

# Center for Spatial Studies Activity Report 2017–2020 and Vision 2020–2023

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## Center for Spatial Studies: Vision 2020–2023

The Center for Spatial Studies engages in convergence research, outreach, and service, to foster spatial thinking and computing within and across all academic disciplines. After focusing on raising awareness (2008–2012), on introducing spatially-enabled knowledge infrastructures (2013–2016), and on spatially-enabled and sensor-driven smart communities (2017–2020), the center is well positioned to address a new cross-cutting theme. Under its new director, Dr. Krzysztof Janowicz (beginning July 2020), the Center will be shifting its focus to *Spatial Data Science* and *Knowledge Graphs*, thereby also connecting more closely to a campus emphasis that has steadily grown over the Center’s past funding period. More specifically, the Center will focus on *spatiotemporally-explicit* machine learning models operating on these graphs.

The Center has already made significant and internationally visible contributions toward this new focus in 2019/2020 by securing a prestigious \$1 million grant as part of NSF’s new Convergence Accelerator initiative (8.5% acceptance rate), obtaining gift grants from industry, hosting an international specialist meeting, publishing papers on the topic in top-tier research outlets both in Geographic Information Science (GIScience) and Computer Science, and participating in several campus efforts, including the Masters of Environmental Data Science (MEDS), the proposal to establish a Bachelor of Science in Data Science, and the proposed Master of Science in GIS (MSGIS). Pursuing this new focus integrates well with UCSB’s and the UC system’s interest in Data Science as well as priorities of industry and government agencies across the country and internationally.

The underlying new paradigm behind knowledge graphs is transformative in a sense that it enables the retrieval, integration, and reuse, of highly diverse datasets across the sciences and (digital) humanities on the level of individual data records, not merely metadata. The Center’s current research on open knowledge networks, for instance, combines soil health data with historic slave trade records to gain a holistic understanding of food systems and their sustainability under social and environmental stress.

Following the insight that understanding *when and where* things happen is key to understanding *why* they happened or will happen<sup>1</sup>, our **vision** is to demonstrate how (geographic) space and time act as convergence catalysts to integrate heterogeneous data across domains to answer complex social and scientific questions that cannot be answered from within one domain alone. Our **mission** is to develop spatially and temporally explicit Artificial Intelligence (AI) techniques for the creation, filtering, linkage, synthesis, prediction, and forecasting of information in large-scale, cross-domain knowledge graphs. A specific application we are pursuing is to provide contextualized, real-time insights for supply chains across different sectors. We aim at demonstrating how—in a densely connected world—this type of application requires data from sources as diverse as transportation, health, climate change, communication, and historical accounts.

Given that these are the Center’s and the new director’s core areas and expertise, the Center’s success stories in 2019/2020, its track record in fostering campus, national, and international cross-disciplinary collaborations, as well as UCSB’s excellence in environmental sciences, GIScience, and computer science, the Center is poised to **provide leadership in spatial data science** and, more

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<sup>1</sup> Warf, Barney, and Santa Arias. “Introduction: the reinsertion of space in the humanities and social sciences.” In *The Spatial Turn*, pp. 17–26. Routledge, 2008.

specifically, in the sub areas of knowledge graphs and spatio-temporal reasoning to lead the field for the UC system as well as nationally and internationally for years to come.

The Center will also redesign its internal structure to implement a faculty affiliate program to make full use of the expertise across campus and foster the joint authoring of competitive proposals to NSF and beyond. The Center has already taken these steps as is evident from the current and pending proposals listed in this report (p. 7), e.g., the proposed virtual AI institute for agriculture and food systems and more specifically AI-driven precision agriculture.

## Activity Report: July 1, 2017 to June 30, 2020

The vision inspiring the Center for Spatial Studies ([spatial@ucsb](mailto:spatial@ucsb)) is that spatial thinking and computing can serve all disciplines and promote interdisciplinary problem solving in a connected world. The Center mission, thus, is to engage in convergence research on how people and technology solve spatial problems in the natural and social sciences, as well as in engineering, the humanities, and the arts with a strong focus on novel computation methods from the data sciences. The University of California has been known as a world leader in the arena of spatial studies, holding a strong reputation worldwide.

This report provides an overview of the Center's personnel, resources, and activities in research, outreach, and education, and describes the Center's initiatives from July 1, 2017 to June 30, 2020. In addition, this report proposes new initiatives for sustaining and expanding the Center's mission on campus, nationally, and internationally.

The Center was founded in July 2007 through an initiative by Michael Goodchild (Director and Prof. Emeritus of Geography), who directed the Center until his retirement in July 2012. Mary Hegarty (Dept. of Psychological & Brain Sciences) served as interim director from 2012 to 2013, until Werner Kuhn was appointed Chair of the Jack and Laura Dangermond Endowment, Director of the Center, and Professor in the Dept. of Geography. Krzysztof Janowicz was appointed Associate Director in the summer of 2017.

The Center provides a number of innovative services to the academic community at UCSB, nationally, and internationally. These include:

- Two regular seminar series (**ThinkSpatial Brown Bags**, **Spatial Technology Lunches**), where each seminar attracts between 20–40 participants. These feature interdisciplinary speakers with valuable research interests that stimulate lively discussions cross-cutting disciplinary boundaries and that would otherwise not be available to the campus community.
- Two annual community outreach events that includes the academic community and the private and public sectors: **spatial@ucsb.local** (including a poster and plenary session, typically attended by 180–250 participants), and **Spatial Lightning Talks** (attended by 60–80 participants). Over time, we have seen an increase in the number and diversity of participants for both events.
- An annual 3-day **specialist meeting** on cross-disciplinary topics attended by national and international participants from industry and academia (20–45 participants, including both graduate students and early career academics as well as established leaders of their respective domains). These meetings have helped the Center to set the agenda on several important topics such as spatially-enabled data discovery and more recently Spatial Data Science. The series has been continuous for 32 years!
- **Office space** for (inter)national visitors and students, fostering knowledge exchange and collaborations; it also provides a **meeting space** that enables the Center to host meetings for its internal and external

activities. For the upcoming period, the Center intends to make even greater use of these resources by hosting regularly scheduled events such as the newly established graduate student-oriented research skills meetings (Spatial Data Hangout series). In February 2020, and fueled by a data donation from the industry, this has led to a subgroup of students and associate director Janowicz to work on a knowledge graph for the new coronavirus (COVID-19) and its impact on global transportation and supply chains. We take pride in our ability to engage students and colleagues with diverse research interests on problems of high importance and timeliness.

In the period covered in this report (2017–2020), the two Center co-directors have received \$1,578,791 in external funding and gifts, and have welcomed eight international scholars for extended visits and collaboration. A prominent highlight during this period is the Center’s adjusted focus on (Spatial) Data Science and, more specifically, knowledge graphs, demonstrated by the Center’s involvement in several campus initiatives, organized events, important grants from NSF and the industry, and several top-tier papers. Encouraged by these successes, the Center will expand its work in this direction for the following period with a particular focus on spatiotemporally explicit methods, models, and services for knowledge graphs.

Through these continued and new initiatives, the Center aspires to maintain its position as a role model and key enabler for spatially-enabled interdisciplinary science on campus, statewide, nationally, and internationally. Further strengthening its extramural funding is another of the Center’s top priorities as is evident by the record of recently acquired and currently pending proposals.

## Personnel

The academic team leading the Center’s activities includes Werner Kuhn (current director) and Krzysztof Janowicz (associate director). Kuhn will step down in June 2020, and Janowicz will assume full directorship of the Center. Going forward, the Center will have only one director, as requested by the Dean.

In winter 2019, Emmanuel Papadakis, a postdoctoral researcher from the University of Salzburg, Austria, was hired to complement the team. Research associates and members of the Executive Committee can be found in Appendices Vc and Vd.

The administrative personnel consists of a 3/4-time administrative coordinator (Karen Doehner), a part-time graduate student to organize the Spatial Technology Lunches and Spatial Lightning Talks and to manage the center website (Anagha Uppal), and part-time IT staff (Guylene Gadal and Alex Feldwinn, for server support, desktop support, and web services management). A complete list of center personnel is available in Appendix V (pp. 26–27).

Going forward we plan to adopt a **faculty research affiliates-based model** as implemented by other centers on campus. This will enable the Center to more effectively lead collaborations between faculty across campus, e.g., the joint acquisition of external grants. We expect that external funding will cover an increasing fraction of the costs for the administrative coordinator and postdocs and have phased our budget request accordingly.

## Research Activities and Funding

The Center’s research over the past years has been driven by the interests and expertise of the Director and Associate Director, enriched and complemented by the interests of Associated Researchers, Visiting

Scholars, and students both at the graduate and undergraduate levels. For the current reporting cycle, the Center has contributed to research by attracting competitive funding for a total of \$1,578,791 (Appendix II, p. 16). This has enabled us to provide a hub for interdisciplinary collaborations on campus, nationally, and internationally, and to produce high-quality research that has resulted in peer-reviewed publications in top-tier outlets in GIScience and Computer Science as is evident by **four best paper awards** within this 3-year period. Below we present an overview of our research, including the research funding obtained by each person. A complete list of their publications can be seen in Appendix Ia (p. 11).

