USC Dornsife
Dana and David Dornsife
College of Letters, Arts and Sciences
Spatial Sciences Institute

SSCI 580 (Section 35890), Spatial Computing

Units: 4

Term — Day — Time: Spring, 2016; Wednesdays and Fridays; 12:00 p.m. – 1:50 p.m.

Location: Allan Hancock Foundation Building, AHF 145 D

Instructor: Wei Yang, Ph.D.
Office: AHF B55A
Office Hours: Wednesdays and Fridays 2:00 p.m. - 3:00 p.m. PT; also available most other days by appointment via email
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IT Help: Richard Tsung
Office: AHF B57B
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Course Description
This class will cover the theoretical foundations, methods, techniques, and software systems for spatial computing. This includes the latest research in a variety of topics that are central to spatial computing, including the geospatial semantic web, geospatial mashups, spatial data mining, geocoding, location-based services, volunteered geographic-information, feature extraction, layer registration and alignment. Students will also gain a deep understanding and hands-on experience in the software for spatial computing, including geographic information systems (e.g., ArcGIS), Geospatial mashups (e.g., Bing Maps, Google Earth), Open Source Software (e.g., QGIS, PostGIS), Python packages related to geospatial analysis (e.g., Tweepy, Geopy, Geoparsing). Students will learn about the wide variety of geospatial data and services available, including how to find relevant data and transform it as needed so that it can be used for solving specific problems.

Learning Objectives
On completion of this course, students will be able to:

- Describe the theoretical foundations of geospatial data and its various representations.
- Select and use the appropriate geographic information system to solve any of a variety of real-world problems.
- Build integrated applications that combine geographic data and applications for processing that data.
- Discuss the relevant spatial computing systems and techniques for working with geospatial data.
- Apply relevant spatial computing techniques to solve spatial problems.
- Critically evaluate spatial computing software and systems and determine whether they have been applied in appropriate ways.

Prerequisite(s): None
Co-Requisite (s): None
Concurrent Enrollment: None
Recommended Preparation: None

Course Structure
This residential course will unfold on a weekly basis. Each week will be focused on a particular aspect of Spatial Computing, delivered through lectures, reading assignments, class participation, and hands-on computer lab assignments. Students are encouraged to bring questions and problems to class to be explored in that congenial setting. The aim is to encourage deep-learning by active participation. In this class the labs are designed to give students first-hand experience with the wide variety of software and programming packages that can be used for spatial computing. At the end of this semester, students will complete a final project including a 10-minute presentation and a final report.

Technological Proficiency and Hardware/Software Required

We have several technologies that will facilitate our course work and our interactions, despite our dispersed locations. These include:

Blackboard – All course materials and correspondence will be posted on the course Blackboard site. As a registered student, you will find this course will show up in your available classes no later than 12:00 noon, PT on the first day of classes. It is here that the day-to-day flow of the course will be recorded.

Discussion boards – On the Blackboard site, we will post a number of discussion threads related to various course topics. These threads are very important in terms of providing support to each other while working on class exercises to share hints and helpful tips, as you would do in a classroom setting. I will check the discussion threads periodically and offer occasional comments. Please send your course instructor an email directly if you have a question or concern that requires my immediate attention.

GIST server and tech support – This course will utilize the SSI GIST Server which is a virtual desktop. You can access the GIST Server at: http://gis-gateway.usc.edu. If you are unable to connect to the server or experience any type of technical issues, send an email using your USC account to GIST Tech Support at gistsupport@dornsife.usc.edu, making sure to copy (cc) me on the email. GIST Tech Support is available Mondays through Fridays, from 10 a.m. to 5 p.m. PT.

Every student should be proficient with the MS Office suite (Excel, PowerPoint, and Word), all of which are available on the GIST Server. Documents in other software formats will not be accepted. In addition, students' personal computer systems must meet several technology requirements:

- An up-to-date computer with a fast Internet connection.
- A functional Web camera together with a microphone or headset for live sessions.
- A modern Web browser (Firefox, IE or Chrome is recommended) to run ArcGIS which is provided online via the GIST Server; you do not need to install ArcGIS on your own computer.

