Cities Untangled: Uncovering Order in Arterial Skeletons of Road Maps

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Abstract

Survey knowledge, as embodied in the road map, has been seen as too slow a navigational aid to function effectively at the speed of life in the smartphone/GPS-app era, capturing as it does details of the highway network that are seen to present too heavy a cognitive load to the user. Yet this very richness offers the promise of enabling the user to navigate with understanding, providing for exible and resilient trip planning. But what if the map's heavy cognitive load was not because of the difficulty in dealing with its heavy load of information, but because that information was unnecessarily disordered? We suggest a comprehensible ordering has always existed within complex-appearing road maps. We propose a model for making this ordering explicit, highlighting a "skeleton" of arterials so as to appear visually untangled. The concept of the Use-Access Island (UAI), a bounded area with a coordinate axis-like array of spanning arteries, is introduced. As ever-finer meshes of these areas are highlighted across a street map, a hierarchy of visually untangled arteries can be rendered. Locations and routings can then be visualized in terms of nested sequences of "untangled" routings. When married to geographical designations, this iterative UAI schematization is designed to embody routing spatial knowledge. Is such an untangled map fast enough? We invite researchers to test the model.

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1 Introduction

In the face of ubiquitous adoption of navigational apps and devices, maps have been getting a bad rap. In 2010, Hirtle delivered a talk [9] to the 20th anniversary meeting of Cognitive and Linguistic Aspects of Space entitled, "Dinosaurs, Slide Rules and Maps," suggesting (slightly tongue-in-cheek) the eventual demise of maps. Yet, as Hirtle points out, the loss of spatial awareness from the use of these apps and devices is a serious problem [12, 22, 23].

People are drawn to these new devices, as road maps *can* be problematic. As Klippel et al. [16] pointed out, "employing a map to create spatial awareness or to provide wayfinding support requires the ability of the map user to establish element-to-element correspondence within and between maps and entities in the real world. The perceptual and cognitive costs of recognizing such correspondences are potentially very high." This can be especially true in cities with complex road networks. As Kuipers [17] speculated, "in an area which is not even topologically close to a grid, finding novel routes or relative positions will be characterized by high error rates, low confidence, and conservative strategies." Montello [21] reinforces that idea with respect to route angularity.

Compromise solutions have been proposed, schematizations designed to restore some spatial awareness to the directions and route maps which these devices and apps generate without the drawback of the heavy cognitive load of a full map. For example, Schmid et al. [25]

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proposed “Route Aware Maps” that added limited road map context at key points along strip maps of routes. Zipf et al. [33] proposed “Focus Maps” that highlight important elements of a full map and fade out the less important.

But what if the cognitive load of full road maps was *not* intrinsic to the density of highway, landmark and area information that they embody? What if instead it was the result of the spatial information being *unnecessarily* disordered in its presentation? What solutions to the problem of restoring spatial awareness would be possible then?

This paper proposes a schematization that does not eliminate any spatial information from a given scale of map but instead highlights an arterial “skeleton” of the highway network so as to reveal a remarkably coherent ordering of highway elements even within complex cities and across a wide range of granularity, up to the level of continent-wide. Our shorthand term for such a schematization is “untangled map.”

We found Freksa’s paper [6] on strong spatial cognition inspiring: the insight to look at spatial problem-solving in physical (bodily) terms and not solely on an “abstract information level,” as in having a robot solve a shortest route problem using string and physical manipulation and not calculation, would seem to hold tremendous promise for AI. There is a sense in which untangled maps can be thought of as “strong,” not to suggest applications for AI or robots, but rather to suggest the “role of the body” – in particular our perceptual machinery – in spatial problem-solving using this schematization. Can road maps overlaid with an organizing skeleton of colored strings, as it were, enable users to simply see their way to destinations on maps, painlessly restoring spatial awareness?

2 What Skeletons Have Been Hiding

Many researchers have noted that local driving experts in major cities typically exhibit a common approach to wayfinding [2, 8, 29]. They rely on what has been termed a “skeleton” of major highways [19], a finding we independently discovered in our work developing maps for wayfinding traffic signage. We called this skeleton “intermediate wayfinding paths” [3] or “tourism areas and corridors” [5]. The experts’ wayfinding strategy consists of finding the most efficient path from the starting point to the skeleton, and then to traverse the skeleton to the turn-off for the most efficient path to the end point. This remarkable result – a small subset of streets being independently discovered for optimizing wayfinding to all destinations in a given area – raises the question: what network properties distinguish these streets from the others?

Benjamin Kuipers [18] proposed a hypothesis: that the skeleton was composed of the streets rich in boundary relations – that is, a street that serves as a boundary between regions containing destinations, and thus rich in turn-offs for those destinations. Tomko et al. [31] proposed a similar approach based on space syntax: suggesting that ranking streets by between-ness centrality values plausibly corresponds to “experiential hierarchies of streets.”

In our two decades of field studies for many of the largest traffic wayfinding sign installations in North America, our mapping of wayfinding skeletons largely agree with the above hypotheses; however, our experience leads us to propose that using such purely computational analyses to determine “the skeleton” misses both cultural and topographical considerations that can affect which highways actually make the cut as the commonly traveled set of core wayfinding corridors. For example, there may be districts of a city with high crime rates that lead drivers to avoid certain arteries. And in a city like Pittsburgh, with its crazy topography of hills and hollows and rivers, there can be both cultural biases rooted in geography (“going south of the Mon River scares me”) and topographical biases (“I avoid tunnels” or “I’m taking Bigelow Blvd, it’s simpler”).