### Werner Kuhn (Director)

**Werner Kuhn** is an information scientist conducting research aimed at improving the usability of spatial data and information. He has collaborated for more than ten years with university libraries in Europe and the United States to bring spatial and temporal search capacities to regular library users and to extend library access mechanisms to research data. His main research contribution during this reporting cycle has been the successful conclusion of the Spatial Discovery project with the UCSB Library (and now also involving the Earth Research Institute as well as two Digital Humanities projects on campus), and the refinement and testing of the theory of Core Concepts of Spatial Information, involving half a dozen graduate students on campus and several international collaborators. These concepts form a high-level language for users of Geographic Information Systems (GIS) and other spatial computing technologies.

### Kuhn Research Funding:

#### Leadership Workshop on Location Analytics in Business

**Recipient:** Werner Kuhn

**Funding:** Esri: \$25,000

Conference support for December meeting held at the Upham Hotel. The meeting was deferred until February due to fires and mudslides in Santa Barbara.

### Krzysztof Janowicz (Associate Director)

**Krzysztof Janowicz** is an information scientist focusing on knowledge graph technologies. His work is driven by a need for better methods to publish, discover, reuse, and integrate data from highly heterogeneous sources with the overarching goal of creating a free, global, and, densely interlinked knowledge graph (coined Open Knowledge Network by NSF). Janowicz is particularly interested in combining work on classical top-down knowledge engineering with novel work on bottom-up, machine-learning methods to the learning of representations in the context of geographic entities (e.g., places) and events (e.g., landslides).

### Janowicz Research Funding:

#### Long Distance Travel in the California Household Travel Survey (CHTS) and Social Media Augmentation

**Recipient:** Kostas Goulias and Krzysztof Janowicz

**Funding: UCConnect:** \$173,409 (continuing from 2016)

The Spatial Center portion of this grant is concerned with the feature extraction of indicators for neighborhood diversity from social sensing sources such as social media to be included into models about long-distance travel.

**Linked Data for the National Map II****Recipient:** Krzysztof Janowicz**Funding:** US Geological Survey (USGS): \$68,402

This grant is part of a series of work about geographic knowledge graphs, and, here, particularly about computational space-time trade-offs for scaling the publication and querying of very large datasets from the US Geological Survey using the Semantic Web / Linked Data technology stack.

**Semantic Application Logic Design for Subject Matter Experts****Recipient:** Krzysztof Janowicz**Funding:** Siemens: \$63,937

This grant is part of a successful collaboration with a major industry partner about the role of semantic technologies and knowledge graphs in the context of question answering. Geographic examples include places of manufacturing, supply chains, and country-specific certificates.

**Semantics and Linked Data Integration for GIS****Recipient:** Krzysztof Janowicz**Funding:** Esri Inc: \$200,000

This grant is concerned with the integration of knowledge graphs into Geographic Information Systems, and, more specifically, with the retrieval and analysis of graph-based data from within a GIS in such a way that the initial data does not have to be flattened on import.

**Internet of Things 2018 Conference Support****Recipient:** Krzysztof Janowicz and Werner Kuhn**Funding:** UCSB College of Letters & Science: \$2,500

Conference support for the organization of the International Internet of Things 2018 conference in Santa Barbara. The Spatial Center acted as main organizer, i.e., local organizers and overall conference chairs. The conference was a success, and Janowicz has been invited to serve on the IoT series steering committee.

**Knowledge Graph-Assisted Knowledge Acquisition from Technical Documents****Recipient:** Krzysztof Janowicz**Funding:** Siemens: \$64,532

This is a follow-up grant as part of a successful collaboration with a major industry partner about the role of semantic technologies and knowledge graphs in the context of question answering. This specific project focuses on extracting knowledge from technical documents.

**Linked Data and Ontologies for Academic Publishing (LDOAP)****Recipient:** Krzysztof Janowicz**Funding:** IOS: \$40,000

This is grant part of a multi-year sequence of grants about the usage of knowledge graph technologies for academic publishing including work on spatial and temporal scientometrics to measure the impact of research topics across geographic space and over multiple years based on both the individual scientists as well as conference series (and journals).

**LD Connect Service Chain****Recipient:** Krzysztof Janowicz**Funding:** IOS: \$20,000

This grant is concerned with the development of an initial prototype for the extraction of scientists, temporal aspects of scientific expertise, the geographic spread of ideas, and similarity search across authors and publications more generally.

#### **NDA**

**Recipient:** Krzysztof Janowicz

**Funding: Oliver Wyman:** \$35,000

This grant is about the usage of spatial data science to predict market fluctuations for a major industry client of our client in the commodity sector.

#### **LD Connect Service Chain II**

**Recipient:** Krzysztof Janowicz

**Funding: IOS:** \$40,000

This grant is a follow-up project that aims to establish a service chain of data products for the extraction of scientists, temporal aspects of scientific expertise, the geographic spread of ideas, and similarity search across authors and publications more generally.

#### **Spatial Data Science Symposium Conference Support**

**Recipient:** Krzysztof Janowicz and Werner Kuhn

**Funding: Esri, Inc:** \$10,000

Conference support for the first Spatial Data Science Symposium 2019 in Santa Barbara.

#### **Multimodal Knowledge Graph Querying and Completion**

**Recipient:** Krzysztof Janowicz

**Funding: Siemens:** \$49,873 (awarded; not yet started)

This is a follow-up grant as part of a successful collaboration with a major industry partner about the role of semantic technologies and knowledge graphs in the context of question answering. This specific project focuses on including multi-model information.

#### **Convergence Accelerator Phase I (RAISE): Spatially-Explicit Models, Methods, and Services for Open Knowledge Networks**

**Recipient:** Krzysztof Janowicz

**Funding: National Science Foundation (NSF):** \$999,547

This grant is the result of the Spatial Center's new focus on knowledge graphs and spatial data science, and a window into our future vision of the Center. It is the first stage for a Phase II proposal for \$5 million to be submitted in April 2020. It combines the Center's expertise in knowledge engineering with its novel work on spatially-explicit machine learning.

#### **Janowicz Pending/Submitted Research Funding**

*The funding amounts reported below reflect the total awarded budgets, but not the amount designated for the Center.*

#### **SCC-IRG Track 1: Creating the Smart Human Rights City: Using Intelligent Information Infrastructure to Facilitate Citizen Engagement and Poverty Reduction**

**Recipient:** Krzysztof Janowicz (UCSB-PI)

**Funding: National Science Foundation (NSF):** \$3,624,580 (overall)

This grant is the result of the Spatial Center's focus on Smart Cities and Smart Campuses in 2018 and 2019. The Center's role in the proposal is focused on the use of social sensing techniques developed by Janowicz to simulate points-of-interest and the interaction of citizens with these POI.



**NRT-HDR: Environmental Data Science Training for Applied Research (EDSTAR)****Recipient:** Kelly Caylor (lead PI); Krzysztof Janowicz (senior personnel)**Funding:** National Science Foundation (NSF): \$2,999,789 (overall)

This grant aims at creating an open, reproducible, and comprehensive training and educational framework for the environmental sciences to close the chasm to the training received by computer scientists.

**AI Institute: Planning: Foundations and Algorithms for Responsible AI****Recipient:** William Wang (lead PI); Krzysztof Janowicz (senior personnel)**Funding:** National Science Foundation (NSF): \$500,000 (overall)

This planning grant aims at preparing a future proposal for an AI institute centered around responsible methods and usage of AI techniques.

**AI Institute: AI FARMS: Artificial Intelligence for Future Agriculture - Research and Methods for Sustainable Food Security****Recipient:** Krzysztof Janowicz (UCSB-PI)**Funding:** National Science Foundation (NSF): \$20,000,000 (overall)

This grant is the result of the Spatial Center's current and future focus on cross-disciplinary knowledge graphs and its spatial data science research at the intersection of classical top-down knowledge engineering and bottom-up, machine learning based approaches to large-scale data integration.

**Resources/Facilities**

Phelps 3510/12 serves as the administrative hub for the Center. It provides space for a 3/4-time office administrative coordinator (Karen Doehner), a post-doctoral researcher (Emmanuel Papadakis), and workstations for graduate students, interns, and international visitors. The space is amenable to hosting our events and meetings, including the Exploration Seminar in Spatial Thinking, the ThinkSpatial brown-bags, and the Technology Lunches, as well as the new Spatial Data Hangouts, workshops, and project meetings. In addition to serving the needs of the Center, the facility is also made available for hosting events organized by the Department of Geography and other campus departments.

