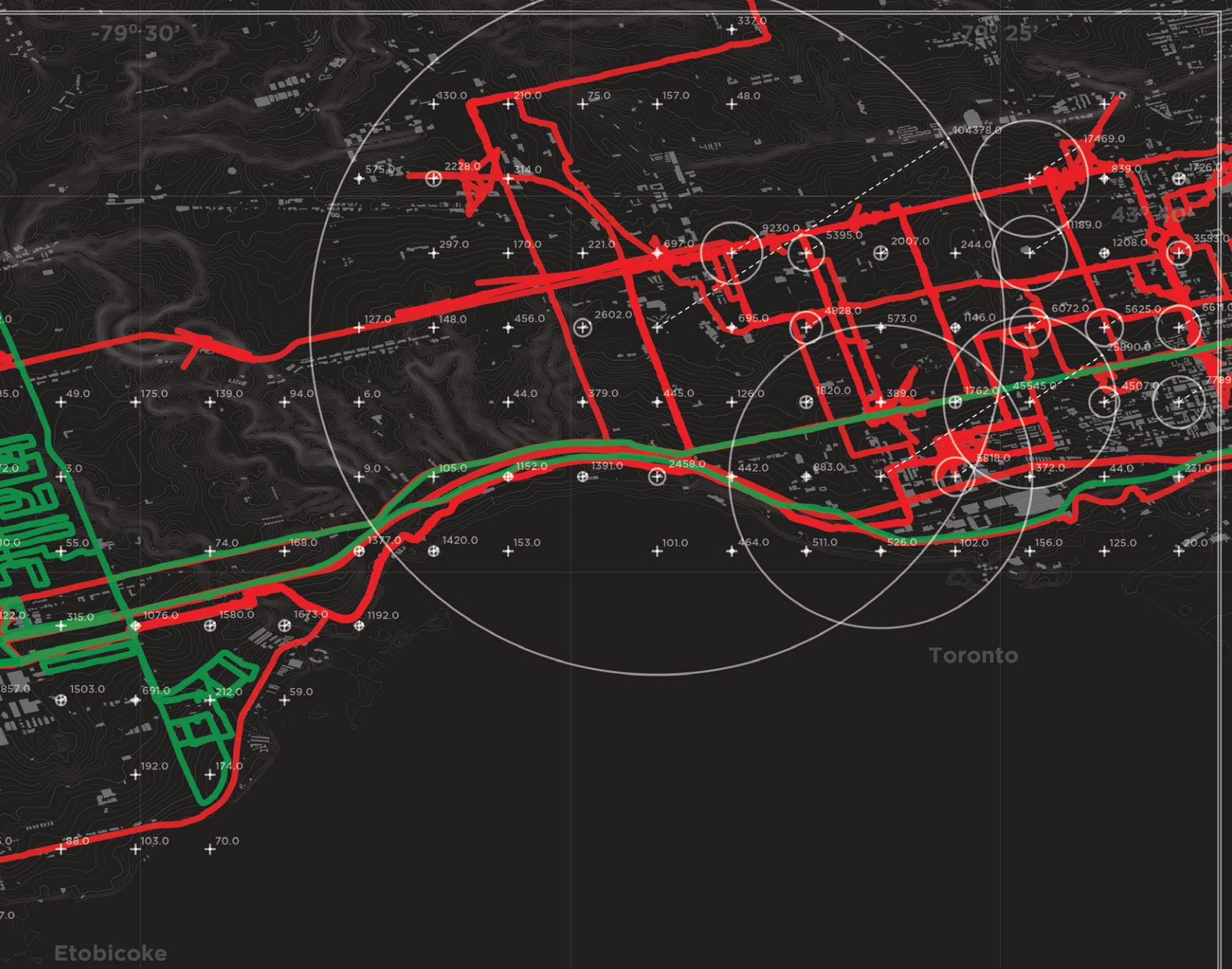
490295.0
233.0
1245.0
736.0
531.0
489.0
505.0
117.0
3579.0
370.0
Lake Ontario
Three Individuals in Ontario, Canada
September 27, 2011 to December 25, 2011
Anita
George
Geoff
North
10 km
48° 30'
*Note: Data was logged one individual at a time due to study restraints. Map by: Geoff Christou, 2013.
-79°
-78° 30'


43° 40'
43° 35'
-79° 35'
Mississauga



Three Individuals in Mississauga and Toronto, Canada

September 27, 2011 to December 25, 2011

Anita

George

Geoff

North

1km

*Note: Data was logged one individual at a time due to study restraints. Map by: Geoff Christou, 2013.


Esquiline
Colliseum
Palatine Hill
Circus Maximus
Caelian
Hill
Hill

A taxonomist such as Carl Linnaeus or George Cuviers, looks at the morphological relations between organisms – the stamens and pistils of plants, the variations between fossils and bones – and so, similarly, relationships between different individuals can be traced in spacetime through the morphology of their worldline. What we see is that as progeny are to parents, so our way of movement is the product of past ways of movement. The worldline shows a process of incremental iteration on the methods of our ancestors. Herbert Spencer, the English philosopher and scientist, in his *Principles of Sociology* (1897) highlights how the algorithms for movement – the rule set for how to get from A to B – are not only passed down, but also built upon:

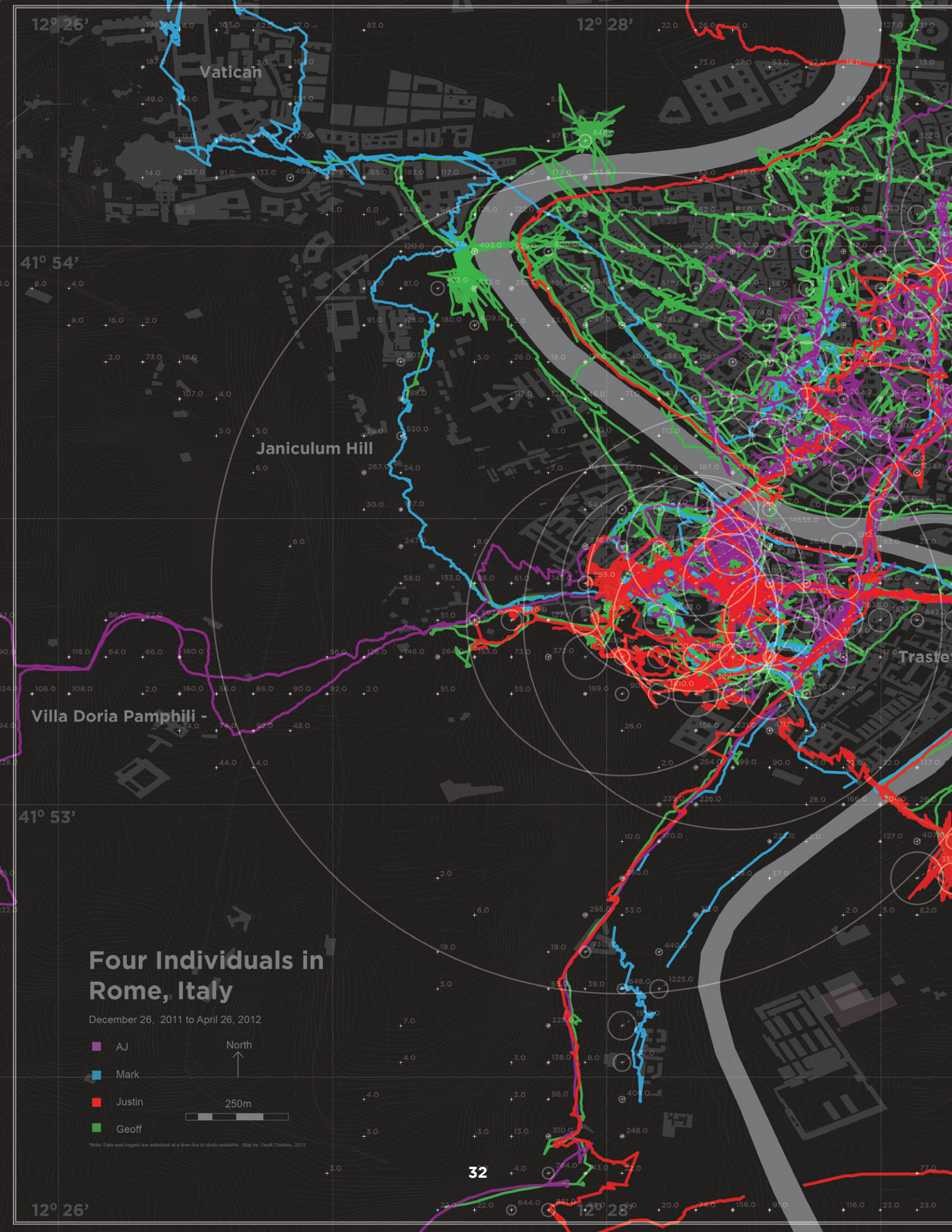
> The fabric of living persons which, in a manufacturing town, produces some commodity for national use, remains after a century as large a fabric, though all the masters and workers who a century ago composed it have long since disappeared... Governing bodies, general and local, ecclesiastical corporations, armies, institutions of all orders down to guilds, clubs, philanthropic associations, etc., show us a continuity of life exceeding that of the persons constituting them. (Spencer)

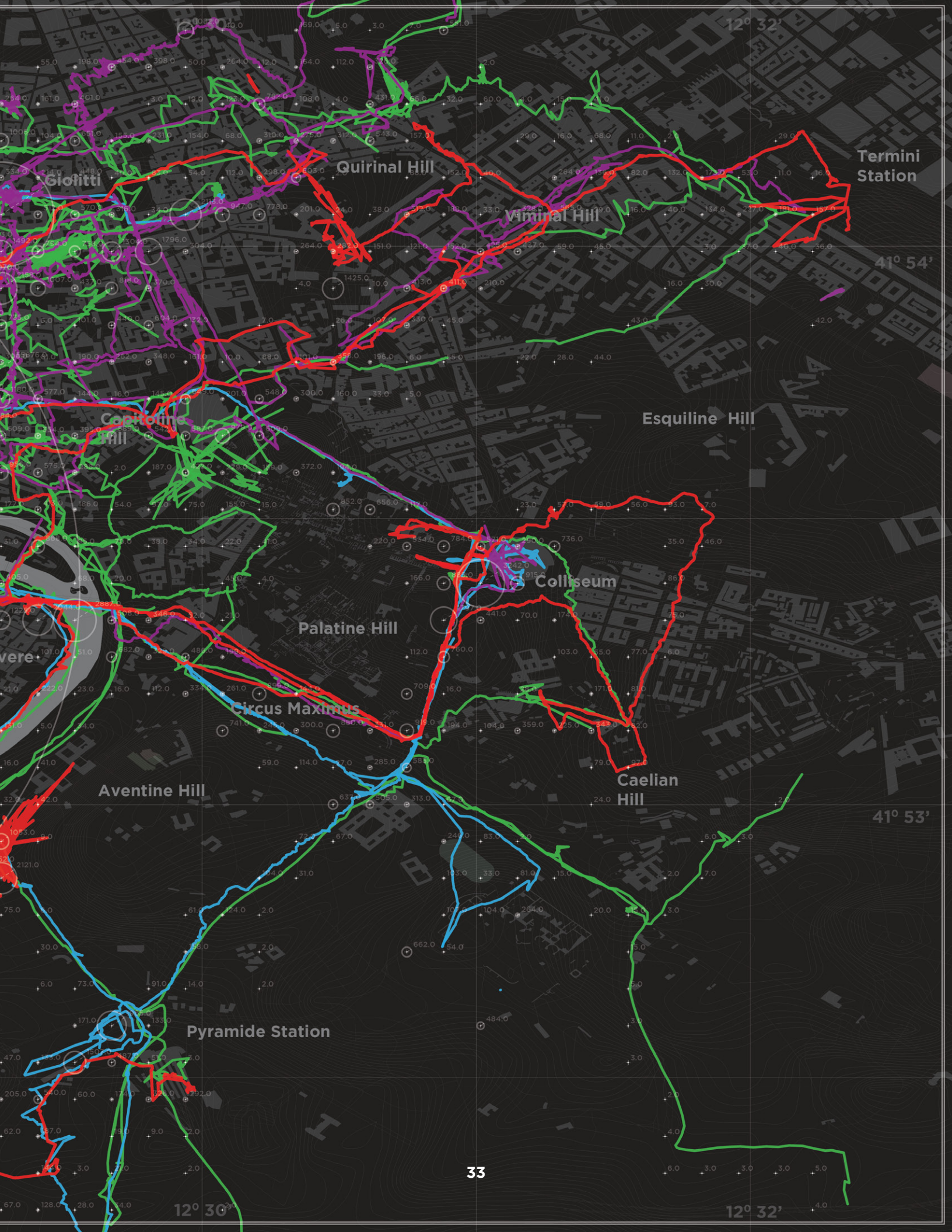
The worldline of each individual embodies the algorithms for various ways of movement. These algorithms undergo a process of selection in which the fit are selected and the unfit are discarded. Through trial and learning, individuals adopt the algorithms which are best suited to their ends.

> Cultural evolution consists of changes in behaviour based not on changes in gene frequencies, but on learning. It may be either vertical

Figure 13 (left): Detail of a map of the GPS data collected from four students in the city of Rome.

Figure 14 (following): Map of the GPS data collected from four students in the city of Rome.


12° 26'
12° 28'
Vatican
41° 54'
Janiculum Hill
Villa Doria Pamphili -
41° 53'
Traste
Four Individuals in Rome, Italy
December 26, 2011 to April 26, 2012
AJ
Mark
Justin
Geoff
North
250m
*Note: Data was logged one individual at a time due to study restraints. Map by: Geoff Christou, 2013.


12° 30'
12° 32'
Giolitti
Quirinal Hill
Termini Station
Viminal Hill
41° 54'
Capitoline Hill
Esquiline Hill
Colosseum
Palatine Hill
Circus Maximus
Caelian Hill
Aventine Hill
41° 53'
Pyramide Station
12° 30'
12° 32'

> (transmission from older to younger generations) or horizontal (as when we imitate the practices of our peers). (Futuyuma)

The result of the process of cultural evolution is a localization of certain practices in space and time. This is what is known as "homophily".