In fact, the cultural/geographical aspects of route selection were central to our sign-planning process. Our skeletal corridors would always be framed in terms of encompassing areas which would be notable for two things: they each comprise a sense of place at a distinct level of granularity and each exhibit a distinct wayfinding skeleton for travel at that level of granularity. Our areas with a sense of place correspond to Lynch's "districts," or at a finer granularity, "nodes." As he put it, districts are areas which the "observer mentally enters 'inside of,' and which are recognizable as having some common identifying character." [19]

In our sign systems, we would coin names for these areas, based on this common identifying character, and then point to the arterial skeleton inside using these names. The purpose was to create a thematic hierarchy of signage, such that an area's signed name would be predictive of the destinations to be found within. Led to a wayfinding corridor component of the skeleton inside the area (the "tourism corridor"), there would then be signs at the turn-offs for individual destinations of tourist or civic interest.

Yes, creating a hierarchy of signing is a common strategy for "wayfinding sign system" designers [7, 24]. However, we found that districts in such systems were often created for promotional or aesthetic purposes and not with regard for how such districts cohere for navigational purposes. That is, paths to districts would be signed that were actually the wrong way to go for some of the destinations within them. In the next section, we introduce the concept of the "Use-Access Island" (UAI), which we use to formalize the idea of the "well-formed" district, one whose arterial skeleton provides for shorter routings to all the destinations within the area when compared with out-of-area routings (starting from area boundary crossings).

While developing our first such sign system for the City of Pittsburgh (1994–1996), we noticed that for all of the city's notorious complexity, these arterial wayfinding skeletons could be rendered with coordinate axis-like simplicity, and at distinct levels of granularity, with one level's coordinate axes serving to organize the next lower level of areas. That is, there was an untangled map of skeletons revealing an inner logic and clarity as to how the city was organized, one level at a time. In 1997, we first published untangled maps in our atlas, "Finding Yourself in Pittsburgh," with UAIs ranging from continent-wide to local neighborhood in size [4]. Several editions of atlases later, we are now developing the *citytunr* app platform based on simultaneously syncing untangled maps for driving, transit and biking. In the next sections, we outline our untangled mapping approach.

3 Constructing the Untangled Road Map

The Use-Access Island shall be defined as a bounded area:

1. that exhibits a distinct sense of place as compared to surrounding areas of comparable geographical extent (e.g., countries, metro regions, cities, city districts, neighborhoods);
2. that encompasses a coordinate axis-like array of the wayfinding skeleton of arterials meeting the Untangling Conditions (as specified on the following pages),
3. and such that, from a given boundary crossing, this skeleton provides for shorter routings to any destination within the area as compared to routings that include out-of-area roads.

The UAI shall be our unit of map untangling: a well-formed "there," as it were. We can point to such a "there" with confidence – by definition, its skeletal elements will be able to lead optimally to turn-offs for all the destinations within the area. At a given level of geographical extent, the collection of UAIs in a region presents readily perceptible local orderings. These UAIs are in turn ordered by coordinate axis-like arterials of the next higher level (in terms of geographical extent) UAIs. And within each UAI, there may be lower order UAIs. The

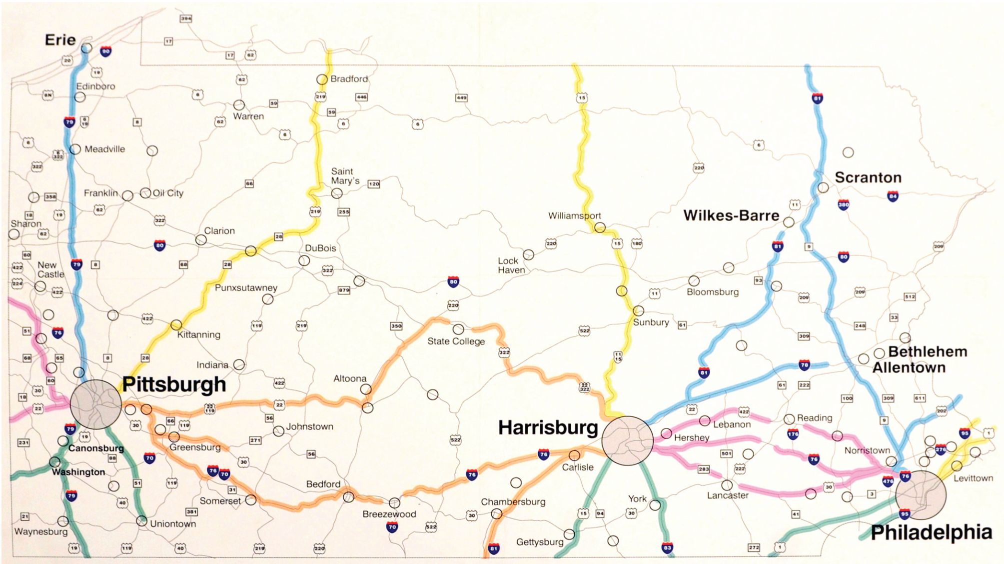


Figure 1 Untangled map of Pennsylvania metro region highways (by the author).

full mechanics of UAI skeleton construction are beyond the scope of this paper (though we do sketch out some of the method in the following), but we begin the mapping out of a UAI by locating a candidate for wayfinding corridor, an artery (or sequence of arteries) that roughly spans the area and that will typically have a high between-ness centrality value and high traffic volume. This corridor then sets the template for determining the given UAI's coordinate axis-like arterial skeleton.

Note that this wayfinding corridor may well correspond to Jiang's [14, 13] "natural road" in the sense that it may consist of "joined road segments based on the Gestalt principle of good continuity." However, unlike Jiang's natural roads that self-organize with respect to predicting traffic flow, the UAI arterial skeletons are *deliberately* organized for the purpose of displaying a ready coherence as coordinate axis-like arrays, with one spanning artery after another highlighted according to the Untangling Conditions below. Thomson [28] did examine the use of natural roads (which he termed strokes) to automatically produce generalizations of road networks that reduce their complexity by eliminating less important streets based on length and road quality. This method, however, did not relate to the generation of perceptible patterns within complex networks.

