Accessibility Analysis at a Fine Spatial Scale

Matthew Wigginton Conway

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Abstract

Accessibility analysis is often applied at the scale of metropolitan regions or larger areas. This study applies accessibility analysis to a very small area with a fine temporal resolution, and explores some of the consequences and challenges to this approach.

Accessibility analysis is frequently applied at macro scales, from metropolitan regions up to large nations (e.g., Busby 2004, ch. 5; Geurs 2006, ch. 4; Weber and Sultana 2013, 447–449). It is also frequently applied over long time scales, as in a before-and-after analysis of the effect of an infrastructural change (e.g. Busby 2004, ch. 5). This project attempts to go the other way and apply this type of analysis to very small areas over short temporal scales. The area studied is campus of the University of California at Santa Barbara, and the adjacent student community of Isla Vista. Accessibility is computed to eateries for each hour of the day for a typical week (similar to Goulias et al. 2013, 6–8), capturing daily and weekly cycles. These are then compiled into animations showing the change in accessibility through time.

1 Methodology

Data on eateries were received from the UCSB Interactive Campus Map project and updated with recent changes. The data contained the opening hours for many of the eateries, but opening hours had to be collected for some. The hours were encoded in a machine-readable format using OpenStreetMap's opening_hours microformat.[1] These data were then used to create 168 files for each hour of the week, indicating which eateries were open at that time, using a script written in JavaScript using node.js.[2] Accessibility was measured at five minutes after the hour. As many eateries close on an even hour, this helps avoid a border effect.

Network data were obtained from the OpenStreetMap (OSM) project.[3] The network data were initially insufficient, so improvements were made and contributed back to the OSM master database. The final data used were retrieved

1. `http://www.netzwolf.info/en/cartography/osm/time_domain/`
2. All of the scripts used in this project are available at `http://www.github.com/mattwigway/temporal-accessibility`.
3. `http://www.openstreetmap.org`

from the OSM database on May 29, 2013 at 8:39 PM UTC; no modifications were made hereafter.

The OSM data were used to build an OpenTripPlanner (OTP) graph so that OTP's batch analyst tools could be used to calculate various accessibility measures. The latest development snapshot available at the time of analysis was used (*OpenTripPlanner* 2013).[4]

Batch analyst configuration files were created for the two modes under analysis, walk and bicycle, and a Python script was used to generate separate files for each mode and time of day. Each time of day file contained all eateries and a weight for each one. An eatery was given a weight of 1 if it was open and 0 if not. Finally, a shell script was used to run batch analyst on each configuration file. This took approximately 4 hours on an 2GHz single-core AMD Athlon64 3200+ with 4GB of RAM running an up-to-date Ubuntu 12.04 LTS install and using OpenJDK version 1.7.0_21. This resulted in a GeoTIFF file for each combination of time of day and mode.

The accessibility measure used was a simple cumulative-opportunity measure:

$$A_i = \sum_{j=1}^{n} \begin{cases} w_j, & \text{if } t_{ij} < t_{max} \wedge t_{ij} > 0 \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

Where A_i is the accessibility at location i, w_j is the weight of opportunity j (0 or 1 in this case, depending on whether the opportunity is open at the current time), t_{ij} is the travel time by the given mode from location i to opportunity j, and t_{max} is the threshold for consideration of an opportunity. t_{max} was set to 5 minutes in this project, because this is half the walking time between two major groups of eateries, those in Isla Vista and those near the University Center. Specifically, OTP-estimated walking time from the intersection of Pardall Rd. and Embarcadero del Norte in Isla Vista and the front of the University Center on campus was used. This is an admittedly small value for the threshold, but the study area is very propinquitous; there are many eateries concentrated in a small area. The $t_{ij} > 0$ constraint is a side effect of how the software works; when a trip cannot be calculated the value is set to zero. Internally t_{ij} is represented in seconds as floating-point values, so this is unlikely to have any effect on the output.

Results were visualized using QGIS[5] and a Python script to render each frame. Color schemes were obtained using ColorBrewer.[6] The frames were then assembled into videos in the Ogg Theora format.