> Homophily is the principle that a contact between similar people occurs at a higher rate than among dissimilar people. The pervasive fact of homophily means that cultural, behavioral, genetic, or material information that flows through networks will tend to be localized. Homophily implies that distance in terms of social characteristics translates into network distance, the number of relationships through which a piece of information must travel to connect two individuals. It also implies that any social entity that depends to a substantial degree on networks for its transmission will tend to be localized in social space and will obey certain fundamental dynamics as it interacts with other social entities in an ecology of social forms. (McPherson)

These social forms have a corporeal manifestation – as Herbert Spencer, aptly called them a "fabric" – in the form of worldlines, the variation of which is due to both internal and external forces.

We act out our ideas, beliefs, and ambitions within a physical world, and move in the material framework established by buildings, cities, roads. The ideas and assumptions which have governed the deposition of matter (architecture, infrastructure) are unique to the culture, place, and time. The shared interpretation of a space by many people (as codified in the laws and traditions) over a long period of time, results in the delimiting of that space in a manner reflective of

Figure 15: Detail of a map of the GPS data collected from four students in the city of Rome.

Figure 16 (following): Detail of a map of the GPS data collected from four students in the province of Lazio, Italy.


Capitol
Hill
Trastevere


12° 15'
12° 30'
42°
Cesano
(Failed trip to Viterbo)
2287.0
4781.0
50.0
364.0
144.0
282.0
141.0
486.0
45.0
551.0
678.0
15.0
12.0
14.0
203.0
55.0
1129.0
5633.
10563.0
202.0
998.0
5443.0
869
40.0
371.0
497.0
119.0
Fiumcinio
International
Airport
41° 45'
2.0
152.0
266.0
372.0
180.0
162.0
303.0
113.0
9.0
18.0
2.0
6514.0
396.0
350.0
44.0
20.0
44.0
53.0
38.0
47.0
33.0
32.0
Ostia Antica
4.0
377.0
3911.0
2.0
26.0
12.0
Mediterranean Sea
12° 15'
12° 30'

Four Individuals in Lazio, Italy

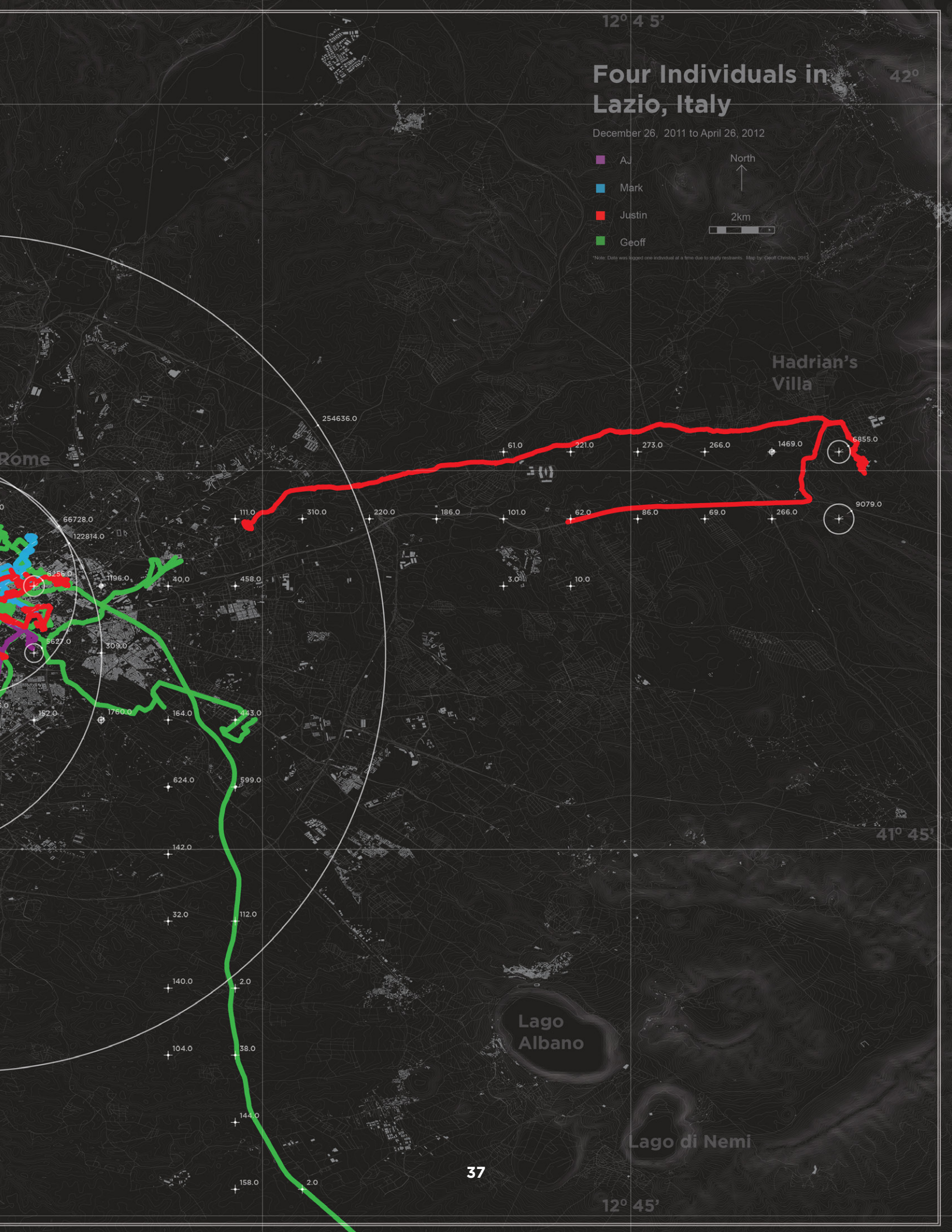
December 26, 2011 to April 26, 2012

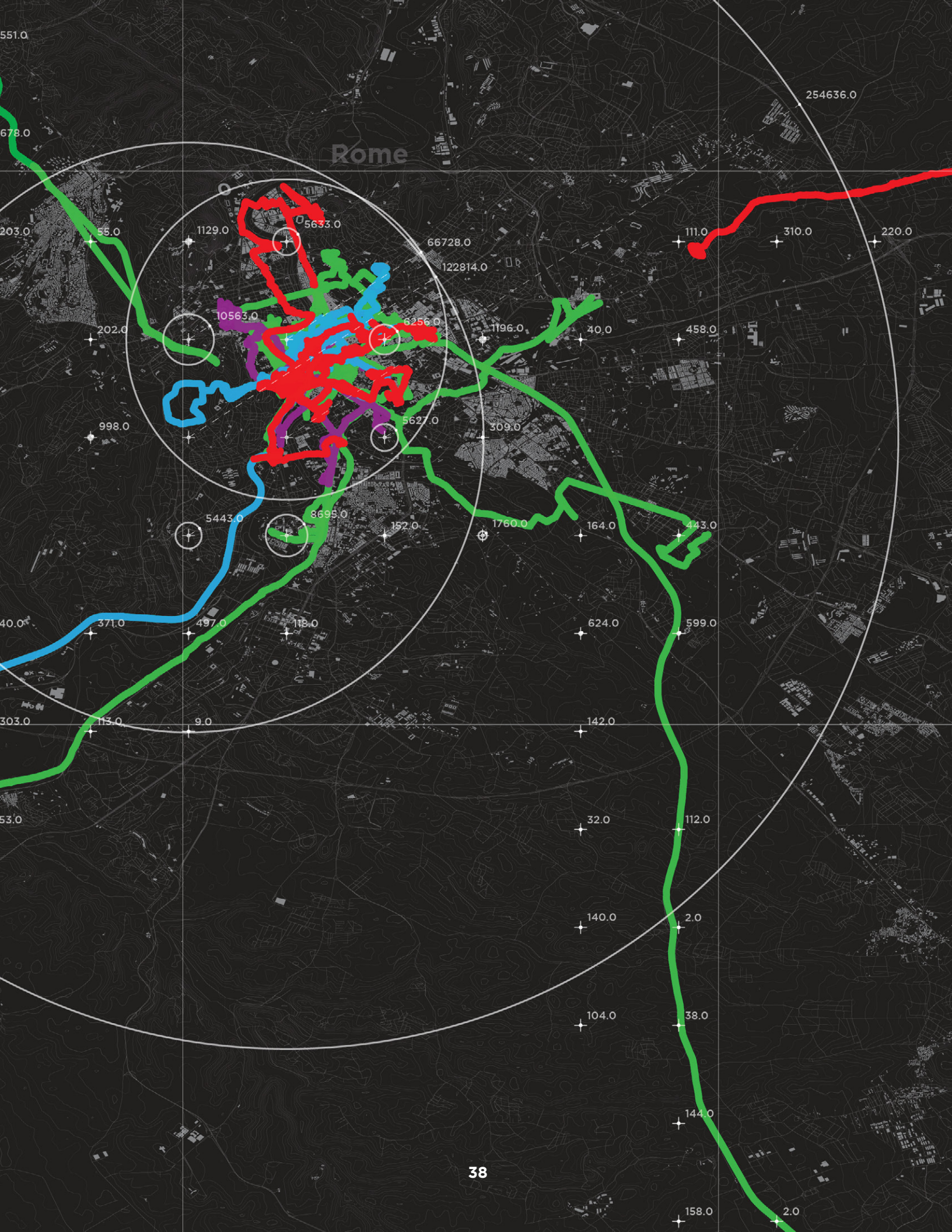
AJ
Mark
Justin
Geoff

North

2km

*Note: Data was logged one individual at a time due to study restraints. Map by: Geoff Christou, 2013




Rome
551.0
678.0
203.0
55.0
1129.0
5633.0
66728.0
122814.0
254636.0
111.0
310.0
220.0
10563.0
202.0
6256.0
1196.0
40.0
458.0
998.0
5627.0
309.0
5443.0
8695.0
152.0
1760.0
164.0
443.0
40.0
371.0
497.0
118.0
624.0
599.0
303.0
113.0
9.0
142.0
53.0
32.0
112.0
140.0
2.0
104.0
38.0
144.0
158.0
2.0

the differential success of these interpretations within a particular environment. When a community, city, or species has existed for a long period of time in the same environment with little external interference, then these algorithms can reach a state of equilibrium that may persist for millennia without variation in what is called an "evolutionary stable strategy". When a 'foreign' set of algorithms enters a place which has equilibrium a process of selection will occur between the sets of algorithms. This will change both of the algorithms as well as the physical environment (architecture, infrastructure). Le Corbusier, the French architect, in *The Radiant City* (1935), points out that changes in the form of dwellings represent significant alterations in the ideas of a culture and their interpretation about how space ought to be occupied:

> The dwelling takes a long time to change its form, modify its principle. When the dwelling changes, that means new customs hold sway... The dwelling changes only at the last moment, almost without the consent of the inhabitant, against the will of the passive forces of preservation.

Whether the environment through which we move has been laid down in a single action, or evolved over millennia, the path we take in it is determined largely by the arrangement of streets and buildings: the hard, heavy objects in our way and around which we must flow (unless we are willing or able to move through them).

From the GPS data it becomes clear that individuals' worldlines are fractaline. Examples of fractals in nature include trees, mountains, clouds, snowflakes, and lightning bolts (see Benoit Mandelbrot's *Fractal Geometry of Nature* for an extensive elaboration of fractals). What unites all the disparate shapes of our worldlines, and makes them

Figure 17: Detail of a map of the GPS data collected from four students in the Province of Lazio, Italy. Rome is in the centre of the detail.

fractals, is that they display the property of self-similarity. A fractal from close or far will appear the same. The worldlines of individuals are fractals because they display the property of self-similarity. Whether 'zoomed in' on a particular neighbourhood, or 'zoomed out' at the scale of a province, at every scale an arborescent structure of bifurcations emerges. Just as trees of different species are fractals, yet the morphology of each varies (compare a deciduous tree to a coniferous tree) so the worldlines in Rome, Mississauga, or Waterloo are fractals even though there is variation in form. In Rome they are curving and sinuous and there are many crossings in the busy piazzas and narrow streets which embody the ideas of the public, social life of the place. In the city of Mississauga they have a space-filling shape reflective of the way of life of the inhabitants who rely on the car, and live private, well-ordered lives with few crossings. In Waterloo, where we witness the students worldlines only while they are on campus, the dynamism and freedom of the students on campus results in a very diffuse shape.

Whether they are in Rome, Mississauga, or Waterloo, each worldline also has a hierarchy of nodes – places where each individual returns or spends more time. For instance, the students in Rome all attended the same school, which we see in their worldlines as a common node. Three of the students lived together, therefore they share the 'school' and 'home' nodes as well as the finite numbers of paths that they could take in getting from one to the other. Because they lived, studied, and walked the same streets and piazzas as each other, the students have, in general, very similar worldlines. It is only as we move farther from the common nodes, into the particularities of each individuals, that distinctions appear.

***

uWaterloo Masterplan

Working with members from the University of Waterloo's Student Success Office, Secretariat, Office of Research Ethics, Office of the Provost of Student and Info Systems and Technology, I developed and deployed a custom-built mobile application for iOS and Android that allowed students to record their faculty, expected year of graduation, favourite colour, and a contact, and would run silently in the background of their smartphones, logging their location via GPS while they were on campus. Working closely with the Student Success Office, and using social media, 367 students participated (surpassing our goal of 300, or 1% of the 30,000 students of the school) and logging over 380,000 GPS points.