When studying a new city, we typically start by looking at the metro region as our first UAI. Unfettered by terrain (or absent grid "planning"), there is typically a city center from which emanate radiating major highways. It is interesting to picture a state like Pennsylvania (Figure 1) as being comprised of three regional UAIs (Pittsburgh, Harrisburg and Philadelphia). Those city centers can be thought of as like great seas to which the rivers of radiating highways are finding their way. These radiating arterials are color-coded so as to provide a consistency from one metro region to the next.

When uncovering coordinate axis-like patterns within city centers, we would come upon bothersome regional highways cris-crossing the local pattern and entangling what otherwise would be a simple rectangular grid. Often such "misbehaving" highways were operating at a coarser level of granularity. By dramatically thickening the lines for such highways, the local visual pattern would become clear, as would the regional one, as distinct sets of coordinate axes.

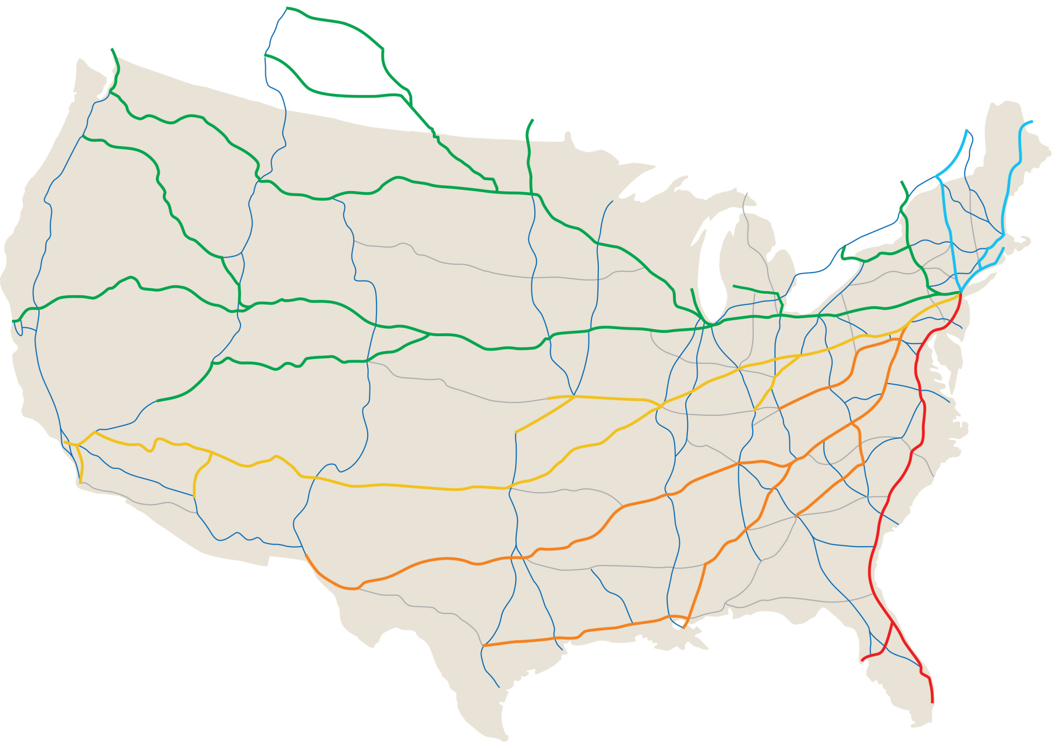


Figure 2 Map of U.S. interstate highways as polar coordinate axes centered on New York City (by the author).

In fact, regional arteries can come upon "misbehaving" highways that are actually operating at a continental level. Early in our work, we treated North America as a single UAI. Traffic engineers see the U.S. Interstate system as largely a rectangular grid.

For the purposes of visually untangling metro region maps, we found rendering the Interstate system as a polar coordinate system centered on New York City would satisfy our graphical requirements (Figure 2). We chose a color-coding scheme that went from a hot red to the south to cold blue to the north. ("Misbehaving" continental elements of the radial system are in gray, acting as their own axis system of shortcuts, as it were.)

The general form for visually untangling a metro region's skeleton takes the appearance of overlapping coordinate axis-like patterns, with each level of granularity distinguished by thickness of line and color (Figure 3). The thicker the line is, the longer the range of effect of the indicated routing. Continental-range radial highways are rendered in bright colors and the "circumferential" highways in dark blue. In the UAI of metro regions, radials are in light blue and circumferentials in yellow. Within the city center, a local grid is indicated with purple and pink axes.

Of course, things can get quite complicated inside a city center. In the real world, grids of roadways bump into barriers, collide with one another, follow old cow paths, are forced to cope with mountains and valleys, and can generally get into all kinds of mischief to keep from looking well-ordered. With the help of graphical conventions that we developed, we have found it possible to resolve any city's wayfinding skeleton into layers of UAIs of comparable geographical extent such that the coordinate axis-like appearance within each UAI can be readily perceived.

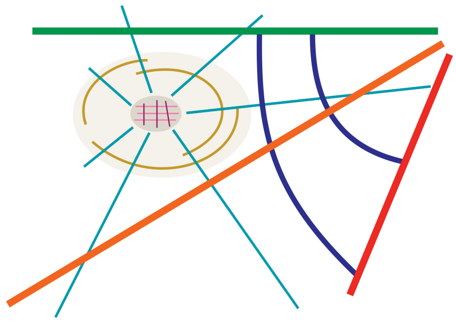


Figure 3 General form of untangling a metro region.