Going forward, we plan to reconfigure our model for specialist meetings, hosting them at the Center instead of at a public venue. Instead of an annual meeting with 20–45 experts, we will implement a more workshop-oriented style by following lessons learned from UCSB's National Center for Ecological Analysis and Synthesis (NCEAS), where Janowicz is serving as a member of the Advisory Committee. Each workshop will be selected from a competitive process by a team of (inter)national experts with the assistance of the Center. The teams that submitted a successful proposal will be able to host a Center co-funded 3-day workshop for 8–12 participants with concrete goals and deliverables. We initially plan to host 3–4 such workshops per year and aim at acquiring additional sponsorship funds from Esri, NSF, and other organizations in order to increase the number and impact of the workshops held each year. Following NCEAS blueprint, we expect this model to lead to several additional cross-disciplinary publications and joint proposals.

Given the planned new faculty affiliation structure, we will also host joint meetings about emerging topics so as to foster joint publications and research grants. In fact, the Center has already started to implement this by leading several large proposals to NSF with contributors across campus.

## Summary and Future Plans

The Center has made very significant contributions to the campus, nationally, and internationally over the past 12 years, building awareness for the role of and need for spatial perspectives in research, initiating new research and educational programs, and nurturing cross-disciplinary collaboration. As detailed in this report, Kuhn and Janowicz have carefully examined the program and recalibrated the Center's mission over the past three years, recasting the initial spirit of the Center to a rapidly changing research, funding, and service landscape. Looking past 2020, the Center seeks to further broaden its international impact by launching new initiatives and by maintaining and strengthening its existing successful programs.

Following the truism that knowing *where* and *when* things happen is critical to understanding *why* and *how* they happened or will happen, the Center will focus on providing international leadership in Spatial Data Science and more specifically in GeoAI techniques for knowledge graphs. Such knowledge graphs are believed to become the backbone of contextualized cyberinfrastructure of the future and are already powering the search engines, business decisions, and question answering systems of major industrial players around the world and the Silicon Valley in particular. The Center has collaborated with two of these international players on constructing their internal knowledge graphs and aims at broadening its engagement with industry partners.

Places connect people, entities, and events together and, thus, are a densely interconnected part of all general-purpose knowledge graphs to date. Despite the key role of space and time for the integration of data across highly diverse domains and sources, handling the spatial and temporal aspects of knowledge graphs remains an open research issue. One common example, are so called spatial and temporal scopes. Statements, in knowledge graphs, are not true or false in general; they depend on the context in which they are made. For instance, many statements are only valid within certain geographic bounds such as the different Kashmir borders represented in datasets from India, Pakistan, and China. Similarly, temporal bounds express the fact that the membership of states in the European Union is changing with time. Interestingly, to date, most knowledge graphs are entirely atemporal and reduce space and places to point coordinates. The Center's work in 2019 and 2020 has shown how to improve these graphs and how these improvements have far-reaching consequences on tasks such as question answering and the prediction of links across entities. In addition, Web-scale knowledge graphs raise the question of provenance and the trustworthiness of statements. Work on these topics (including a geospatial dimension) is also on the agenda of UCSB's Center for Information Technology & Society (CITS) and the new Center for Responsible Machine Learning. Janowicz is a faculty affiliate of both and, hence, we believe that this topic can easily foster inter-center collaboration.

Abstracting from these examples, the Center's research has demonstrated—through publications in leading outlets and a large grant as part of NSF's new Convergence Accelerator initiative—that spatially-explicit models (here in the context of machine learning) substantially outperform more general models when applied to geographic data across a spectrum of tasks ranging from similarity-based information retrieval to the classification of building facades from street imagery. The Center will continue this new trajectory to provide the models, methods, and services that will spatiotemporally enable large-scale, highly heterogeneous knowledge graphs and show-case their application in domains as diverse as sustainability of food systems, supply chain management, health, and the coordination of humanitarian aid.

## New Research Initiatives

For the next three years, the Center will start several new initiatives. A vignette of selected projects in the areas of Spatial Data Science and knowledge graphs that we started in 2020 are listed below.

### Spatiotemporally-scoped Expertise Knowledge Graph and Similarity Services

The Center recently teamed up with Direct Relief to develop an expertise database to speed up the process of identifying domain experts for developing humanitarian aid emergencies. More concretely, Direct Relief often faces the situation where they have to identify experts in domains such as infectious diseases, reproductive health, emergency medicine, or transmission mapping to assist with their humanitarian aid. Expertise, however, is spatiotemporally scoped. Somebody may have worked on yellow fever 10 years ago but may have moved on to another topic since then. Similarly, an expert may be very well-versed about Ethiopia, but her knowledge may not be readily applicable to Brazil. In addition, some researchers can provide their own expertise in the field. Information about expertise over space and time is sparse. Janowicz and his team have developed the methods to model and predict expertise as well as online services for suggesting similar experts from examples during their research with IOS Press. Over the next years, we plan to adapt and improve our work to utilize knowledge graphs and machine learning to assist Direct Relief by providing a software tool to identify experts. We plan to collect data on campus first, and then grow the dataset globally.

### GeoAI and Knowledge Graphs for the Commodity Sector and Supply Chain Management

In today's world everything is connected to everything else. Events in one part of the world rapidly impact other, distant regions. For instance, a local drone attack on Saudi Arabian oil installations has had world-wide effects and was even described as a "game change" for stock markets and crude prices. Individually, such events are outliers and, thus, have not been considered in forecasting models, e.g., in the commodity sector. Jointly, however, and on a global scale, these events are not rare and they impact many actors such as states and companies across the globe. Wildfires, hurricanes, major strikes, local conflicts, migrations world-wide (among other events) all impact an increasingly densely connected network of actors. Modern knowledge graph technologies together with information extraction tools and natural language models have recently been applied to extract and contextualize relevant information on-the-fly to inform decision makers. Interestingly, these tools barely consider geographic space beyond point coordinates and cannot aggregate individual places to regions. Similarly, they do not capture temporal relations that are not explicitly mentioned in the source data. In 2020, the Center has developed a first demonstrator that spatially contextualized and enriches data with and will develop the methods needed for a working pilot over the next years in collaboration with partners from the commodity and supply chain sectors, e.g., in the agricultural domain.

### Geographic Knowledge Summarization

While summarization (e.g., from texts), has received considerable attention over the past years, knowledge graphs summarization (i.e., finding a subgraph that retains the significant substructures and meaning of the original graph) is still in its infancy. Graphs such as DBpedia have thousands of statements

about cities, such as Los Angeles, yet only a fraction of those are of value for any individual task. Going beyond individual places to regions, such as Southern California, complicates matters further as multiple source nodes must be summarized and interconnected. Early work performed by the Center in 2019 shows how work from Cognitive Science can help in finding the right balance between summarizing what is common to a region while also retaining its individual characteristics (e.g., as compared to other regions or neighborhoods). By studying methods for improved geographic knowledge graphs summarization, the Center will improve the retrieval of relevant geographic information as well mitigate the risk of drowning in data.

### Expansion of Outreach and Collaborations on Campus and Beyond

In pursuing these new challenges, the Center will continue to provide stimulating research and learning opportunities for students and faculty—opportunities that are not necessarily available in their home departments—by maintaining and further evolving its current initiatives,\* including:

- ThinkSpatial Brown-bag Lectures (*cl*)
- Spatial Technology Lunches (*cl*)
- Exploration Seminars (*c*)
- Specialist and expert meetings, un-conferences (*clni*)
- Annual outreach events (e.g., [spatial@ucsb.local](mailto:spatial@ucsb.local)) (*cln*)
- Internships for local, national, and international students during the academic year (*lni*)
- Accumulation of contents and organizing events for the Collaboratory (*cl*)
- Co-hosting and inviting prominent speakers to campus (*c*)
- Hosting and co-organizing prominent international events, e.g., conferences (*i*)
- Proposal Writing (*cn*)

\* Events designate *c* are on the campus level, *l* include the local community, *n* the national level, and *i* the international level.

In general, for the 2020–2023 period, the center aims at an increased focus on its international outreach mission. Setting the stage for expanding this new focus, the Center hosted the Internet of Things 2018 conference. Further, Janowicz is currently program chair of the international GIScience 2020 conference as well as program chair of the resource track of the International Semantic Web conference 2020.

### National and International Networking

The success of the Center for Spatial Studies continues to inspire similar efforts at other universities in the United States and internationally. Over the past years, we have taken the initial steps required to turn the many informal links between “spatial centers” into a global network. The primary goal of such a network will be to share experiences, strategies, program elements, and tools more effectively. Discussions with partners at several universities in the U.S., Canada, Australia, New Zealand, and Europe are under way to make such a network a reality. These discussions confirm the strong and growing interest in bridging geographical distance and collaborating in the creation of spatially empowered universities. Through our efforts UCSB has been acknowledged as a world leader in this effort. The university can cement that leadership through continued support and commitment to the Center for Spatial Studies.