The data collected on the students' worldlines shows that the primary orientation of pedestrian traffic on campus is east-west, and that there are currently two major arteries. This east-west connection demonstrates the importance of the city of Kitchener-Waterloo in the lives of students, more so than is currently acknowledged in the 2009 uWaterloo masterplan. This is not the only discrepancy between the information revealed by the worldlines and the proposals in the masterplan; indeed the data demonstrates that the "first key move" of the masterplan requires revisiting. The masterplan proposes the construction of a north-south pedestrian circulation spine through campus:

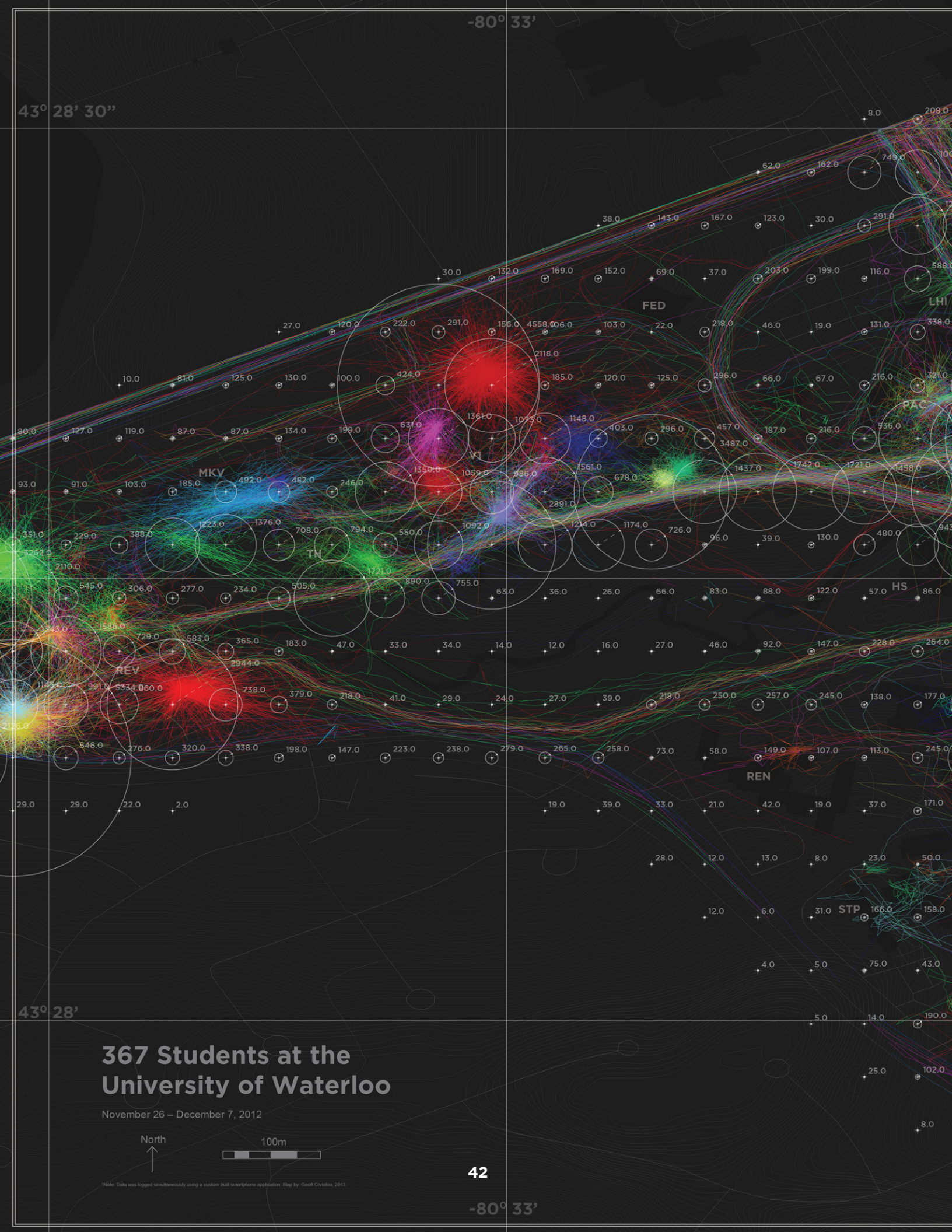
An interactive map, built for students, faculty, and staff to be able to access the findings, can be found at **uwaterloo.ca/sso/map**

> The primary element of the pedestrian network is a central circulation spine. The spine is proposed as a "main street" along which services and amenities will be focused (2009 uWaterloo Masterplan).

The main pedestrian arteries are revealed by the worldlines to run in an east-west orientation for every faculty but Applied Health Sciences (which uses the campus in a unique north-south orientation). It

Figure 18 (following): Map of 367 Students at the University of Waterloo.

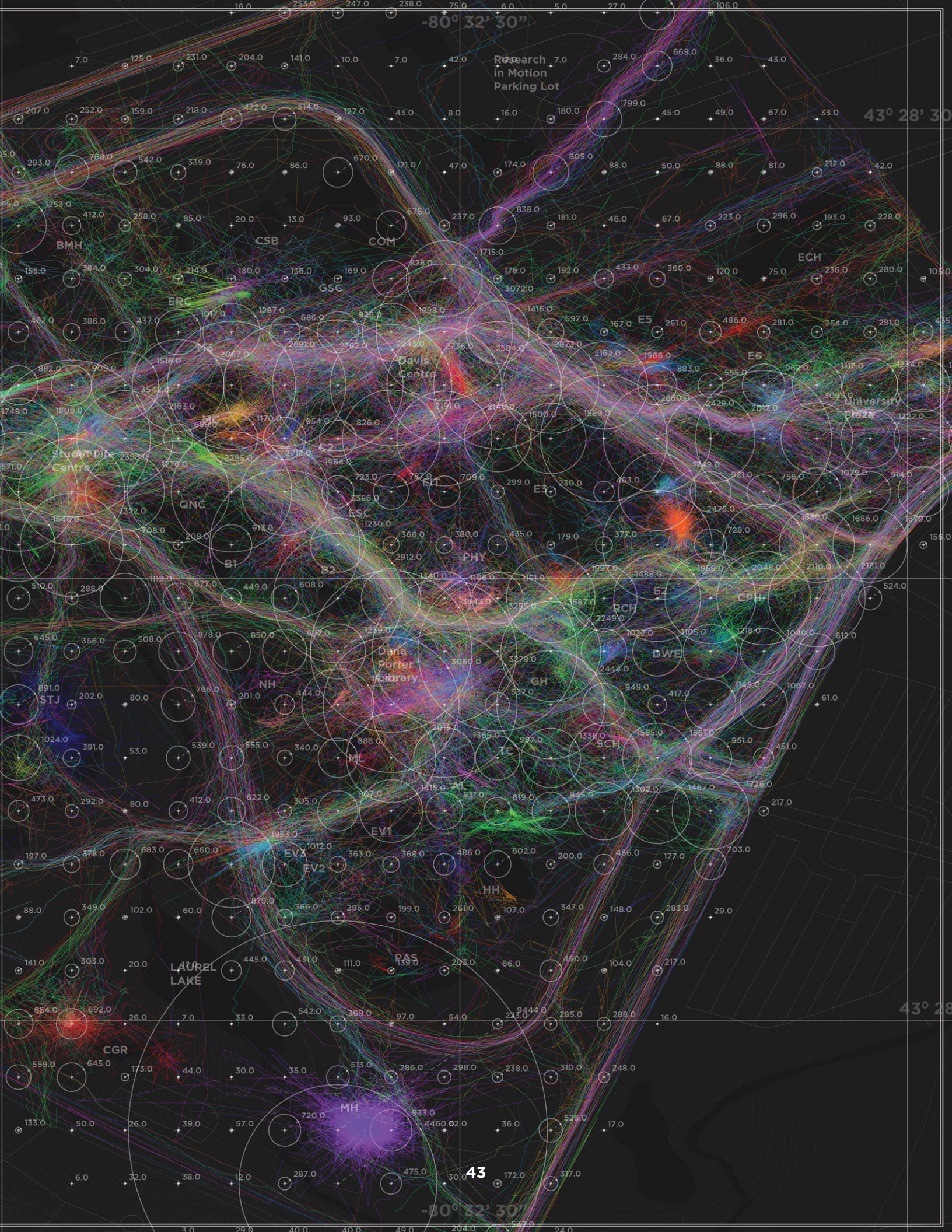
Figure 19 (next following): Detail of Map of 367 Students at the University of Waterloo.



367 Students at the University of Waterloo

November 26 – December 7, 2012

*Note: Data was logged simultaneously using a custom built smartphone application. Map by: Geoff Christou, 2013.


-80° 32' 30"
Research in Motion Parking Lot
43° 28' 30
BMH
CSB
COM
ECH
GSC
ERC
E5
E6
Davis Centre
University Plaza
Stuart Pike Centre
QNC
ESC
E3
PHY
B1
B2
E2
RCH
CPH
DWE
Dana Porter Library
NH
GH
STJ
SCH
EV1
EV3
EV2
HH
LAUREL LAKE
CGR
MH
43° 28
-80° 32' 30"


CSB
COM
GSC
Davis
Centre
E2
E1
E3
ESC
PHY
E2


46.0
67.0
223.0
296.0
193.0
228.0
ECH
433.0
360.0
120.0
75.0
236.0
280.0
E5
167.0
251.0
486.0
281.0
254.0
281.0
2162.0
1966.0
E6
883.0
555.0
962.0
1112.0
2860.0
2428.0
2012.0
3065.0
1389.0
1749.0
921.0
756.0
1079.0
463.0
2475.0
1836.0
1686.0
728.0
377.0
1997.0
1959.0
2048.0
2110.0
2181.0
1488.0
E2
524.

would therefore be more appropriate to develop the 'main pedestrian artery' along the east-west axis of campus. Deploying resources along this axis would leverage extant pedestrian flows and address the university's connection to the city. If the university were to continue focusing resources and capital on the north-south spine this would be a misallocation of millions of dollars.

Another discrepancy between the masterplan and the reality of how students use campus, is that what is called the Transit Gateway in the masterplan is actually one of the most significant connections between the university and the city. This space currently is among the poorest, ugliest, and least pedestrian friendly on campus (see photos at left) and is almost completely ignored by the masterplan. Any investment in this area will improve the quality of students experience and directly address an area completely overlooked by both the masterplan and the university.

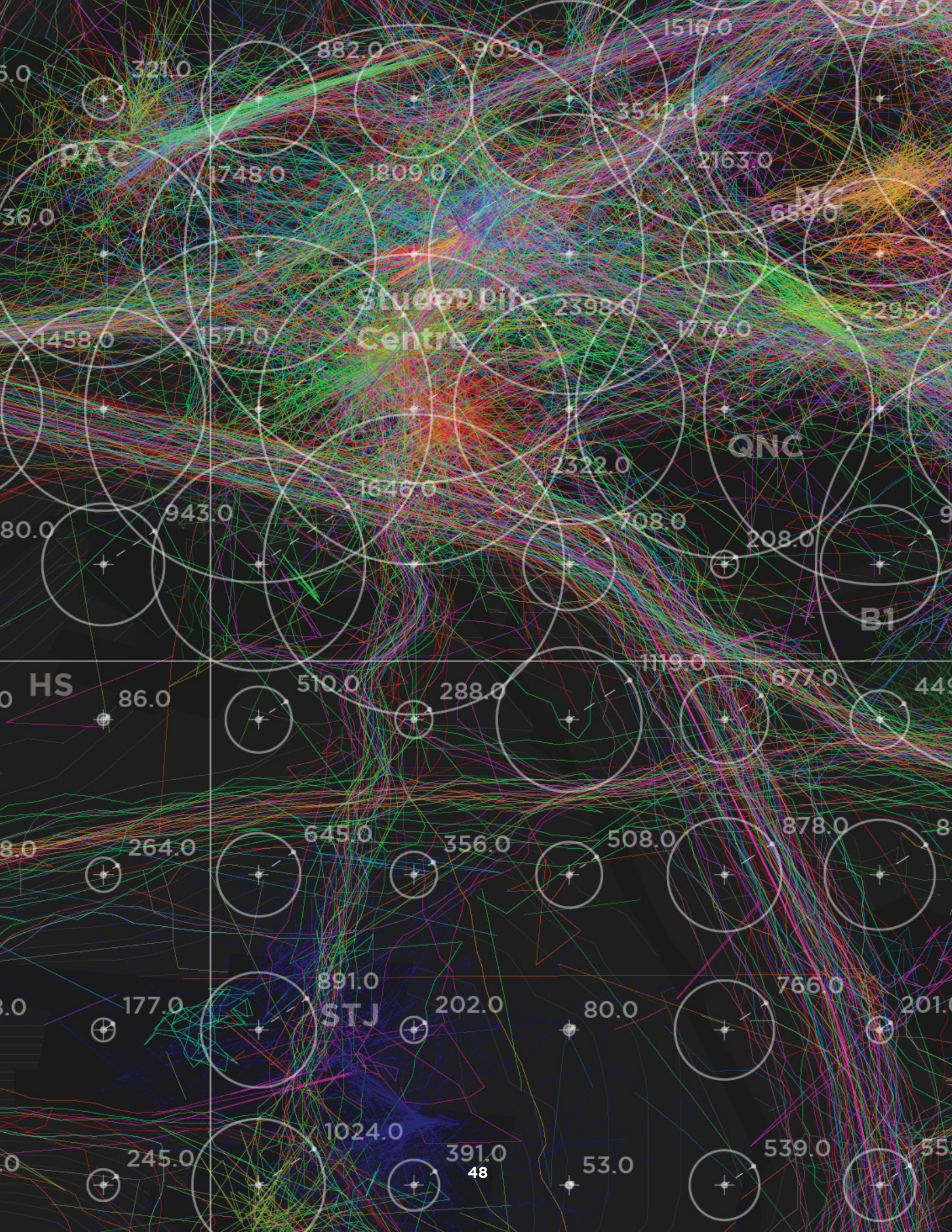
Instead of misallocating millions of dollars to entrench misguided plans borne from the whim and opinions of a planning firm (Urban Strategies), university funds and resources can be used to improve the actual main gateways into campus, affirm the university's commitment to providing a quality learning environment for their students (whom they describe as 'clients'), and provide a vibrant connection to the city and region, allowing untold synergies. It is sobering to consider that these decisions, (which at the scale of a campus are worth millions of dollars, and billions at the scale of cities) are being made without any testing of assumptions, and that their success or failure is based more on chance then design. Far from adding value to their clients it may be easily seen from the above discrepancies that the work of this firm inflicts lasting harm upon its clients. It is in the interest of those about to allocate capital towards a project to know if their assumptions about the space in which they are about to intervene are based on accurate data.