All of the software used, including the scripts, is open source. This has many benefits. Firstly, these tools are accessible to anyone with the computing power[7]

4. The software's assumptions about bicycling permissions were modified slightly for this project; the version actually used is at `https://github.com/mattwigway/OpenTripPlanner/commit/b3dc38b`

5. `http://www.qgis.org`

6. `http://colorbrewer2.org`

7. Computing power is a minor issue; this analysis was performed on a desktop computer that is 10 years old. Projects with a larger area, of course, require more computing power.

and interest to use them. This is especially valuable in terms of the analysis. Journey planning and travel time calculation software is far more complicated than can be described by a few formulae in an article. The software necessarily incorporates many assumptions about walking speeds, delays at intersections, and many other things. By using open-source software, all of these assumptions can be examined by looking at the source code.

2 Results

The animated maps of accessibility are available at `http://www.indicatrix.org/ucsb-accessibility`. When looking at the map showing accessibility by walking, one sees that there are many opportunities in Isla Vista (to the west), and a good number on campus (to the east). The cycling map shows less variation between campus and Isla Vista; due to the increased speed of the bicycle, almost all of the eateries open at a given time are accessible by bicycle within 5 minutes. The same cutoff (that is, the same value of t_{max}) for the cumulative aggregation was used for both modes, to facilitate comparisons, but this value captures variation in the walking times much better than in the cycling times.

A static map was also made for lunchtime on a Tuesday, as this is a time when many people are looking for an eatery (Figure 1; K. Goulias, pers. comm.). Here one can see that cycling accessibility is much greater than walking accessibility due to shorter travel times; with a bicycle, Isla Vista eateries are easily accessible from campus, and vice-versa. The high accessibility in the area near north of the University Center (Figure 2) is an artifact of the cumulative accessibility measure used. This area is within 5 minutes of many Isla Vista eateries as well as the University Center eateries, so both are included in its accessibility. If distance-decay were being used, the eateries accessible at this location would be discounted; being five minutes from each of two eateries is not necessarily twice as good as being at one eatery and ten minutes from the other.

The animations capture both a daily and a weekly cycle. In the daily cycle, opportunities increase in the morning and decrease in the evening, unsurprisingly. On campus, the increase starts later, and the decrease earlier, than in Isla Vista. The eateries on campus largely serve a workday (or school day) crowd, with little available in the evening. The eateries in Isla Vista serve a residential population, but one that is often home at midday; as students, schedules are not 8 to 5 but are often in small chunks scattered throughout the day. Thus, Isla Vista can support a large amount of secondary diversity (restaurants in this case) despite having only a single primary use (residence). People still appear at different times of day (and night), which satisfies Jacobs's formulation for city diversity (Jacobs [1961] 2011, 198). Isla Vista and the University are clearly delimited. They meet Kevin Lynch's well-known definition of districts: they "can be recognized internally" and can be "mentally [gone] inside of," as when someone says "I'm on campus" or "I'm in IV" (Lynch 1960, 66). That said, they are also very close to each other and thus traveling from one to the other to reach an opportunity is not overly burdensome.

The most dominant component of the weekly cycle is that the eateries on campus are largely not open on the weekends. The weekend days don't show two areas of accessibility, but rather just the one centered on Isla Vista.

Another component is that some eateries stay open later on the weekends than on weekdays. This is hard to see in the animations, but Figure 3 shows the additional eateries open at 1:05 AM on Saturday morning morning compared to 1:05 AM on Tuesday morning. They are few, but there are some.

Two additional cycles could be hypothesized, but are not discernible from the present analysis. One is a quarterly cycle; at the end of the quarter and into final exams, many eateries have extended hours to accommodate the number of students who wish to study late at night. The other would be an annual cycle; it is likely that during summer, when many students are not present, the hours of some establishments are reduced.

One challenge with mapping accessibility over such a small area is that slight errors in the network or in the assumptions of the trip planner can lead to large errors (percentage-wise) in the final result. For instance, if travel time is over or underestimated by, say, 1 minute, that could be 30% of the total trip time. This issue encompasses a number of specific problems, which are described below.