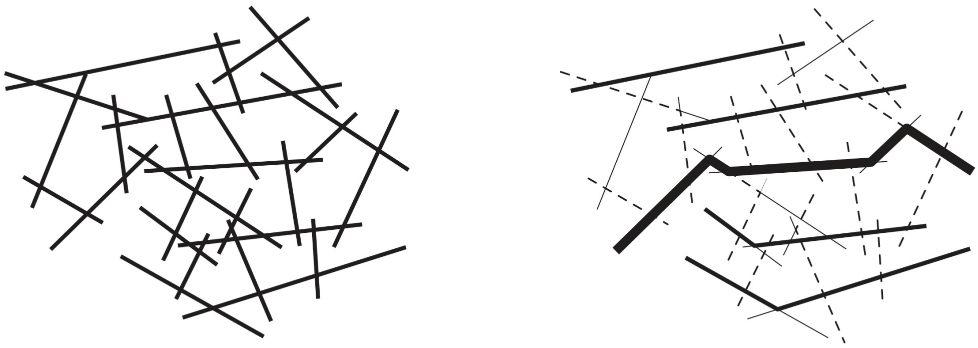


Figure 4 Pick-up Sticks Map – before untangling (left) and after (right).

For example, to point to a particularly perverse possibility, we created a pick-up sticks-like map (Figure 4), and then "untangled" it by resolving it into four implied layers of routings (thick black, thin black, dashed lines and light gray lines).

The Pick-Up Sticks Map meets our Untangling Conditions for an untangled map, as follows:

1. Skeletal arteries shall be rendered as a coordinate axis (rectangular or polar) of a recognizable type (radiating, circumferential, x-axis, y-axis) when they share the same general sense of flow for that type over the range of their encompassing UAI.
2. No axis of a given type for a given UAI shall cross another of the same type.
3. A given UAI may exhibit more than one layer of coordinate axes, as long as each layer is assigned a distinct degree of line thickness or color-type (bright colors vs gray tones, for example).
4. A coordinate axis arterial may branch at either end or both ends, as long as the branchings do not cross one another and they exhibit the same general sense of flow.

Not allowing like-axes to cross, though permitting them to branch, have proven sufficient in practice to preserve the appearance of coordinate axis-like ordering with the help of our graphical conventions: we allow for "connectors" and "separators" within our wayfinding skeletons. If you look closely at our Pennsylvania example above, we did not connect the orange arterials emanating from Pittsburgh to the ones from Harrisburg. In practice, a section of the meeting point would be rendered in gray. In general, the highways of one

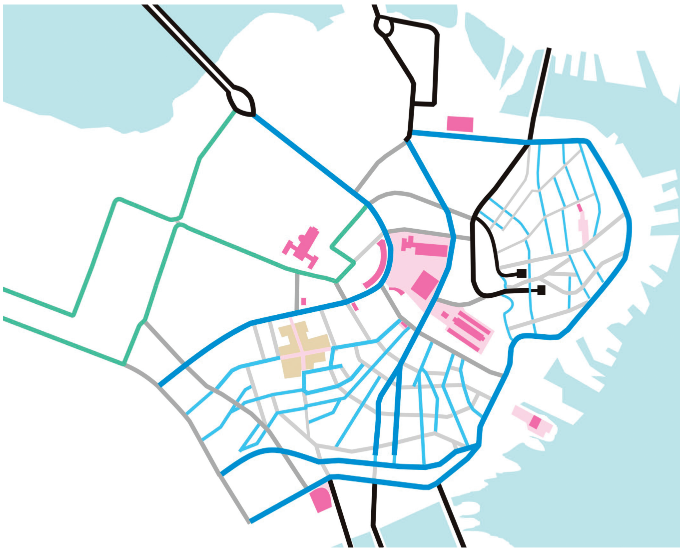


Figure 5 Boston untangled (by the author).

coordinate system can interconnect with the highways of another in a not well-behaved way, whether in the same UAI or neighboring UAIs or overlapping UAIs of differing granularity. This corresponds to how highways have been built over time, or by different entities at the same time in neighboring places. An 1890s road grid can be served by a 1930s era bypass highway which in turn can be served by a 1960s era expressway. How these highways of different eras interconnect is often not pretty (not orderly in appearance, in other words).

The solution is to allow for what we term routing objects – series of road segments that serve to link skeletal elements of different coordinate axis systems. We typically use gray tones to indicate such connectors. Note that connectors can even be quite long, serving as shortcuts cutting across an otherwise orderly grid. By having them join the family of gray connectors, they become their own level of meta-axes as it were. What we have found is that with the use of these connectors and separators, map readers appear able to readily perceive the coordinate-like systems of different types across multiple layers.

4 Dealing with Terrain and "Naturalistic" Street Plans

Given an unlimited number of layers, and the availability of connectors and separators, in theory there is no network that cannot be resolved into a technically untangled map. In practice, there is a bit of human artistry at work to produce maps in which humans can readily perceive the layers of skeletal elements as coordinate axis-like.

Terrain can obviously distort the shape that skeletons take. In Figure 5, the UAI of Boston's North End and Downtown is spanned by three thick blue arterials that roughly correspond to the shape of the encompassing peninsula. When the middle arterial branches threaten to touch the outer one, we introduce separators. As these arterials curve around the UAI, they serve to define three smaller UAIs, each with its own rectilinear-like grid of light blue and gray elements. Black lines are the major incoming highway connectors. The pair of green lines span the Back Bay/Beacon Hill UAI as an unusual one-way pairing.

Terrain can actually be a friend of order, even when it would at first appear to be the enemy. Pittsburgh's South Side Slopes (Figure 6) are a notorious tangle of switchbacks.