Figure 20: Views of current major pedestrian entrances to the University of Waterloo campus.

These space are ignored in the 2009 uWaterloo Masterplan. The main entrances to campus are unknown to planners and were brought to light via mapping the worldlines of students. A little attention in these spaces could have a lot of effect: a latent opportunity can be easily seized.

The data also shows that the orientation of the "first key move" in the uWaterloo Masterplan, a pedestrian artery across campus, needs to be rotated by 90 degrees.

Figure 21 (next): Detail of Map of 367 Students at the University of Waterloo.


882.0
909.0
1516.0
321.0
3542.0
PAC
1748.0
1809.0
2163.0
MC
1458.0
1571.0
2398.0
2295.0
1776.0
QNC
2322.0
1646.0
943.0
708.0
208.0
B1
HS
86.0
510.0
288.0
1110.0
677.0
264.0
645.0
356.0
508.0
878.0
177.0
891.0
STJ
202.0
80.0
766.0
1024.0
245.0
391.0
53.0
539.0


Davis
Letter to Descartes
Centre
1191.0
2140.0
1500.0
1170.0
954.0
826.0
C2
2712.0
1964.0
723.0
787.0
EXT
709.0
299.0
E3
230.0
3386.0
ESC
1230.0
366.0
380.0
435.0
179.0
2912.0
PHY
E2
1340.0
1196.0
1161.0
608.0
3045.0
3255.0
907.0
1279.0
Dana
Porter
Library
3060.0
3278.0
NH
GH
444.0
537.0
2015.0
1369.0
997.0
888.0
340.0
TC
ML


PIAZZA
NAVONA
PIAZZA MAGNANI
S. Luigi
PANTEON
MONTE
CITORIO
Piaz. Colonna
PIAZZA DI PIETRA
S.
Ignazio
PIAZZA DI SPAGNA
MINERVA
COLLEGIO ROMANO
Palazzo
Panfilj
Andrea
Pal.
di
Venezia
S.
Marco
PIAZZA S. DI VENEZIA
S. Carlo
Mont Imperiale
CAMPIDOGLIO
ISOLA DI
Tiente
or quattro

Weathered Stone Steps

Every thought that passes through the mind helps to wear and tear it, and to deepen the ruts, which, as in the streets of Pompeii evince how much it has been used.

- Thoreau. 1863

Figure 22: *Pianta Grande di Roma* (1736-1748) by Giambattista Nolli.

A map of Rome, including the interior of buildings, made using the same tool a surveyor uses to survey mountains and streams.

Journal Entry from January 15, 2012:

> *... entering the dark portico of the Pantheon: past the doors and under the lintels, into the expansive open area known as the Rotonda, all the time upon the blood red and honey yellow marble floor whose surface has hosted feet for almost two millennia and is covered by what is still the world largest unreinforced concrete dome. In the centre of this dome there is an 8.7m occulus open to the elements (rain and snow can stream inside and there are smoothly sculpted drains in the marble flooring beneath to allow for this). Around the walls are niches which are now filled with the tombs of kings and artists as well as an altar to the Christian god.*

The Pantheon was built 2039 years ago by Marcus Agrippa to celebrate his victory in the Battle of Actium. It is a microcosm of the universe: a temple to all the gods. The version which survives today has stood for 1883 years, but its life began very shabbily. The original Pantheon burned down only a century after completion. It was rebuilt shortly after by the emperor Domitian, and burned down again thirty years later, before finally being rebuilt again by the emperor Hadrian.

To map the worldlines of people in the Pantheon, I visited with a floor plan of the building by the architect Andrea Palladio and a red felt-tipped pen. In the snow covered fields individuals paths were like the course of rivers, whereas in the Pantheon the worldlines are like an eddy in a river, forming a gyre.

Considering the morphology of the worldlines which emerge, the most obvious conclusion is that the orientation of all the worldlines have a major axis that points slightly off of north. Why was this particular orientation chosen? The Pantheon was built on the empty field of the

Figure 23: *Photo of Pantheon, April 8, 2013 (2766 AUC)* by Gemma Selvenera.

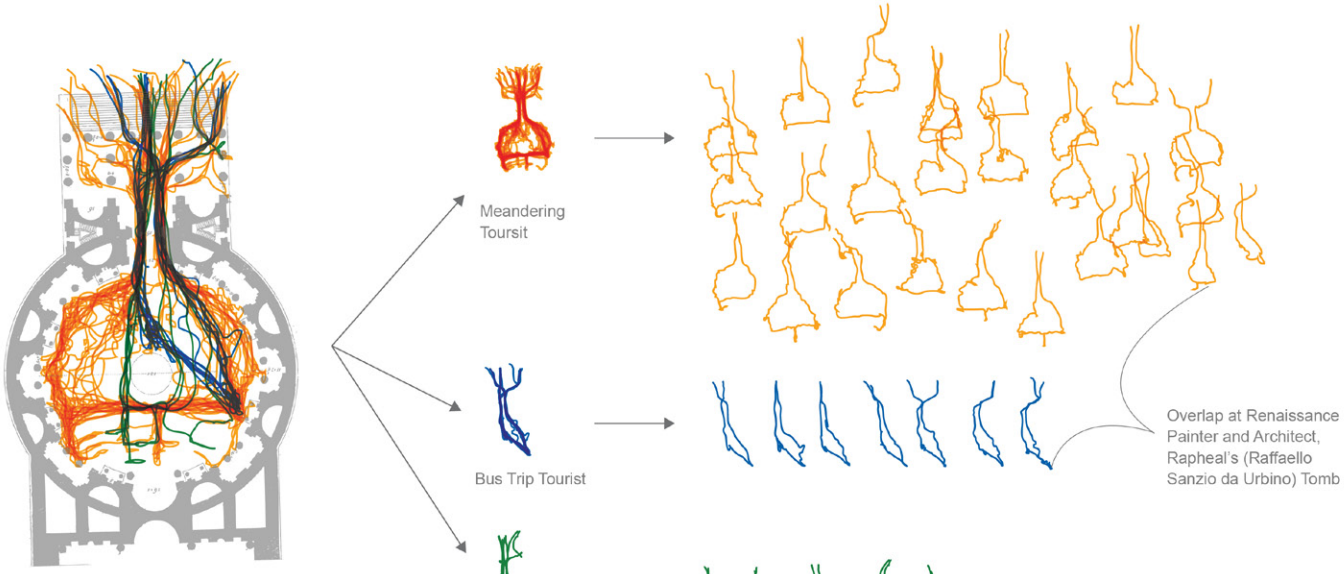
A photo depicting the solar alignment which occurs to mark the day that Rome was founded. The building, and therefore the paths we take contain this general orientation. This orientation, though a very simple move, represents a complex idea about the relationship between Rome and the universe: marking the day of Romes founding on April 8th, 2766 years ago.

Campus Martius to mark a specific moment in the year. The Gregorian Calender, in operation at the time of the Pantheon's construction, was 13 days ahead of the Julian Calendar under which we now operate. On April 8th, which Romans considered April 21, the sun at its zenith (see Figure 23) pierces through the occulus in the Rotunda and out the front door of the Pantheon, illuminating the marble arch and lintel with a halo of light. On this day 2,765 years ago, Rome was founded. For the rest of the year, sunlight streaming through the occulus is trapped within the Pantheon. The sightly off-north orientation of the major axis of the worldlines is due to the expression of a specific idea in historical space, according to a historic method of reckoning time.

The worldlines in the Pantheon belong to three *genera* – to borrow the taxonomist's name for groups of related things. Each have similarities that distinguish them from the others and internally represent the expression of a similar idea for how the expansive rotonda should (or can) be navigated (see Figure 24). The first *genus* is the *Meandering Tourist*, characterized by an inspection of every surface of the building, stopping at certain places for a few seconds. Often the *Meandering Tourist* had an audio guide or tour book which they would consult for instruction on where to go and when to stop. There is an relationship between the *Meandering Tourist* and the tradition of the Grand Tour, where people travelled to complete themselves through observance of the "great" works of the past (hence the thorough perambulation). The second *genus* is the *Bus Trip Tourist*, who only went into the centre of the building, then to Raphael's tomb, then left. This is a stripped down, "digest" version of the *Meandering Tourist*, and is thus a more modern child of both it and the *Grand Tourist*. The third is the *Penitent Catholic*, who without preamble went to the pews

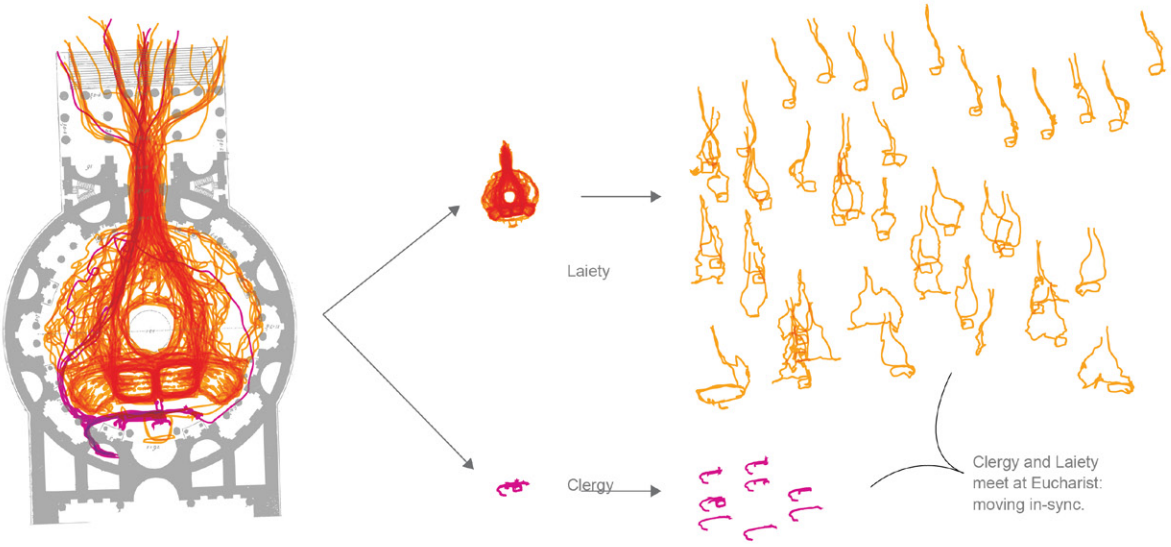
Figure 24: Map of worldlines in the Pantheon during tourists hours and Roman Catholic Mass.

The genera of paths are intelligible from each other by their unique morphologies. Each represents the expression of a different set of ideas.



Pantheon
Dimensions: 75 x 35 metres
Built: 127 CE
Geographic coordinates: 41.8986°N 12.4768°E
Mapped: Februar 13, 2012, 5:45-6:45 pm

North



Chiesa Santa Maria dei Martiri (Pantheon)
Titular Status: Minor basilica,
Dimensions: 75 x 35 metres
Built: 127 CE (Consecrated 609 CE)
Geographic coordinates: 41.8986°N 12.4768°E
Mapped: March 4, 2012, 10:00am Mass

North

at the front and sat for a period of time before leaving. This *genus* is the reason the Pantheon still stands, for during the decline and fall of Rome it was only the Pantheon's consecration as a Catholic Church that protected it. There was no prohibition on the route that each of the individuals could have taken in the Pantheon, yet each *genera* has a similar nature. All three *genera* of path are influenced by the insertion of the Catholic Church pews. Where it was once possible for people to form centripetally, now, like a rock placed in a river, people (except the *Penitent Catholic)* must flow around the pews. A further and perhaps more substantial deflection occurs in the centre of the Rotonda, because the area underneath the occulus has been roped off. Whoever installed the ropes is expressing an idea of how the space can be occupied and – just as in the maps of Rome, Mississauga, and Waterloo – they express this idea by placing something in the way to deflect the paths of people. A similar deflection, or rather sorting, is seen in the entrance foyer, in which a rope divides an "entrance", on the west from an "exit" on the east.

Generally, we may say that the worldlines in the Pantheon show individuals with different ideas and very little cooperation, because there are no coordinated movements across *genera*. To better understand the shape of worldlines when a group of people are in agreement and make a synchronous movement, I mapped four Catholic Masses in one day.

Catholic Churches, and in particular those in Rome, represent an explicit and largely stable shape with over 2,000 years of history. Herbert Spencer highlights how ecclesiastical institutions represent a symbiotic and cohesive force across generations*:*

> Looking at it generally, we may say that ecclesiasticism stands for the principle of social continuity. Above all other agencies it is that

> which conduces to cohesion; not only between the coexisting parts of a nation, but also between its present generation and its past generations. In both ways it helps to maintain the individuality of the society... Ecclesiasticism... has for its function to preserve in force the organized product of earlier experiences versus the modifying effects of more recent experiences.

The four masses whose spacetime shape I documented in Rome were the 10:00am in Chiesa Santa Maria dei Martiri (Pantheon), the 11:30am in il Gesu, the 5:30pm in Basilica Santa Maria di Trastevere, and the 6:45pm Byzantine Rite in Basilica Santa Maria di Trastevere.

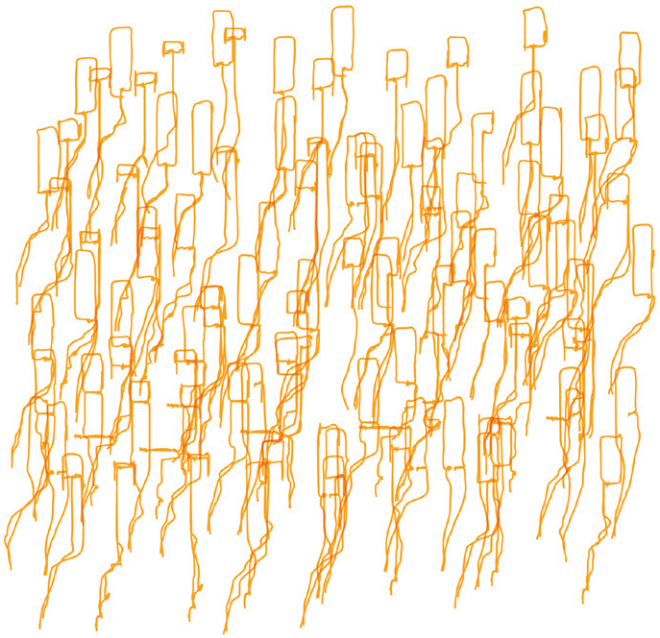
In the maps which emerge, the variation not only within the same mass, but also across multiple churches, shows the particular forces that each Mass's liturgy has been subject to as it moved through spacetime. The resultant morphology indicates how it has altered, mutated, drifted in response to the conditions it has faced on its journey to the present. Each liturgy has interacted with forces in the environment, such as the design of the church building, as well as with itself, through variations within the liturgy. While the beliefs of the faith are codified, the way they are expressed in space is never the same twice – different environments impose unique constraints. Like a medieval palimpsest, in which multiple authors have commented on the same tome, the spacetime shape of the Catholic mass in each church bears the impact of the various people and events that have influenced it.

