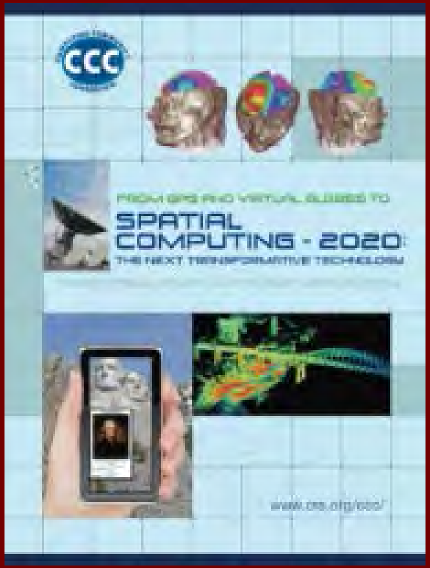
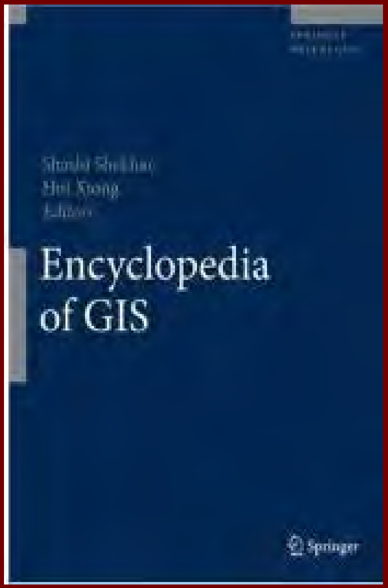
A Spatial Computing Journey

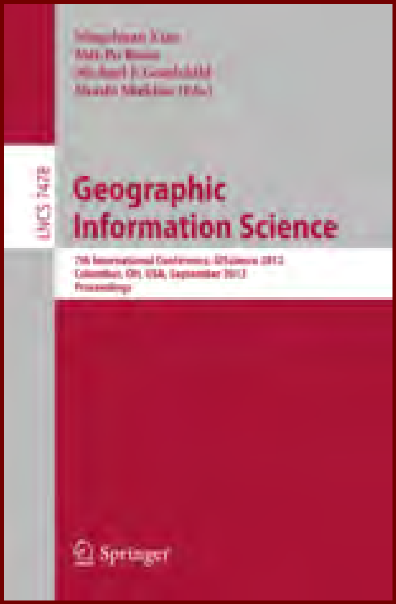
Remarks for UCGIS Education Award

May 2015.



Shashi Shekhar
McKnight Distinguished University Professor
Department of Computer Science and Eng.
University of Minnesota
www.cs.umn.edu/~shekhar





Early Influences

- All I know about GIS, I learned from Geographers!
  - And I used that to discover limitations of Computer Science
  - It helped advance Computer Sc. While helping application domains
- University of Minnesota
  - R. McMaster (MGIS), W. Craig, F. Harvey (U-Spatial, MN Future Workshop),
  - T. Burk (Map Server), S. Ruggles (NSF Datanet Terrapop)
- NCGIA, UCGIS and International
  - M. Goodchild, D. Mark, M. Egenhofer, M. Worboys, …
  - Jack Dangermond, Harvey Miller (NSF GIS and Data Mining workshop)
  - Canada (GEOIDE), Ireland (Geo-computation Center, NUI), UQU (Saudi Arabia)
  - India (GIS Center @ IIT-Mumbai, UNDP Project), China (Wuhan U, Beijing U),
- Sponsors
  - NSF, USDOD, NASA, USDOT, MnDOT, UMN, Ford, …

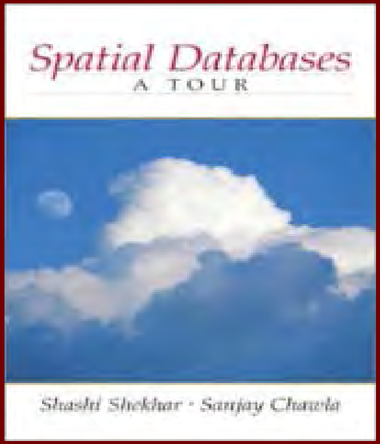
Curriculum & Courses

Professional Master of GIS degree at UMN (w/ Prof. R. McMaster)

CSCI 5715 – From GPS and Google Maps to Spatial Computing (Fall 2015)

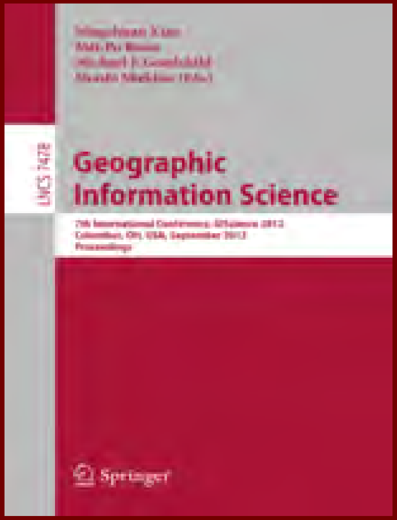
Note: Coursera MOOC (Fall 2014, ?Fall 2015)