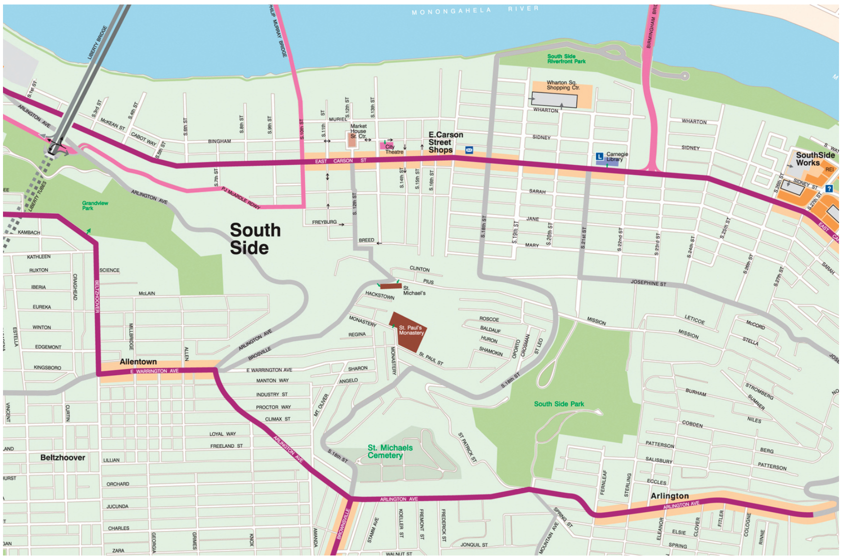


Figure 6 Pittsburgh's South Side Slopes, Untangled (by the author).

Visitors often get lost as routings twist and turn, out of sight of any orienting landmarks. But it turns out that a very simple grid lurked under this apparent disorder.

One street traces the river valley, and it is simple to follow: East Carson St. At the top of the hill, there are a series of streets that trace the ridgeline. One of the tricks the area likes to play on motorists is that it can be difficult to determine how to stay on the ridge. For example, at one five-point intersection, the road ahead that dips is actually the one that eventually rises back up and stays on the ridgeline. The roads ahead that are rising in the immediate view are the ones that just out of sight precipitously drop down to the valley floor.

We solved this by placing signs specifically to keep people on the ridge, and then placing signs for the turns to take you back to the valley floor. At its essence, the terrain is actually enforcing a simple grid of river valley artery, ridgeline artery, and the switchbacks that run between them. No one could perceive that from immediate environmental cues.

In Figure 6, the valley floor route and the ridgeline route are in purple, and the switchbacks running between them are in gray. The pink routes are "y-axis" routings for the Pittsburgh-wide UAI.

Of course, humans can be the design agent behind apparent complexity, independent of terrain. Pinehurst Village in North Carolina is infamous for its naturalistic, curving layout of streets, with few intersections at right angles and with many of them having multiple streets converging simultaneously, and curvaceously. The Village was designed by Olmsted, Olmsted & Eliot [26], including the same Olmsted responsible for the design of the intense tangle of paths that comprises the Central Park "rambles" in New York City. With heavy tree cover and primary landmarks well hidden from nearby state highways, Pinehurst poses a serious navigational challenge to visitors. This is truly a UAI with no apparent coordinate system axes in sight (Figure 7).

It turns out there is a solution for untangling this UAI. In the smaller scale map of the Pinehurst area (Figure 8), the surrounding regional state highways are marked in purple and pink. We have also noted the major landmarks: the Carolina Inn, the #2 Golf Course's clubhouse, the Holly Inn, and the village's business district (shaded in light tan).

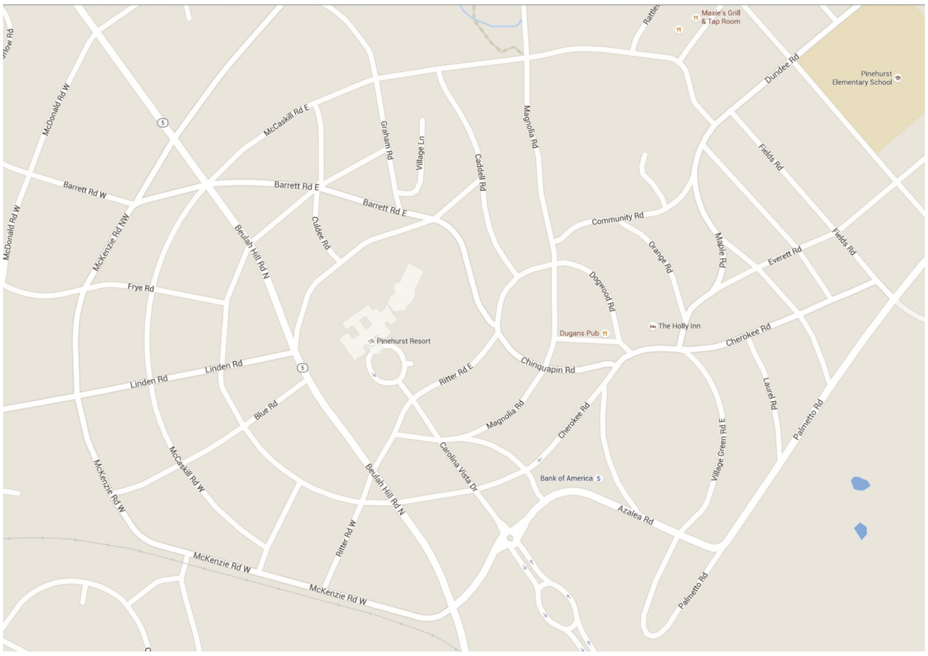
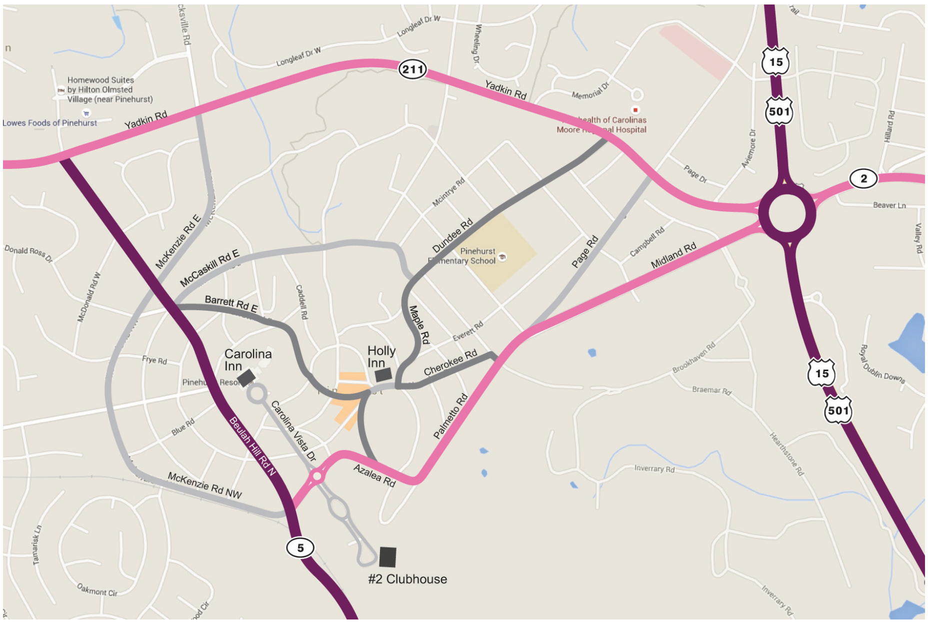