Required Readings and Supplementary Materials

1. Clarke K C (2011) *Getting Started with Geographic Information Systems* (Fifth Edition). Upper Saddle Creek, NJ, Prentice Hall (Chapters 2 and 3)
2. Clemmer G (2013) *The GIS 20 Essential Skills.* Redlands, CA, Esri Press
3. Shekhar S, Zhang P, Huang Y, and Vatsavai R R (2003) Trends in spatial data mining. In Kargupta H and Joshi A (eds) *Data Mining: Next Generation Challenges and Future Directions.* Cambridge, MA, AAAI/MIT Press: 357-380
4. Microsoft (2013) Bing Maps Videos. WWW document, http://www.microsoft.com/maps/developers/videos.aspx
5. Google (2013) Google Earth Tutorials. WWW document, http://www.google.com/earth/outreach/tutorials/all.html

6. Wong J and Hong J I (2007) *Making Mashups with Marmite: Towards End-User Programming for the Web.* Pittsburgh, PA, Carnegie Mellon University, Human-Computer Interaction Institute Paper No 65 (available at http://repository.cmu.edu/hcii/65)
7. Intel (2012) Mashmaker Intel® Mash Maker: Mashups for the Masses. WWW document, http://software.intel.com/en-us/articles/intel-mash-maker-mashups-for-the-masses
8. Tuchinda R, Szekely P, and Knoblock C A (2008) Building mashups by example. In *Proceedings of the International Conference on Intelligent User Interfaces*, Gran Canaria, Canary Islands, Spain
9. Gupta S and Knoblock C A (2010) Building geospatial mashups to visualize information for crisis management. In *Proceedings of the Seventh International Conference on Information Systems for Crisis Response and Management (ISCRAM 2010),* Seattle, Washington
10. Wang G, Yang S, and Han Y (2009) Mashroom: End-user mashup programming using nested tables. In *Proceedings of the Eighteenth International World Wide Web Conference (WWW 2009),* Madrid, Spain: 861-870
11. Jiang B (2012) Volunteered Geographic Information and computational geography: New perspectives. In Sui D, Elwood S, and Goodchild M F (eds) *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice.* Berlin, Springer: 125-138
12. Goodchild M F and Li L (2012) Assuring the quality of volunteered geographic information. *Spatial Statistics* 1: 110-120
13. Junglas I A and Watson R T 2008 Location-based services. *Communications of the ACM* 51(3): 65-69
14. Dey A K and Abowd G (2000) Towards a better understanding of context and context-awareness. In *Proceedings of the Computer Human Interactions 2000 Workshop on The What, Who, Where, When, and How of Context-Awareness,* The Hague, The Netherlands
15. Myles G, Friday A, and Davies N (2003) Preserving privacy in environments with location-based applications. *Pervasive Computing* 2(1): 56-64
16. Bakshi R, Knoblock C A, and Thakkar S (2004) Exploiting online sources to accurately geocode addresses. In *Proceedings of the Twelfth ACM International Symposium on Advances in Geographic Information Systems,* Washington, DC: 194-203
17. Goldberg D W and Cockburn M G (2010) Improving geocode accuracy with candidate selection criteria. *Transactions in GIS* 14(S1): 129-146
18. Goldberg D W, Wilson J P, and Cockburn M G (2010) Toward quantitative geocode accuracy metrics. In *Proceedings of the Ninth International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences,* Leicester, United Kingdom: 329-332

19. Goldberg D W, Knoblock C A, and Wilson J P (2007) From text to geographic coordinates: The current state of geocoding. *Journal of the Urban and Regional Information Systems Association* 19(1): 33-46
20. Davis C A Jr, Fonseca F T, and Borges K A V (2003) A flexible addressing system for approximate geocoding. In *Proceedings of the Fifth Brazilian Symposium on GeoInformatics,* Campos do Jordao, Brazil
21. Zandbergen P A (2008) A comparison of address point, parcel and street geocoding techniques. *Computers, Environment and Urban Systems* 32: 214-232
22. Knoblock C A (2012) Reduce data overload. *Earth Imaging Journal* March/April 2012: 28-30
23. Lieberman M D, Samet H, Sankaranarayanan J, and Sperling J (2007) STEWARD: Architecture of a spatio-textual search engine. In *Proceedings of the Fifteenth ACM International Symposium on Advances in Geographic Information Systems*, Seattle, Washington: 186-193
24. Lieberman M D, Samet H, and Sankaranarayanan J (2010) Geotagging: Using proximity, sibling, and prominence clues to understand comma groups. In *Proceedings of the Sixth Workshop on Geographic Information Retrieval,* Zurich, Switzerland
25. Amitay E, Har'El N, Sivan R, and Soffer A (2004) Web-a-where: Geotagging Web content. In *Proceedings of Twenty-seventh International Conference of the ACM Special Interest Group on Information Retrieval (ACM SIGIR 2004),* Sheffield, United Kingdom
26. Rauch E, Bukatin M, and Baker K (2003) A confidence-based framework for disambiguating geographic terms. In *Proceedings of the 2003 HLT-NAACL Workshop on Analysis of Geographic References,* Edmonton, Alberta: 50-54
27. McCurley K S (2001) Geospatial mapping and navigation of the Web. In *Proceedings of the Tenth International World Wide Web Conference,* Hong Kong
28. Quercini G, Samet H, Sankaranarayanan J, and Lieberman M D (2010) Determining the spatial reader scopes of news sources using local lexicons. In *Proceedings of the Eighteenth ACM International Conference on Advances in Geographic Information Systems,* San Jose, California: 43-52
29. Manola F and Miller E (2004) Rdf primer. Technical report, W3C. http://www.w3.org/TR/2004/REC-rdf-primer-20040210/.
30. W3C (2004) Rdf vocabulary description language 1.0: Rdf schema. Technical report, W3C, February 2004. http://www.w3.org/TR/2004/REC-rdf-schema-20040210/.
31. Harris S and Seaborne A (2012) Sparql 1.1 query language. Technical report, W3C. http://www.w3.org/TR/2012/PR-sparql11-query-20121108/.
32. Markus K, Frantisek S, and Horrocks I (2012) A description logic primer. http://arxiv.org/pdf/1201.4089.pdf.
33. Swartz A (2002) The Semantic Web in Breadth. WWW document, http://logicerror.com/semanticWeb-long