In common, all four masses show the existence of two *genera* of worldline: the *Clergy* and *Laity*. These two *genera* differ significantly in their shape yet it is clear they participate towards the same end, in that they loop about each other, and move in a co-ordinated manner

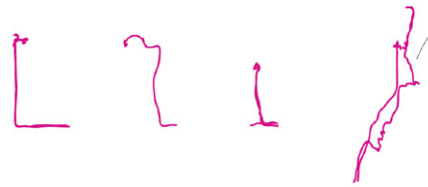
Chiesa del Gesù
Titular Status: Church
Dimensions: 75 x 35 metres
Built: 1568 CE
Geographic coordinates: 41°53′45″N 12°28′47″E
Mapped: March 4, 2012, 11:30am Mass

North

Laiety



Clergy

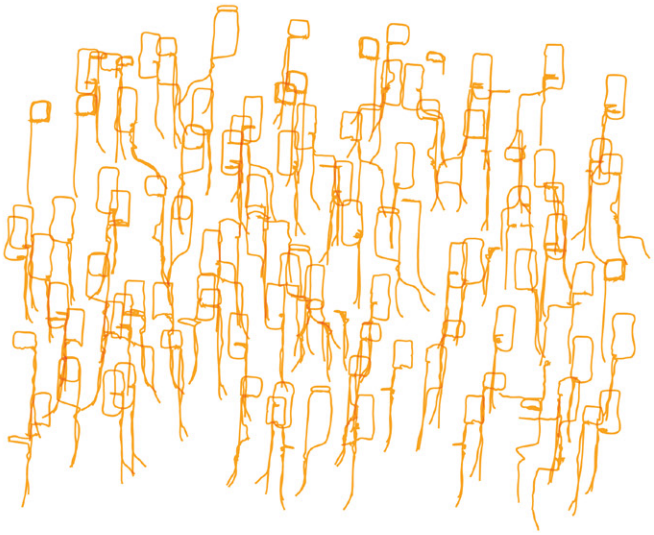


This priest performed the majority of the liturgy at il Gesu.

Santa Maria in Trastevere
Titular Status: Minor basilica
Dimensions: 56 x 30 metres
Built: 200 CE
Geographic coordinates: 41°53′22″N 12°28′11″E

North

Laiety



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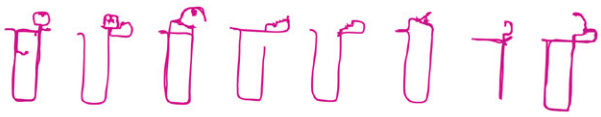


The liturgy at the SMdiT Roman Catholic Mass (as well as Byzantine Catholic Mass) involved more loops, both around the altar, and around the Laiety, then any of the other churches mapped perhaps indicating an association with more Orthodox Christian liturgical traditions.

(see Figure 25). There are also different hierarchies visible within the *Clergy*'s path, each having a specific liturgic function. This function first began as almost nothing when the penitent and reverent gathered at a small shrine marking the tomb of St. Peter on the Vatican hill (which, before hosting the magnificent St. Peter's Basilica was a necropolis). Around this tomb not only artefacts and vast architectures grew, but also roles and rites.

> Societies, like living bodies, begin as germs - originate from masses which are extremely minute in comparison with the masses some of them eventually reach. That out of small wandering hordes have arisen the largest societies is a conclusion not to be contested. (Spencer)
>
> In Societies, as in living bodies, increase of mass is habitually accompanied by increase of structure. (Spencer)
>
> While the body which maintains the observances of a cult grows in mass, it also increases in structure; and whether the cult is an indigenous or an invading one, there hence results a hierarchy of sacerdotal functionaries analogous in its general principles of organization to the graduated systems of politic functionaries. (Spencer)
>
> 'In the very earliest period, the Christian society presented itself as a simple association of a common creed and common sentiments... We find among them [the first Christians] no system of determinate doctrines, no rules, no discipline, no body of magistrates... In

Figure 25: Map of worldlines of Roman Catholic Masses.

The two *genera* of path which are the *Laity* and *Clergy*, are symbiotic and work together during the time of the Mass. This sort-of co-ordination is often seen in rituals and ecclesiastical events, though it also seen in political assemblies and generally all formal assemblages of people.

> proportion as it advanced... a body of doctrines, of rules, of disciplines, and of magistrates, began to appear.' (Spencer quoting M. Guizot)
>
> .... within the clerical class proper, have arisen not only various ranks from Pope down to acolyte, but various kids of functionaries -- dean, priest, deacon, chorister, as well as others classed as curates and chaplains. (Spencer)
>
> .... in proportion as the number of proselytes increased, the services of additional but subordinate officers were required; and we soon meet, in the more celebrated churches, with subdeacons, lectors or cantors, exorcists, acolythists, and ostiarii or door-keepers... (Spencer.)
>
> At Cluny, the biggest and most influential monastic centre of the eleventh and twelfth centuries, the liturgy grew so much and became so complicated that it swallowed up the time allotted to study and manual labour. (Watson)

Within the apparent homogeneity of the *Laity*'s path, on closer inspection, one finds some who have taken the Eucharist, visible as an extra loop. This loop has not always existed in the *Laity*'s path because the Eucharist was at times reserved only for the *Clergy*. Even if we do not have access to the history that tells us this loop is from those taking the Eucharist, we can still see an idea enacted in close co-ordination with the *Clergy's* movement, inferring a relationship.

Different shared interpretations occupy the same space differently. This is seen in a secular way, by comparing the three *genera* in the

Pantheon, with the two in the same building, when it is known as Chiesa Santa Maria dei Martiri, during mass. It is also seen in the Roman Catholic Mass and the Byzantine Catholic Mass, both of which are held in Basilica Santa Maria di Trastevere.

The Byzantine Catholic Church is a semi-autonomous Church under the auspices of the Pope. The worldlines of each churches mass, though quite similar, contain differences (I was only able to make a map of the Roman Catholic Rite, and so the differences are drawn from my notes rather then a map). During the Byzantine Rite, the *Clergy* make additional loops around the *Laity*, as well as movements up the central aisle, a practice which shows their affinity to the Orthodox Church. ttt

***

Drunkard's Walk

Journal Entry from Random Walk, March 22, 2012:

> *Three times by the door of my own house. Twice past the entrance to a restaurant in front of which sit a half dozen black gleaming Mercedes with security guards milling about in front, in preparation for the imminent VIP's departure (feel like a security risk). Almost random walked to the top of a mountain - halfway up the Janiculum hill! ... getting strange... feel like ending... only been an hour... Should I?... but what if I shouldn't? I'll ask the random app... apparently I have to continue... but seriously... that's enough!*

The American physicist Leonard Mlodinow in *The Drunkard's Walk* (2008) suggests that our path is governed by randomness:

> In the scientific study of random processes the drunkard's walk is the archetype. In our lives it also provides an apt model, for like the granules of pollen floating in the Brownian fluid, we're continually nudged in this direction and then that one by random events. As a result, although statistical regularities can be found in social data, the future of particular individuals is impossible to predict, and for our particular achievements, our jobs, our friends, our finances, we all owe more to chance than many people realize.... in all except the simplest real-life endeavors unforeseeable or unpredictable forces cannot be avoided, and moreover those random forces and our reactions to them account for much of what constitutes our particular path in life.

To attempt an answer to the question of randomness in our lives, I used two strategies: the first was an empirical test in which I went on a random walk, while the second was a quantitative distributions analysis of GPS data points. For the random walk I used a smartphone application to randomly select which street to take every time I came to an intersection in the city of Rome, while carrying a GPS, and making notes. I set out to complete two hours of random walking.

This proved impossible. The experience was traumatic, and I do not recommend it to anyone. From this experiment I learned quite definitively that I do not move randomly. The amount of psychological 'pressure' which built up after only a few dozen random decisions was overwhelming, and I began to enter a state of extreme anxiety, verging on panic. Those who assert the operation of randomness in the lives of others should perhaps first test this idea on themselves.

To add further light to the supposed operation of randomness in our lives, I did a second test involving a quantitative analysis of the

distribution of GPS data over the landscape in Rome, Mississauga and Waterloo. To do this I developed a variation of a box-counting algorithm in *processing* in which a matrix is projected onto the landscape and a count is made of how many GPS points fall into each cell of the matrix (see Figure 26). The next step is to make a histogram (a diagram which shows the frequency of a variable's occurrence within a set) by taking every cell of the matrix and placing them into bins with all other cells with the same amount of points. The amount of cells with the same amount of GPS signatures are then counted and this is plotted as a graph showing the distribution of the data (see Figure 27).

*A direction for future inquiry is to explore individuals worldlines using a box-counting algorithm in order to calculate their 'fractal dimension' (which we hypothesize to be a non-integer). Studying the resultant dimensions and their variation may provide a more accurate, less computationaly intensive way of modelling people and cities then current cellular automata and other simulations.

What the histograms of the GPS data I collected in Rome, Mississauga, and Waterloo show is that the distribution of people across a landscape follows an inverse relationship best described by the equation:

$$y=1/(x^k)$$

Where "y" is the number of points a person visits, "x" is amount of time spent at a specific point, and "k" is a value which allows the curve to best fit the data.

From these histograms (see Figure 27), we see that people spend a lot of time at a small set of points (long low tail to the histograms at right) and small amounts of time at a large amount of points. This distribution shows that people have tendencies towards certain regions of space. If human movement is random then we would not expect there to be any tendency towards a small number of specific regions of space and we would see what is called a standard distribution, more familiarly known as a 'bell curve'*.

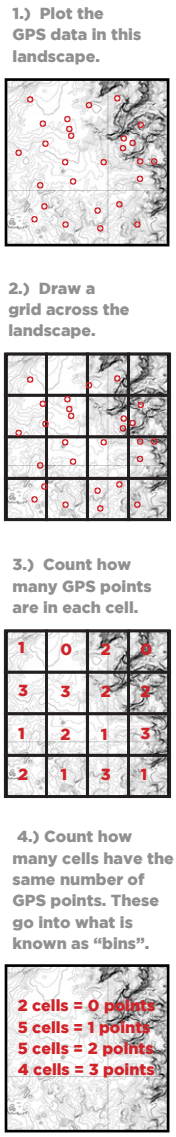


Figure 26 : Diagram illustrating method used to calculate the distribution of people across a landscape.

* In going through my early notes, I had hypothesized that our distribution across a landscape would follow a standard distribution (bell curve). From this test, it becomes clear that my hypothesis was incorrect.

The only certainty in a random walk is that the fulfilment of our circadian rhythms, our sustentation, and hydration will happen only through chance; and if we move randomly here is a high probability we will quickly dehydrate, starve, and die.

How within the framework of matter in the environment, and the culture and beliefs of the time, does our unique shape in spacetime come about, if not randomly?

***

Maps in Maps

The shape of our worldlines is the result of our situation, our memory and the ideas we have about the present and the future. At the most fundamental level, the movement we engage in heedlessly is intimately tied to our homeostasis. The American professor of cognitive science, Douglas Hofstadter, writes in *Godel, Escher, Bach* (1979):

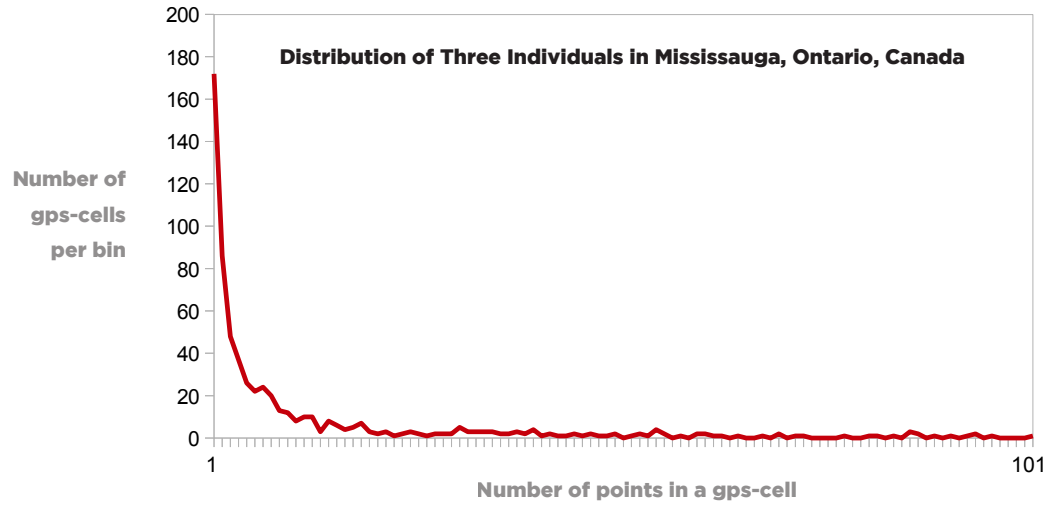
> There are some pathways -- you can think of them as pathways either in a [Atlas] or in a brain -- which are taken routinely in going from one place to another...The pathways which one relies on over and over again are pathways which incorporate knowledge... These stable, reliable pathways are what constitute knowledge. Pieces of knowledge merge gradually with beliefs, which are also represented by reliable pathways...