Figure 7 BEFORE – Screen shot of Google Map of Pinehurst (Map data ©2017 Google).

Highlighting arteries that optimally connect the commercial district with the surrounding regional highways yields a pattern of roads radiating out from the Holly Inn. This turns out to be appropriate, as the Holly Inn was the very first large structure in Pinehurst. Note that right in front of the Holly Inn, we use light gray as a separator between the two sets of radiating dark-gray lines to make explicit this radiating structure. The other thick light gray lines represent highly traveled shortcuts between highways as well as a circuit around the residential area west of Route 5. These act as circumferential routings with respect to the Holly Inn. Lastly, the straight, thin light-gray lines highlight the route connecting the two most important places in Pinehurst: the Carolina Inn and the Clubhouse for one of the world's most famous golf courses.

Note that there is nothing in the actual environment of the physical streets marked in the grays above, both light and dark, to distinguish them from the other original village streets; the spanning artery designations above are an artifact of the untangling process, made up to help navigation in the Village. Clearly, the Olmsteds had no intention of making navigation easy inside Pinehurst. (The straight ceremonial street connecting the Carolina Inn to the Clubhouse was a later addition, not part of the original design of curvaceous streets.)

Now imagine someone with the "after" map in Figure 8 on the screen of a smartphone, with the pulsating blue dot showing his or her position, per GPS. We would propose that such a person would have little trouble keeping track of where they are with respect to any destination, and immediately appreciate how to head to where they want to head, as compared to how they would feel with the unmodified Google map. They would have a sense of how the village "works." Zooming in and out of this map would be able to reveal far more details, within an instantly available Village-wide context.



■ **Figure 8** AFTER – untangled version of Pinehurst at smaller scale (by the author).

5 Untangled Maps: Determining Routes

In both Hirtle et al. [11] and Tomko et al. [30], the difficulties in communicating navigational instructions are explored. In particular, the latter states: "While maps – a medium to capture survey spatial knowledge – have been extensively studied in terms of spatial data quality, to our knowledge such frameworks do not exist for route spatial knowledge."

We propose that iterating UAI-untangling across a region may well provide such a mapping framework. Since in iterative UAI untangling, arterials are rendered explicitly in terms of their here-to-there function within each UAI, how does this aid the user in actual route determination? For one, there is a hierarchy of "chunking" of routes which Klippel et al [15] and others have assumed to be "crucial for . . . conceptualization of routes."

Consider a routing between a given point A and point B (Figure 9a). In general, the routing between them can be constructed in terms of UAIs as follows. There exists a UAI that contains both points and spanning elements of the arterial skeleton (for example, the Pennsylvania Turnpike running between a destination in the Pittsburgh area and one in the Philadelphia area).

There will then be a UAI that contains each of the end points that intersects with each end of the spanning artery (say, regional expressways connecting to exits at either end of the Turnpike) as illustrated in Figure 9b.

This process can be iterated to the finest-grain mesh of UAIs, with spanning arterials eventually passing close to the end points, leaving only local non-arterials to traverse to the destination (typically a matter of no more than few blocks from the nearest UAI arterial), as illustrated in Figure 9c.

At each point in the selection of a spanning arterial, the user sees an explicit set of options from which to choose that are able to be chunks of nine options or less [20, 15]. If, in a given UAI, there are more than 9 spanning arterials of a given axis type, color differences can be introduced to chunk the arterials into groups of nine or less.