34. Palmer S B (2001) The Semantic Web: An Introduction. WWW document, http://infomesh.net/2001/swintro/
35. Fonseca F T (2008) Geospatial semantic web. In Shekhar S and Xiong H (eds) *Encyclopedia of GIS.* Berlin, Springer: 388-391 (follow the "Open URL", read pp. 367-376 in NetLibrary).
36. Egenhofer M J (2002) Toward the semantic geospatial web. In *Proceedings of the Tenth ACM International Symposium on Advances in Geographic Information Systems,* McLean, Virginia: 1-4
37. Kuhn W (2005) Geospatial semantics: Why, of what, and how? In Spaccapietra S and Zimányi E (eds) *Journal on Data Semantics III.* Berlin, Springer-Verlag Lecture Notes in Computer Science Vol. 3534: 1-24
38. Becker C and Bizer C (2009) Exploring the geospatial semantic web with DBpedia Mobile. *Web Semantics: Science, Services and Agents on the World Wide Web* 7: 278-286
39. Koubarakis M, Kyzirakos K, Karpathiotakis M, Nikolaou Ch, Sioutis M, Garbis G, and Bereta K (2012) Introduction in stRDF and stSPARQL. WWW document, http://www.strabon.di.uoa.gr/files/stSPARQL_tutorial.pdf
40. Parundekar R, Knoblock C A, and Ambite J L (2010) Aligning ontologies of geospatial linked data. WWW document, http://www.isi.edu/integration/papers/parundekar10-lstd.pdf
41. Janowicz K, Scheider S, Pehle T, and Hart G (2012) Geospatial semantics and linked spatiotemporal data: Past, present, and future. Semantic Web 3: 321-332 (available at http://www.semantic-web-journal.net/content/geospatial-semantics-and-linked-spatiotemporal-data-–-past-present-and-future)
42. Gupta S and Knoblock C A (2010) A framework for integrating and reasoning about geospatial data. In *Proceedings of the Sixth International Conference on Geographic Information Science (GIScience 2010)*, Zurich, Switzerland
43. Michalowski M and Knoblock C A (2005) A constraint satisfaction approach to geospatial reasoning. In *Proceedings of the Twentieth National Conference on Artificial Intelligence (AAAI '05)*, Pittsburgh, Pennsylvania
44. O'Brien M A and Irvine J M (2004) Information fusion for feature extraction and the development of geospatial information. In *Proceedings of the Seventh International Conference on Information Fusion,* Stockholm, Sweden
45. Savopol F and Armenakis C (2002) Merging of heterogeneous data for emergency mapping: Data integration or data fusion? *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences* 34(4/w4): 668-674
46. Chen C-C, Knoblock C A, and Shahabi C (2006) Automatically conflating road vector data with orthoimagery. *GeoInformatica* 10: 495-530
47. Chen C-C, Knoblock C A, and Shahabi C (2008) Automatically and accurately conflating raster maps with orthoimagery. *GeoInformatica* 12: 377-410