## Appendix I: Publications and Presentations 2017–2020

### Appendix Ia. Publications

#### Publications by Werner Kuhn

##### Articles in refereed journals

- 2018 S. Winter, M. Egenhofer, **W. Kuhn**, Martin Raubal. Special Section in Honor of Andrew U. Frank. *International Journal of Geographical Information Science* 32(12): 2497–2500.
- 2018 A. Degbelo, **W. Kuhn**. Spatial and temporal resolution of geographic information: An observation-based theory. *Open Geospatial Data, Software and Standards* 3(1): 12.
- 2018 S. Scheider, J. Hahn, P. Weiser, **W. Kuhn**. Computing with cognitive spatial frames of reference in GIS. *Transactions in GIS* 22(5): 1083–1104.
- 2018 L. Jiang, P. Yue, **W. Kuhn**, C. Zhang, C. Yu, X. Guo. Advancing interoperability of geospatial data provenance on the web: Gap analysis and strategies. *Computers & Geosciences* 117: 21–31.
- 2018 A. Comber, **W. Kuhn**. Fuzzy difference and data primitives: A transparent approach for supporting different definitions of forest in the context of REDD+. *Geographica Helvetica* 73(2): 151–163.
- 2018 S. Lafia, **W. Kuhn**. Spatial Discovery of Linked Research Datasets and Documents at a Spatially Enabled Research Library. *Journal of Map & Geography Libraries* 14(1): 21–39.
- 2019 R. S. Purves, S. Winter, **W. Kuhn**. Places in Information Science. *Journal of the Association for Information Science and Technology* (11): 1173–1182.
- 2019 T. Hervey and **W. Kuhn**. Using provenance to disambiguate locational references in social network posts. *International Journal of Geographical Information Science* 33(8): 1594–1611.

##### Articles in refereed conference and workshop proceedings (full papers only)

- 2017 T. Hervey, D.W. Phillips, **W. Kuhn**. Categorizing Cognitive Scales of Spatial Information. International Conference on Spatial Information Theory, 63–66.
- 2017 L. Jiang, **W. Kuhn**, P. Yue. An interoperable approach for Sensor Web provenance. 2017 6th International Conference on Agro-Geoinformatics, 1–6
- 2017 F. Kollasch, **W. Kuhn**. The Concept of Location in Astronomic Spaces. International Conference on Spatial Information Theory, 67–71.
- 2018 S. Lafia, **W. Kuhn**. Ontology-Aided Spatialization of Field Station Research. *AGUFM 2018*, IN53C-0625.

#### Publications by Krzysztof Janowicz

##### Articles in refereed journals

- 2017 Vardeman II, C., Krisnadhi, A., Cheatham, M., **Janowicz, K.**, Ferguson, H., Hitzler, P., and Buccellato, A. An Ontology Design Pattern and Its Use Case for Modeling Material Transformation. *Semantic Web* 8(5): 719–731.
- 2017 Gao, S., **Janowicz, K.**, Montello, D., Hu, Y., Yang, J.-A., McKenzie, G., Ju, Y., Gong, L. Adams, B., and Yan, B. A Data-Synthesis-Driven Method for Detecting and Extracting Vague Cognitive Regions. *International Journal of Geographical Information Science* 31(6): 1245–1271.
- 2017 Gao, S., **Janowicz, K.**, and Couclelis, H. Extracting Urban Functional Regions from Points of Interest and Human Activities on Location-based Social Networks. *Transactions in GIS*. 21: 446467.

- 2017 McKenzie G. and **Janowicz, K.** ISED: Constructing a high-resolution elevation road dataset from massive, low-quality in-situ observations derived from geosocial fitness tracking data. *PLOS ONE* 12(10): e0186474. <https://doi.org/10.1371/journal.pone.0186474>.
- 2018 van den Brink, L., Barnaghi, P., Tandy, J., Atemezing, G., Atkinson, R., Cochrane, B., Fathy, Y., Castro, R.G., Haller, A., Harth, A. and **Janowicz, K.**, Kolozali, S., van Leeuwen, B., Lefrançois, M., Lieberman, J., Perego, A., Le Phuoc, D., Roberts, B., Taylor, K, and Troncy, R. Best Practices for Publishing, Retrieving, and Using Spatial Data on the Web. *Semantic Web Journal*; IOS Press.
- 2018 Mai, G., **Janowicz, K.**, Hu, Y., and Gao, S. ADCN: An anisotropic densitybased clustering algorithm for discovering spatial point patterns with noise. *Transactions in GIS*, 22(1): 348–369.
- 2018 Cheatham, M., Krisnadhi, A., Amini, R., Hitzler, P., **Janowicz, K.**, Shepherd, A., Narock, T., Jones, M. and Ji, P. The GeoLink Knowledge Graph. *Big Earth Data*; Taylor and Francis. DOI: 10.1080/20964471.2018.1469291.
- 2018 Haller, A., **Janowicz, K.**, Cox, S., Lefrancois, M., Taylor, K., Le Phuoc, D., Lieberman, J., Garcia-Castro, R., Atkinson, R., and Stadler, C. The Modular SSN Ontology: A Joint W3C and OGC Standard Specifying the Semantics of Sensors, Observations, Sampling, and Actuation. *Semantic Web Journal*; IOS Press. DOI: 10.3233/SW-180320.
- 2018 Davis, A. W., McBride, E. C., **Janowicz, K.**, Zhu, R., and Goulias, K. G. Tour-Based Path Analysis of Long-Distance Non-Commute Travel Behavior in California. *Transportation Research Record*, 0361198118778926. DOI: 10.1177/0361198118778926.
- 2018 **Janowicz, K.**, Haller, A., Cox, S., Le Phuoc, D., and Lefrancois, M. OSA: A Lightweight Ontology for Sensors, Observations, Samples, and Actuators. *Journal of Web Semantics*; Elsevier. DOI: 10.1016/j.websem.2018.06.003.
- 2019 Mai, G., **Janowicz, K.**, Yan, B., and Scheider, S. Deeply Integrating Linked Data with Geographic Information Systems. *Transactions in GIS*, 2019. DOI:10.1111/TGIS.12538.
- 2019 Regalia, B., **Janowicz, K.**, and McKenzie, G. Computing and Querying Strict, Approximate, and Metrically-Refined Topological Relations in Linked Geographic Data. *Transactions in GIS*, 2019.
- 2019 Zhu, R., **Janowicz, K.**, and Mai, G. Making Direction a First-Class Citizen of Tobler’s First Law of Geography. *Transactions in GIS*.
- 2019 Yan, B., **Janowicz, K.**, Mai, G., and Zhu, R. A Spatially-Explicit Reinforcement Learning Model for Geographic Knowledge Graph Summarization. *Transactions in GIS*.
- 2019 Yang, J., Tsou, M., **Janowicz, K.**, Clarke, K., and Jankowski, P. Reshaping the urban hierarchy: Patterns of information diffusion on social media, *Geo-spatial Information Science*, DOI: 10.1080/10095020.2019.1641970

### Articles in refereed conference and workshop proceedings (full papers only)

- 2017 McKenzie, G. and **Janowicz, K.** The Effect of Regional Variation and Resolution on Geosocial Thematic Signatures for Points of Interest. *AGILE 2017 Conference on Geographic Information Science*, Springer, pp. 237–256.
- 2017 Regalia, B., **Janowicz, K.**, and McKenzie, G. Revisiting the representation of and need for raw geometries on the linked data web. *Proceedings of the Workshop on Linked Data on the Web (LDOW), CEUR Workshop Proceedings* (2017).
- 2017 Zhu, R., Kyriakidis, P., and **Janowicz, K.** Beyond Pairs: Generalizing the Geo-dipole for Quantifying Spatial Patterns in Geographic Fields. *AGILE 2017 Conference on Geographic Information Science*, Springer, pp. 331–348. **\*Best Paper Award**

