# GEOSPATIAL DATA APPLICATIONS

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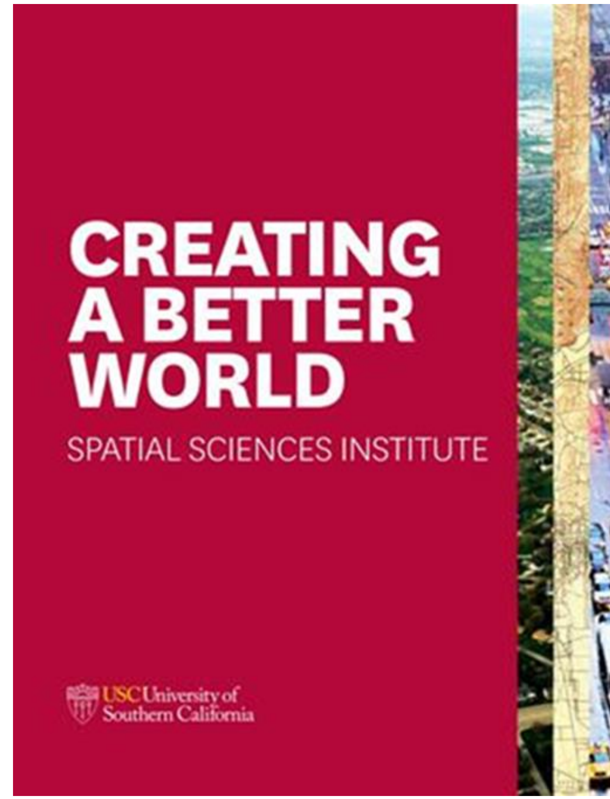
Spatial Sciences Institute

# Outline

- **The Spatial Sciences**
- **Geospatial Big Data**
- **Geospatial Applications**
  - Fitness for Use and Geospatial Metadata
  - Choice of Data Model (Part I)
  - Choice of Data Model (Part II)
  - Choice of Map Projection and Coordinate System
- **The Geospatial Value Proposition**
- **Geospatial Applications**
  - Natural resources
  - Protecting critical infrastructure
  - Food and nutrition security
  - Urban tree canopy
- **Closing Comments**



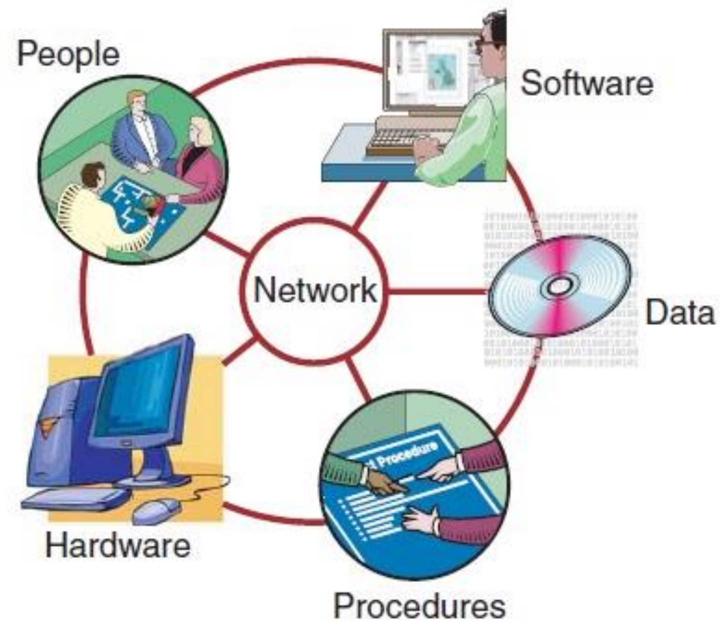
# The Spatial Sciences

as a field of study and body of knowledge and skills around which one might build a successful career

# The spatial sciences …

Combine <u>multidisciplinary</u> fields of scientific study with geospatial technologies including Geographic Information Systems, Global Positioning Systems, and Remotely Sensed Imagery


http://hyperphysics.phy-astr.gsu.edu/hbase/gps.html




https://umar-yusuf.blogspot.com/2016/11/Difference-between-GISystem-GIScience-and-GIService.html

# Spatial sciences graduates …

- Will possess an advanced knowledge of these technologies, experience in the interpretation and processing of satellite images as well as other digital data streams, a broad understanding of computer applications and database management …


**and the spatial principles and methods used to characterize the role of location in the functioning of the Earth and everything people do on it**

# The current geospatial domain …

University Consortium for Geographic Information Science

acm SIGSPATIAL

alteryx

Google earth engine

Matlab

R

CARTODB
Geospatial database on the cloud

Google Maps

PostGIS

SuperMap

esri

GRASS GIS

pysal
Python Spatial Analysis Library

+ a b | e a u

GeoDa

MapBox

QGIS ® Trademark

Whitebox

The International Association of Chinese Professionals in Geographic Information Science, 1992.

FGDC
FEDERAL GEOGRAPHIC DATA COMMITTEE

USGIF
Build the Community
Advance the Tradecraft
Accelerate Innovation

OGC®
Open Geospatial Consortium, Inc.

GIS Certification Institute

# Esri's Geospatial Ecosystem …


**Powered by cloud computing and a growing geospatial infrastructure**

**User styles**

Maps
ModelBuilder
Python notebooks
Runtime SDKs
AI Assistants

**Analytics**

Spatial analysis
Spatial modeling

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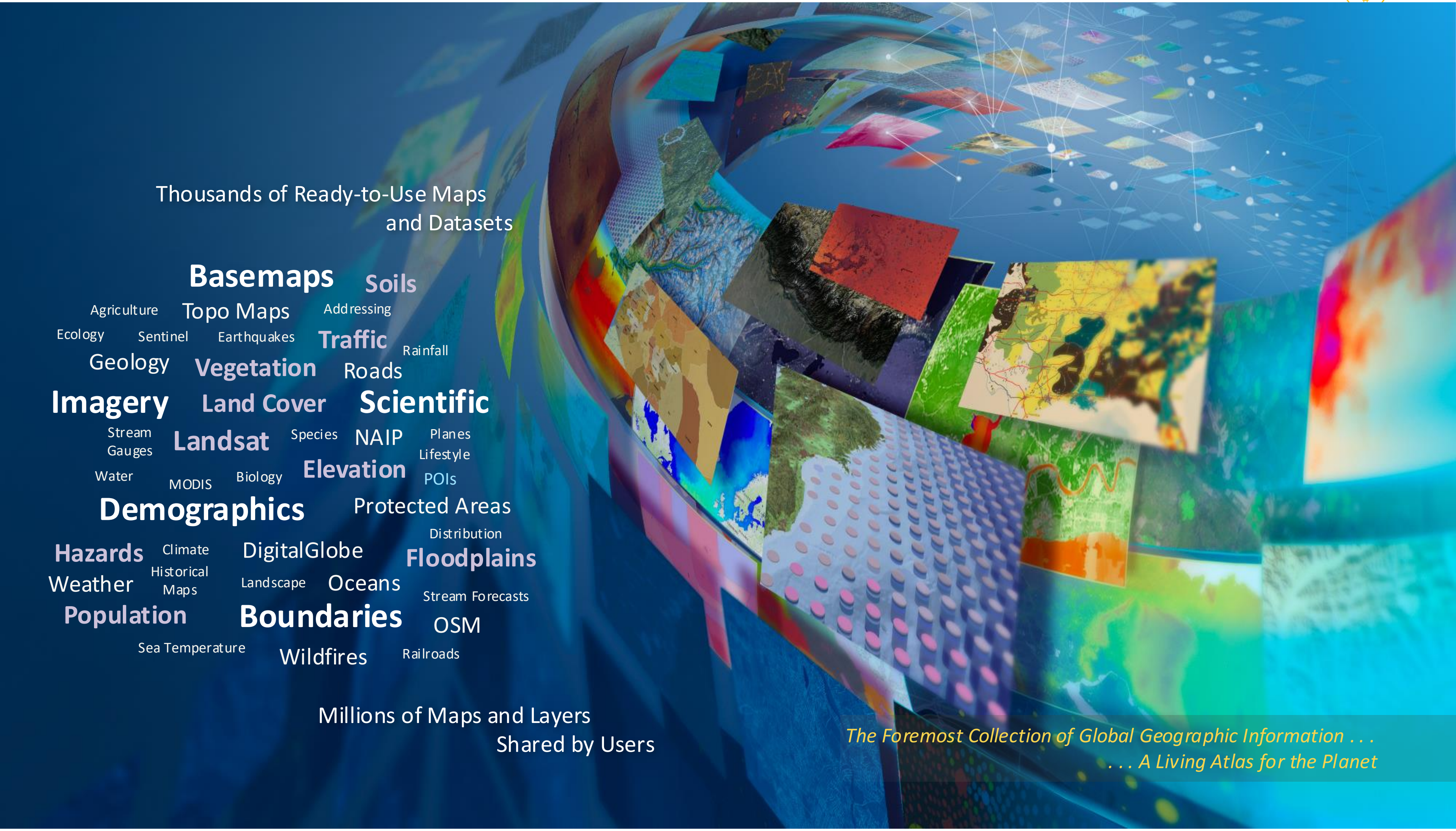
Artificial Intelligence
Deep learning
Machine learning

# Esri's Living Atlas of the World



# Geospatial Big Data

## Geospatial Applications in a World Awash with Geospatial Data

# Geospatial data sources and styles

- Location-based devices and services
- Volunteered and ambient geographic information
- Remote sensing
  - In-situ sensing
  - Traditional satellite and high-altitude airborne remote sensing systems
  - Nanosatellites
  - Street-level imagery
  - Unmanned aerial systems
- Sensor networks and the Internet of Things
- 3D modeling, video, and virtual and augmented reality systems
  - Digital twins and building information models
  - 3D city models
  - Spatial video
  - Virtual and augmented reality systems