48. Wu X, Carceroni R, Fang H, Zelinka S, and Kirmse A (2007) Automatic alignment of large-scale aerial rasters to road-maps. In *Proceedings of the Fifteenth ACM International Symposium on Advances in Geographic Information Systems,* Seattle, Washington: 1–8
49. Zitova B (2003) Image registration methods: A survey. *Image and Vision Computing* 21: 977-1000
50. Chiang Y-Y (2009) Harvesting Geographic Features from Heterogeneous Raster Maps. Unpublished PhD Dissertation, Department of Computer Science, University of Southern California (Chapter 2, pp. 12-57)
51. Li L, Nagy G, Samal A, Seth S C, and Xu Y (2000) Integrated text and line-art extraction from a topographic map. *International Journal of Document Analysis and Recognition* 2: 177-185
52. Kerle N and de Leeuw J (2009) Reviving legacy population maps with object-oriented image processing techniques. *IEEE Transactions on Geoscience and Remote Sensing* 47: 2392-2402
53. Pouderoux J, Gonzato J C, Pereira A, and Guitton P (2007) Toponym recognition in scanned color topo- graphic maps. In *Proceedings of the Ninth International Conference on Document Analysis and Recognition (ICDAR 2007),* Curitiba, Paraná, Brazil: 531-535
54. Leyk S and Boesch R (2010) Colors of the past: color image segmentation in historical topographic maps based on homogeneity. *GeoInformatica* 14: 1-21

Description and Assessment of Assignments

Your grade in this class will be determined on the basis of several different assessment tools:

Resume Assignment (2%): Please prepare your resume in the SSI template which will be provided to you. Unless you opt out, your resume will be included in the Spatial Sciences Institute Graduate Programs Resume Book. This resume book is compiled annually and, along with our web presence, is used to promote our programs, and more importantly, your skills, experience and professional aspirations.

Reading Assignments (26%): Students will be assigned weekly reading assignments.

Class Participation (26%): There will be weekly discussion on the lectures and reading assignments.

Lab Assignments (18%): Students will be assigned 9 labs during the entire.

Final (28%): Students are required to submit a final project proposal (8%) in the middle of the semester. Students will submit a final project report (10%) and make a presentation (10%) at the end of the semester.

Grading Breakdown

Assignments	Number	Points	% of Grade
Resume Assignment	1	2	2
Reading Assignments	13	2	26
Class Participation	13	2	26
Lab Assignments	9	2	18
Final Project, components			
- Final Project Proposal	1	8	8
- Final Project Presentation	1	10	10
- Final Project Report	1	10	10
Totals	**39**	**-**	**100**

Assignment Submission Policy

Assignments will be submitted for grading via Blackboard using the due dates specified in the Course Schedule below.

Additional Policies

Students are expected to attend and participate in every class session and to complete and upload all assignments before the deadlines detailed in the Course Schedule. Students can turn in a lab assignment up to seven days late with a 20% penalty.

Course Schedule: A Weekly Breakdown

	Topics / Daily Activities	Readings and Homework	Deliverables/Due Dates
Week 1 Jan. 11	**Introduction/Spatial Data Basics:** Brief introductions with a discussion of class goals, technology, plans, and expectations. Basics of spatial data, incl. representations of spatial data, coordinate systems, datums, projections, etc.	Clark (2011) Resume Assignment Class Participation Assignment (short survey) Access GIST Server Assignment	Submit Resume Assignment no later than 11:00 p.m. on Wednesday, Jan. 13 Submit Class Participation Assignment no later than 11:00 p.m. on Wednesday, Jan. 13 Complete Access GIST Server Assignment in class on Friday, Jan. 15
Week 2 Jan. 19	**Geographic Information Systems:** Hands-on use of ArcGIS to develop familiarity with the basic capabilities of GIS systems.	Clemmer (2013) Class Preparation Assignment (short reading response) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Jan. 20

			Complete Access GIST Server Assignment in class on Friday, Jan. 22
Week 3 Jan. 25	**Spatial Data Mining:** Introduction to techniques for spatial data mining.	Shekhar et al. (2003); Class Preparation Assignment (short reading response) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Jan. 27 Complete Access GIST Server Assignment in class on Friday, Jan. 29
Week 4 Feb. 1	**Online GIS and Geospatial Mashups:** A discussion and hands-on training with online GIS software, with a particular focus on Google Map and Google Earth. Introduction to the research, tools, and techniques for building online integrated applications with geospatial data, focusing on the ability to rapidly compose new applications from available sources and services.	Microsoft (2013) and Google (2013) Class Preparation Assignment (short reading response) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Feb. 3 Complete Access GIST Server Assignment in class on Friday, Feb. 5
W**eek 5** Feb. 8	**Volunteered Geographic Information (VGI):** Recent developments in volunteered geographic information (VGI), including the widely used sources, techniques for crowd-sourcing data, and attempts to evaluate the quality of VGI data.	Wong & Hong (2007); Intel (2012); Tuchinda et al. (2008); Gupta & Knoblock (2010); Wang et al. (2009); Jiang (2012); Goodchild & Li (2012) Class Preparation Assignment (short reading response) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Feb. 10 Complete Access GIST Server Assignment in class on Friday, Feb. 12
Week 6 Feb. 16	Location-based Services and Privacy: Various features of successful modeling applications, including the need for authenticity (i.e., the evaluation of the model relative to the real system), parsimony (i.e., the desirability of keeping things simple and avoiding unnecessary	Junglas & Watson (2008); Dey & Abowd (2000); Myles et al. (2003) Class Preparation Assignment (short reading response) Final Project Proposal	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Feb. 17 Discuss and Write a Final Project Proposal in class on Friday, Feb. 19