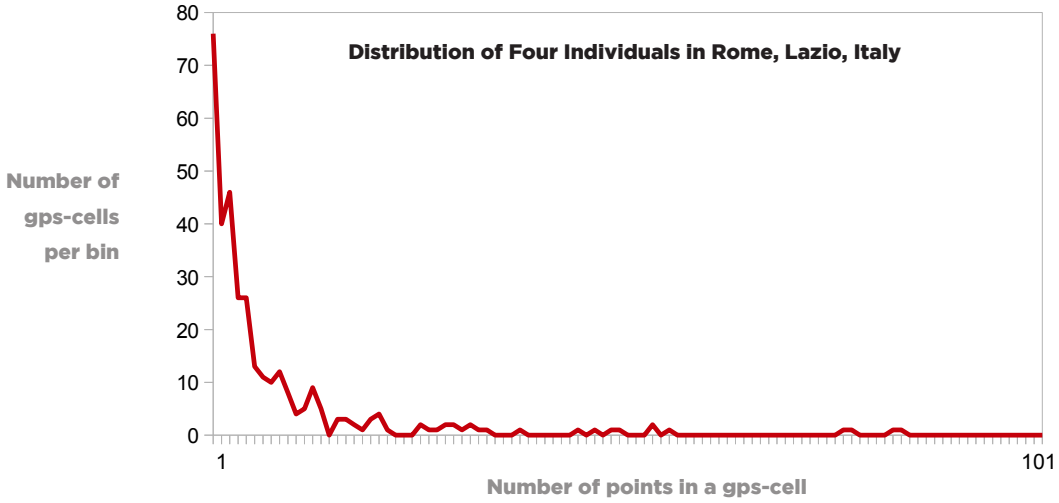
Erwin Schrodinger, an Austrian physicist and philosopher, in *Mind and Matter* (1958) provides a rough outline for how these reliable pathways might look:

> We follow the habitual path to our workshop, cross the road at the customary places, turn into side-streets, etc., whilst our thoughts

Figure 27: Histograms showing the distribution of people in Mississauga, Rome, and Waterloo. Thanks to my brother Alex Christou for his help in the creation of these graphs.

In the plots at right, I have not plotted all the cells which have zero GPS points in them in order to make apparent the resolution of the tail of the curve.


Distribution of Three Individuals in Mississauga, Ontario, Canada
Number of gps-cells per bin
200
180
160
140
120
100
80
60
40
20
0
1
101
Number of points in a gps-cell


Distribution of Four Individuals in Rome, Lazio, Italy
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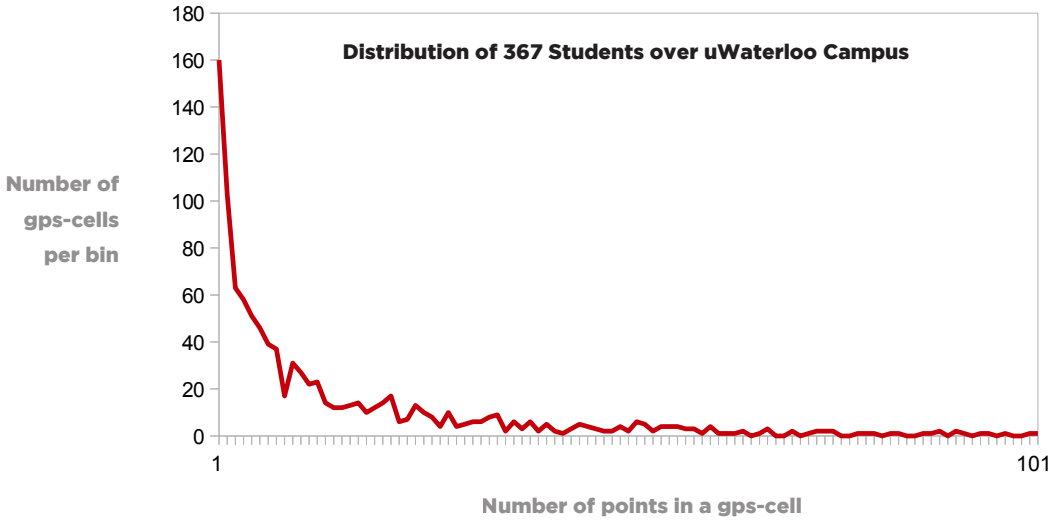
Number of points in a gps-cell


Distribution of 367 Students over uWaterloo Campus
Number of gps-cells per bin
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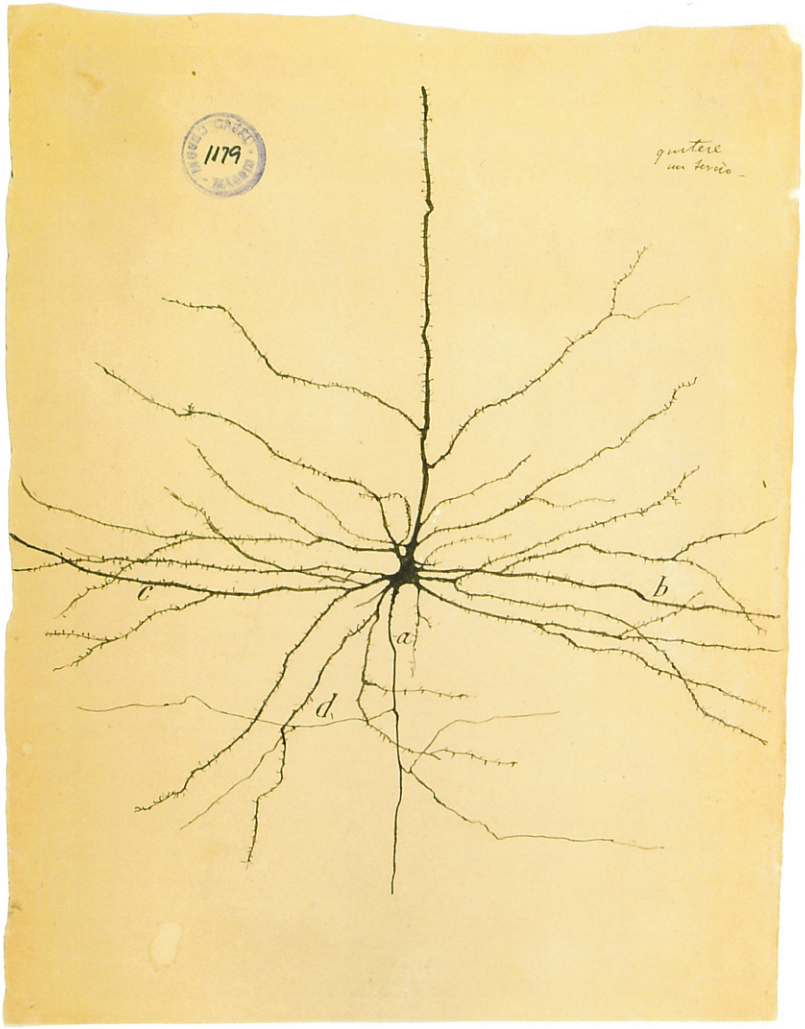
Number of points in a gps-cell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> are occupied with entirely different things... Faced with changing alternatives, bifurcations may develop and may be fixed in the same way. We branch off to the University Lecture Rooms or to the Physics Laboratory at the right point without much thinking, provided that both are frequently occurring destinations.

The way we move when we know where we are going, and do not need a map, is derived from a process within us in which we experience a correspondence to the environment just as the cartographer maps the terrain. My authority in the field of physiology is nonexistent, so I will quote from a series of recent journal articles published by neuroscientists, in order to seek an answer to the question: "How within the framework of matter in the environment, and the culture and beliefs of the time, does our unique shape in spacetime come about?"

> A hand is a good example. It is made of bones, muscles, tendons, connective tissue, a network of blood vessels and another of nerve pathways, and several layers of skin, all put into place according to a specific architectural pattern. When such a biological object moves in space it performs an action, for example, your hand pointing at me. Both object and action are physical events in space and time. Now, when neurons arranged in a two-dimensional sheath are active or inactive according to the inputs they receive, they create a pattern. When the pattern corresponds to some object or action it constitutes a map of something else, a map of that object or action. Grounded as it is in the activity of physical cells, the pattern is just as physical as the objects or actions it correspond to. The pattern is momentarily drawn in the brain, carved in the brain by its activity. (Damasio)

Figure 28: *Pyramidal Neuron.* By Santiago Ramon y Cajal, 1899. From *Portraits of the Mind.*

Cajal was among the first to study individual neurons within the human brain by using the Golgi staining technique and shared the Nobel Prize in Medicine 1906 for his pioneering work to open up the terrain of our neurology.

He compiled his observations as drawings and descriptions of the various shapes, configurations, and connections that he observed under a microscope and comments in the two volume *Histology of the Nervous System*.

Part of the energy related to sensation is transferred to cortical neurons and, voila, the experience is stored... Later, often much later, the stored experience can be retrieved or reactivated under the influence of new external or internal impulses. (Cajal)

A primary cerebral map may be considered to be a translation that makes it possible to sample and preserve selected coherent portions of the gross topographic order of the external scene in time and space. (Edelman. 1989)

A cardinal feature of mammalian neural organization is the topographic mapping of the external environment onto sensory areas of the neocortex... In both the hippocampus and the [entorhinial cortex], different cells fire at different locations such that, collectively, the cells form neural maps of all locations in local space. (Stensola et al)

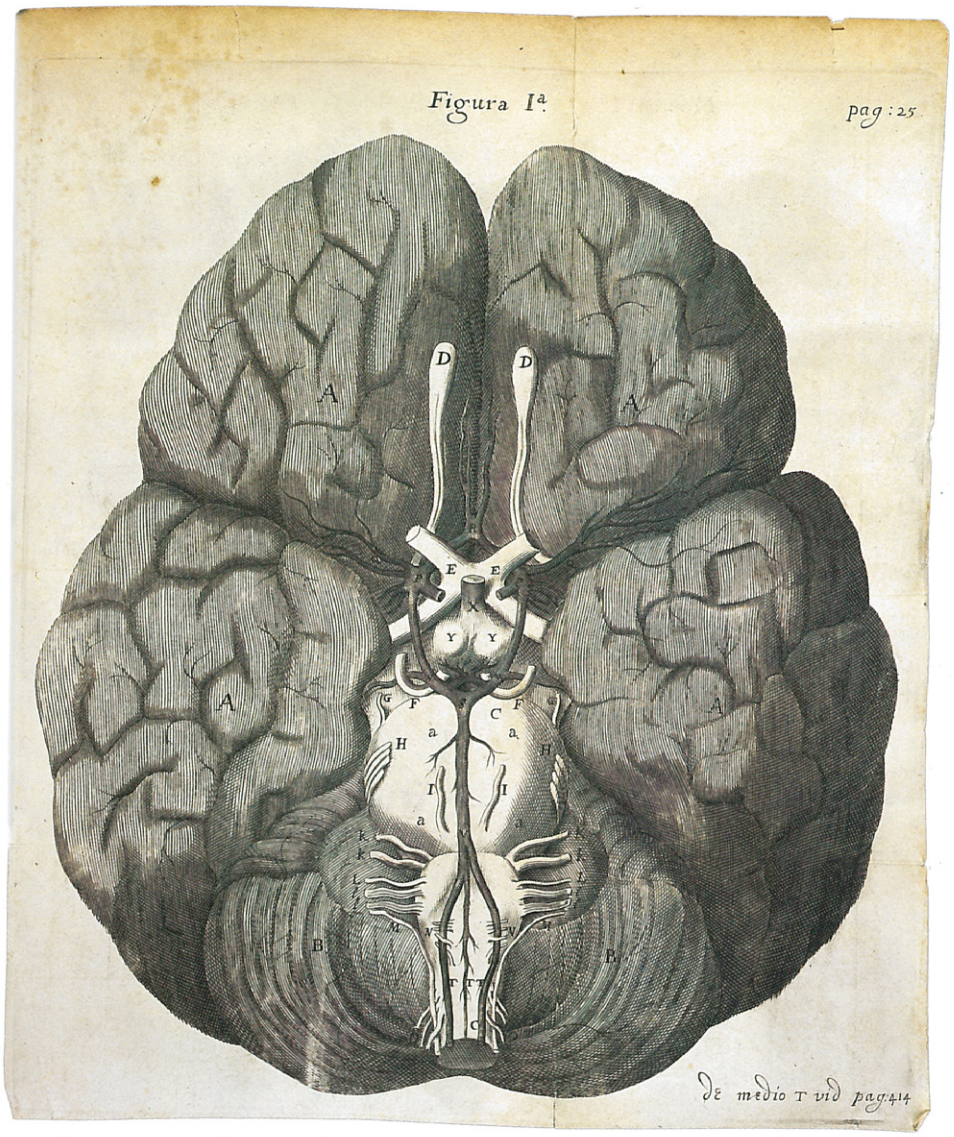
According to this hypothesis, our knowledge of the external world resides entirely in the assembly of functional connections established between different categories of representational neuron. (Cajal)

The arrangement of the cerebral cortex into vertically organized assemblies not only serves to map multidimensional properties of a given a modality onto a two-dimensional sheet.., but also helps "translate" certain physical properties of the real-world object (such as orientation, pitch, etc.) into neural properties at defined locations... While sampling systems and motion systems are inherently Euclidean... there is no single object-centered axis or

Figure 29: *View of a human brain from below*. By Thomas Willis and the architect Christopher Wren, 1664. From *A Portrait of the Mind*.

Our brains have two hippocampi, which are part of the limbic system, and located in the medial-temporal lobe. Many neurons in the hippocampus of rats and mice respond as place cells, which fire when they are in certain environments.