- 2017 Hitzler, P., Gangemi, A., **Janowicz, K.**, Krishnadi, A., and Presutti V. Towards a simple but useful ontology design pattern representation language. 8th Workshop on Ontology Design and Patterns (WOP2017) co-located with ISWC 2017, October 22, 2017, Vienna, Austria.
- 2017 Regalia, B., **Janowicz, K.** and Mai, G. Phuzzy.link: A SPARQL-Powered Client-Sided Extensible Semantic Web Browser. VOILA 2017: Visualization and Interaction for Ontologies and Linked Data. 3rd International Workshop co-located with ISWC 2017, October 22, 2017, Vienna, Austria.
- 2017 Yan, B., **Janowicz, K.**, Mai, G., and Gao, S. From ITDL to Place2Vec – Reasoning About Place Type Similarity and Relatedness by Learning Embeddings From Augmented Spatial Contexts. In Proceedings of the 25th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems (ACM SIGSPATIAL 2017) DOI: 10.1145/3139958.3140054.
- 2018 Regalia, B., **Janowicz, K.**, Mai, G., Varanka, D., and Utery, E.L. GNIS-LD: Serving and Visualizing the Geographic Names Information System Gazetteer as Linked Data. 15th ESWC Conference, 3–7 June, Heraklion, Crete. Springer, LNCS; pp. 528–540.
- 2018 Mai, G., **Janowicz, K.**, and Yan, B. Combining Text Embedding and Knowledge Graph Embedding Techniques for Academic Search Engines. 4th Workshop on Semantic Deep Learning (SemDeep-4)
- 2018 Hu, Y., and **Janowicz, K.** An empirical study on the names of points of interest and their changes with geographic distance. GIScience 2018: 10th International Conference on Geographic Information Science. Leibniz International Proceedings in Informatics (LIPIcs). DOI: 10.4230/LIPIcs.GISCIENCE.2018.5 **\*Best Paper Award**
- 2018 Yan, B., **Janowicz, K.**, Mai, G., and Zhu, R. xNet+SC: Classifying Places Based on Images by Incorporating Spatial Contexts. GIScience 2018: 10th International Conference on Geographic Information Science. Leibniz International Proceedings in Informatics (LIPIcs). DOI: 10.4230/LIPIcs.GISCIENCE.2018.17.
- 2018 Mai, G., **Janowicz, K.**, and Yan, B. Support and Centrality: Learning Weights for Knowledge Graph Embedding Models. 21st International Conference on Knowledge Engineering and Knowledge Management (EKAW 2018).
- 2019 Mai, G., Yan, B., **Janowicz, K.**, and Zhu, R. Relaxing Unanswerable Geographic Questions Using A Spatially Explicit Knowledge Graph Embedding Model. In: *Proceedings of AGILE 2019*, June 17–20, 2019, Limassol, Cyprus. **\*Best Paper Award**
- 2019 Yan, B., Walker, M., and **Janowicz, K.** A Time-Aware Inductive Representation Learning Strategy for Heterogeneous Graphs. 15th International Workshop on Mining and Learning with Graphs.
- 2019 Cai, L., **Janowicz, K.**, Yan, B., Mai, G., and Zhu, R. TransGCN: Coupling Transformation Assumptions with Graph Convolutional Networks for Link Prediction. *The Tenth International Conference on Knowledge Capture*. **\*Best Paper Award**
- 2019 Mai, G., **Janowicz, K.**, Yan, B., Zhu, R., Cai, L., and Lao, Ni. Contextual Graph Attention for Answering Logical Queries over Incomplete Knowledge Graphs. *The Tenth International Conference on Knowledge Capture*.
- 2020 Mai, G., **Janowicz, K.**, Yan, B., Zhu, R., Cai, L., and Lao, N. Multi-Scale Representation Learning for Spatial Feature Distributions using Grid Cells, In: *Proceedings of ICLR 2020*, Apr. 26–30, 2020, Addis Ababa, ETHIOPIA.
- 2020 Mai, G., **Janowicz, K.**, Prasad, S., Shi, M., Cai, L., Zhu, R., Regalia, B., and Lao, N. Semantically-Enriched Search Engine for Geoportals: A Case Study with ArcGIS Online. In: *Proceedings of AGILE 2020*.
- 2020 McKenzie, G., **Janowicz, K.** and Kessler, C. Uncovering spatiotemporal biases in place-based social sensing. In: *Proceedings of AGILE 2020*.

### Fully reviewed book chapters

- 2018 **Janowicz, K.**, McKenzie, G., Hu, Y., Zhu, R., and Gao, So. Using Semantic Signatures for Social Sensing in Urban Environments. *Mobility Patterns, Big Data and Transport Analytics*. Fully reviewed short papers and partially (or non-) reviewed publications and content editorials

### Fully reviewed short papers and partially (or non-) reviewed publications and content editorials

- 2017 Lehmann, J., Soeren A., Capadisli, S., **Janowicz, K.**, Bizer, C., Heath, T., Hogan, A., and Berners-Lee, T. LDOW2017: 10th Workshop on Linked Data on the Web. In *Proceedings of the 26th International Conference on World Wide Web Companion*, pp. 1679–1680. International World Wide Web Conferences Steering Committee, 2017.
- 2017 **Janowicz, K.** and McKenzie, G. How “Alternative” are Alternative Facts? Towards Measuring Statement Coherence via Spatial Analysis (Vision Paper). In *Proceedings of the 25th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems (ACM SIGSPATIAL 2017)*.
- 2018 Stella, S., Hitzler, P., and **Janowicz, K.** On the Quality of Vocabularies for Linked Dataset Papers Published in the Semantic Web Journal. *Semantic Web* 9(2), 2018
- 2018 Mai, G., **Janowicz, K.**, Prasad, S. and Yan, B. Visualizing The Semantic Similarity of Geographic Features. *Proceedings of 21st Conference on Geo-information science (AGILE 2018)*, June 12–15, 2018, Lund, Sweden.
- 2018 Mai, G., **Janowicz, K.**, Hu, Yingjie, Gao, S., Zhu, R., Yan, B., McKenzie, G., Uppal, A., and Regalia, B. Collections of Points of Interest: How to Name Them and Why it Matters. Workshop on Spatial Big Data and Machine Learning in GIScience.
- 2018 **Janowicz, K.**, Hitzler, P., Regalia, B., Mai, G., Delbecque, S., Frohlich, M., Martinent, P., and Lazarus, T. On the Prospects of Blockchain and Distributed Ledger Technologies for Open Science and Academic Publishing. *Semantic Web* 9(5), 2018.
- 2018 McKenzie, G and **Janowicz, K.** OpenPOI: An Open Place of Interest Platform. 10th International Conference on Geographic Information Science (GIScience 2018)
- 2018 **Janowicz, K.**, Yan, B., Regalia, B., Zhu, R., and Mai, G. Debiasing Knowledge Graphs: Why Female Presidents are not like Female Popes. International Semantic Web Conference (ISWC) 2018.
- 2019 **Janowicz, K.**, Gao, S., McKenzie, G., Hu, Y., Bhaduri, B. GeoAI: Spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond. *International Journal of Geographical Information Science*, 1–12.

### Appendix Ib. Presentations

The following presentations have described the work of the Center to audiences worldwide.

#### Presentations by Werner Kuhn

- 2018 Improving discovery of open civic data. S. Lafia, A. Turner, **W. Kuhn**. 10th International Conference on Geographic Information Science (GIScience 2018)
- 2019 Towards a usability scale for participatory GIS. A. Ballatore, W. McClintock, G. Goldberg, **W. Kuhn**. The Annual International Conference on Geographic Information Science, 327–348
- 2019 Enabling the Discovery of Thematically Related Research Objects with Systematic Spatialization. S. Lafia, C. Last, **W. Kuhn**. 14th International Conference on Spatial Information Theory (COSIT 2019)
- 2019 Talk of the Town: Discovering Open Public Data via Voice Assistants (Short Paper). S. Lafia, J. Xiao, T. Hervey, **W. Kuhn**. 14th International Conference on Spatial Information Theory (COSIT 2019)



## Presentations by Krzysztof Janowicz

This list contains talks given by Janowicz (excluding those that were given by others about joint research, e.g., at conferences).

- 2017 Linked Data for the National Map. *Invited Speaker* at CEGIS 2017
- 2017 SOSA & SSN: An Overview of the OGC/W3C Semantic Sensor Network Ontology. *Invited Speaker* at ESIP: Drone and Semantic Groups
- 2017 Linked Data and the Digital Humanities A Match Made in Heaven or Hell? *Keynote* at Geo-Humanities 2017 at SIGSPATIAL 2017
- 2018 Spatial Analysis, Spatial Thinking, GIS. *Opening Presentation* at Leadership Workshop on Location Analytics in Business
- 2018 GIScience and Geography. *Speaker* at CAP Board Meeting, UCSB
- 2018 Linked Data for the National Map. *Invited Speaker* at IS-GEO
- 2018 Top-Down AND Bottom-Up. *Invited Speaker* at 2018 CGA Conference: Illuminating Space and Time in Data Science
- 2018 The Golledge Lecture: Three Provocative Ideas at the Intersection of Cognitive Geography and Spatial Data Science. *Invited Speaker*
- 2018 Ontological Considerations in Creating and Using Corpora in GIScience. *Keynote* at Corpus in GIScience Workshop at GIScience 2018
- 2018 SOSA for Social Sensing. *Keynote* at 2nd International Workshop on Semantic Interoperability and Standardization in the IoT (SIS 2018)
- 2019 Social Sensing: Learning Semantic Signatures from Data Traces. *Invited Speaker* at Gießener Abendgespräche, University of Gießen
- 2019 Social Sensing Techniques for Geographic Knowledge Graphs. *Invited Speaker* at GIScience Colloquium, University of Salzburg
- 2019 Social Sensing Techniques for Geographic Knowledge Graphs *Invited Speaker* at Spatial Cognition Colloquium, University of Bremen