The cycling map is most likely systemically underestimated slightly. OpenTripPlanner currently does not model bicycle parking, which is a minor issue in the context of trip planning in a large city. Indeed, the trip planner cannot know if the user has private bicycle parking at their destination, for example. Also, in many places, it is considered acceptable to lock one's bicycle to a signpost or other convenient item, so long as one is not blocking traffic. At UCSB, this is not the case; bikes must be parked in designated bike parking areas or they will likely be impounded. The time it takes to park one's bike could be a significant part of total trip time given the short lengths of the trips, as previously mentioned. The bike does increase one's accessibility (usually),[8] but not as much as the maps might lead one to believe.

Additionally, microaccessibility analysis requires a very accurate network, with all links represented. Particularly on a campus, this can be difficult. Campuses tend to have a very complex network of small paths that must be digitized. At UCSB, additional paths were digitized for this project, but the initial goal was only to correct a few areas, and as such a systematic survey was not undertaken. In the interests of time, some area of campus were not surveyed at all, and the existing data in OSM was used. Most areas of campus were walked and notes were used to improve OSM data, but a more rigorous study would need to do a more systematic survey.

Also, on a university campus and at the micro scale of analysis, there are many links that are not paths. For instance, Figure 4 shows an area where there are no direct links, but cutting across the basketball courts allows one to easily make a long trip much shorter. Also, one often cuts through buildings

8. Unless one is traveling across a large no-cycling area, in which case one must go around or walk one's bike.

to reach one's goal. For instance, the quickest way from the north to south sides of the University Center is to go through the building (Figure 5). The building is not, however, open 24/7, so additional modelling of the opening hours of parts of the network would be needed, as well as path data through buildings. Neither cutting across areas not designated for walking nor cutting through buildings is modelled in this study. Modelling paths across sports areas is difficult because one must know whether it is appropriate to cut across a particular field. Modelling paths through buildings is difficult because one must know the internal path structure of the building as well as the hours the building is open.

Traversal permissions are another issue when modelling any environment, but a campus in particular. A conversation with a UC police officer shed some light on this. At UCSB, cycling is a primary mode of transport, and there are strict regulations about where cycling is allowed, with paths that forbid cycling as well as paths that are for the exclusive use of cyclists. One issue with routing is that it can be difficult to know *a priori* what paths allow a particular traversal mode. In some areas, the rules are rarely followed; in many residential areas it is technically illegal to cycle but cycling is common. For the purposes of this analysis, cycling was forbidden in these areas. In addition, an oversight in the analysis allowed cycling on a few small plazas where it should not have been allowed. These represent a very small percentage of any trip.

Some artifacts are present around intersections, where intersections appear to be more accessible than the middle of blocks. This is a known issue with OpenTripPlanner that is being addressed (A. Byrd, pers. comm., June 6, 2013). It was initially thought to occur only when measuring cycling accessibility, but it appears to occur also when measuring walking accessibility (see, for example, Figure 3). This issue should be addressed soon.

Maintaining the eateries dataset is also difficult, as there is much turnover of businesses in Isla Vista. For example, between the time data was collected for this project and the project was completed, a 7-Eleven opened with much fanfare in the study area. The hours can also be difficult to obtain; not all stores post hours, and in some cases hours from different sources (e.g. a sign and the website, or the website and an employee) are contradictory.

3 Further Research

As mentioned previously, there are limits to the simple cumulative-accessibility measure used in this study. It does not discount opportunities by distance but rather simply decides whether an opportunity is to be counted or not based on a threshold. This simplistic measure was chosen for this study because it does not require the estimation of function parameters, other than the relatively understandable threshold (t_{max}; Equation 1). This parameter was estimated in this case based on the travel time between the centers of two areas of activity and did not require behavioral research. Travel survey data could, of course, provide a better estimate for t_{max}.