- Conceptual Data Models
- Logical Data Models (e.g., SQL3/OGIS)
- Physical Data Models
- Spatial Networks, Routing Algorithm
- Spatial Data Mining



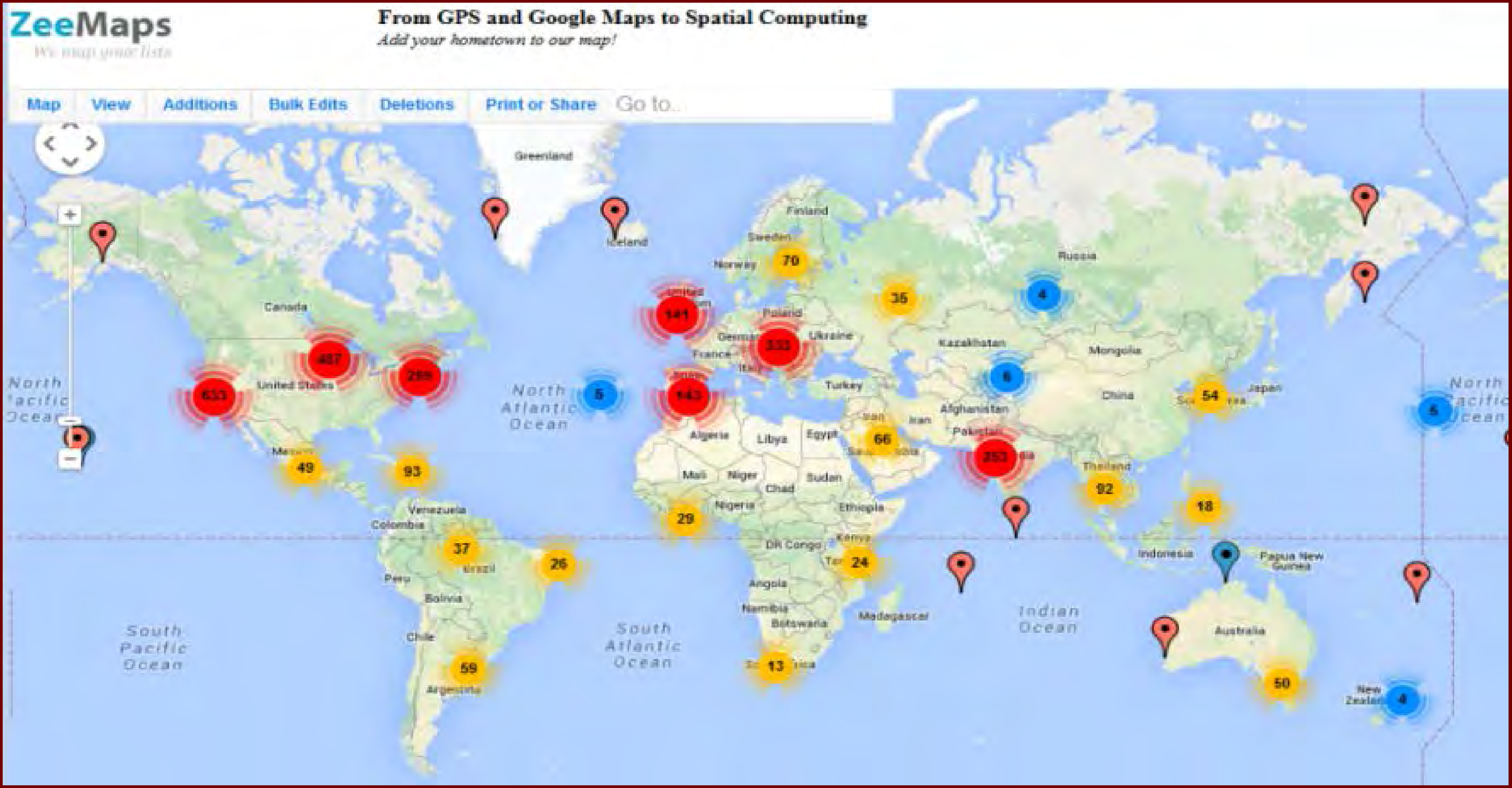
CSCI 8715 – Spatial Database Research (Spring 2016)

- Research Literature
- Trends: Spatial Big Data,
  Spatio-temporal,
  IoT, VGI, …
- Research Projects



Coursera MOOC (w/ Prof. B. Hecht)

- Coursera MOOC: From GPS and Google Earth to Spatial Computing
  - 21,844 students from 182 countries (Fall 2014)
  - 8 modules, 60 short videos, in-video quizzes, interactive examinations, …
  - 3 Tracks: curious, concepts, technical
  - Flipped classroom in UMN on-campus course



From GPS and Google Maps to Spatial Computing

Add your hometown to our map!