## Ic: Awards, Krzysztof Janowicz

- **2017** Best Paper Award at AGILE 2017 Conference on Geographic Information Science
- **2018** Best Paper Award at GIScience 2018 Conf. on Geographic Information Science
- **2019** Best Paper Award at AGILE 2019 Conference on Geographic Information Science
- **2019** Best Paper Award at K-CAP 2019 Intern. Conference on Knowledge Capture

## Appendix II. Summary of Research Funding 2017–2020

Funding Agency	Title	Award
<b>Werner Kuhn</b>		
Esri Inc., Contribution for Specialist Meeting	2017, Leadership Workshop on Location Analytics in Business	\$25,000
<b>Krzysztof Janowicz</b>		
USGS	Linked Data for the National Map II	\$68,402
Esri Inc.	Semantics & Linked Data Integration for GIS	\$200,000
UCSB College of Letters and Science Conference Support	Internet of Things 2018	\$2,500
Siemens	Knowledge Graph-Assisted Knowledge Acquisition from Technical Documents	\$64,532
IOS	LD Connect Service Chain	\$20,000
Oliver Wyman	NDA	\$35,000
IOS	LD Connect Service Chain II	\$40,000
Esri Inc.	Spatial Data Science Symposium Conference Support	\$10,000
Siemens	Multimodal Knowledge Graph Querying and Completion	\$49,873
NSF	Convergence Accelerator Phase I (RAISE): Spatially-Explicit Models, Methods, and Services for Open Knowledge Networks	\$999,547
<b>Janowicz Total</b>		<b>\$1,553,791</b>
<b>Kuhn and Janowicz Total</b>		<b>\$1,578,791</b>
<b>Janowicz Pending</b>		
NSF	SCC-IRG Track 1: Creating the Smart Human Rights City: Using Intelligent Information Infrastructure to Facilitate Citizen Engagement and Poverty Reduction	\$3,624,580
NSF	AI Institute: AI FARMS: Artificial Intelligence for Future Agriculture— Research and Methods for Sustainable Food Security	\$20,000,000
NSF	NRT-HDR: Environmental Data Science Training for Applied Research	\$2,999,789
NSF	AI Institute: Planning: Foundations and Algorithms for Responsible AI	\$500,000
<b>Janowicz Pending Total (not Center share)</b>		<b>\$27,124,369</b>
<b>Total Kuhn , Janowicz Funding</b>		<b>\$28,703,160</b>

## Appendix III: Educational Initiatives

One of the Center's goals has been to increase student access to courses and instructional materials that build spatial intelligence enhancing the impact of spatial thinking on campus and beyond. Efforts in this direction have included the development of an undergraduate **Minor in Spatial Studies** (recently transferred to the Department of Geography) and the **Exploration Seminar in Thinking Spatially in the Arts and Sciences**; summer internships for undergraduate students; postgraduate student involvement and support; curation and maintenance of extensive online resources.

### Appendix IIIa. Thinking Spatially in the Arts and Sciences

#### April 4–June 8, 2018

**Werner Kuhn** (Dept. of Geography and Center for Spatial Studies)  
*Why does Spatial Thinking Matter?*

**Volker Welter** (History of Art & Architecture)  
*Learning to Dwell in Space*

**Susan Cassels** (Dept. of Geography)  
*Migration and the Transmission of Infectious Diseases*

**Mary Hegarty and Daniel Montello** (Depts. of Psychological & Brain Sciences and Geography)  
*Sense-of-Direction: Are You a Space Wizard or Just Lost in Space? Part I*

**Kate McDonald** (Dept. of History)  
*Spatial Humanities*

**Mary Hegarty and Daniel Montello** (Depts. of Psychological & Brain Sciences and Geography)  
*Sense-of-Direction: Are You a Space Wizard or Just Lost in Space? Part II*

**Volker Welter** (Dept. of History of Art & Architecture)  
*FL Wright's Broadacre City vs. Boutwell/Mitchel's Continuous City for 1 Billion Inhabitants*

**Kim Yasuda** (Dept. of Art Studio)  
*The Price of a Good Time*

**Krzysztof Janowicz** (Dept. of Geography)  
*Places and Signatures*

#### April 4–June 5, 2019

**Werner Kuhn** (Dept. of Geography)  
*What does "Thinking Spatially" Mean? Why does it Matter?*

**Christopher Pilafian** (Dept. of Theater and Dance)  
*Charting Choreographic Space: Spatial Relationships Part I*

**Will McClintock** (Dept. of Marine Science)  
*Marine Spatial Planning and Equitable Decisions using SeaSketch*

**Mary Hegarty and Daniel Montello** (Depts. of Psychological & Brain Sciences and Geography)  
*Sense-of-Direction: Are You a Space Wizard or Just Lost in Space?*

**Christopher Pilafian** (Dept. of Theater and Dance)  
*Charting Choreographic Space: Spatial Relationships Part II*

**Kate McDonald** (Dept. of History)  
*Tokyo Heterotopia: Tourism and Spatial Narratives at the 2020 Olympics?*

**Matt Hall** (Exec. Vice Chancellor and Chief Information Officer)

*The World of Warcraft and Lord of the Rings Online—Mapping a Narrative Space with MMORPGs*

**Volker Welter** (Dept. of History of Art & Architecture)

*Frank Lloyd Wright's Broadacre City*

**Susie Cassels** (Dept. of Geography)

*Migration and the Transmission of Infectious Diseases*

**Werner Kuhn** (Dept. of Geography)

*Moving Ahead*

### **Appendix IIIb. Academic Minor in Spatial Studies**

Created by Don Janelle, the **Minor in Spatial Studies** was inaugurated in 2011. It was administered through the Center, with Karen Doehner serving as student advisor until September 2018 when it was transferred to the Department of Geography at the request of the Dean. Werner Kuhn continues to serve as academic advisor for this successful program.

Because the Center no longer administers this program, students who have graduated with the minor are not listed here.

## Appendix IV: Academic Events

### IVa. ThinkSpatial Brown-bag Forum

Year-round lecture and discussion series

This is the Center's flagship event series consisting of brown-bag lunch presentations on a broad range of perspectives about interdisciplinary spatial thinking. Sessions average 20+ attendees, with some speakers and topics attracting as many as 40.

#### 2017–2018

- 3/6/18 **Tim DeVries** (Dept. of Geography, UCSB)  
*Assimilating Spatial Data into a Global Ocean Model*
- 2/20/18 **Pyry Kettunen** (Finnish Geospatial Research Inst.)  
*How to Strengthen Technological Support for Wayfinding and Spatial Communication with Context-Dependent Landmarks and Geo-Pictures*
- 2/6/18 **Edzer Pebesma** (Institute for Geoinformatics, Univ. of Muenster)  
*How can units of measurement improve spatial data science?*
- 1/30/18 **Vena Chu** (Dept. of Geography, UCSB)  
*Hydrologic Dynamics of the Greenland Ice Sheet*
- 11/21/17 **Alexander Franks** (Dept. of Statistics, UCSB)  
*From Pixels to Points: Using Tracking Data to Measure Performance in Professional Sports*
- 11/14/17 **Amr El Abbadi** (Dept. of Computer Science, UCSB)  
*LocBorg: Location Privacy while Preserving Online Persona*
- 10/31/17 **Clodoveu Davis** (Dept. of Computer Science, UCSB)  
*Spatial Integrity Constraints from Conceptual Modeling and their support in Spatially-extended DBMSs*
- 10/10/17 **Matto Mildenerger** (Dept. of Political Science, UCSB)  
*The Spatial Distribution of U.S. Climate and Energy Beliefs*

#### 2018–2019

- 3/12/19 **Linda Adler-Kassner** (Director, Center for Innovative Teaching, Research, and Learning Associate Dean, Undergraduate Education, UCSB)  
*Spatial Thinking as a Heuristic: Shaping Learning about Teaching*
- 3/5/19 **Grant McKenzie** (Dept. of Geography, McGill University)  
*Scooter-pocalypse: The When, Where, and Why of Scooter-sharing Services*
- 12/11/18 **Wolfgang Maaß** (Saarland University)  
*Tapping into the Human Data Space: Predicting the Treatment Success of Obese Children*
- 11/13/18 **Markus Hoffmann** (Google)  
*Quantum Computing @Google*
- 10/23/18 **Elisabete Silva** (LISA Lab, University of Cambridge)  
*Coming Home to the Land of Dynamic Spatial Analysis and Simulation: Adaptive Planning Policy and Practice in a Seamless and Fast-Moving Digital World*
- 10/2/18 **Qinghua Ding** (Dept. of Geography, UCSB)  
*Recent Slow Melt of Arctic Summer Sea Ice caused by Tropical SST Changes*

## 2019–2020

- 1/14/20 **Somayeh Dodge** (Dept. of Geography, UCSB)  
*Multiscale Modeling and Analysis of Movement*
- 1/21/20 **Emmanuel Papadakis** (Center for Spatial Studies, UCSB)  
*Bridging Space and Place in Geographic Information Systems*
- 3/3/2020 **Ambuj K. Singh** (Dept. of Computer Science)  
*Inferring Network Structure and Flows using Partial Observations*
- 3/10/20 **Claudio Fogu** (Dept. of French and Italian, UCSB)  
*The Fishing Net and the Spider Web—Making Italians Making Southerners*
- 3/17/20 **Anna Trugman** (Dept. of Geography)  
*The Geography of Forest Hydraulic Trait Compositions*

## IVb. Spatial Technology Lunches

This series originated as an occasional, small student forum to discuss technological developments and, over the years, it has grown in popularity and demand to become a more regular event that draws attendance from students and faculty/researchers alike.