Moreover, travel data could provide a basis for estimating parameters to more accurate models. For instance, in a gravity-based model, the function and its parameters could be estimated based on travel data (Geurs 2006, 33). One issue with collecting travel data at this micro scale is privacy; very specific data would need to be gathered and analyzed. Aggregation even to the level of a TAZ would be unwise. One must also question whether established measures of accessibility scale well to such a small environment.

This would lead logically to combining and analyzing quantitative accessibility analysis with survey data. For instance, Sara Matthews has analyzed modal choice at Humboldt State University in the context of residential location and sense of place (among other variables; Matthews 2012a, 2012b). Her article focuses on trips to Humboldt State University; a similar survey could be used to analyze the effects of accessibility to many opportunities.

Behavioral influences on accessibility could also be considered. As previously mentioned, Isla Vista and the campus could be considered separate districts in Lynch's schema (Lynch 1960, 66–78). It would be interesting to see if this divide influences perceptions of accessibility.

Cognitive regionalization is a phenomenon that has been documented in the literature at macro scales. For example, it has been shown that when given a distance estimation task, there are clearly defined regions, and between-region distances are overestimated relative to within-region estimates (Friedman and Montello 2006, 340). Care should be taken applying this research to micro scales; a critical difference is that, at the micro scale, people have likely experienced the distances in question directly. That said, it would be interesting to see if a similar effect is observed between districts.[9] If between-district distances are overestimated relative to within-district, that would change accessibility in this case since there are two well-defined districts. Eateries in other clusters would be undervalued relative to eateries in the cluster one currently occupies.

4 The Usefulness of Standalone Accessibility Measures

One could criticize standalone activity measures as tools for decision support, especially ones using simplistic measures such as the cumulative-opportunities measure used herein. With advanced activity-based models like SimAGENT (Southern California Association of Governments) and SF-CHAMP (San Francisco County Transportation Authority), these simple measures of accessibility would seem obsolete. However, there are several benefits. Accessibility measures, especially ones like the cumulative-opportunities measure used here, are very understandable for both the public and non-technical decision makers. Thus, they can be used to present in an understandable manner proposals that have been tested using more complex models.

9. The author does not know of any research that does this.

They can also play a role in individual decision support. Noted transit planner Jarrett Walker has promoted isochrone-generating tools for two purposes: promoting understanding of the consequences of location choices, and helping people to see the possibilities afforded by the transport network (Walker 2012). Generating single-location isochrones, or accessibility measures such as these, could allow people to make informed decisions about locating residences or small businesses, things not usually studied quantitatively. Indeed, Walk Score® provides services to real-estate brokers and individuals, providing this type of analysis to inform location choices (Walk Score®).

5 Conclusion

This study examined accessibility to eateries at the University of California, Santa Barbara, using the open-source OpenTripPlanner software. A simple cumulative-opportunities accessibility measure was used. The study was performed at a micro scale of analysis; the study area is small and relatively dense. The temporal scale was also small; measures showing accessibility at each hour of every day during a typical week were generated. Several challenges with accessibility analysis at this scale were encountered; accurate networks are paramount, and small errors in absolute terms can be very large in relative terms. Further research would involve correlating the results of this study with behavioral data, as well as looking at the behavioral and perceptual assumptions of the model of accessibility itself. In any further research, it is important to bear the effects of scale in mind; techniques which are effective at the metropolitan scale may not be at the micro scale. The measure, while simplistic, is valuable as an understandable way to present transport information.