	complications), transparency (i.e., the need for clear documentation and user-friendly organization of both the model and the documentation), and patience (i.e., the fact that it takes time to construct and/or implement a model).		
Week 7 Feb. 22	**Geocoding:** Methods and approaches to linking addresses to location	Bakshi et al. (2004); Goldberg & Cockburn (2010); Goldberg et al. (2007, 2010); Davis et al. (2003); Zandbergen (2008) Class Preparation Assignment (short reading response) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Feb. 24 Complete Access GIST Server Assignment in class on Friday, Feb. 26
Week 8 Feb. 29	**Linking Text to Location:** Methods and approaches for linking textual information to geographic locations.	Knoblock (2012); Lieberman et al. (2007, 2010); Amitay et al. (2004); Rauch et al. (2003); McCurley (2001); Ouercini et al. (2010) Class Preparation Assignment (short reading discussion) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Mar. 2 Complete Access GIST Server Assignment in class on Friday, Mar. 4
Week 9 Mar. 7	**Geospatial Semantic Web Basics:** Semantic Web basics of representing and querying data. Methods for representing and reasoning about geospatial data using the infrastructure of the Semantic Web.	Manola & Miller (2004); W3C (2004); Harris & Seaborne (2012); Markus et al. (2012); Swartz (2002); Palmer (2001); Fonseca (2008); Egenhofer (2002); Kuhn (2005); Becker & Bizer (2009) Class Preparation Assignment (short reading discussion) Access GIST Server Assignment	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Mar. 9 Complete Access GIST Server Assignment in class on Friday, Mar. 11
Week 10 Mar. 21	**Geospatial Linked Data:** Research and techniques for creating and using geospatial linked data.	Koubarakis et al. (2012); Parundekar et al. (2010); Janowicz et al. (2012) Class Preparation Assignment (short reading discussion)	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Mar. 23

		Access GIST Server Assignment	Complete Access GIST Server Assignment in class on Friday, Mar. 25
Week 11 Mar. 28	**Spatial Data Reasoning:** Introduction to techniques for spatial data reasoning.	Gupta & Knoblock (2010); Michalowski & Knoblock (2005); O'Brien & Irvine (2004); Savopol & Armenakis (2002) Class Preparation Assignment (short reading discussion) Final Project	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Mar. 30 Discuss and Prepare Final Project in class on Friday, Apr. 1
Week 12 Apr. 4	**Registering and Aligning Geospatial Layers:** Discussion of techniques for automatically aligning various geospatial layers, including both vector and raster layers.	Chen et al. (2006, 2008); Wu et al. (2007); Zitova (2003) Class Preparation Assignment (short reading discussion) Final Project	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Apr. 6 Discuss and Prepare Final Project in class on Friday, Apr. 8
Week 13 Apr. 11	**Extracting Features from Raster Maps:** Methods for extracting features from scanned raster maps.	Chiang (2009); Li et al. (2000); Kerle & de Leeuw (2009); Pouderoux et al. (2007); Leyk & Boesch (2010) Class Preparation Assignment (short reading discussion) Final Project	Submit Class Preparation Assignment no later than 11:00 p.m. on Wednesday, Apr. 13 Discuss and Prepare Final Project in class on Friday, Apr. 15
Week 14 Apr. 18	Final Project Presentation	Final Project Presentation	Complete Final Project Presentation on Wednesday, Apr. 20 or 22
Week 15 Apr. 25	Final Project Report	Final Project Report	Submit Final Report no later than 11:00 p.m. on Wednesday, Apr. 27

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious

consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* http://studentaffairs.usc.edu/scampus/. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://www.usc.edu/schools/GraduateSchool/academic_conduct.html.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu or to the *Department of Public Safety* http://capsnet.usc.edu/department/department-public-safety/online-forms/contact-us. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* https://dsp.usc.edu/ provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* http://emergency.usc.edu will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.