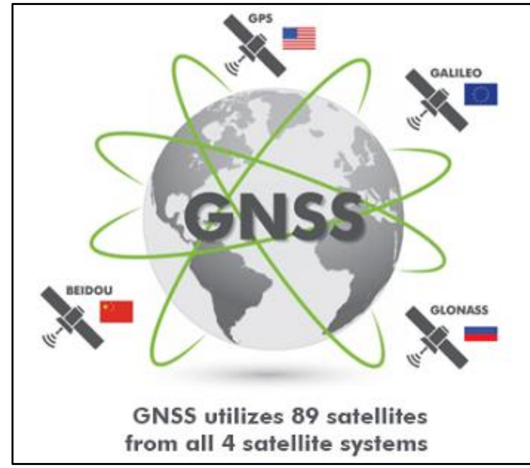
# Location-based devices and services

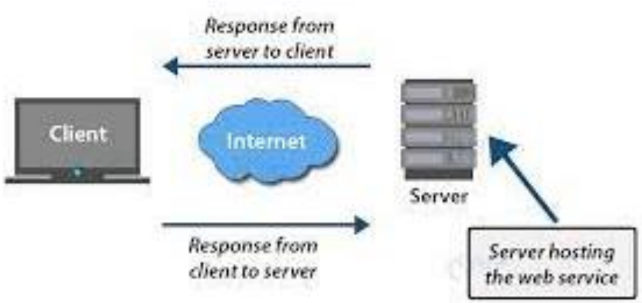
Smart phone

RFID

Wi-Fi

Bluetooth




Web services

WeChat

WhatsApp

flickr

myspace

# Volunteered and ambient geographic information

GLOBE

SAHANA EDEN

Mapillary

OpenStreetMap
The Free Wiki World Map

Ushahidi

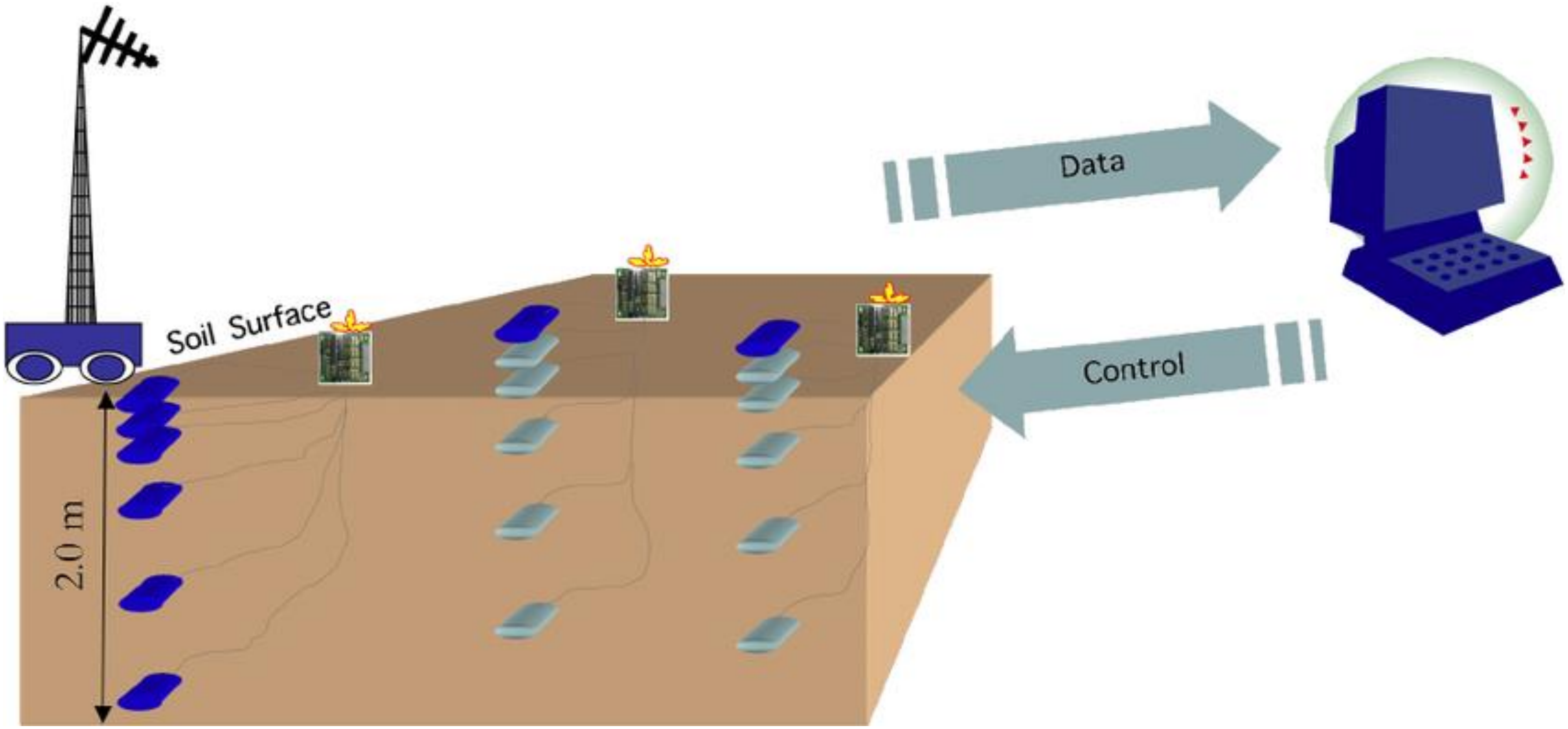
eBird

wikimapia

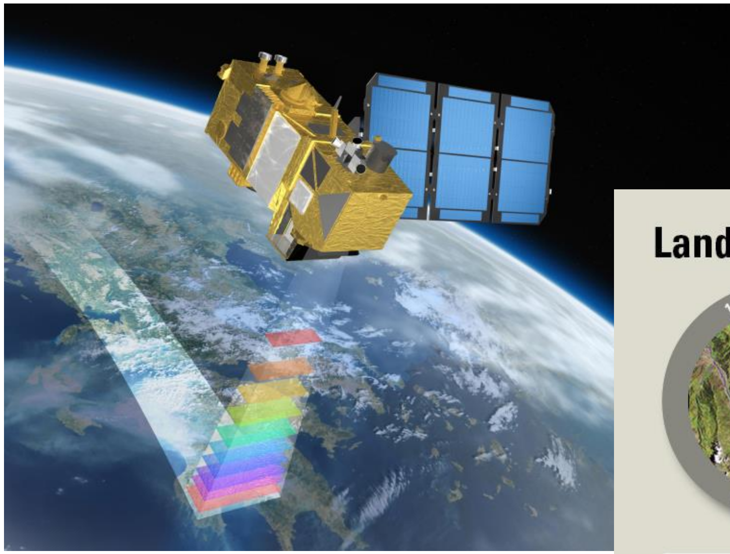
DRONESTAGRAM
Share Drone Images and Explore the World !

AllTrails

# In-situ remote sensing



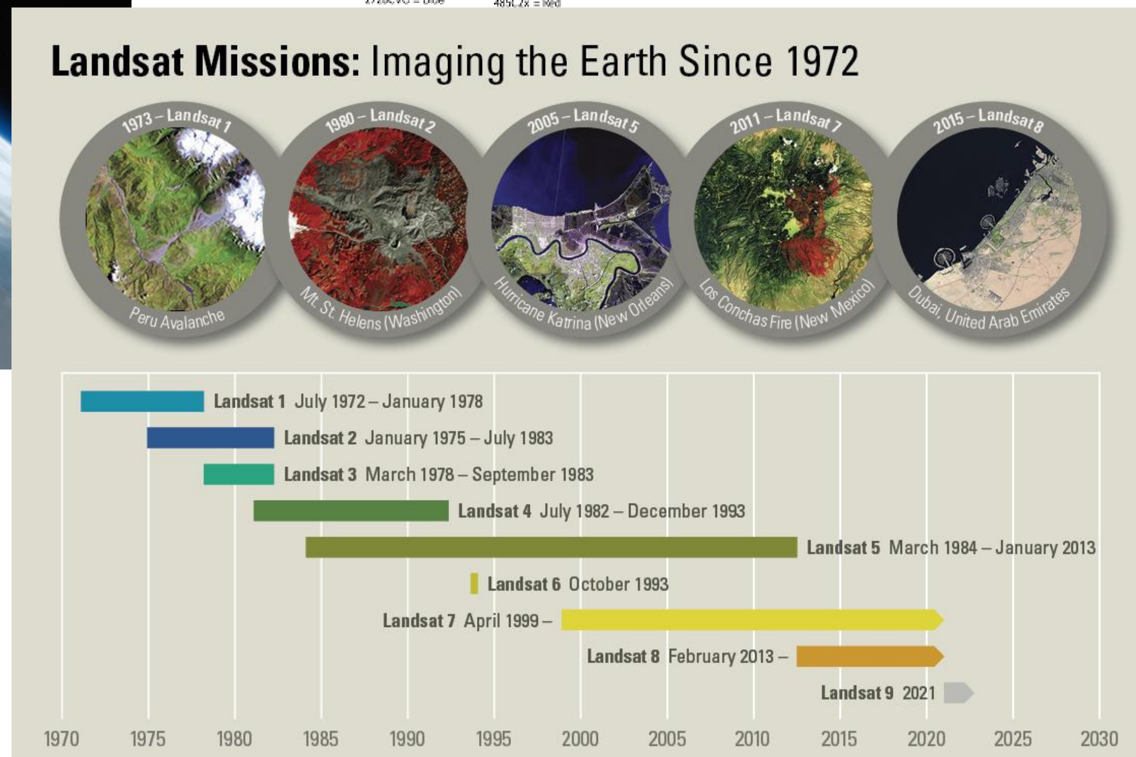
# Satellite remote sensing



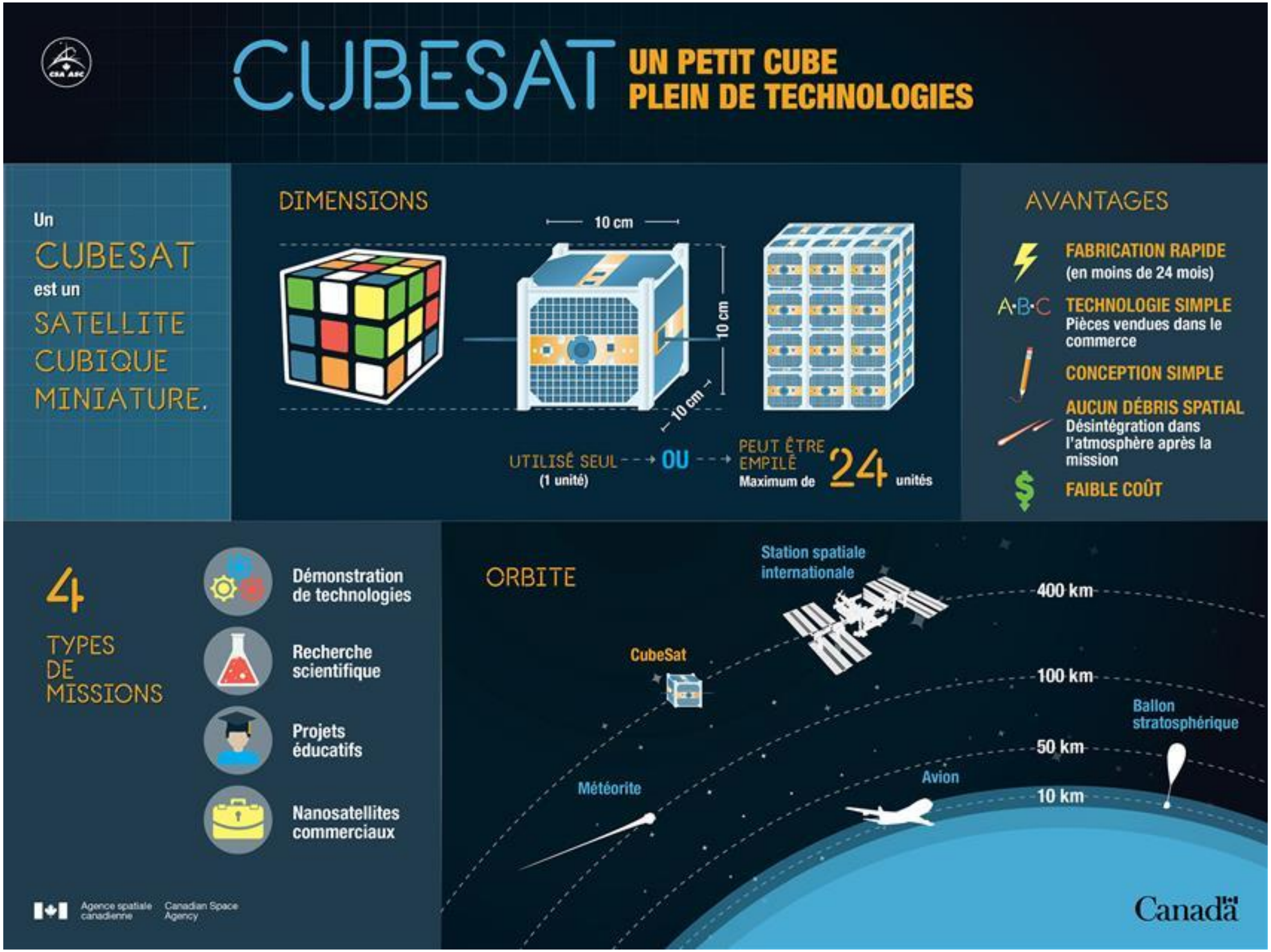
GRACE

SMAP
Soil Moisture Mapping

Pantone Colors
2728CVC = Blue
485C2x = Red




NASA MODIS
Moderate Resolution Imaging Spectroradiometer


CUBESAT
UN PETIT CUBE PLEIN DE TECHNOLOGIES
Un CUBESAT est un SATELLITE CUBIQUE MINIATURE.
DIMENSIONS
10 cm
10 cm
10 cm
UTILISÉ SEUL (1 unité)
OU
PEUT ÊTRE EMPILÉ Maximum de 24 unités
AVANTAGES
FABRICATION RAPIDE (en moins de 24 mois)
A·B·C
TECHNOLOGIE SIMPLE Pièces vendues dans le commerce
CONCEPTION SIMPLE
AUCUN DÉBRIS SPATIAL Désintégration dans l'atmosphère après la mission
FAIBLE COÛT
4 TYPES DE MISSIONS
Démonstration de technologies
Recherche scientifique
Projets éducatifs
Nanosatellites commerciaux
ORBITE
Station spatiale internationale
400 km
CubeSat
100 km
Ballon stratosphérique
50 km
Avion
10 km
Météorite
Agence spatiale canadienne
Canadian Space Agency
Canadä