The entorhinial cortex, is the main gateway between the hippocampus and the neocortex. Many neurons here, in rats, mice and humans act as grid cells, projecting a triangulated Cartesian grid onto the environment, which scientists believe aids in planning which direction to head.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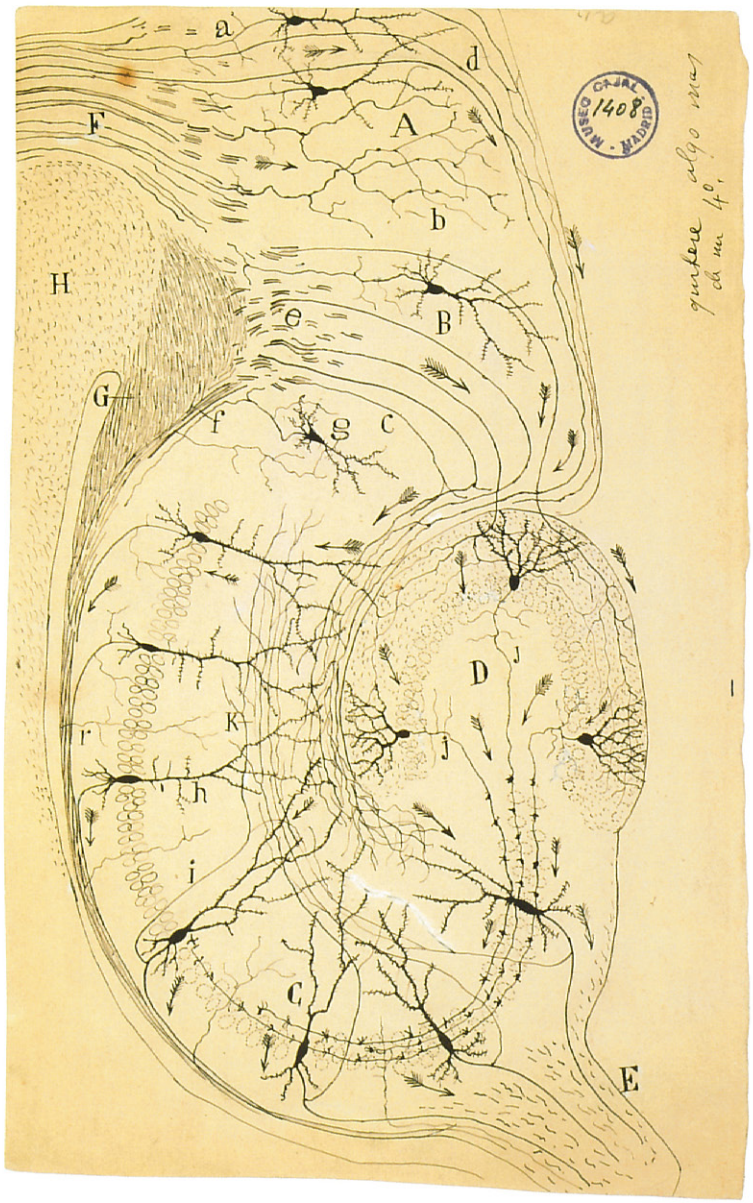
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> organism-centered axis. Instead, co-ordinate axes are defined as necessary, depending upon the properties of the sensory channel or the act... There exists a series of simultaneous and independent or quasi-independent coordinate origins defined by each modality, submodality, and channel. (Edelman,1989)

> You will discover, in each cortical layer that you inspect, a sheath-like structure that essentially resembles a two-dimensional square grid... you can imagine something like the plan of Manhattan, but you must leave Broadway out because there are no major oblique lines in the cortical grid. The arrangement, you realize, is ideal for overt topographical representation of objects and actions. (Damasio)

When we say "a map is stored in us, of an environment" what we mean is that populations of cells known as neurons are dedicated to environment, and via their configuration, preserve information about this environment for later access. A neuron is an electrically and chemically excitable cell that processes, conveys, and stores information. The major components of a neuron are its body, where the nucleus is and the mitochondria are manufactured; its dendrites, the arboresque growths that connect the neuron to other neurons; and it's axon, which can stretch over one metre in humans, and is responsible for conducting impulses from other neurons. Neurons are connected via synapses which are located between the axon and the dendrites and allow electrical impulses and chemicals to be carried from one neuron to another. Via the concerted firing of many millions of neurons we become sensate. Neurons take up space and have a latitude, longitude, and altitude, though they constantly move and shift (a recent discovery

Figure 30: *Diagram of the Human Hippocampus.* By Santiago Ramon y Cajal, 1901.

"London cab drivers, noted for their geographic prowess, were recently discovered to have peculiarly shaped hippocampi... neurons in this structure encode a spatial map of their environment" from *Portraits of the Mind.*

known as neuroplasticity). The fact that our memories have a measurable volume in physical space is well demonstrated in a study conducted on London taxi drivers:

> The professional dependence on navigational skills in licensed London taxi drivers is associated with a relative redistribution of gray matter in the hippocampus... this finding indicates the possibility of local plasticity in the structure of the healthy adult human brain as a function of increasing exposure to an environmental stimulus... (Hassabis)

There are neurons, known as place cells, located in our hippocampus, that fire with marked activity when we are in a location that corresponds to what is known as the "place field" of the cell. This means the place field of each neuron will fire when we are in a specific location.

> .. a specific item of information, a real world distance, can be stored in an individual plastic synapse that connects a pair of place cells. A network recurrently connected by such synapses can be shown to contain enough information to find optimal paths in open space, to compute detours and take shortcuts... (Isaac)

In a process known as 'remapping', a single place cell can have multiple place fields corresponding to distinct, disparate locations. Another type of neuron, known as a grid cell, is located near the hippocampus in a region called the dorsocaudal medial entorhinial cortex (dMEC) and works in a similar fashion to place cells: firing when we are in specific locations in the environment. Unlike place cells, which fire only when they are in one of the place fields for that cell, grid cells fire whenever we cross the vertex of a grid of equilateral triangles that we project onto the external environment.

> The representation of place, distance and direction in the same network of dMEC neurons would permit the computation of a continuously updated metric representation of the animal's location... This study points to the dMEC as part of a neural map of the spatial environment. The basic unit of the map is the grid cell, whose multiple discrete firing fields invariantly form a stable, regularly tessellating structure of equilateral triangles. Grid spacing, grid orientation and field size were topographically organized, with minimal variation locally, but significant variation across the surface of the dMEC. (Hafting, 2005)

The hypothesized function of the triangular euclidean grid we project onto our environment lets us plan our next position, direction, and speed. This matrix forms the basis for integrating multiple sources of information and deciding on the course to set. These cells were predicted in 1996 and only discovered in 2005, so there remain many questions about this seemingly inherent biological mapping system. However, it is clear that we make maps of our environments which we carry around within us as populations of representational neurons. It is also clear that we store specific location information in a corresponding way within our minds via place cells, and that we then project a matrix onto our environments which we use to make decisions and set directions via grid cells. It is important to note that the 'environment' is not limited to what is outside of the skin.

> The human brain is a born cartographer, and the cartography began with the mapping of the body inside which the brain sits. (Edelman, 1989)

There are maps of the body and maps of the environment in our brains. These maps combine in "considered" movement, which is the pursuit of specific aims and directions in space and across time.

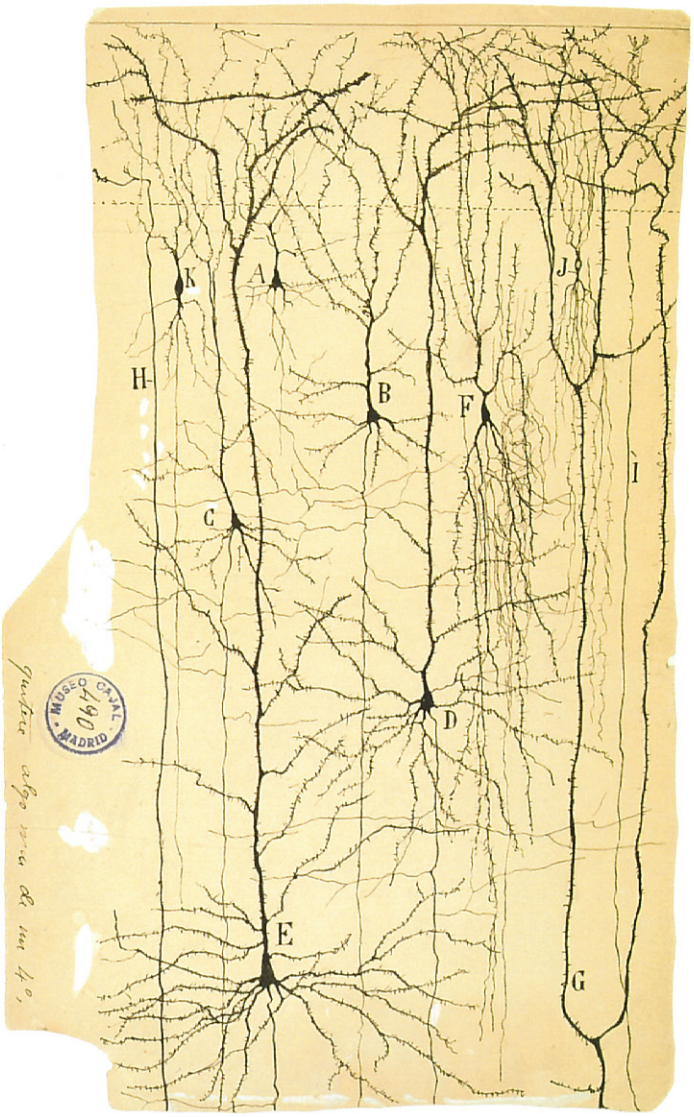
> The brain... makes maps of its own maps, or "categorizes its own categorizations," and does so by a process that can ascend indefinitely to yield an ever more generalized picture of the world. (Sacks)

Our worldine is the result of decisions in the environment about moving from one moment to the next: stop, go forward, back left, right, up, down. We make these decisions by way of a series of interconnected maps, composed of the arrangement, configuration, and functioning of our nervous system.

> The visual system of the monkey, for example, has over thirty different maps, each with a certain degree of functional segregation (for orientation, color, movement, and so forth), and linked to the others by parallel and reciprocal connections. Reentrant signaling occurs along these connections. This means that, as groups of neurons are selected in a map, other groups in reentrantly connected but different maps may also be selected at the same time. Correlation and coordination of such selection events are achieved by reentrant signaling and by the strengthening of interconnections between the maps within a segment of time. (Edelman, 1993)

> The perception of a grandmother, or say, of a chair, depends on the synchronization of a number of scattered mappings throughout the visual cortex: mappings relating to many different perceptual

Figure 31: *Neocortex.* By Santiago Ramon y Cajal, 1901. from *Portraits of the Mind.*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> aspects of the chair [size, shape, color, "leggedness", relation to other chairs]... Such a correlation is possible because of the very rich connections between the brain's maps, connections that are reciprocal, and may contain millions of fibers. (Sacks)

We can map both the environment and ourselves as a the result of many thousands of generations of interaction with our environments. Over a billion-and-a-bit years, the strategies that have bestowed success on our ancestors were rewarded by being passed forward. Our ability to remember, plan, move and maintain our body's homeostasis in changing environments and scenarios is the result of the successful navigation of our ancestors through their own present.

***

Frayings and Frappings

It was not I who begot you. It was the dead --
my father, and his father, and their forebears,
all those who through a labyrinth of loves
descend from Adam and the desert wastes
of Cain and Abel, in a dawn so ancient
it has become mythology by now,
to arrive, blood and marrow, at this day
in the future, in which I now beget you.
I feel their multitudes. They are who we are,
and you among us, you and the sons to come
that you will beget. The latest in the line
and in red Adam's line. I too am those others.
Eternity is present in the things
of time and its impatient happenings.

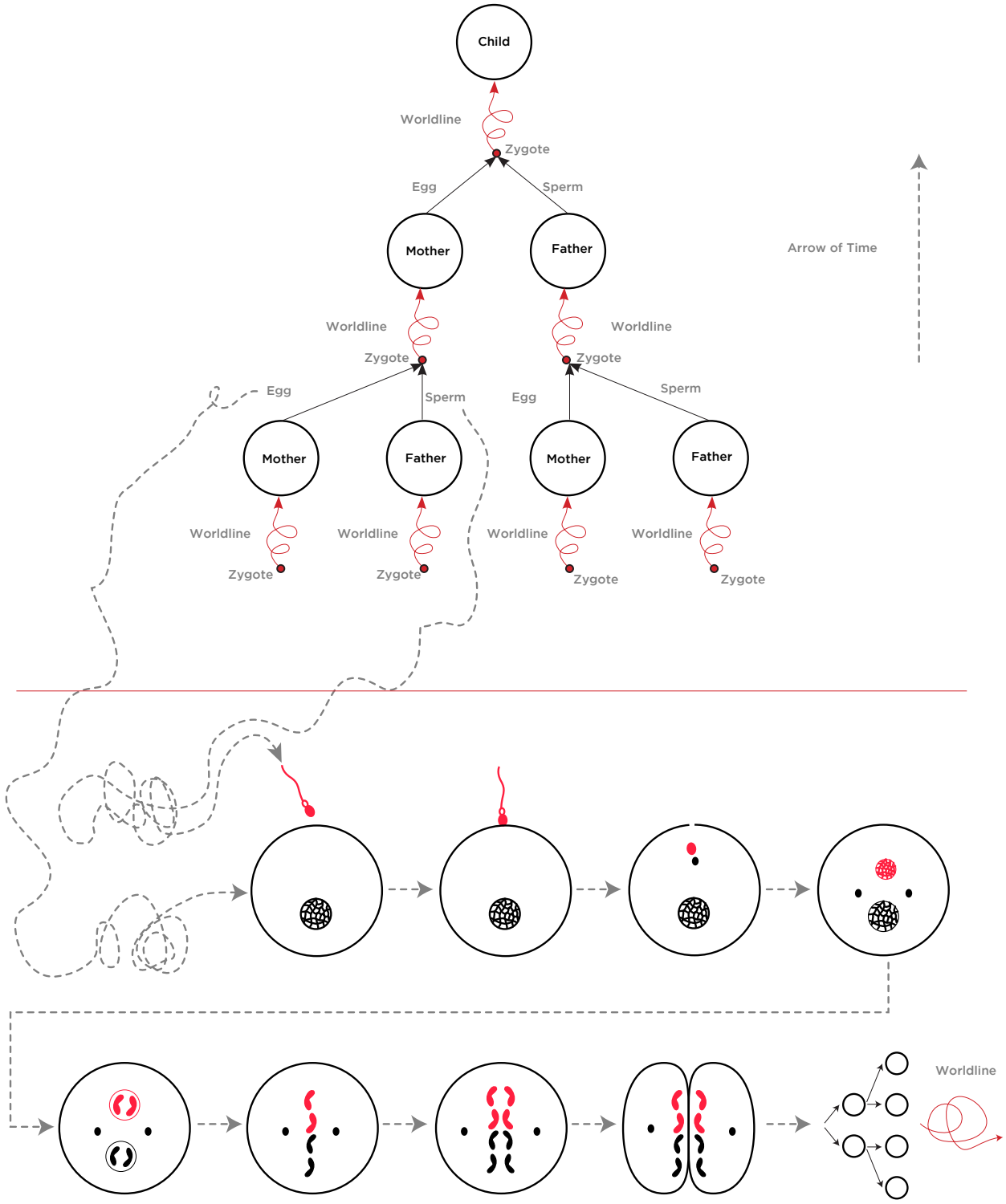
-A.R. Borges. To the Son

Thought Experiment:

> *.... my worldline goes back to the moment of my conception. Past this I must follow my parent's worldlines... so to follow my own worldine back in time, I come to the point of my fertilization, at which time I must now follow two worldlines back.... back day-by-day, month-by-month, year-by-year... I come to a point where my parents were themselves conceived by their own parents. At this point, I must follow four worldlines. This process of exponential bifurcation continues: my grandparents each had two parents and they each had two parents, and so on. Having begun following merely my own worldline, I am now following four, eight, sixteen worldlines... all at once. This process of exponential increase continues. However the exponential increase in worldlines is not always seen -- incest can and did occur either through proclivity or necessity (population bottlenecks, founder's effects, and so on).... continue to imagine the worldine of my ancestors back past the oldest known relative in my family tree...*

Cladistics, literally the study of branches, is a method of understanding relationships between things via their shared and measurable characteristics. It proposes that organisms belonging to a group share an evolutionary history, have a common ancestor, undergo a process of speciation resulting in bifurcations (i.e., variation within parent and progeny), and that this all occurs in spacetime.