Alumni in Academia

Current Students

Alumni in Industry

Alumni in Government Agency

Spatial Computing: Xformative Impact & Potential

- Transformed our lives though understanding saces and places
  - Examples: localization, navigation, site selection, mapping,
  - Examples: spatial context, situation assessment (distribution, patterns), …

ESRI ArcGIS X™

SaTScan™
Software for the spatial, temporal, and space-time scan statistics

OGC™
Open Geospatial Consortium, Inc.

ORACLE®
SPATIAL

IBM Smarter Planet

Google™ Earth

bing™ maps

OpenStreetMap

Ushahidi

waze
Outsmarting Traffic, Together.

The Changing World of Spatial Computing

	Last Century	**Last Decade**
Map User	Well-trained few	Billions
Mappers	Well-trained few	Billions
Software, Hardware	Few layers, e.g., Applications: Arc/GIS, Databases: SQL3/OGIS	Almost all layers
User Expectations & Risks	Modest	Many use-case & Geo-privacy concerns

CCC Visioning Workshop: Making a Case for Spatial Computing 2020

(cra.org/ccc/spatial_computing.php)

Funded Visioning Activities

Disaster Management · SEES IT · HealthIT · Interactive Tech · Architecture · XLayer · Robotics · Learning Tech · Open Source · Cyber Physical Systems · Global Development · Theoretical CS · Big Data Computing · NetSE · Spatial Computing

From GPS and Virtual Globes to Spatial Computing-2020

About the workshop

This workshop outlines an effort to develop and promote a unified agenda for Spatial Computing research and development across US agencies, industries, and universities. See the original workshop proposal here.

Spatial Computing

Spatial Computing is a set of ideas and technologies that will transform our lives by understanding the physical world, knowing and communicating our relation to places in that world, and navigating through those places.

The transformational potential of Spatial Computing is already evident. From Virtual Globes such as Google Maps and Microsoft Bing Maps to consumer GPS devices, our society has benefitted immensely from spatial technology. We've reached the point where a hiker in Yellowstone, a schoolgirl in DC, a biker in Minneapolis, and a taxi driver in Manhattan know precisely where they are, nearby points of interest, and how to reach their destinations. Large