# Street-level imagery

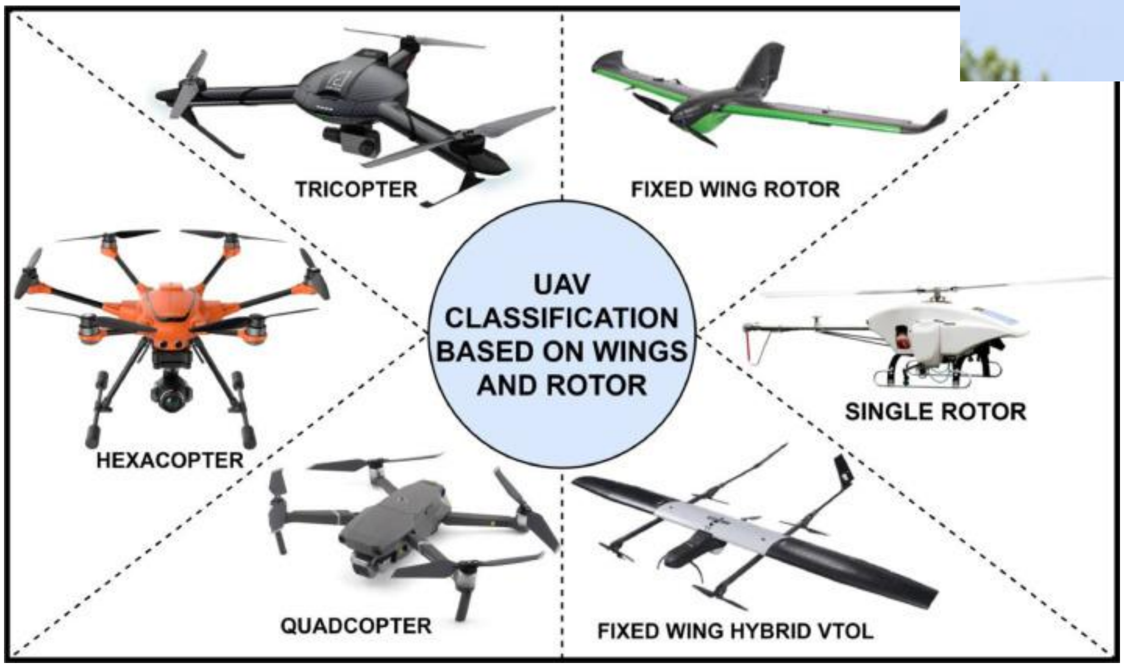
OpenStreetCam

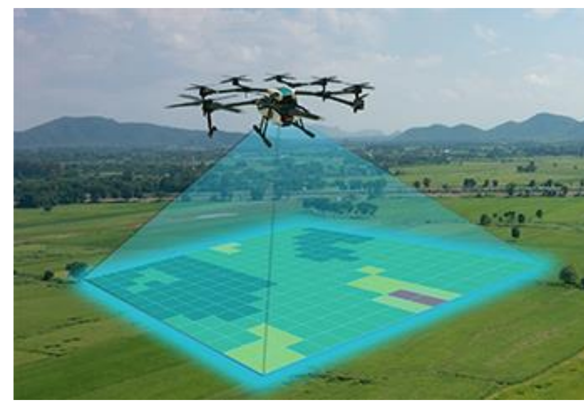
Mapillary

Bing maps

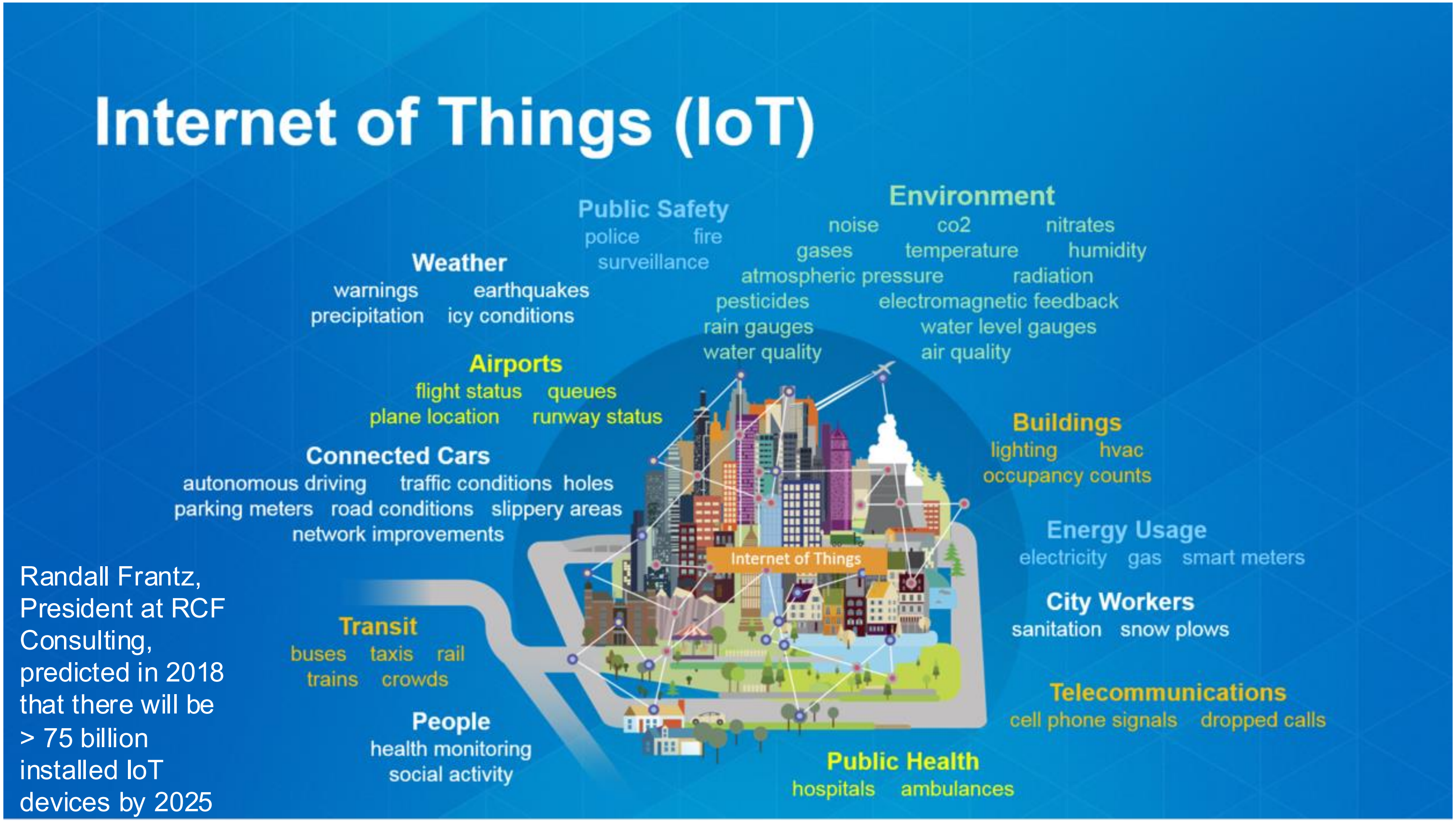
cyclomedia
Smart Imagery Solutions

# Unoccupied aerial systems



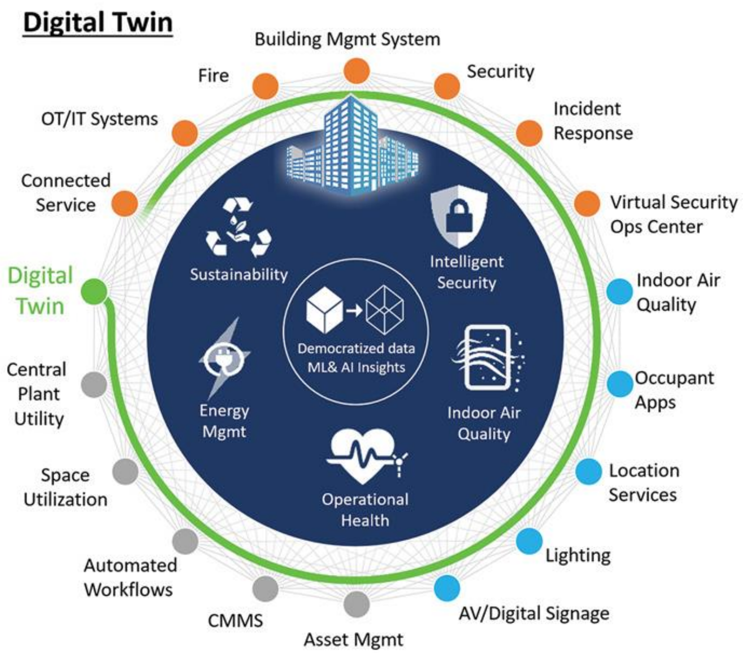



# Sensor networks & the Internet of Things

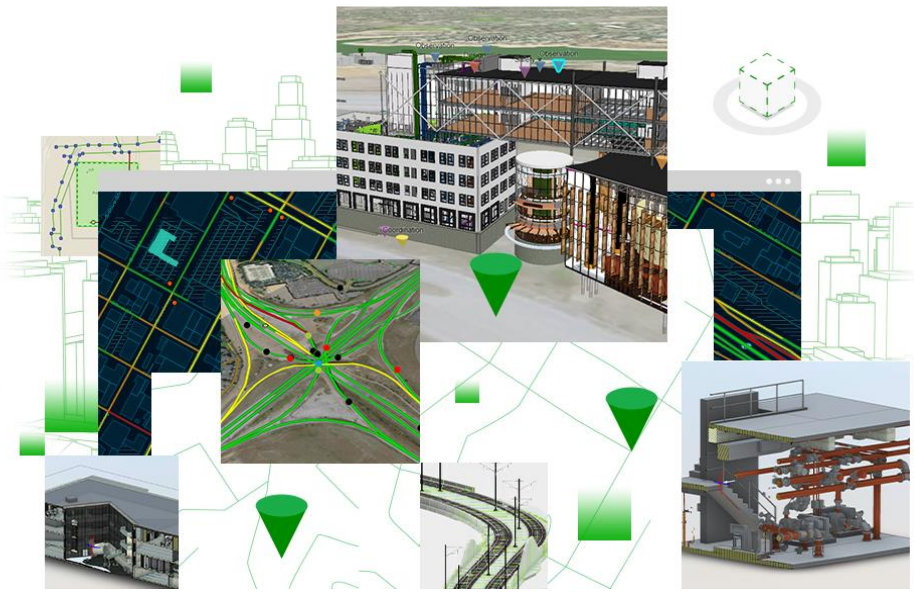



Randall Frantz, President at RCF Consulting, predicted in 2018 that there will be > 75 billion installed IoT devices by 2025

# 3D modeling, spatial video, augmented and virtual reality systems



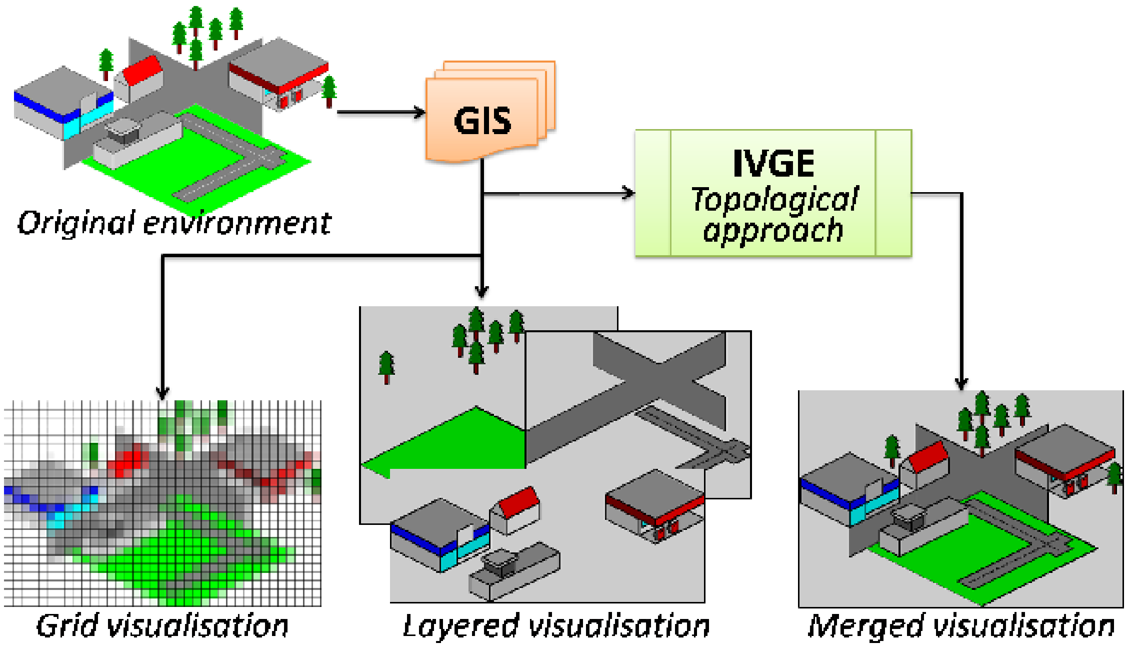

ArcGIS GeoBIM

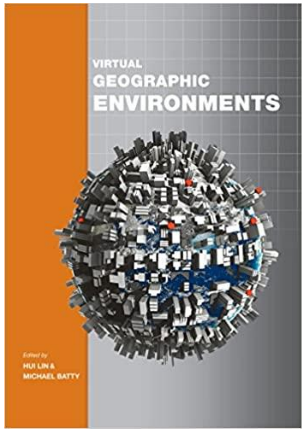


SmartCity

AUTODESK.