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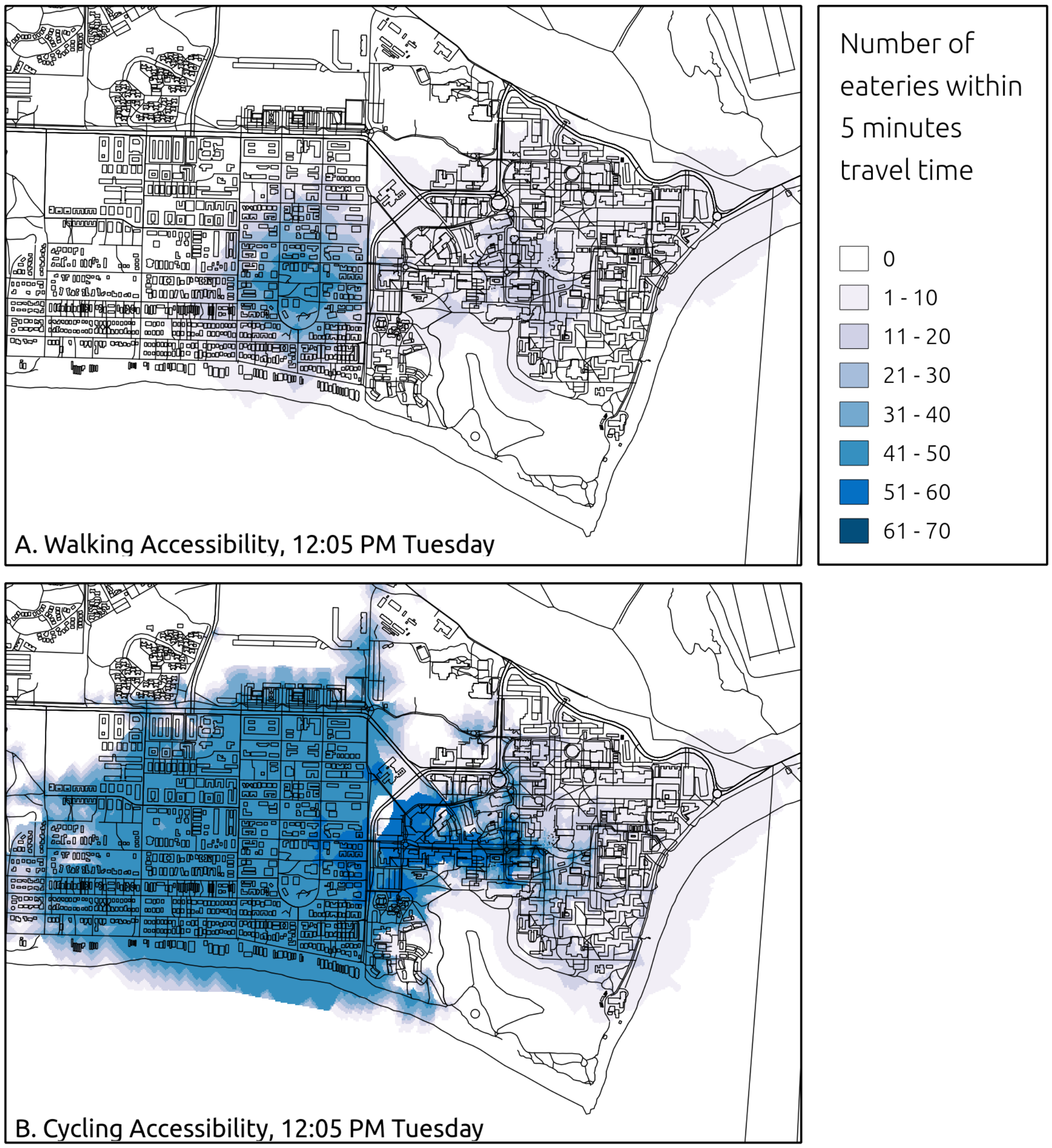

Figure 1: Accessibility to eateries at lunchtime (12:05 PM) on a Tuesday, from locations on campus and in Isla Vista, by cycling and walking