## 2017–2018

- Aaron Bagnell** (Marine Science/Geography), *Monitoring Ocean Acidification on Your Mobile Device*
- Alexandru Nichersu** (European Institute for Energy Research (EIFER)), *Spatio-temporal Data Integration for an Integrated Approach in the Modelling of the City-wide Energy Chain*
- Erin Wetherley** (Geography), *Evaluating Vegetation Type Effects on Land Surface Temperature at the City Scale*
- Sinan Yuan** (Tianjin University), *Experimental VR Research on Spatial Cognition in Chinese Traditional Villages*
- Jorge Chen** (Geography), *How Well can a \$750 DIY LiDAR Scanner Scan?*
- Marthe Wens** (Visiting Ph.D. student), *Integrating Heterogeneous, Dynamic Adaptation Behaviour in Drought-risk Modeling*

## 2018–2019

- Jeff Onsted** and **Nathaniel Roth** (California Department of Conservation), *Science and Spatial Technology at the California Department of Conservation*

## 2019–2020

- Dan Baci** (Department of English, UCSB), *The Geography of Cultures: New Methods for Decoding, Analysis and Synthesis*
- Roland Knapp** (Sierra Nevada Aquatic Research Laboratory and Marine Science Institute, UCSB), *Disease Spread through Mountain Yellow-Legged Frog Populations in the Sierra Nevada*
- Maygan Cline** (Geosyntec), *Spatial Techniques for Environmental Engineering in Environmental Consulting / Careers in Environmental Consulting for Ph.D. Graduates*

## Appendix IVc. Spatial Lightning Talks

An annual outreach event, the **Lightning Talks** feature a full slate of 3-minute talks on spatial topics during a lunch period. It typically features 12 presentations and is attended by more than 70 people from many walks of life from across campus and the community.

### 2017–2018 (Crystal Bae)

**Keith Clarke:** The Honda Point Disaster

**Jeremy Douglass:** Panelcode

**Paul Wilson:** Mapping Thomas

**Joshua Kuntzman:** UCSB Crossroads

**Lily Cheng:** Left Hand, Right Hand

**James Caesar:** Thomas Fire: Don't Fight the Scenario

**Thomas Crimmel:** The Abridged History of the Digital Desktop

**William Yim:** Focus

### 2018–2019 (Anagha Uppal)

**John Lee:** Race and Space on an American College Campus, 1886–1888

**Thomas Hervey:** Travel Spaces and their Stories

**Skona Brittain:** Space-Filling Curves

**Mike Johnson:** An R-based Ecosystem for Earth System Data

**George Legrady:** 3D Data Visualization Fundamentals from MAT 259 Course

**Keith Clarke:** Where is Nowhere?

**Ethan Turpin & David Gordon:** An Interactive Fire, Water and Climate Model

**Dan Montello:** Fifty-Four Forty or Fight!

**Greg Hillis:** Mandalas: Buddhist Maps of Perfection

**Aaron Bagnell:** Fuzzy Oceans: Clustering Water Masses to Overcome Local Sampling Bias

**Ken Dunkley:** COOL Terroir: Place and the Character and Quality of Food and Beverages

**Tom Ekman:** Exploring a Watershed with Mexican Youth

### 2019–2020 (Anagha Uppal)

**Keith Clarke:** Why Map Rozel Point?

**Clayton Nall:** Why Partisans don't Sort

**Joel Salzman:** The Best Places to Vote in California

**Nick Triozzi:** Drones and Thermal Imagery for Archaeological Survey

**Margaret Fisher:** Taking up Space: Large(st) Animals and the Collective Literary Unconscious

**Paul Wilson:** Where do we Live?

**Eduardo Romero:** High Frequency Radar in the Santa Barbara Channel

**Louis Graup:** Fire and Water: A Spatial Connection

**Wendy Meiring:** Collaborations through Time and Space

**Thomas Crimmel:** Ancient Real Estate at the Maya Center of El Pilar

**Pratik Raghunath:** Spaces of Hope under State Terrorism

**Zoe Hinck:** Mapping Professional Networks

## **Appendix IVd. Specialist Meetings**

Each **specialist meeting** typically convenes 25–45 researchers from around the world to discuss a single cutting-edge topic, and to formulate a community research agenda. Fifty such meetings have been held since 1988, with support from a variety of funding sources, including NSF, NIH, Google, and Esri.

### **2017–2018**

#### **Leadership Workshop on Locational Analytics in Business**

January 31–February 2, 2018

Location Analytics is the subset of Business Analytics that is concerned with gaining insights by analyzing the spatial component of business data. Leading retail, real estate, finance, manufacturing, and logistics firms, among others, implement location strategies to gain competitive advantage. Furthermore, a new generation of business researchers and educators is beginning to recognize location analytics as a distinctive professional specialty. The role of academics in this field can be to simplify location analysis, propose innovative new theories and methodologies, and educate business and technology leaders. This 3-day workshop prepared selected early-career researchers to do just that. Participants interacted with leading scholars in geographic information science and other related fields, and led breakout discussions on relevant subtopics.

### **2018–2019**

#### **International Conference on the Internet of Things**

October 15–18, 2018

Attended by more than 90 participants and being part of the long-lasting IOT conference series, the conference discussed the rapid advancement and ubiquitous penetration of mobile networks, Web-based information creation and sharing, and how software-defined networking technology enable us to sense, predict and control the physical world using information technology. To maximize the social and economic benefit of the technology, issues of interoperability, data and service mash-ups, the development of open platforms, and standardization across technology layers were discussed. The Center was the main organizer as the topic was one of our focal areas in 2017-2020. The conference was a success and Janowicz was invited to serve on the IOT series' Steering Committee.

#### **Spatial Discovery III**

May 1–3, 2019

Discovery III, the third and final specialist meeting on the topic of spatial discovery, marks the culmination of research and prototyping efforts to make research data discoverable by location. The meeting will expand discussions from the prior meeting held in May 2017, with the substantial new turn toward discovery in topic spaces. Recent developments at UCSB include experimentation with the expansion of visualization in ArcGIS Online to topic spaces and the propelling of research data curation efforts on



campus through an NSF-supported pilot project. In addition to sharing and discussing research and development, the meeting seeks to discuss future prospects for enabling spatial discovery in a university library setting. Building on the productive disciplinary mixes of the 2015 and 2017 meetings, librarians will again meet with GIS and information retrieval experts.

## 2019–2020

### Spatial Data Science Symposium

December 9–11, 2020

Space and time matter not only for the obvious reason that everything happens somewhere and at some time, but because knowing where and when things happen is critical to understanding why and how they happened or will happen. Spatial data science is concerned with the representation, modeling, and simulation of spatial processes, as well as with the publication, retrieval, reuse, integration, and analysis of spatial data. It generalizes and unifies research from fields such as geographic information science, geoinformatics, geo/spatial statistics, remote sensing, and transportation studies, and fosters the application of methods developed in these fields to outside disciplines ranging from the social to the physical sciences. In doing so, research on spatial data science must address a variety of new challenges that relate to the diversity of the utilized data and the underlying conceptual models from various domains, the opportunistic reuse of existing data, the scalability of its methods, the support of users not familiar with the language and methods of traditional geographic information systems, the reproducibility of its results that are often generated by complex chains of methods, the uncertainty arising from the use of its methods and data, the visualization of complex spatiotemporal processes and data about them, and, finally, the data collection, analysis, and visualization playing out in near real-time. The meeting brought together 43 academic and industry representatives from fields such as geographic information science, geoinformatics, geo/spatial statistics, remote sensing, and transportation studies, with interest in setting an interdisciplinary research agenda to advance spatial data science methods and practice, both from scientific and engineering viewpoints. The feedback was very positive and participants expressed a strong interest in a follow-up, larger event in 2020 or 2021.

### Appendix IVe. [spatial@ucsb.local](mailto:spatial@ucsb.local) Poster and Plenary Session

This annual outreach event strives to foster relations between the academic and non-academic local community, drawing participation from Santa Maria, Santa Barbara, and Ventura Counties. The community is invited to participate in and attend a **poster and plenary session**, as well as the Channel Islands Regional GIS (CIRGIS) quarterly meeting. Posters feature the work of UCSB students and faculty, as well as community projects. Typically, 30 to 40 participants display their research in a poster format or as computer-based demonstrations, and have an opportunity to explain their work to attendees and visitors.