# 3D modeling, spatial video, augmented and virtual reality systems



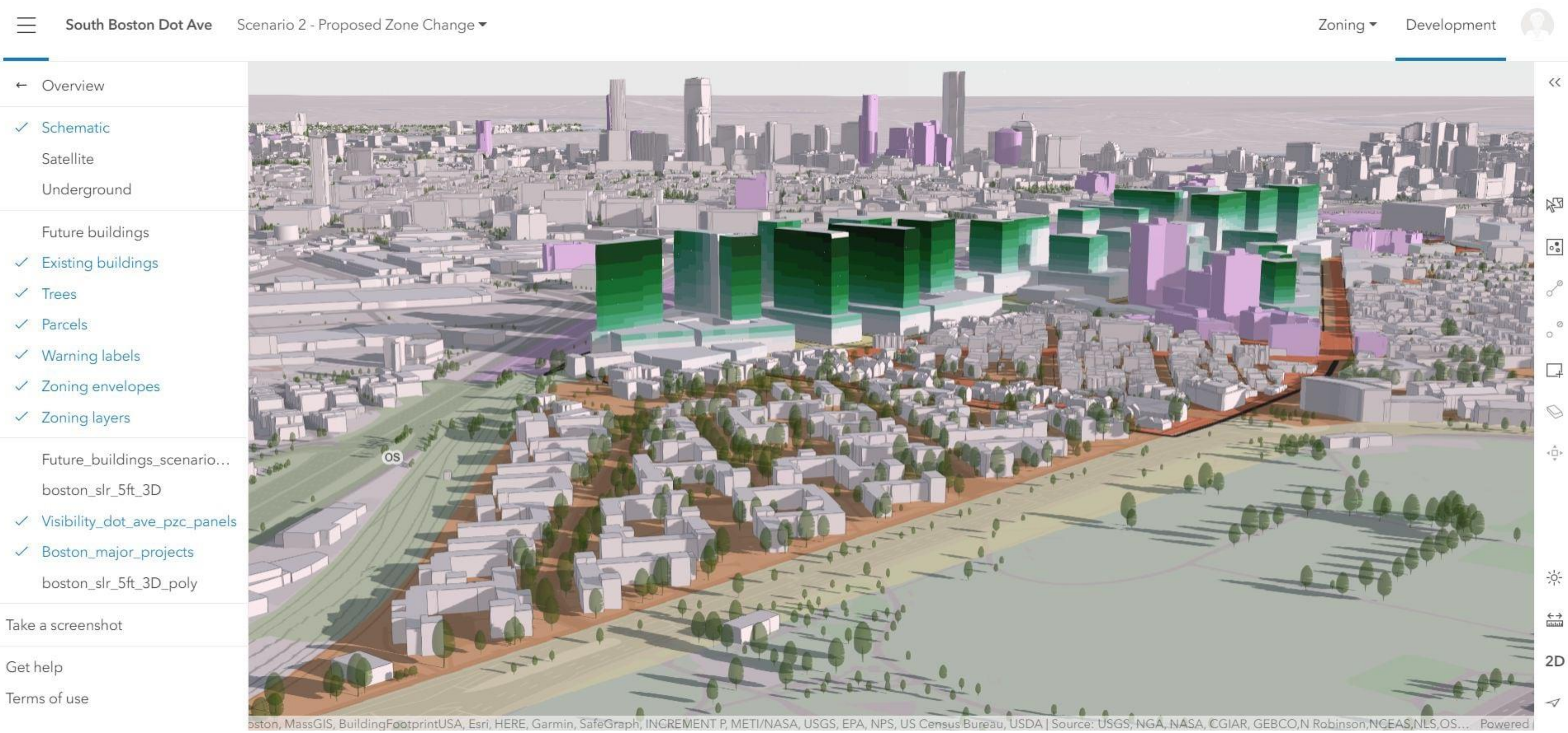




**Lin & Batty (2011)**

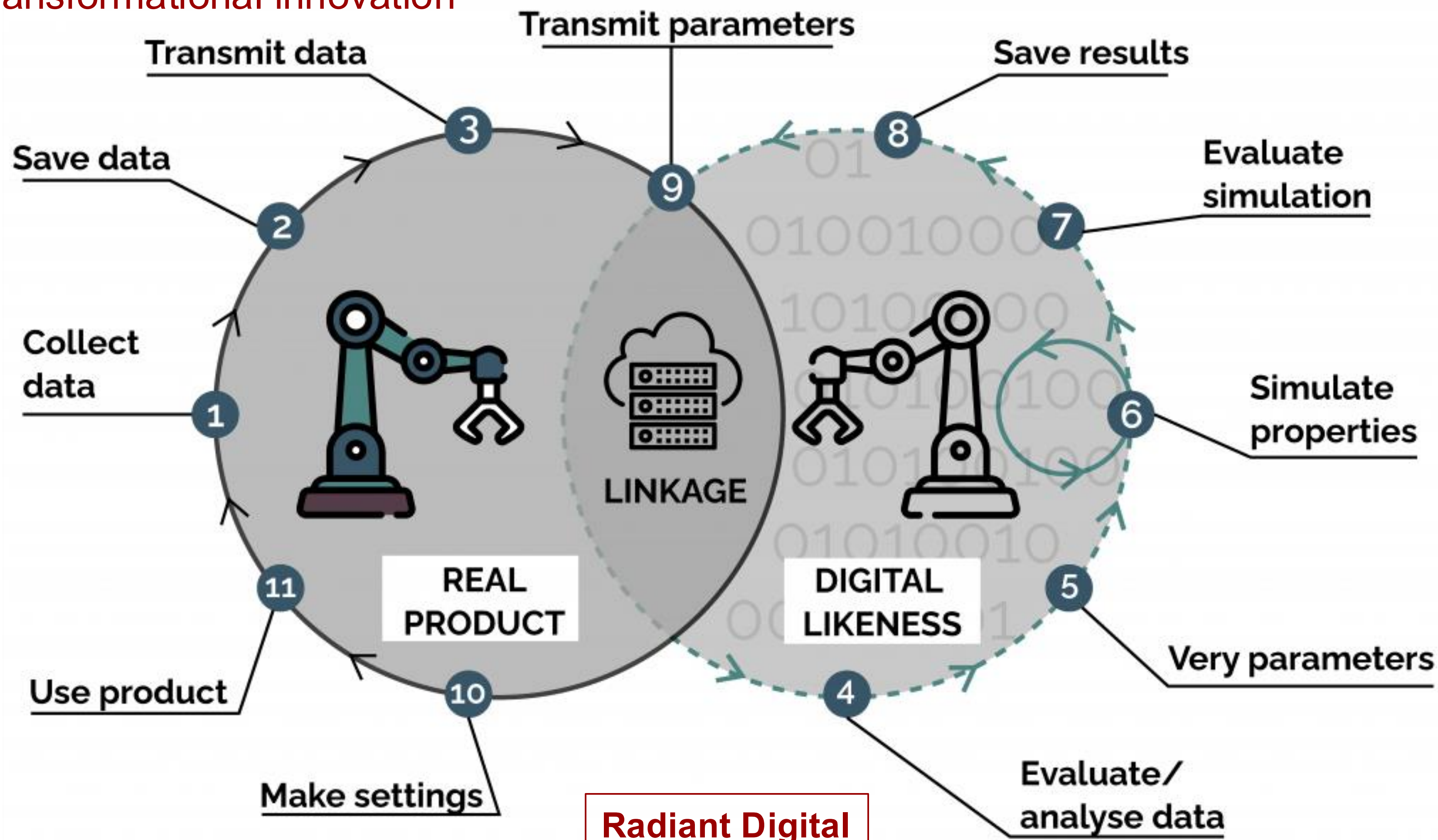
unity UNREAL ENGINE

**Hudson-Smith & Batty (2021)**

# Digital twins



# Digital Twin: Connecting the virtual and physical worlds to accelerate transformational innovation




Radiant Digital

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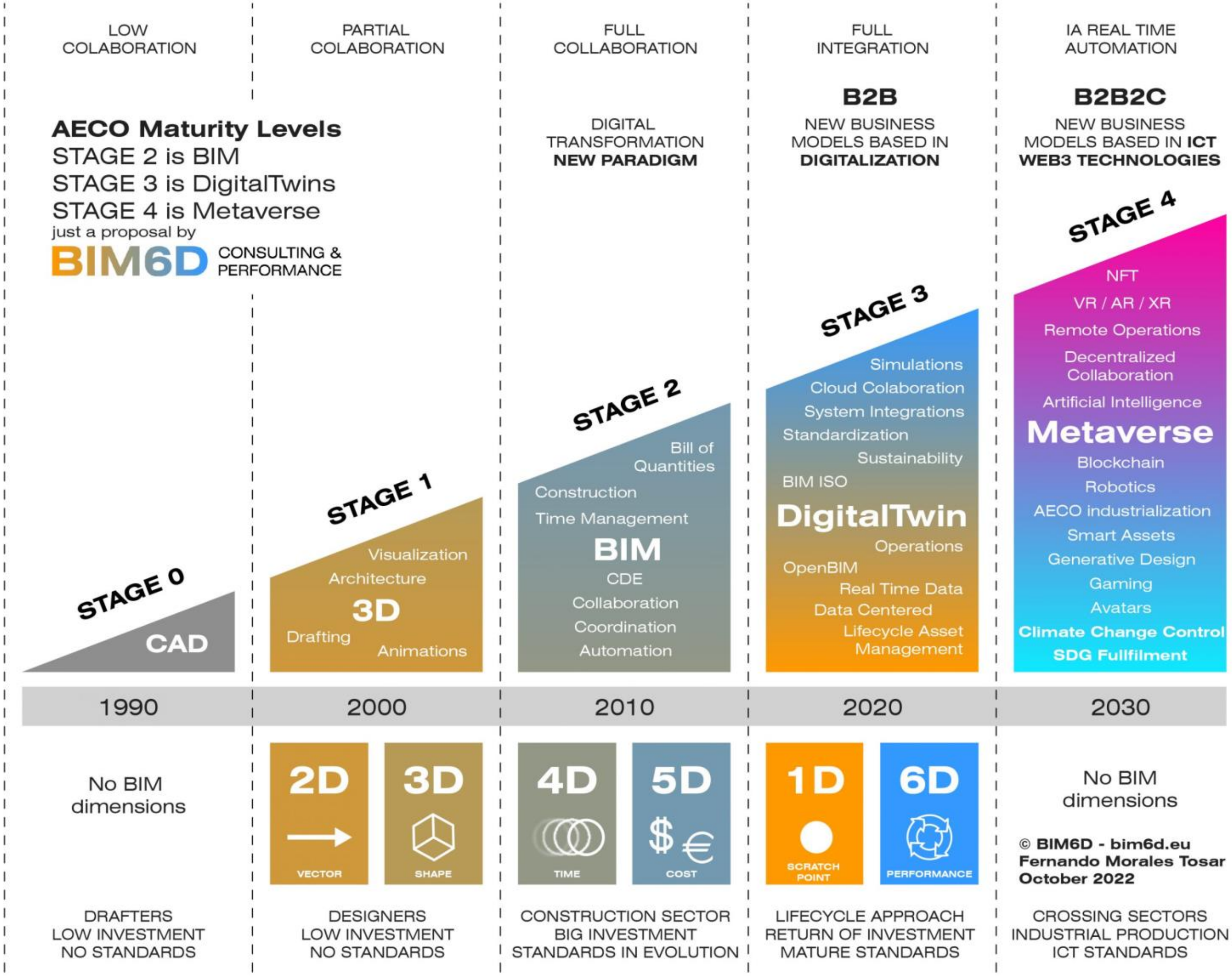
# Digital twins