Logistics

Date: Sept. 10th-11th, 2012
Location: Keck Center
Hotel: Liaison Hotel

Steering Committee

Erwin Gianchandani

Hank Korth

Organizing Committee

Peggy Agouris, George Mason University

Walid Aref, Purdue University

Michael F. Goodchild, University of California - Santa Barbara

Workshop Participants

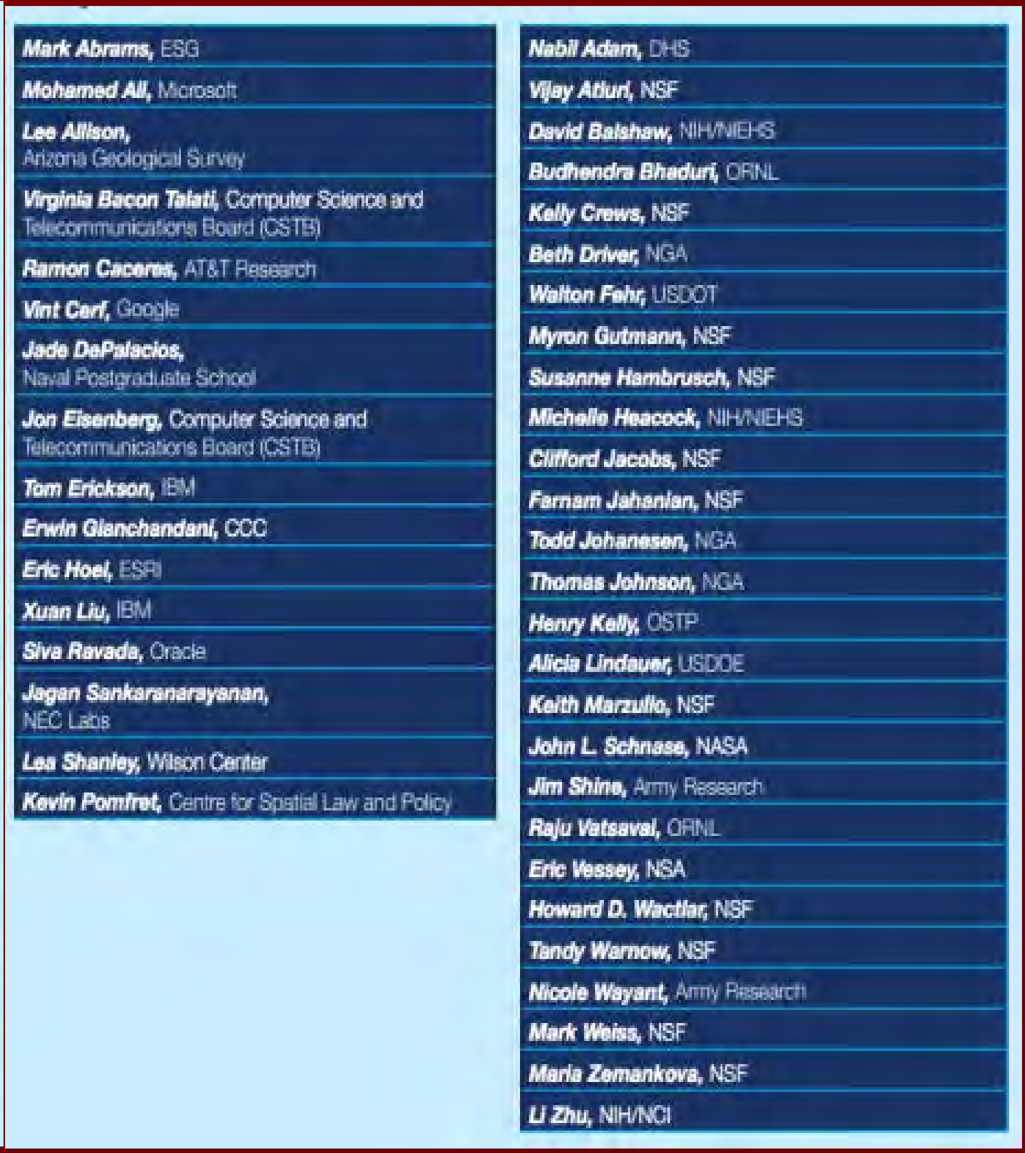
Academia

Peggy Agouris, George Mason University
Divyakant Agrawal, University of California Santa Barbara
Cecilia Aragon, University of Washington
Walid G. Aref, Purdue University
Elisa Bertino, Purdue University
Henrik Christensen, Georgia Institute of Technology
Isabel Cruz, University of Illinois at Chicago
Michael R. Evans, University of Minnesota
Steven Feiner, Columbia University
Jie Gao, Stony Brook University
Michael Goodchild, University of California Santa Barbara
Sara Graves, University of Alabama Huntsville
Rajesh Gupta, University of California San Diego
Chuck Hansen, University of Utah
Stephen Hirtle, University of Pittsburgh
Krzysztof Janowicz, University of California Santa Barbara
John Jensen, University of South Carolina
Daniel Keefe, University of Minnesota
John Keyser, Texas A&M University
Craig A. Knoblock, Information Sciences Institute
Hank Korth, Lehigh University
Benjamin Kuipers, University of Michigan
Vipin Kumar, University of Minnesota
Richard Langley, University of New Brunswick
Chang-Tien Lu, Virginia Tech
Dinesh Manocha, University of North Carolina
Edward M. Mikhail, Purdue
Harvey Miller, University of Utah
Joe Mundy, Brown University
Dev Oliver, University of Minnesota
Rahul Ramachandran, UA Huntsville
Norman Sadeh, CMU
Shashi Shekhar, University of Minnesota
Daniel Z. Sui, Ohio State
Roberto Tamassia, Brown University
Paul Torrens, University of Maryland
Shaowen Wang, University of Illinois at Urbana-Champaign
Greg Welch, University of North Carolina
Ouri E. Wolfson, University of Illinois at Chicago
Mike Worboys, University of Maine
May Yuan, University of Oklahoma
Avideh Zakhor, University of California Berkeley

>30 Universities

Industry

Government



Mark Abrams, ESG
Mohamed Ali, Microsoft
Lee Allison, Arizona Geological Survey
Virginia Bacon Talati, Computer Science and Telecommunications Board (CSTB)
Ramon Caceres, AT&T Research
Vint Cerf, Google
Jade DePalacios, Naval Postgraduate School
Jon Eisenberg, Computer Science and Telecommunications Board (CSTB)
Tom Erickson, IBM
Erwin Gianchandani, CCC
Eric Hoel, ESRI
Xuan Liu, IBM
Siva Ravada, Oracle
Jagan Sankaranarayanan, NEC Labs
Lea Shanley, Wilson Center
Kevin Pomfret, Centre for Spatial Law and Policy

14 Organizations

Nabil Adam, DHS
Vijay Atluri, NSF
David Balshaw, NIH/NIEHS
Budhendra Bhaduri, ORNL
Kelly Crews, NSF
Beth Driver, NGA
Walton Fehr, USDOT
Myron Gutmann, NSF
Susanne Hambrusch, NSF
Michelle Heacock, NIH/NIEHS
Clifford Jacobs, NSF
Farnam Jahanian, NSF
Todd Johanesen, NGA
Thomas Johnson, NGA
Henry Kelly, OSTP
Alicia Lindauer, USDOE
Keith Marzullo, NSF
John L. Schnase, NASA
Jim Shine, Army Research
Raju Vatsavai, ORNL
Eric Vessey, NSA
Howard D. Wactlar, NSF
Tandy Warnow, NSF
Nicole Wayant, Army Research
Mark Weiss, NSF
Maria Zemankova, NSF
Li Zhu, NIH/NCI