The sessions attract between 180 and 250 participants for the program. Thematic topics and speakers for these events are listed below:

#### [spatial@ucsb.local2018—Improving Information Accuracy for Extreme Events \(June 6, 2018\)](#)

**Speakers:**

**Chris S. Renschler**, (Dept. of Geography, University at Buffalo (SUNY), Dept. of Biological and Environmental Engineering, University of Tokyo)  
*Integrated Extreme Events Management: Communicating Processes and Options for Stakeholders*

**Jessica White** (Direct Relief International, Research Analyst)  
*Communications for Humanitarian Crisis Response: Using Data to Help Those Who Need It Most*

**CIRGIS Presenters:**

**Zacharias Hunt** (GIS Manager, Z-WORLD GIS, CIRGIS Past-President and Board Member)  
*Post-Thomas Fire Hydrology and Flood Hazard Mapping*

**Hassan Kasraie** (Kasraie Consulting, CIRGIS Past-President and Board Member)  
*Montecito Mudslides—Road to Recovery with GIS*

[spatial@ucsb.local2019—Spatial Data for Smarter Cities \(June 6, 2019\)](#)

**Speakers:**

**Mahnoosh Alizadeh** (Dept. of Electrical and Computer Engineering, UCSB)  
*Opportunities and Challenges of Transportation Electrification in Smart Cities*

**Konstadinos (Kostas) Goulias** (Dept. of Geography, UCSB)  
*Activity-Travel GeoSimulation for Smart City Planning, Design, and Operations*

**CIRGIS Presenters:**

**Kurt Shellhause** (Kasraie Consulting, Water Resource Engineer)  
*Thinking Inside the Box, Outside the Box, and about What could Destroy our Box*

[spatial@ucsb.local2020—Sea Level Rising \(June 3, 2020\)](#)

**Speakers:** TBA

**CIRGIS Presenters:** TBA

## Appendix IVf. Spatial Data Science Hangout

This new initiative was begun in February 2019. To bridge the interaction across the various subcommunities of GIS and GIScience, the Center explored the possibility that Spatial Data Science may be an opportunity to establish an overarching, unifying community of researchers interested in scientific aspects of representing, publishing, retrieving, and integrating spatial data that is strong enough to make a long-term impact with a particular focus on graduate students.

Initiating the **Spatial Hangout** in 2019 as an informal forum for discussion, the Center invited all students interested in Spatial Data Science to initiate a series of discussion with the goal to also inform the planning for the Spatial Data Science symposium in December 2019. Spatial Data Science Hangouts were held on February 26, March 18, May 10, October 17, and November 19, 2019. Conversations soon spun off into an active Slack channel for data scientists to converse and ideate. These hangouts are planned going forward for the coming years. For now, and starting in early February 2020, the hangouts have resulted in an interest group of students that work with Janowicz on modeling the effects of the new coronavirus on transportation networks and supply chain management in the context of knowledge graphs.

## IVg. Organization of Scientific Events

### Events Co-organized by Krzysztof Janowicz

- 2017 *Program Chair* 9th International Conference on Knowledge Capture (K-CAP 2017)
- 2017 *Co-Chair* Linked Data on the Web Workshop co-located with WWW 17 (LDOW 2017)
- 2017 *Co-Organizer* GeoVoCamp Washington DC 2017
- 2017 *Co-Organizer* Leadership Workshop on Location Analytics in Business (Spatial Center)
- 2018 *Program Chair* 1st United States Semantics Symposium (US2TS 2018)
- 2018 *Co-Organizer* Symposium on Blockchain and Distributed Ledger Technologies for Spatial Information and Analysis
- 2018 *Co-Chair* Linked Data on the Web Workshop co-located with WWW 18 (LDOW 2018)
- 2018 *General Chair* 8th International Conference on the Internet of Things (IOT 2018)
- 2019 *Main Organizer* 1st Spatial Data Science Symposium (SDSS)
- 2019 *Program Chair* 2nd United States Semantics Symposium (US2TS 2019)
- 2019 *Program Chair* 16th Extended Semantic Web Conference (ESWC)
- 2019 *Co-Chair* Linked Data on the Web Workshop at WWW 19 (LDOW/LDDL 2019)
- 2019 *Co-Chair* 1st International Workshop on Sensors and Actuators on the Web (SAW2019)
- 2019 *Co-Chair* 10th Workshop on Ontology Design and Patterns (WOP2019)
- 2020 *Program Chair* Resource track chair of Intern. Semantic Web Conference 2020 (ISWC)
- 2020 *Program Chair* 11th Intern. Conf. on Geographic Information Science (GIScience 2020)

## Appendix V: Collaboration, International and Local

### Appendix Va. Interdisciplinary Research Collaboratory

The Center has played a pivotal role in conceiving and implementing the **Interdisciplinary Research Collaboratory**, a campus-wide initiative in collaboration with the UCSB Library. Championed by Kuhn and Denise Stephens and Kristin Antelman (university librarians, UCSB Library). The Collaboratory provides a physical environment for researchers to collaborate, explore, and resolve disparate questions using digital tools and focusing on qualitative and quantitative research across the physical and social sciences, as well as the humanities. The Collaboratory and its facilities support data creation, curation, and analysis—particularly spatial analysis—locally and globally, raising the visibility and impact of research.

To support the development of the Collaboratory, the Center co-organized two Expert Meetings on Spatial Discovery (June 2015, May 2017) and hosted a third meeting in May 2019 (Appendix IVd).

### Appendix Vb. Visitors (2017–2020)

To facilitate international scientific networking and collaborative research, the Center hosted productive visits by eight scholars and scientists during this period. Visitors have given presentations in the ThinkSpatial Brown-bag series, interacted and collaborated with UCSB faculty and students in research and educational activities, and have participated in Center-sponsored workshops and specialist meetings. This list demonstrates the range of scholars who have conducted their research at the Center.

<b>Kazem Afradi</b>	University of Tehran	February–July 2020
<b>Nick Guidice</b>	University of Maine	January–February 2020
<b>Ekaterina Egorova</b>	Swiss National Science Foundation	September 2019–March 2020
<b>Weiming Huang</b>	Lund University	September–November 2019
<b>Carlos Carbonell Carrera</b>	La Laguna University	March–June 2019
<b>Pyry Kettunen</b>	Finnish Geospatial Research Institute	February–August 2018
<b>Emmanuel Papadakis</b>	University of Salzburg	March–August 2017
<b>Marc Thiemann</b>	University of Bremen	January–June 2017

### Appendix Vc. Undergraduate Student Interns

#### 2017-2018

Sooraj Sekhar	Geography
Jiamin Tan	Geography
Ankush Rayabhari	Computer Science

#### 2018-2019

Nate Diamond

#### 2019-2020

Julia Santos	Geography
Cara Chinn	Environmental Studies

## Appendix Vd: Executive Committee Members

The Center has routinely consulted with a diverse cross-campus **Executive Committee**, consisting of prominent UCSB faculty engaged in spatial research, to ensure that interdisciplinary perspectives are well represented in the design of the Center's programs.

<b>Werner Kuhn</b>	Director, Center for Spatial Studies, Department of Geography
<b>James Frew</b>	Bren School of Environmental Science and Management
<b>Michael Goodchild</b>	Director Emeritus, Department of Geography
<b>Mary Hegarty</b>	Department of Psychological and Brain Sciences
<b>Donald Janelle</b>	Emeritus Researcher, Department of Geography
<b>Krzysztof Janowicz</b>	Associate Director, Department of Geography
<b>JoAnn Kuchera-Morin</b>	Allosphere, Media, Arts, and Technology Program
<b>Will McClintock</b>	Department of Marine Science
<b>Wendy Meiring</b>	Department of Statistics and Applied Probability
<b>Stuart Sweeney</b>	Department of Geography
<b>Ann Taves</b>	Department of Religious Studies
<b>Matthew Turk</b>	Department of Computer Science and Media, Arts, and Technology Program

## Appendix Ve: Research Associates

A number of research associates have contributed to the Center's activities and intellectual growth.

<b>Mary Hegarty</b>	Department of Psychological and Brain Sciences
<b>Andrew Stull</b>	Department of Psychological and Brain Sciences

## Appendix Vf: Graduate Student Involvement and Support

In its educational efforts, the Center involves and supports graduate students in a variety of ways that are advantageous to their professional development. Initiatives such as the annual Lightning Talks and monthly Spatial Technology Lunches (currently run by Anagha Uppal); and the discovery project (involving Sara Lafia). Not only does the Center provide work space for students, but financial support for student travel to conferences and workshops is offered, to provide them with opportunities for presenting their work in a professional venue, learning, and networking.

<b>Crystal Bae</b>	Department of Geography
<b>Thomas Hervey</b>	Department of Geography
<b>Sara Lafia</b>	Department of Geography
<b>Anagha Uppal</b>	Department of Geography
<b>Behzad Vahedi</b>	Department of Geography
<b>Jinyi Xiao</b>	Department of Geography