As a classification system, the 'output' of cladistics is a tree diagram, a familiar example is the family tree (see Figure 32). Extending the consideration of cladistics beyond a diagram, positing, as in the thought experiment, that every bifurcation that makes up a "family tree" has


Child
Worldline
Zygote
Egg
Sperm
Mother
Father
Arrow of Time
Worldline
Zygote
Worldline
Zygote
Egg
Sperm
Egg
Sperm
Mother
Father
Mother
Father
Worldline
Zygote
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a real latitude, longitude, altitude, and that every one of our ancestors has a worldine, then cladistics is physically evidenced in worldlines. Cladistics is a description of the physical process by which life is carried forward, the 'morphology of selection', the bifurcating and joining of worldlines.

> We have proved that there exists a trajectory of stepwise change connecting beetle to deer and, by implication, a similar trajectory from any modern animal to any other modern animal. (Dawkins, 1982)

Our genome is the product of two half-chromosomes fusing, an act known as fertilization (see Figure 32). This process involves two gametes – cells containing half of a human's chromosomes – joining to produce a cell known as a zygote; the replication of the zygote produces our billions of cells.

> Let me use the word 'pattern' of an organism in the sense in which the biologist calls it 'the four-dimensional pattern', meaning not only the structure and functioning of that organism in the adult, or in any other particular stage, but the whole of its ontogenetic development from the fertilized egg cell to the stage of maturity, when the organism begins to reproduce itself. Now, this whole four-dimensional pattern is known to be determined by the structure of that one cell, the fertilized egg... what is passed on by the parent to the child is not just this or that peculiarity, a hooked nose, short fingers, a tendency towards rheumatism, haemophilia, dichromas, etc... but actually it is the whole (four-dimensional) pattern of the 'phenotype ... the visible and manifest nature of the individual,

Figure 32 (top): The Family Tree.

Our heredity can be represented by a cladistic diagram. If we imagine this diagram to have occurred across spacetime, so that at every point in time, our ancestors had a location in space, then we can see this process of joining and bifurcations plays out like the branches of a tree across the landscape. We can see the process of worldlies fusing by looking more closely at the moment of fertilization.

Figure 33 (bottom): Fertilization .

When the sperm and egg (which have at all times had a location, contain half of the DNA of their progenitors, and have preserved this information as protein chains for more then a billion years) join, fusion occurs making a single cell known as a zygote. The DNA is then duplicated, paired, and squeezed apart. to form two cells identical cells. This process continues to create the billions of cells in our bodies.

which is reproduced without appreciable change for generations, permanent within centuries, -- though not within ten thousand years -- and borne at each transmission by the material structure of the nuclei of the two cells which unite to form the fertilized egg. (Schrodinger)

Both gametes have a worldine originating from the reproductive organs of our parents. The worldline which connects us to our ancestors is direct and unbroken and is composed of the fusion of many previous worldlines. With advances in our understanding of genetic analysis, as well as drastic reductions in the cost of sequencing our DNA, it is possible to piece together the approximate worldline of my very distant ancestors by identifying mutations shared among living and dead humans (and organisms at-large) for the last 75,000 years, and in theory, well past this.

As humans left Africa, they migrated across the globe in a web of paths that spread out like the branches of a tree, each limb of migration identifiable by a marker in our DNA. (The National Genographic Project)

My Mother's ancestors went around the east side of the Black Sea and up into what is now Germany before eventually ending up in England. My Father's ancestors went west of the Black Sea, and established themselves in what is now the Balkans, where they remained for ten thousand-plus years.

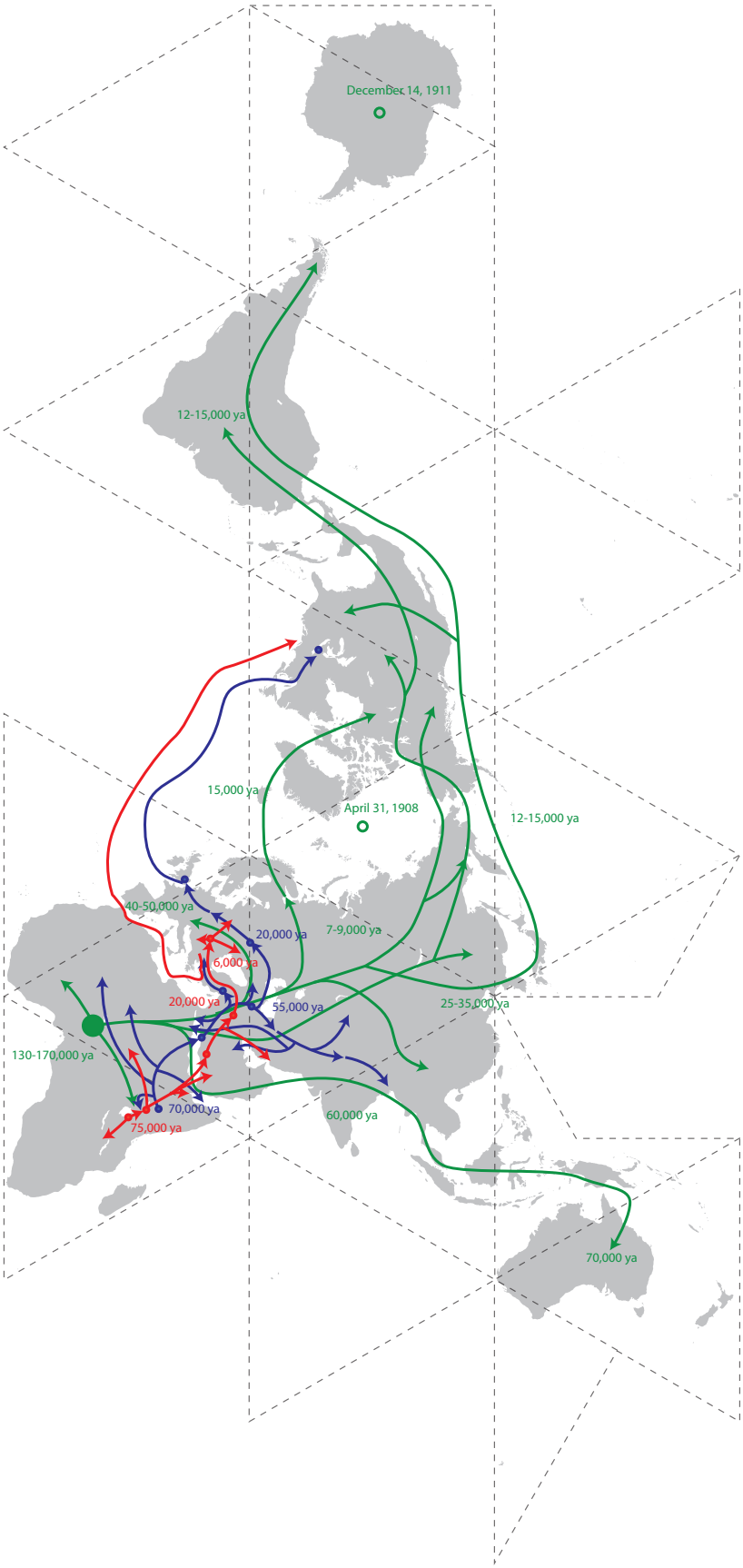
The length and the continuity of our worldlines across the vast gulf of time is punctuated, at the rhythm of each generation, by a vibrant highly-individual course.

Figure 34: Map of my family's worldlines from 130,000 years ago to present.

"Confess then, naught from nothing can become, since all must have their seeds, wherefrom to grow, wherefrom to reach the gentle fields of air." -Lucretius in *De rerum natura*.

Advances in gene sequencing have allowed scientists to study the route that our very distant ancestors took in their migration from Africa by comparing genetic and morphologic variation in living populations of people as well as the remains of the other species and sub-species of the genus Homo which existed in history.

My Mothers ancestors are in Red, my Father's in Blue, and the general route of *Homo sapiens* is in green. Data is from the MitoMap (a database of polymorphisms and mutations of the human mitochondrial DNA) as well as my own DNA (processed by the National Genographic Project).


December 14, 1911
12-15,000 ya
15,000 ya
April 31, 1908
12-15,000 ya
40-50,000 ya
20,000 ya
7-9,000 ya
6,000 ya
20,000 ya
55,000 ya
25-35,000 ya
130-170,000 ya
70,000 ya
75,000 ya
60,000 ya
70,000 ya

Each of our ancestor's decisions have produced their unique worldlines. It has been orthodoxy since Charles Darwin, the British natural philosopher, promulgated the theory of evolution to attribute the variation in organisms to the differential success of mutations passed on during reproduction. However increasing evidence is pointing to the importance of an organism's behaviour during the course of its life, in modification rather then merely random mutations. Jean Baptiste Lamarck, the French natural philosopher, strongly and with remarkable lucidity, pointed this out over fifty years before Darwin published his theory and Darwin himself, in the introduction of the first edition of *The Origin of Species* (1859) said: "I am convinced that natural selection has been the main, but not the exclusive means of modification." While the course of our development across generations is determined largely by our genes, an increasing importance is being placed on the effect of our behaviour on the expression of our genes, and how this can be passed from parent to progeny (this field is known as epigenetics).

The shape of our worldline (as well as our physiology) is determined not only by the differential success of mutation, but also by decisions and behaviours that our ancestors made in the course of their lives, as well as their interactions with the external environment. These decisions have brought our ancestors from the oceans, onto land, and across the continents, to where we are today. All of these forces, as well as our own ideas and interactions with the world at-large, have imparted a unique trajectory onto each of our worldlines.

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> "What alone can our teaching be? - That no one gives a human being his qualities: not God, not society, not his parents or ancestors, not he himself... No one is accountable for existing at all, or for being constituted as he is, or for living in the circumstances and surroundings in which he lives. The fatality of his natures cannot be disentangled from the fatality of that which has been and will be. He is not the result of a special design, a will, a purpose; he is not the subject of an attempt to attain to an 'ideal man' or an 'ideal of happiness' or an 'ideal of morality' -- it is absurd to want to hand over his nature to some purpose or other. We invented the concept 'purpose'; in reality purpose is lacking.... One is necessary, one is a piece of fate, one belongs to the whole, one is in the whole -- there exists nothing which could judge, measure, compare, condemn our being for that would be to judge, measure, compare, condemn the whole.... But nothing exists apart from the whole! (Nietzsche)

The space of cause and effect is a terrain perpetually occluded, a *terra incognita,* in which cognizance is had only as indistinct shadows, instincts, fears, revelations. Penetrating eyes unaided and across myriad generations have seen what is hidden in these depths and have shared this with us in their paintings, sculptures, myths, and rites. We become aware of this world, and the possibilities inherent in it only while we stand before these exceptional works; even then we know them only as the briefest tears in the indefatigable horizon which otherwise shields us from seeing, knowing, cause and effect.

Our science, our reason, our skepticism and assurance keep us from this world. We refuse the unpredictable, non-repeatable, non-falsifiable nature of these insights and so develop scopes, aids to vision, which seem to allow us to peer into the world which the artists, philosophers,

priests, and liminals have seen, recounted, promised. With these scopes (telescopes, microscopes, etc.) we form a system of verisimilitudes.

As Galileo peers through a lens and beholds the twinkle of the Jovian moons, and Antonie Van Leeuwenhoek the tremulous basis of all life, so the thread that we have woven through time and space – the vast and wonderful net of relations, which bind and separate us – is only visible through a lens. Briefly, before we are pried from this lens, by the demands and travails of life, the causal world is visible and we see as if we were immortals, outside the arrow of time. At these moments we are witness to a world in which one thing leads to another and all things tend to and are borne from the same source. A world which is familiar, and yet ever elusive. Footprints in the snow, worn doorhandles, and the weathered stone steps all show us that this world, the one behind our sight, is yet present, and though we cannot see it, by these traces we are reminded of our participation in it.

Farewell,

-GGC

Figure 35: A photo of a footprint on the moon. Taken by Buzz Aldrin, July 21, 1967.

Neil Armsotrong, was the first to walk on the moon and remarked as he did so: *"That's one small step for a man, one giant leap for mankind"*

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