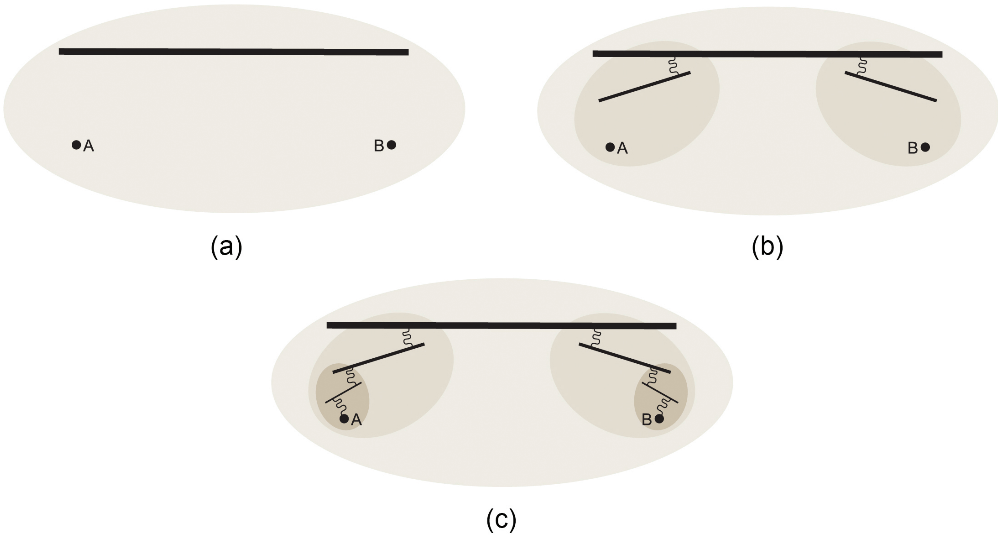


Figure 9 UAI route construction.

For example, in our polar coordinate-like interpretation of the U.S. Interstate system (Figure 2), we introduced four color groupings for the radials (ranging from hot red aiming south to ice blue aiming north). Likewise, if there are more than nine UAIs to choose from at a given level of the arterial selection process, the UAIs can be grouped in chunks of nine or fewer by introducing a hierarchy in thematic titles and area coloring.

In this way, at any point in the arterial selection process, through the organization of groupings of UAIs into a commonly understood geographical progression (e.g., state to region to neighborhood), the user faces a relatively small number of comparative choices at each level of granularity.

In our firm's work, we have applied iterative UAI untangling to more than a dozen major metro areas in the US and Canada. Over the past two years, we've also applied the process to transit maps to particularly interesting effect. For example, the official system map for the 100+ bus routes of Pittsburgh is so complex as to be largely indecipherable for most routings in the central core. In tests with our untangled version, users were able to simply "see" their way by bus with confidence, handily beating the time it takes just to enter a destination address in Google maps. (See the transit tab at `citytunr.com`, our Pittsburgh web app that is in beta, which also includes untangled "slippy maps" at four zoom levels for driving and biking.)

6 Concluding Thoughts: What Use Are Untangled Maps?

In the Theme Section Editorial of the opening issue of the *Journal of Spatial Information Science*, Tenbrink and Winter [27] discuss the difficulty the current state of automatically-generated spatial information has in being "cognitively suitable" for the user. The problem appears to boil down to integrating what is relevant to the user over granularity. On the other hand, "in spite of the complex relationship between granularity and relevance, humans typically manage to present information in an integrated and coherent way, switching flexibly and smoothly between levels of granularity according to the expected relevance for the information seeker." [27] It goes on to suggest that "research in this area can take two approaches: either an empirical approach, studying the human ability to learn about it; or an engineering approach, implementing and testing models of this capacity in spatial information systems." We propose that iterated UAI untangling as a model for capturing routing spatial knowledge is suitable for testing.

Note that we are not suggesting that simply showing untangled maps on small screens would fully replace automated systems as *the* solution. However, as Klippel et al. [16] point out, "it becomes critical to find mechanisms that preserve structurally and cognitively salient patterns to enable environmental learning and create spatial awareness." For example, we can imagine a hybrid system, in which GPS-based, turn-by-turn instructions are provided in the context of an untangled map system, perhaps most suitably on a tablet-like screen, as comes standard in a Tesla automobile, for instance. Users would be able to apprehend the untangled structure of routings as they went along, feeling oriented at each turn to both that structure and to their position relative to the desired destination. They could also decide if the "optimal" routing provided by their navigational device makes sense given the availability of nearby routings perceived amongst the untangled arteries. Quick changes to where they want to head or how they want to get there could potentially be enacted by the user without having to take time to transmit a changed destination and/or routing-preference to the GPS system. They would simply see how that new routing would work in the untangled mapping. Moreover, as the user gets near to their destination, an untangled map that makes travel to parking options transparent would provide a capability that most current systems lack.

Is there a route-determining application of untangled maps that would be better without any routing-automation beyond fine-grain parking finding? Untangled bus-transit maps may be an example. Automatic transit directions have a checkered history of directing users on convoluted itineraries when a simple one is possible [10] – if a user could determine a transit routing with just a glance at an untangled map, and at the same time attain a mastery of how transit works in a city, an automatic app might seem a fussy (and unreliable) bother by comparison.

There is another type of application we have in mind as well. In the context of the supposed coming age of the self-driving car, we heard the chief engineer for Google's effort on the "60 Minutes" TV program bragging that all someone will need to do is "plug in their destination and go." [32] That's fine if all you want to do is visit your Aunt Martha, but what if you are new to an area and want to explore the possibilities? Most automated map systems feel cumbersome at best in their indices and/or search strategies for displaying destination options – they certainly do not convey a sense of how a city "works." It would seem, then, that a map interface that could capture such spatial knowledge of a city and empower users' choices based on multi-granular spatial awareness of destination options could be a powerful application for such vehicles, an interface that potentially enables the user to "know the city" better and faster than existing systems.

Does the untangled map system truly work fast enough to be cognitively suitable for the above semi-automated and non-automated applications? When is such navigation faster and more satisfying an experience for the user than with automated systems [1]? When is the flexibility and resilience of navigating with the aid of untangled survey knowledge a clear advantage? As of yet, there has not been rigorous testing of this model; we invite researchers to test the cognitive suitability of untangled maps.