## and the Metaverse

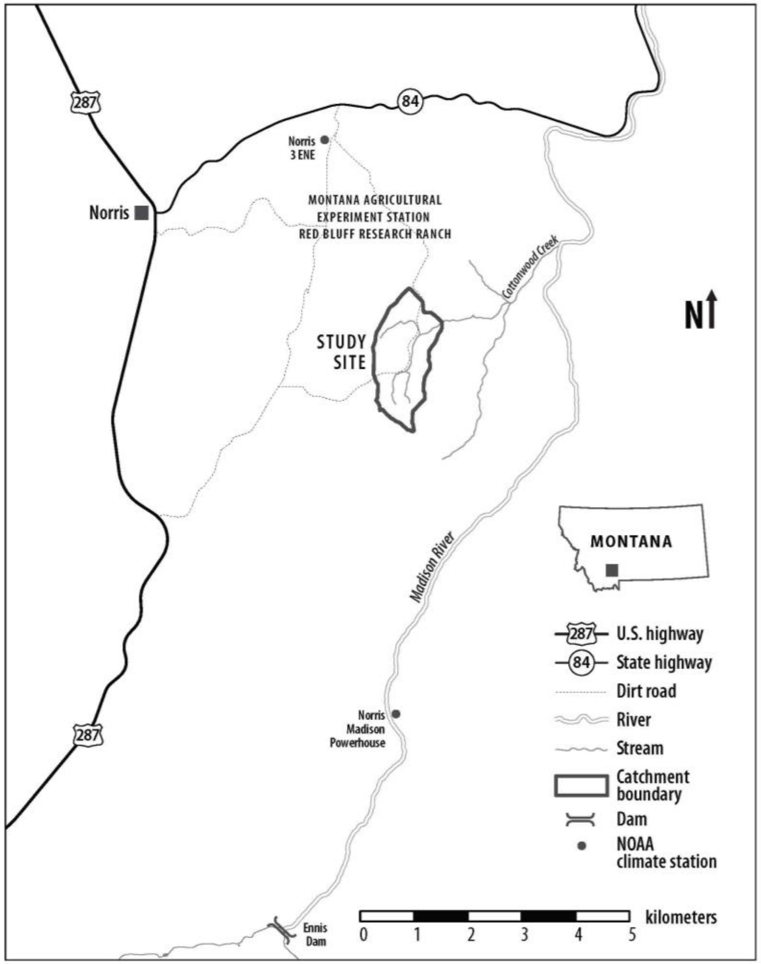


# Geospatial Applications

## Fitness for Use and Geospatial Metadata

# A typical Montana landscape …

# Building blocks …



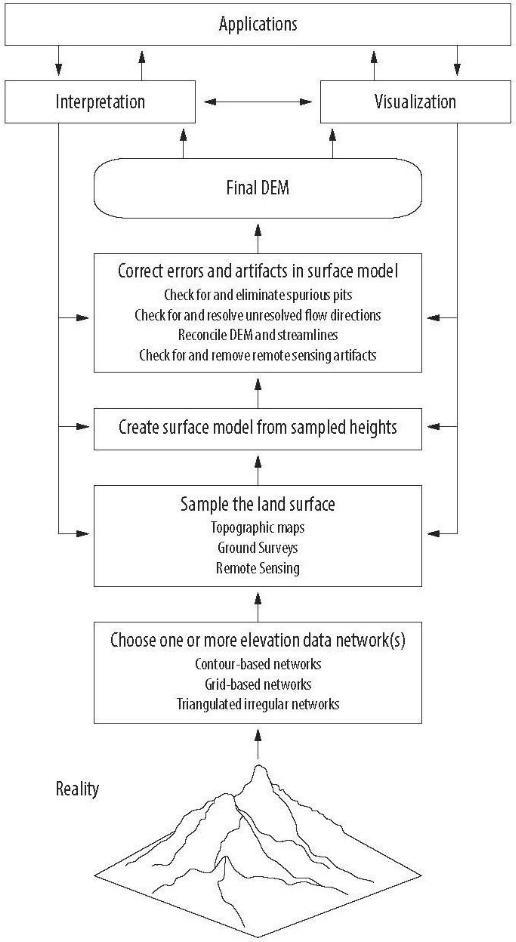
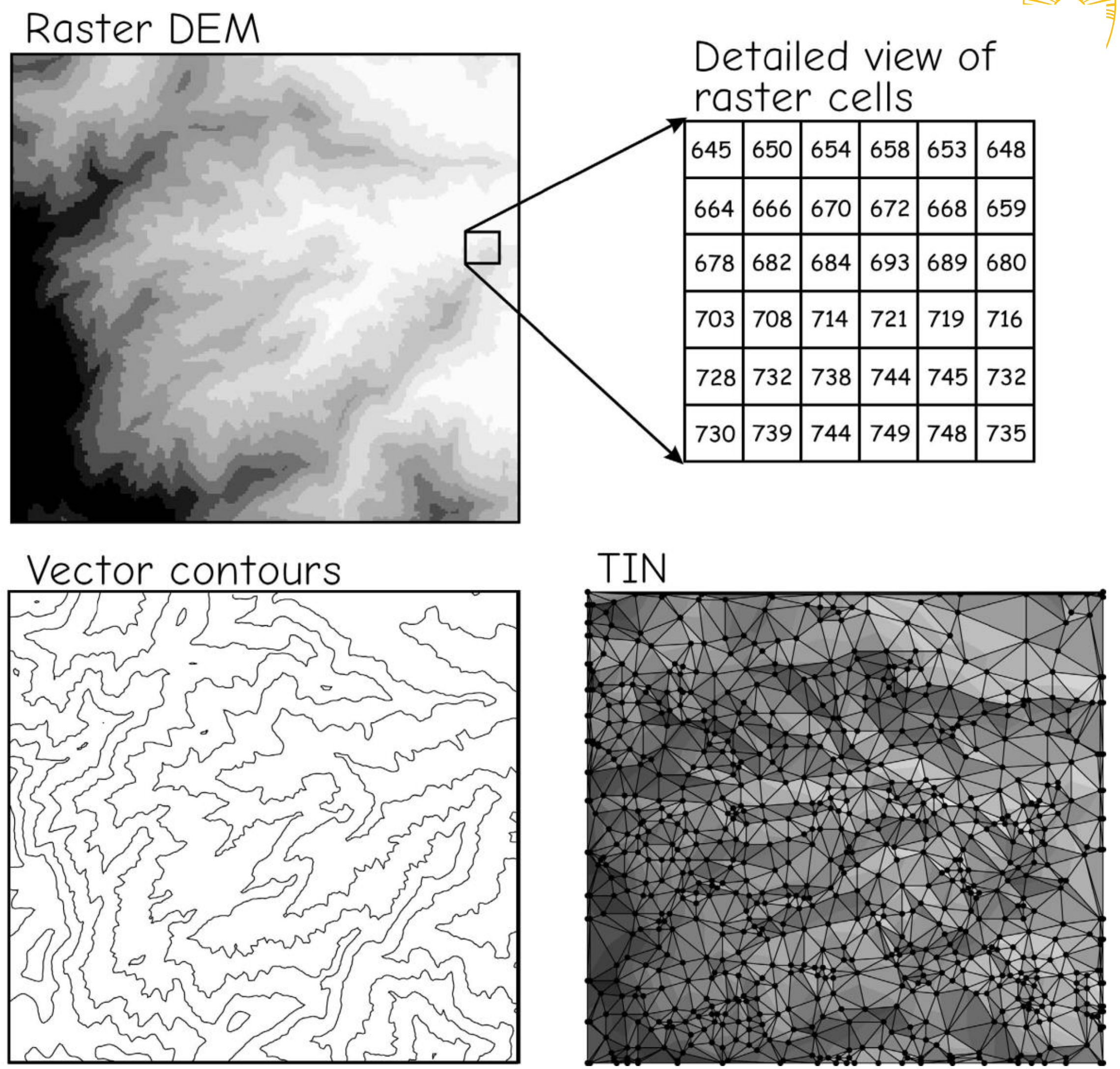
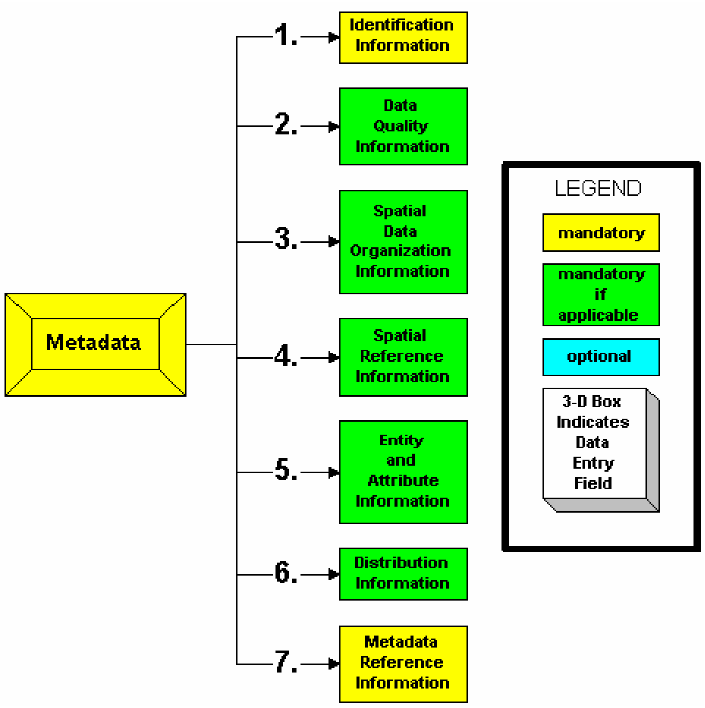



**Fig. 2-42:** Data may often be represented in several data models. Digital elevation data are commonly represented in raster (DEM), vector (contours), and TIN data models (Bolstad)



# Role of metadata and fitness-for-use

- How can one judge the quality and fitness-for-use of a data set?
- **The most popular answer is likely to suggest one checks the metadata**
- A metadata report is an explicit assessment of the quality of a data set and something that should accompany the data
- Numerous organizations have created standards for spatial data quality metadata, including the U.S. Federal Geographic Data Committee



# Metadata

- Metadata is information about data
- Similar to a library catalog record, metadata records document the who, what, when, where, how, and why of a data resource
- Geospatial metadata describes maps, Geographic Information System (GIS) files, imagery, and other location-based data resources
- The Federal Geographic Data Committee (FGDC) is tasked by Executive Order 12906 to enable access (see GeoPlatform.gov) to National Spatial Data Infrastructure (NSDI) resources and by OMB Circular A-16 and the A-16 Supplemental Guidance to support the creation, management, and maintenance of the metadata required to fuel data discovery and access