12 Agencies

Workshop Highlights

Agenda

- Identify fundamental research questions for individual computing disciplines
- Identify cross-cutting research questions requiring novel, multi-disciplinary solutions

Organizing Committee

- Peggy Agouris, George Mason University
- Walid Aref, Purdue University
- Michael F. Goodchild, University of California - Santa Barbara
- Erik Hoel, Environmental Systems Research Institute (ESRI)
- John Jensen, University of South Carolina
- Craig A. Knoblock, University of Southern California
- Richard Langley, University of New Brunswick
- Ed Mikhail, Purdue University
- Shashi Shekhar, University of Minnesota
- Ouri Wolfson, University of Illinois -
- May Yuan, University of Oklahoma

Workshop Highlights

Pull Panel: National Priorities, Societal Applications of Spatial Computing

Chair: Henry Kelly, OSTP

Members

US-DoD: Eric Vessey

US-DoD: Todd Johanesen

NIH/NIEHS: Michelle Heacock

NASA: John L Schnase

DHS: Nabil Adam

NSF EarthCube: Clifford Jacobs

DOT: Walton Fehr

DOE: Alicia Lindauer

Push Panel: Spatial Computing (SC) Platform Trends, Disruptive Technologies

Chair: Dinesh Manocha, UNC

Members:

Graphics & Vision: John Keyser, TAMU

Interaction Devices: Steven Feiner, Columbia University

LiDAR : Avideh Zakhor, UCB

GPS Modernization: Mark Abrams, Advisor to USG

Cell Phones: Ramon Caceres, AT&T

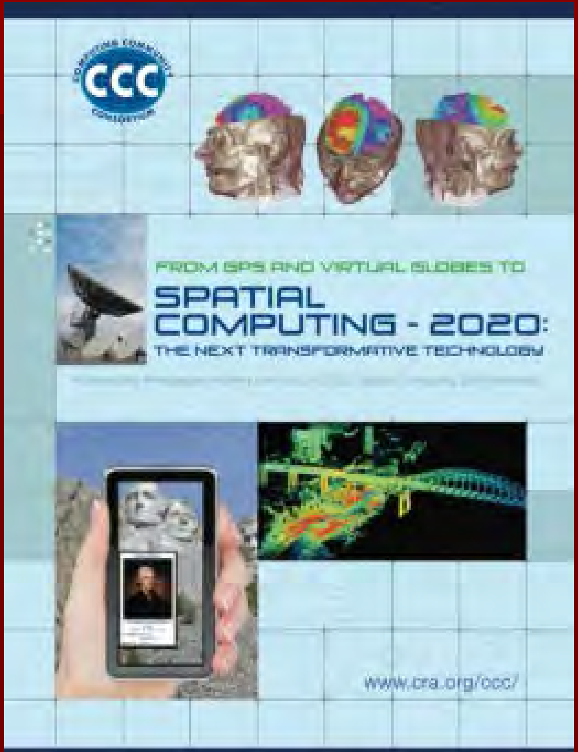
Indoor Localization: Greg Welch, UNC

Internet Localization: Rajesh Gupta, UCSD

Cloud Computing: Divyakant Agarwal, UCSB

Report and Brochure

- From GPS and Virtual Globes to Spatial Computing 2020, CCC Report, 2013. www.cra.org/ccc/visioning/visioning-activities/spatial-computing



FROM GPS AND VIRTUAL GLOBES TO

SPATIAL COMPUTING - 2020:

THE NEXT TRANSFORMATIVE TECHNOLOGY

www.cra.org/ccc/

SPATIAL COMPUTING 2020 VISIONING WORKSHOP

For more details, see the full report at www.cra.org/ccc

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This work was supported by the Computing Community Consortium, which is managed by the Computing Research Association (CRA) and by the National Science Foundation (NSF) through award #0637190.

Publication date: June 2013.

Established in 2006 through a Cooperative Agreement between the National Science Foundation (NSF) and the Computing Research Association (CRA), the CCC serves as a catalyst and enabler for the computing research community. Its goals are to unite the community to contribute to shaping the future of the field; provide leadership for the community, encouraging revolutionary, high-impact research; encourage the alignment of computing research with pressing national priorities and national challenges (many of which cross disciplines); give voice to the community, communicating to a broad audience the many ways in which advances in computing will create a brighter future; and grow new leaders for the computing research community.