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References

1 Barry Brown and Eric Laurier. The normal natural troubles of driving with GPS. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 1621–1630. ACM, 2012.
2 William G. Chase. Spatial representations of taxi drivers. In *The acquisition of symbolic skills*, pages 391–405. New York: Plenum, 1982.
3 Robert Firth. Comprehensive Interim Report on Pittsburgh's Visitor-Path Wayfinding Sign System. Delivered to the Carnegie Institute, Pittsburgh, PA, 1994.
4 Robert Firth. *Finding Yourself in Pittsburgh*. Pittsburgh: Informing Design, Inc., 1997.
5 Robert Firth. Maryland's Statewide Tourist Area and Corridor Signing Program. Maryland State Highway Administration, 2014. `http://www.roads.maryland.gov-/OOTS/TAC_Brochure.pdf`.
6 Christian Freksa. Strong spatial cognition. In S. Fabrikant, M. Raubal, M. Bertolotto, C. Davies, S. Freundschuh, and S. Bell, editors, *Spatial Information Theory (COSIT 2015)*, volume 9368 of *Lecture Notes in Computer Science*, 2015.
7 David Gibson. *The Wayfinding Handbook*. Pinceton Architectual Press, New York, 2009.
8 Reginald G. Golledge. *Wayfinding behavior: Cognitive mapping and other spatial processes*. JHU press, 1999.
9 Stephen Hirtle. Dinosaurs, Slide Rules and Maps. Presentation to Cognitive and Linguistics Aspects of Space, 2010(a).
10 Stephen Hirtle. *Geographical design: Spatial cognition and geographical information science*. Morgan & Claypool Publishers, 2011.
11 Stephen Hirtle, Kai-Florian Richter, Samvith Srinivas, and Robert Firth. This is the tricky part: When directions become difficult. *Journal of Spatial Information Science*, 2010(1):53–73, 2010.
12 Toru Ishikawa, Hiromichi Fujiwara, Osamu Imai, and Atsuyuki Okabe. Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology*, 28(1):74–82, 2008. `doi:10.1016/j.jenvp.2007.09.00239`.
13 Bin Jiang. Street hierarchies: a minority of streets account for a majority of traffic flow. *International Journal of Geographical Information Science*, 23(8):1033–1048, 2009.
14 Bin Jiang, Sijian Zhao, and Junjun Yin. Self-organized natural roads for predicting traffic flow: a sensitivity study. *Journal of statistical mechanics: Theory and experiment*, 2008(07):P07008, 2008.
15 Alexander Klippel. Wayfinding choremes: Conceptualizing wayfinding and route direction elements. *Spatial Information Theory*, 1, 2003.
16 Alexander Klippel, Stephen Hirtle, and Clare Davies. You-are-here maps: Creating spatial awareness through map-like representations. *Spatial Cognition & Computation*, 10(2-3):83–93, 2010.
17 Benjamin Kuipers. Modeling spatial knowledge. *Cognitive science*, 2(2):129–153, 1978.
18 Benjamin Kuipers, Dan G Tecuci, and Brian J Stankiewicz. The skeleton in the cognitive map: A computational and empirical exploration. *Environment and behavior*, 35(1):81–106, 2003.
19 Kevin Lynch. *The image of the city*. Cambridge: MIT press, 1960.
20 George A. Miller. The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological review*, 63(2):81, 1956.
21 Daniel R Montello. Spatial orientation and the angularity of urban routes: A field study. *Environment and Behavior*, 23(1):47–69, 1991.
22 Daniel R. Montello. Cognitive research in GIScience: Recent achievements and future prospects. *A research agenda for geographic information science*, pages 61–91, 2009.

23 Avi Parush, Shir Ahuvia, and Ido Erev. Degradation in spatial knowledge acquisition when using automatic navigation systems. In *International Conference on Spatial Information Theory*, pages 238–254. Springer, 2007.

24 Romedi Passini. *Wayfinding in architecture.* New York: Van Nostrand Reinhold Co. Limited., 1984.

25 Falko Schmid, Kai-Florian Richter, and Denise Peters. Route aware maps: Multigranular wayfinding assistance. *Spatial Cognition & Computation*, 10(2-3):184–206, 2010. doi:10.1080/13875861003592748.

26 Robert A. M. Stern, David Fishman, and Jacob Tilove. *Paradise planned: the garden suburb and the modern city.* The Monacelli Press, 2013.

27 Thora Tenbrink and Stephan Winter. Presenting spatial information: Granularity, relevance, and integration. *Journal of Spatial Information Science*, 2010(1):49–51, 2010.

28 Robert Thomson and Rupert Brooks. Exploiting Perceptual Grouping for Map Analysis, Understanding and Generalization: The Case of Road and River Networks. *Graphics Recognition Algorithms and Applications*, pages 148–157, 2002.

29 Sabine Timpf, Gary Volta, David Pollock, and Max Egenhofer. A conceptual model of wayfinding using multiple levels of abstraction. *Theories and methods of spatio-temporal reasoning in geographic space*, pages 348–367, 1992.

30 Martin Tomko and Kai-Florian Richter. Defensive wayfinding: Incongruent information in route following. In *International Workshop on Spatial Information Theory*, pages 426–446. Springer, 2015.

31 Martin Tomko, Stephan Winter, and Christophe Claramunt. Experiential hierarchies of streets. *Computers, Environment and Urban Systems*, 32(1):41–52, 2008.

32 Bill Whitaker. Hands off the wheel. Retrieved January 16, 2017, from. http://www.cbsnews.com/news/self-driving-cars-google-mercedes-benz-60-minutes/.

33 Alexander Zipf and Kai-Florian Richter. Using focus maps to ease map reading – developing smart applications for mobile devices. *Künstliche Intelligenz. Sonderheft Spatial Cognition*, 4(02):35–37, 2002.