# Geospatial Data Applications

## Choice of Data Model (Part I)

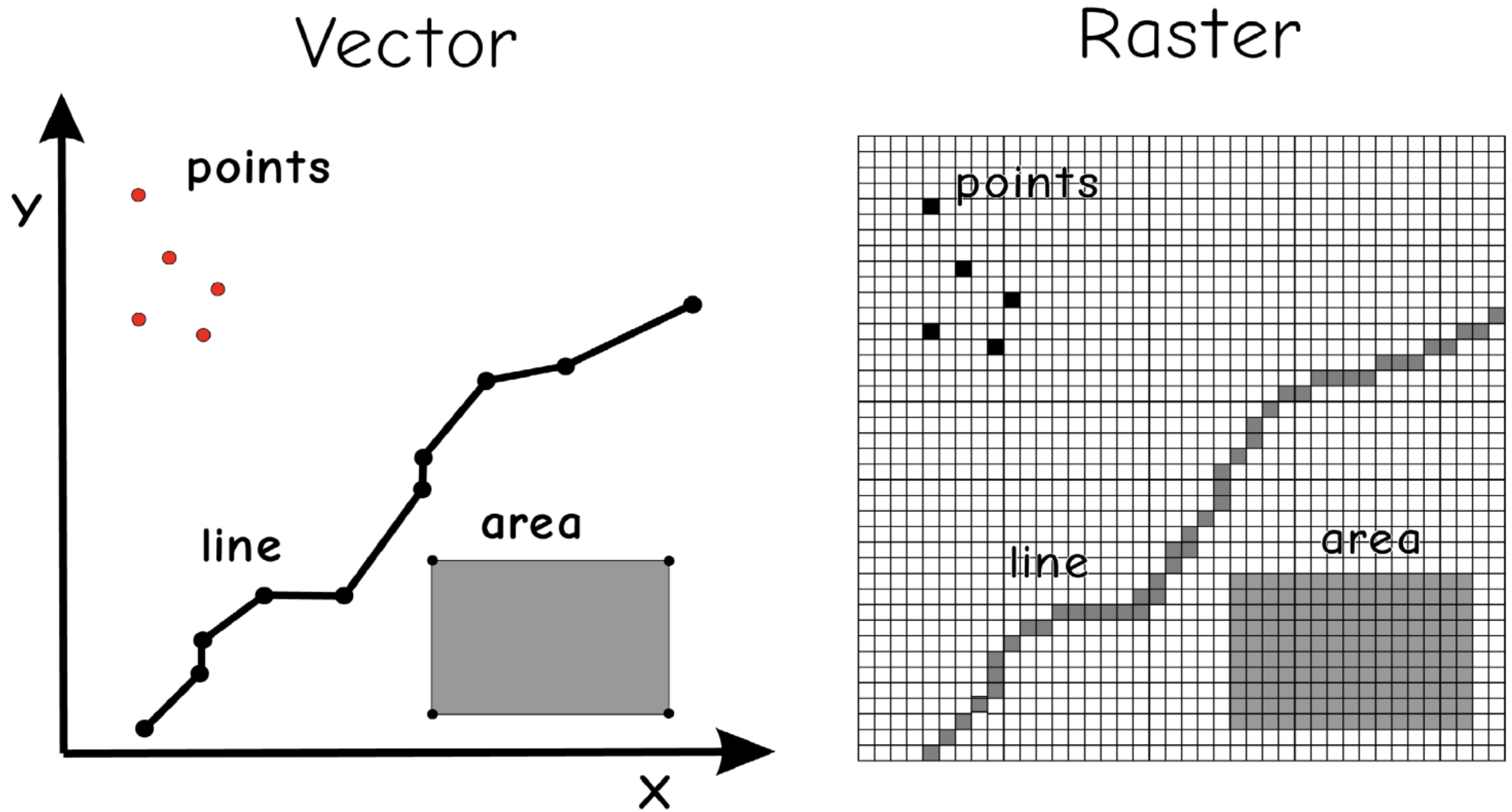



**Fig. 2-19:** Vector and raster data models (Bolstad)

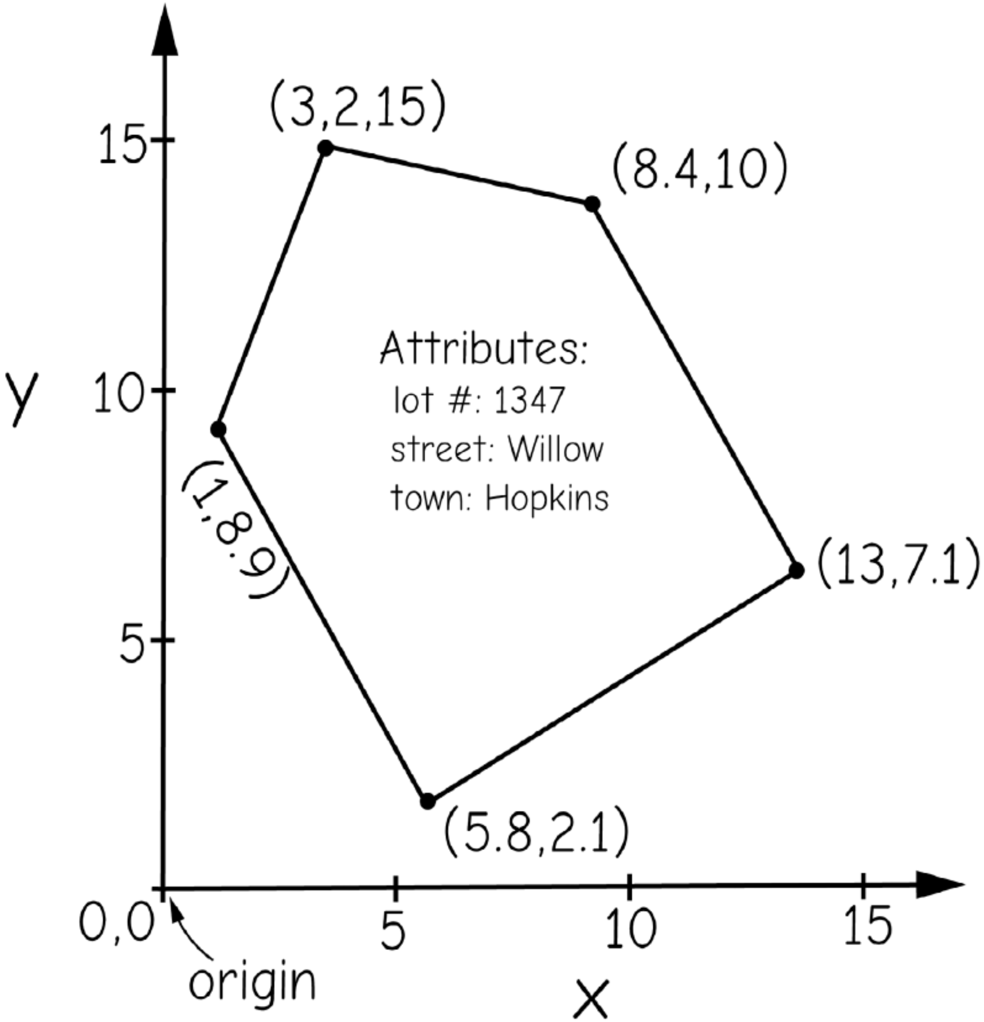



**Fig. 2-4:** Coordinate and attribute data are used to represent spatial entities (Bolstad)

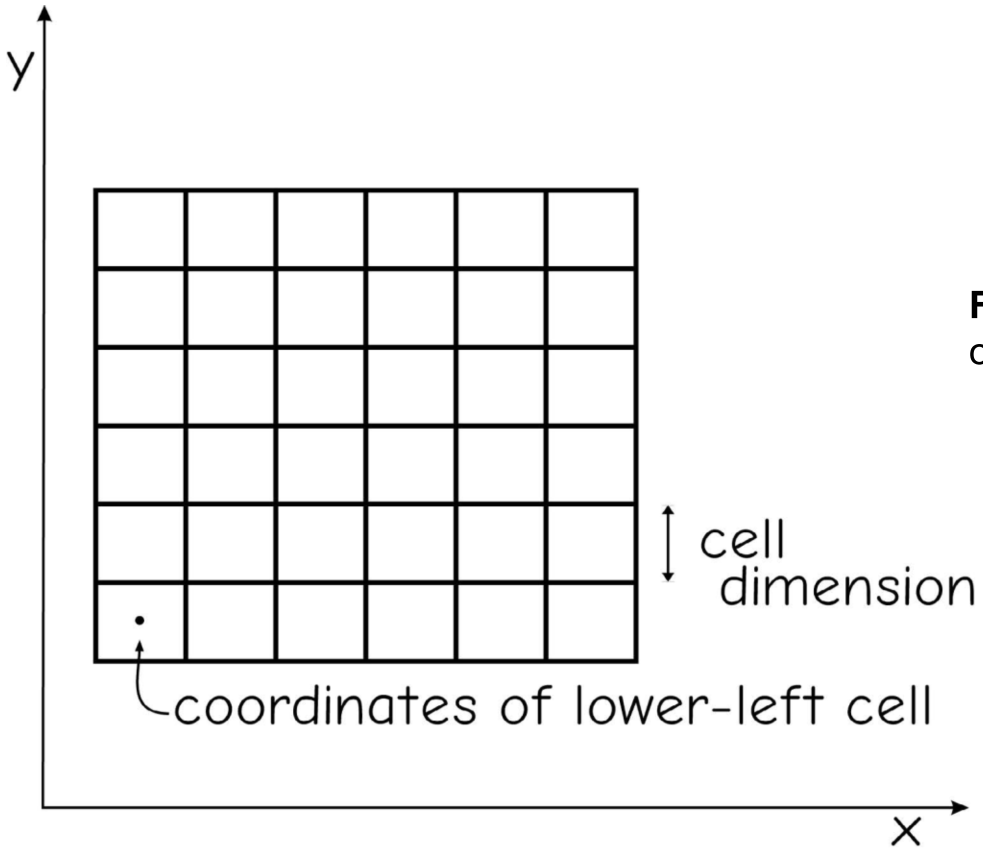



**Fig. 2-30:** Important defining characteristics of a raster data model (Bolstad)

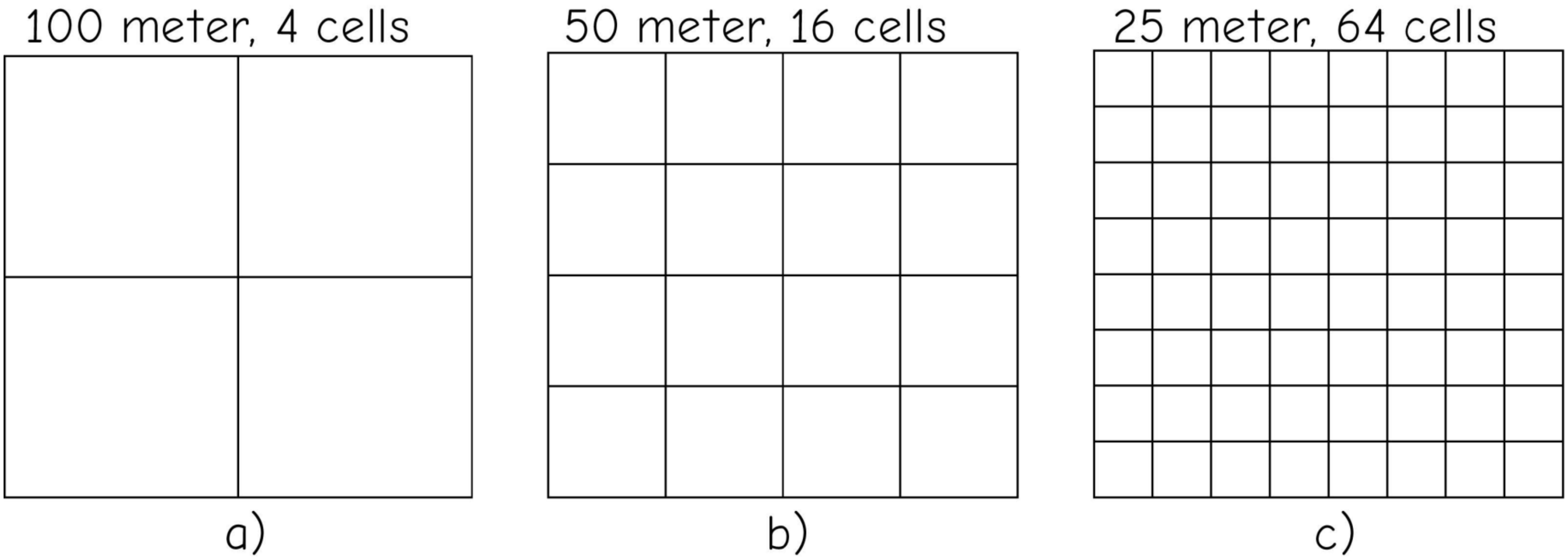



**Fig. 2-31:** The number of cells in a raster data set depends on the cell size. For a given area, a linear decrease in cell size causes an exponential increase in cell number, e.g., halving the cell size causes a four-fold increase in cell number (Bolstad)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| a | a | a | a | r | f | f | a | a | a | a | a |
| a | a | a | a | r | f | f | a | a | a | a | a |
| a | a | a | f | r | f | f | a | a | a | a | a |
| a | a | a | r | r | f | f | a | a | a | a | a |
| a | a | a | r | f | f | f | a | a | a | a | a |
| a | f | f | r | f | f | f | a | a | a | a | a |
| a | f | f | r | f | u | f | a | a | a | a | a |
| h | h | h | h | h | h | h | h | h | h | h | h |
| f | f | r | u | u | u | u | a | a | a | a | a |
| f | f | r | f | u | u | a | a | a | a | a | a |
| f | f | f | r | f | f | a | a | a | a | a | a |
| f | f | f | f | r | f | a | a | a | a | a | a |