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FROM GPS AND VIRTUAL GLOBES TO

SPATIAL COMPUTING - 2020

A CATALYST AND ENABLER
for the computing research community

SPATIAL COMPUTING

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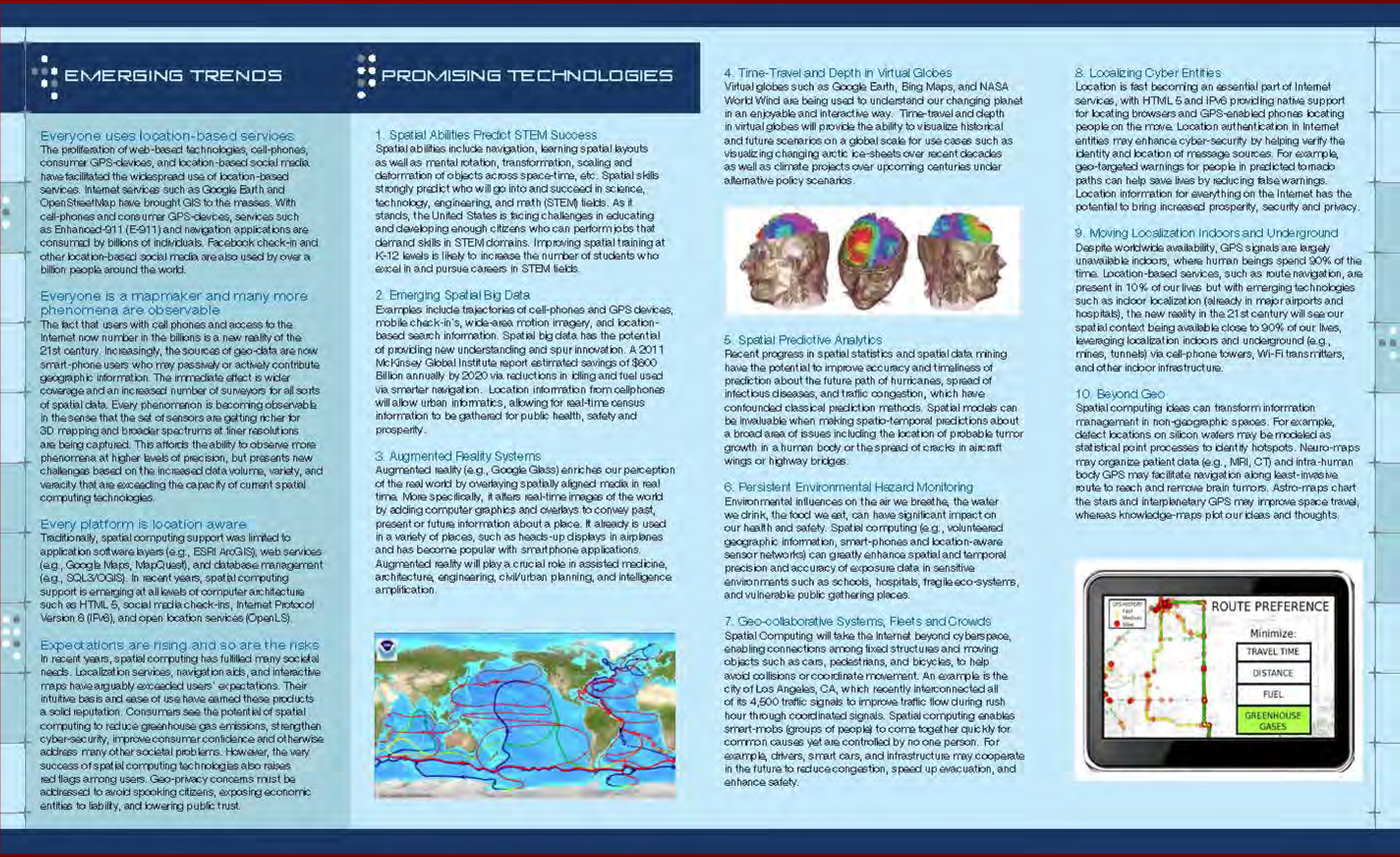
Brochure - Backside



EMERGING TRENDS

Everyone uses location-based services

The proliferation of web-based technologies, cell-phones, consumer GPS-devices, and location-based social media have facilitated the widespread use of location-based services. Internet services such as Google Earth and OpenStreetMap have brought GIS to the masses. With cell-phones and consumer GPS-devices, services such as Enhanced-911 (E-911) and navigation applications are consumed by billions of individuals. Facebook check-in and other location-based social media are also used by over a billion people around the world.

Everyone is a mapmaker and many more phenomena are observable

The fact that users with cell phones and access to the Internet now number in the billions is a new reality of the 21st century. Increasingly, the sources of geo-data are now smart-phone users who may passively or actively contribute geographic information. The immediate effect is wider coverage and an increased number of surveyors for all sorts of spatial data. Every phenomenon is becoming observable in the sense that the set of sensors are getting richer for 3D mapping and broader spectrums at finer resolutions are being captured. This affords the ability to observe more phenomena at higher levels of precision, but presents new challenges based on the increased data volume, variety, and veracity that are exceeding the capacity of current spatial computing technologies.