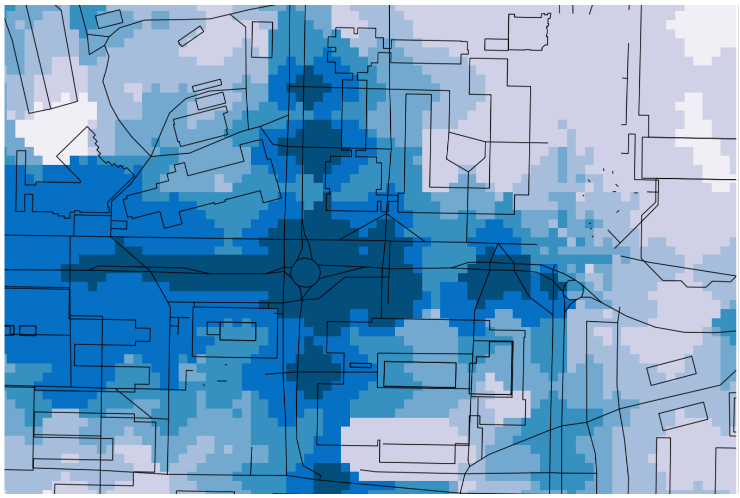

Figure 2: Cycling accessibility to eateries, at roundabout north of the University Center. Detail of Figure 1.

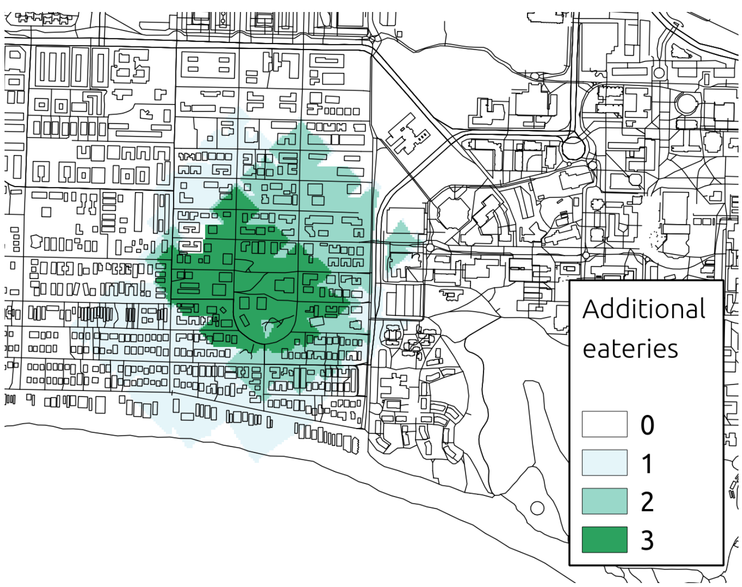

Figure 3: The difference in walking accessibility between Saturday morning and Tuesday morning, at 1:05 AM. There are a few more businesses open Saturday morning.

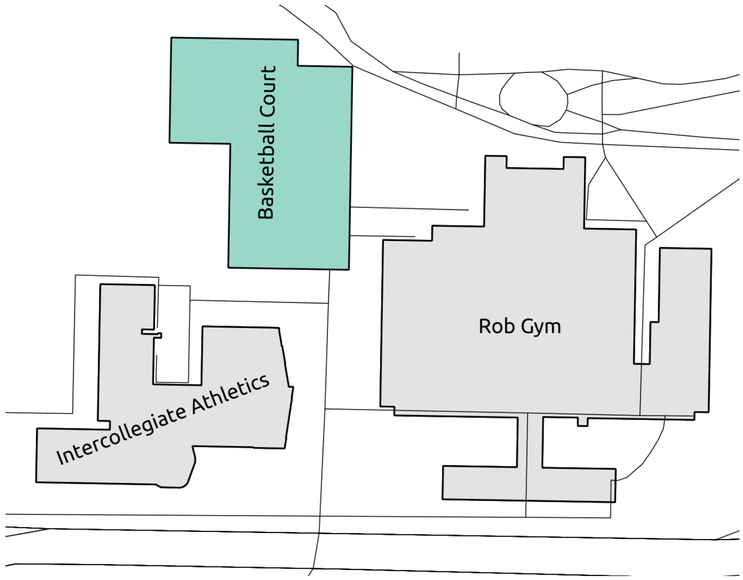

Figure 4: The basketball court by Robertson Gym. It is much shorter to cut across the court than to go around on a dedicated footpath.