a = agriculture
u = developed
f = forest
r = river
h = highways

**Fig. 2-32:** Discrete or categorical data may be represented by codes in a raster data layer (Bolstad)

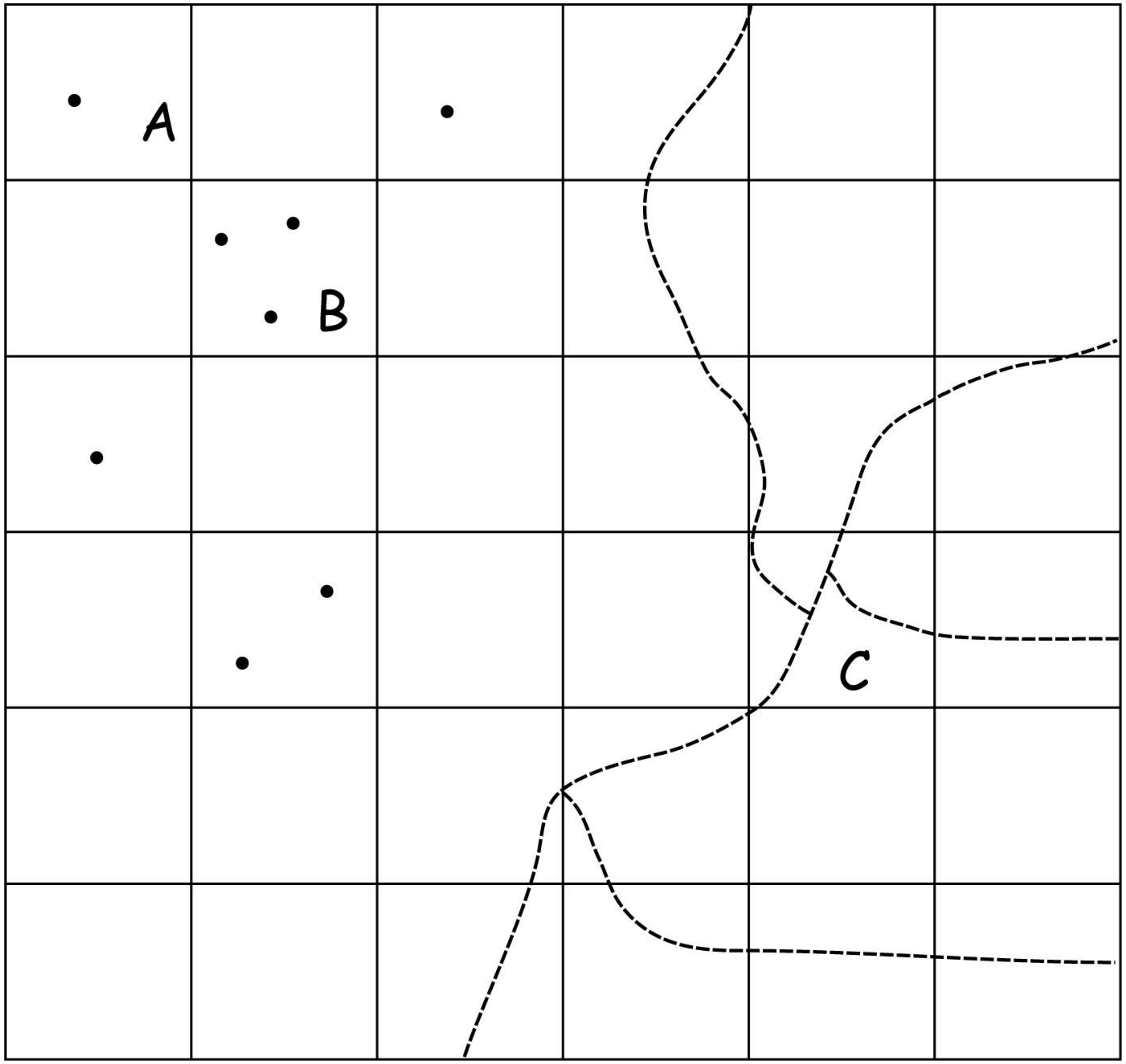



**Fig. 2-33:** Raster cell assignments requires decisions when multiple objects occur in the same cell (Bolstad)

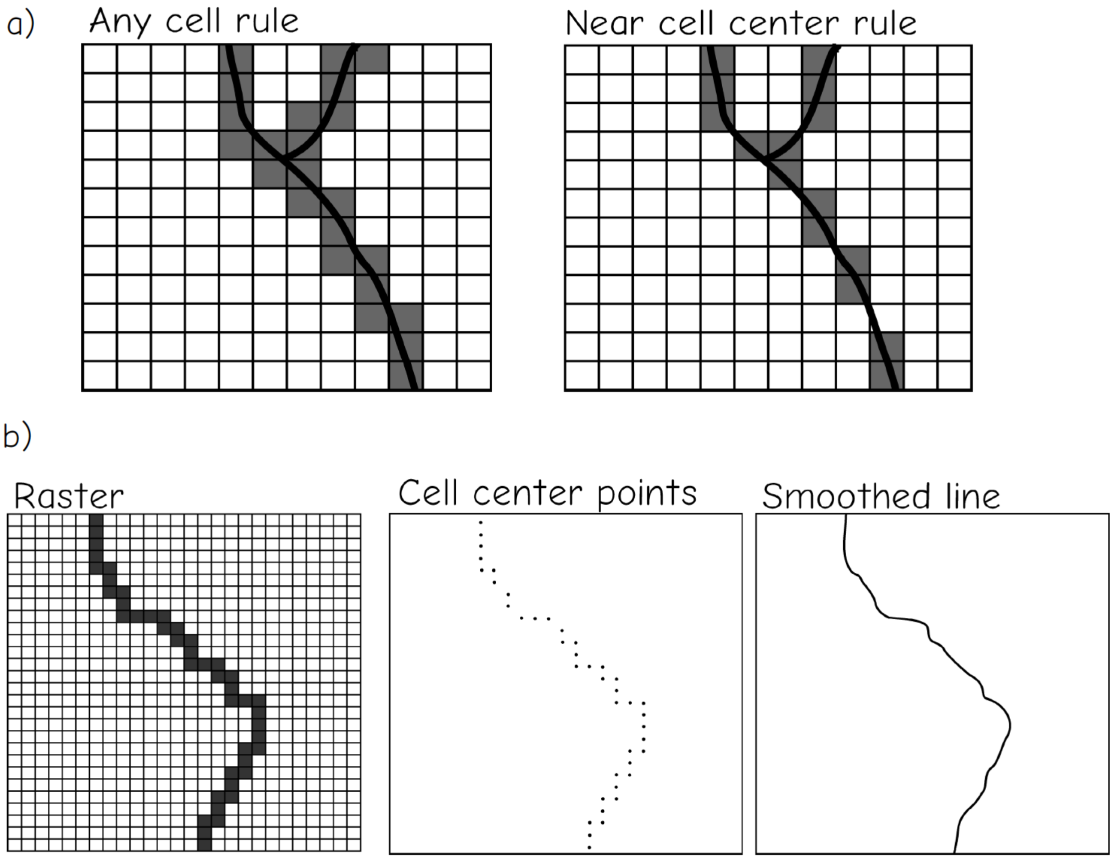



**Fig. 2-36:** Vector to raster conversion (a) and raster to vector conversion (b). In (a), cells are assigned to a raster if they intersect with a converted vector. The left and right panels show how two assignment rules result in different raster coding near lines. Panels in (b) show how raster data many be converted to vector formats, and may involve line smoothing or other operations to remove the “stair-step” effect (Bolstad)

# Geospatial Data Applications

## Choice of Data Model (Part II)

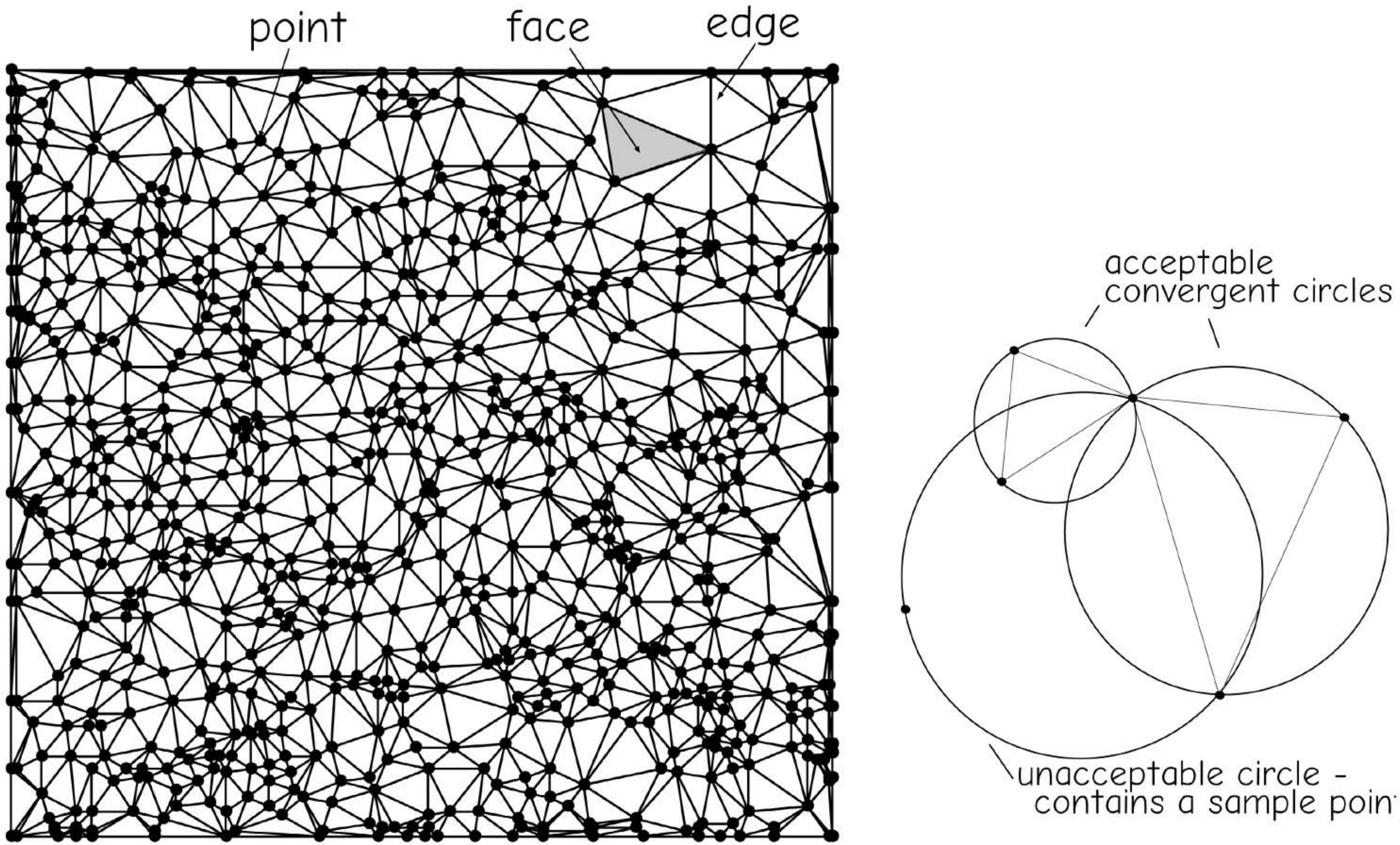
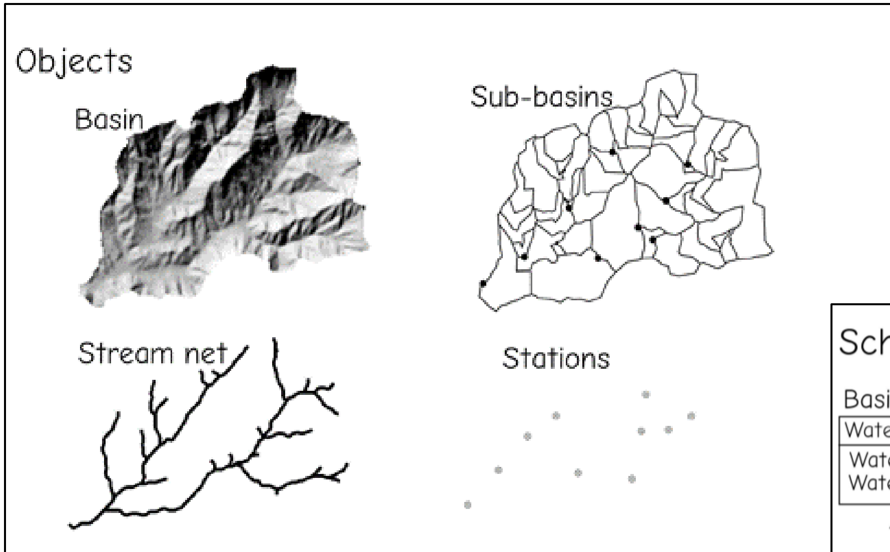



**Fig. 2-37:** A TIN data model defines a set of adjacent triangles over a sample space (left). Sample points, facets, and edges are components of TIN data models. Triangles are placed by convergent circles. These intersect the vertices of a triangle and contain no other possible vertices (right) (Bolstad)