Every platform is location aware

Traditionally, spatial computing support was limited to application software layers (e.g., ESRI ArcGIS), web services (e.g., Google Maps, MapQuest), and database management (e.g., SQL3/OGIS). In recent years, spatial computing support is emerging at all levels of computer architecture such as HTML 5, social media check-ins, Internet Protocol Version 6 (IPv6), and open location services (OpenLS).

Expectations are rising and so are the risks

In recent years, spatial computing has fulfilled many societal needs. Localization services, navigation aids, and interactive maps have arguably exceeded users' expectations. Their intuitive basis and ease of use have earned these products a solid reputation. Consumers see the potential of spatial computing to reduce greenhouse gas emissions, strengthen cyber-security, improve consumer confidence and otherwise address many other societal problems. However, the very success of spatial computing technologies also raises red flags among users. Geo-privacy concerns must be addressed to avoid spooking citizens, exposing economic entities to liability, and lowering public trust.

PROMISING TECHNOLOGIES

1. Spatial Abilities Predict STEM Success

Spatial abilities include navigation, learning spatial layouts as well as mental rotation, transformation, scaling and deformation of objects across space-time, etc. Spatial skills strongly predict who will go into and succeed in science, technology, engineering, and math (STEM) fields. As it stands, the United States is facing challenges in educating and developing enough citizens who can perform jobs that demand skills in STEM domains. Improving spatial training at K-12 levels is likely to increase the number of students who excel in and pursue careers in STEM fields.

2. Emerging Spatial Big Data

Examples include trajectories of cell-phones and GPS devices, mobile check-in's, wide-area motion imagery, and location-based search information. Spatial big data has the potential of providing new understanding and spur innovation. A 2011 McKinsey Global Institute report estimated savings of $600 Billion annually by 2020 via reductions in idling and fuel used via smarter navigation. Location information from cellphones will allow urban informatics, allowing for real-time census information to be gathered for public health, safety and prosperity.

3. Augmented Reality Systems

Augmented reality (e.g., Google Glass) enriches our perception of the real world by overlaying spatially aligned media in real time. More specifically, it alters real-time images of the world by adding computer graphics and overlays to convey past, present or future information about a place. It already is used in a variety of places, such as heads-up displays in airplanes and has become popular with smartphone applications. Augmented reality will play a crucial role in assisted medicine, architecture, engineering, civil/urban planning, and intelligence amplification.

4. Time-Travel and Depth in Virtual Globes

Virtual globes such as Google Earth, Bing Maps, and NASA World Wind are being used to understand our changing planet in an enjoyable and interactive way. Time-travel and depth in virtual globes will provide the ability to visualize historical and future scenarios on a global scale for use cases such as visualizing changing arctic ice-sheets over recent decades as well as climate projects over upcoming centuries under alternative policy scenarios.

5. Spatial Predictive Analytics

Recent progress in spatial statistics and spatial data mining have the potential to improve accuracy and timeliness of prediction about the future path of hurricanes, spread of infectious diseases, and traffic congestion, which have confounded classical prediction methods. Spatial models can be invaluable when making spatio-temporal predictions about a broad area of issues including the location of probable tumor growth in a human body or the spread of cracks in aircraft wings or highway bridges.

6. Persistent Environmental Hazard Monitoring

Environmental influences on the air we breathe, the water we drink, the food we eat, can have significant impact on our health and safety. Spatial computing (e.g., volunteered geographic information, smart-phones and location-aware sensor networks) can greatly enhance spatial and temporal precision and accuracy of exposure data in sensitive environments such as schools, hospitals, fragile eco-systems, and vulnerable public gathering places.

7. Geo-collaborative Systems, Fleets and Crowds

Spatial Computing will take the Internet beyond cyberspace, enabling connections among fixed structures and moving objects such as cars, pedestrians, and bicycles, to help avoid collisions or coordinate movement. An example is the city of Los Angeles, CA, which recently interconnected all of its 4,500 traffic signals to improve traffic flow during rush hour through coordinated signals. Spatial computing enables smart-mobs (groups of people) to come together quickly for common causes yet are controlled by no one person.. For example, drivers, smart cars, and infrastructure may cooperate in the future to reduce congestion, speed up evacuation, and enhance safety.

8. Localizing Cyber Entities

Location is fast becoming an essential part of Internet services, with HTML 5 and IPv6 providing native support for locating browsers and GPS-enabled phones locating people on the move. Location authentication in Internet entities may enhance cyber-security by helping verify the identity and location of message sources. For example, geo-targeted warnings for people in predicted tornado paths can help save lives by reducing false warnings. Location information for everything on the Internet has the potential to bring increased prosperity, security and privacy.