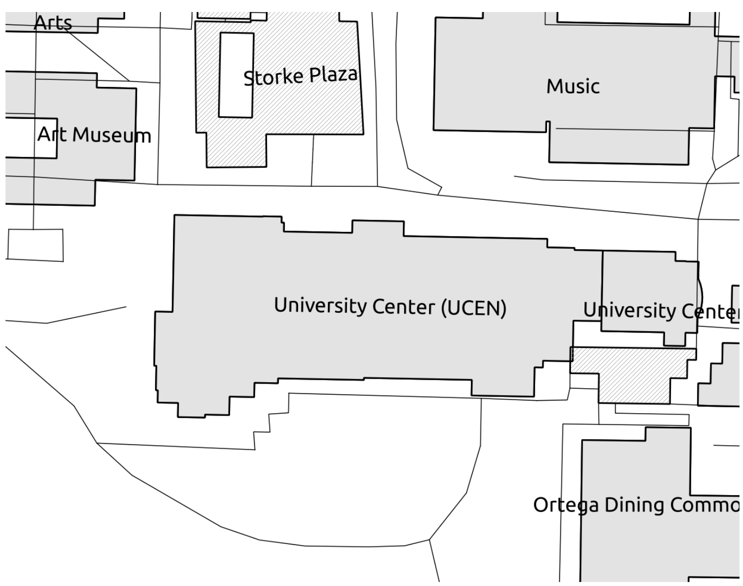

Figure 5: The University Center. It is much shorter to cut through the building to get from the north to south sides than it is to go around.

References

Busby, Jeffrey R. 2004. "Accessibility-Based Transit Planning." Master's, Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/32414.

Friedman, Alinda, and Daniel R. Montello. 2006. "Global-Scale Location and Distance Estimates: Common Representations and Strategies in Absolute and Relative Judgments." *Journal of Experimental Psychology. Learning, Memory, and Cognition* 32, no. 2 (March): 333–46. ISSN: 0278-7393. doi:10.1037/0278-7393.32.3.333. http://www.ncbi.nlm.nih.gov/pubmed/16569150.

Geurs, Karst. 2006. *Accessibility, Land Use and Transport: Accessibility Analysis of Land-Use and Transport Developments and Policy Strategies.* Delft: Eburon. http://igitur-archive.library.uu.nl/dissertations/2006-0613-200112/.

Goulias, Konstadinos G., Chandra R. Bhat, Ram M. Pendyala, Yali Chen, Rajesh Paleti, Karthik Konduri, Seo Youn Yoon, and Daimin Tang. 2013. *SimAGENT Overview.* Technical report. Santa Barbara, CA: Southern California Association of Governments. http://www.scag.ca.gov/modeling/pdf/ABM/ABMreport01_Overview.pdf.

Jacobs, Jane. (1961) 2011. *The Death and Life of Great American Cities: 50th Anniversary Edition.* Reprint, New York: Modern Library. Citations refer to the Modern Library edition.

Lynch, Kevin. 1960. *The Image of the City.* Cambridge, MA: The MIT Press.

Matthews, Sara E. 2012a. "How Space and Place Influence Transportation Trends at Humboldt State University." *The California Geographer* 52:1–17. http://hdl.handle.net/10211.2/2930.

———. 2012b. *To Drive or Bike: Examining Transportation Choices at Humboldt State University.* Paper presented at the annual meeting of the California Geographical Society, Davis, CA, April 27th–29th.

OpenTripPlanner. 2013. Commit 6d8a9b78b66efe2e800971ba75c58c496e98cecd, with slight modifications. http://opentripplanner.org.

Walk Score®. *For Real Estate Professionals.* Accessed June 9, 2013. http://www.walkscore.com/professional/real-estate-professionals.php.

———. *WalkScore.com.* Accessed June 9, 2013. http://www.walkscore.com/.

Walker, Jarrett. 2012. *The Need for Maps of Your Freedom.* http://www.humantransit.org/2012/11/the-need-for-maps-of-your-freedom.html.

Weber, Joe, and Selima Sultana. 2013. "Why Do So Few Minority People Visit National Parks? Visitation and the Accessibility of "America's Best Idea"." *Annals of the Association of American Geographers* 103 (3): 437–464.

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