9. Moving Localization Indoors and Underground

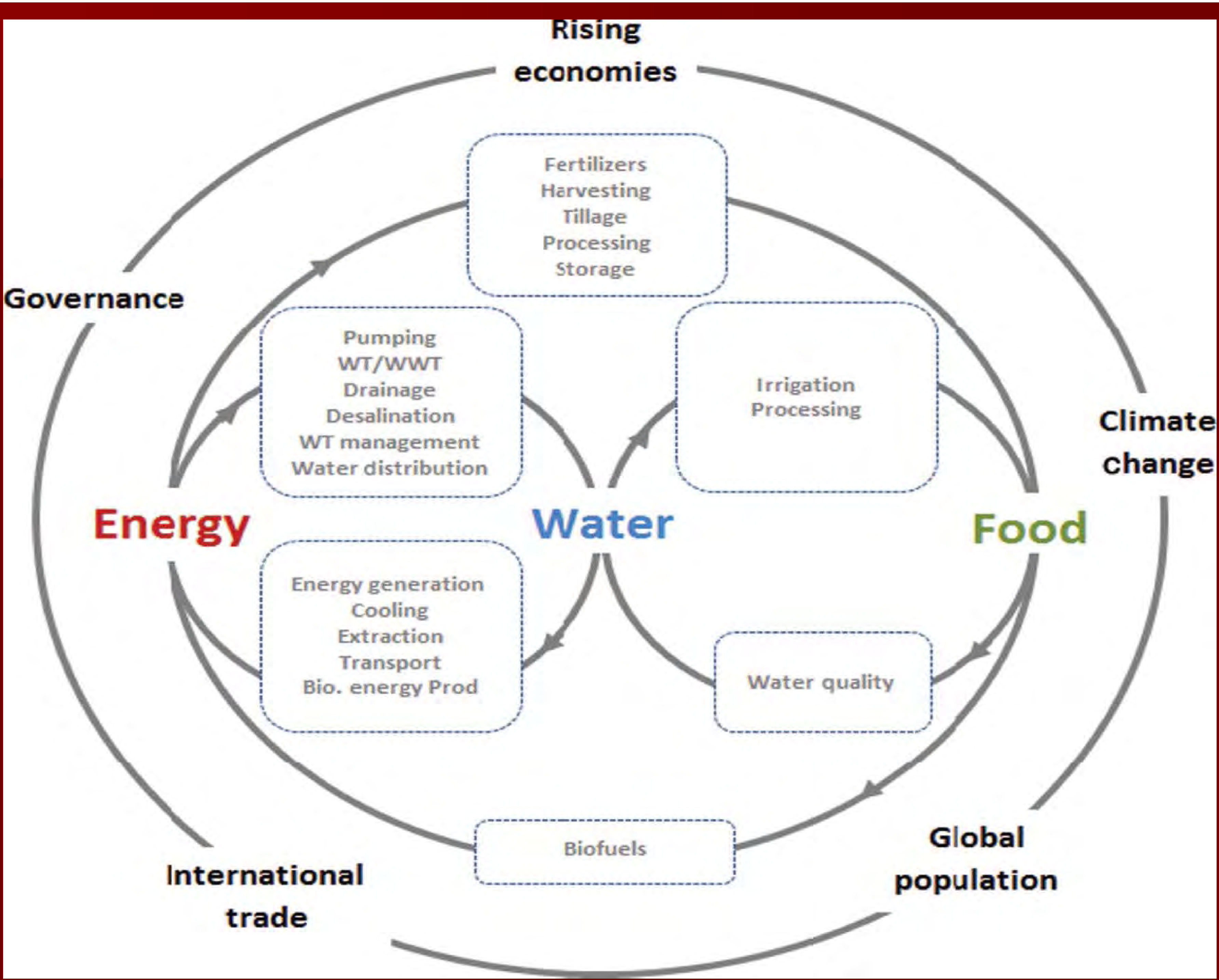
Despite worldwide availability, GPS signals are largely unavailable indoors, where human beings spend 90% of the time. Location-based services, such as route navigation, are present in 10% of our lives but with emerging technologies such as indoor localization (already in major airports and hospitals), the new reality in the 21st century will see our spatial context being available close to 90% of our lives, leveraging localization indoors and underground (e.g., mines, tunnels) via cell-phone towers, Wi-Fi transmitters, and other indoor infrastructure.

10. Beyond Geo

Spatial computing ideas can transform information management in non-geographic spaces. For example, defect locations on silicon wafers may be modeled as statistical point processes to identify hotspots. Neuro-maps may organize patient data (e.g., MRI, CT) and intra-human body GPS may facilitate navigation along least-invasive route to reach and remove brain tumors. Astro-maps chart the stars and interplanetary GPS may improve space travel, whereas knowledge-maps plot our ideas and thoughts.

A Current Opportunity : NSF INFEWS

Interaction of Food System with Energy and Water Systems *[Mohtar 2012].*



Rising economies

Governance

Climate change

Global population

International trade

Fertilizers
Harvesting
Tillage
Processing
Storage

Pumping
WT/WWT
Drainage
Desalination
WT management
Water distribution

Irrigation
Processing

Energy

Water

Food

Energy generation
Cooling
Extraction
Transport
Bio. energy Prod

Water quality

Biofuels