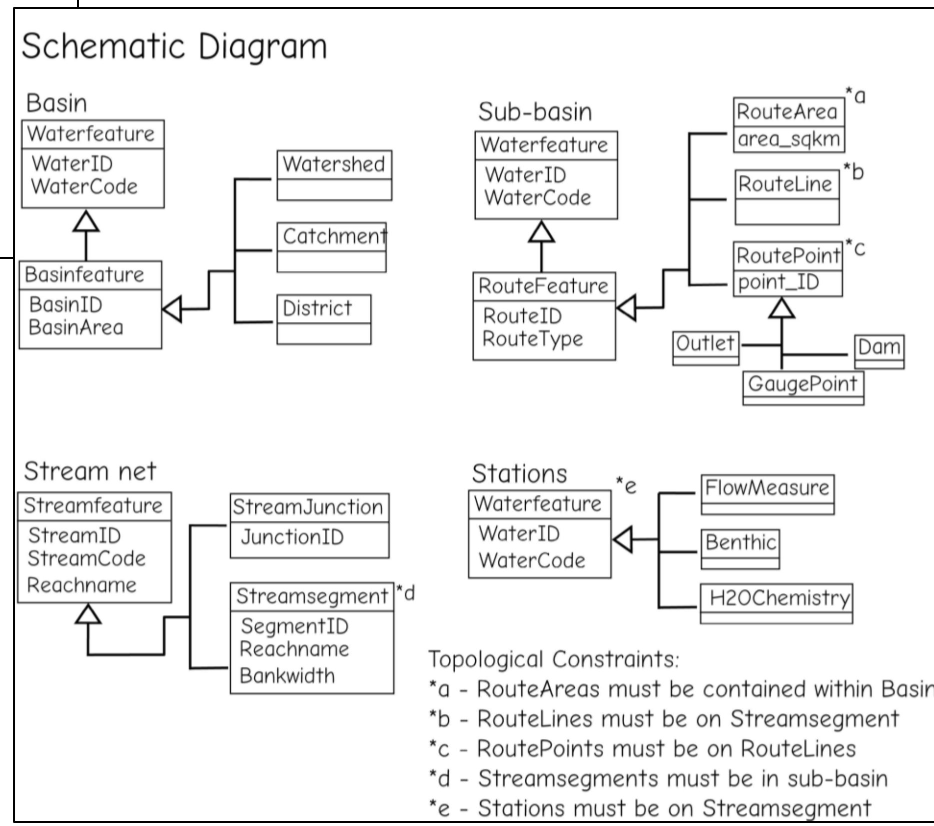




**Fig. 2-39:** Object-oriented data models allow us to encapsulate complex objects that may be a combination of many different features and feature types, while explicitly identifying the embedded complexity in a standard way. Constraints such as topological relationships across objects may also be represented (Bolstad)

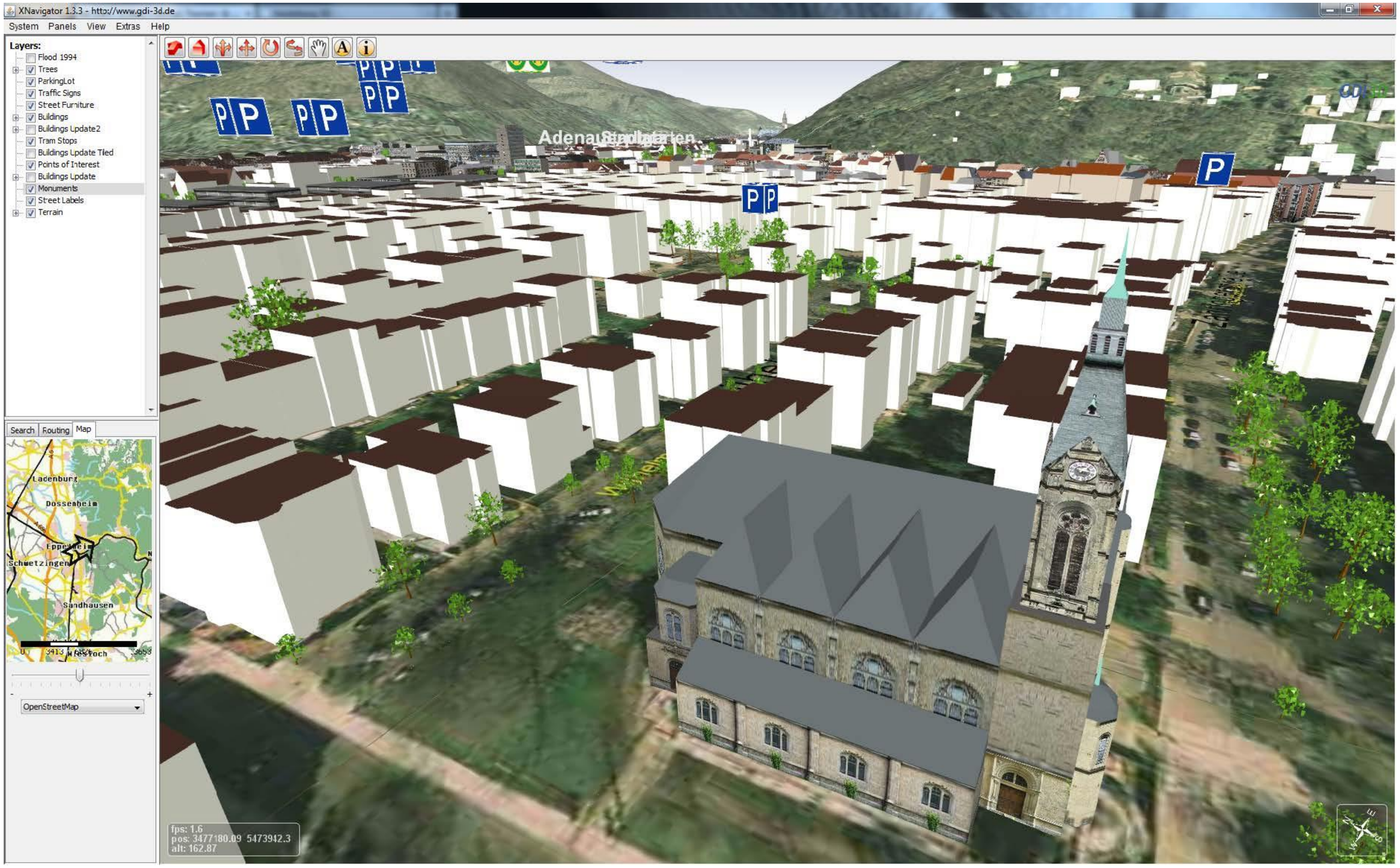



**Fig. 2-41:** An example of a reality mesh as a 3-D model. Surface geometry is recorded in a 3-D triangulated irregular network, while a corresponding "texture" surface is projected on to corresponding facets (Bolstad)

# Geospatial Data Applications

## Choice of Map Projection and Coordinate System

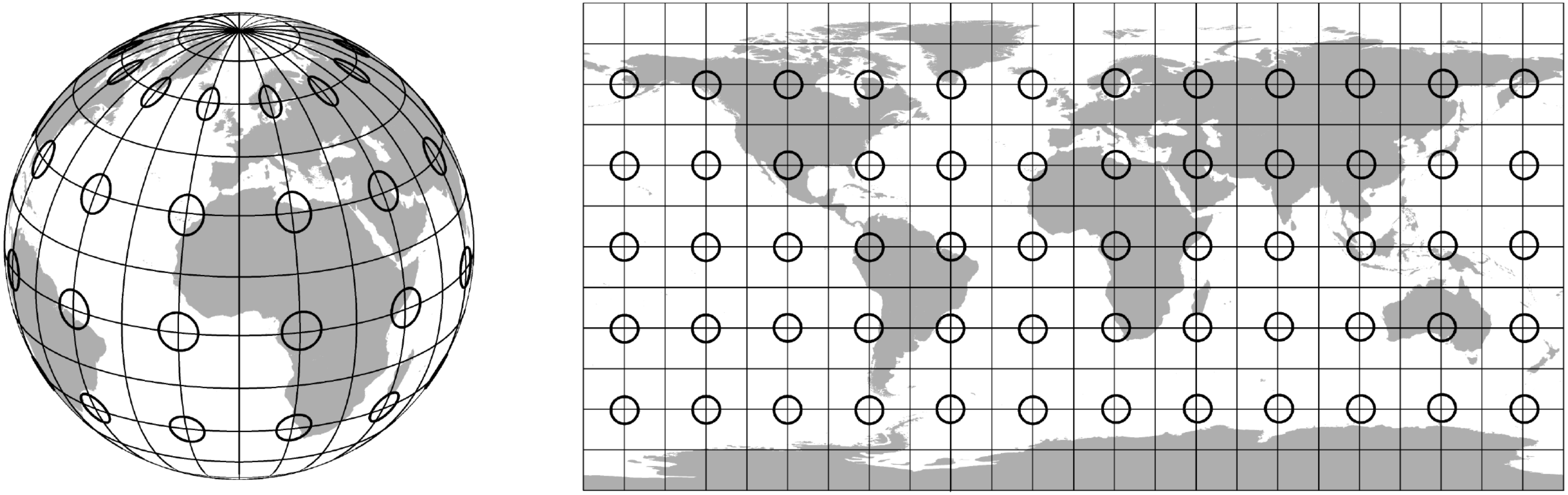


**Fig. 2-7:** Geographic coordinates on a spherical (left) and Cartesian (right) representation. Notice that "circles" defined by a 5-degree radius do not form circles on the Earth's surface near the poles, as shown on the spherical representation (left), but appear as circles on the highly distorted Cartesian plot of geographic coordinates (right). This figure illustrates both that (a) the surface distance for a unit of longitude changes depending on your location on Earth, and (b) a Cartesian plot of geographic coordinates is highly distorted (Bolstad)

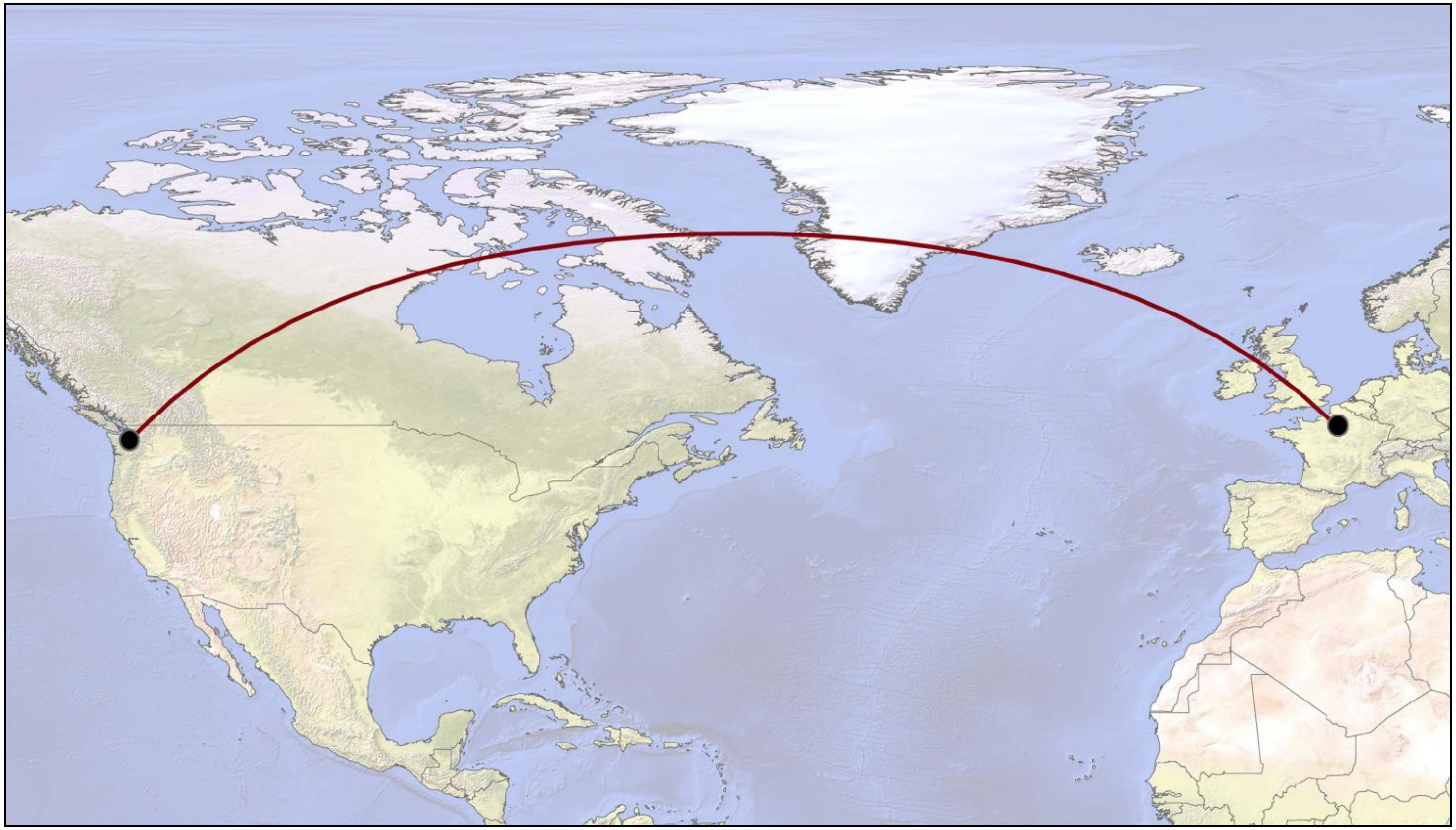


**Fig. 3-36:** Curved representations of straight lines are a manifestation of projection distortion. A great circle path, shown above, is the shortest route when flying from Paris to Seattle, and commonly appears distorted when displayed (Bolstad)

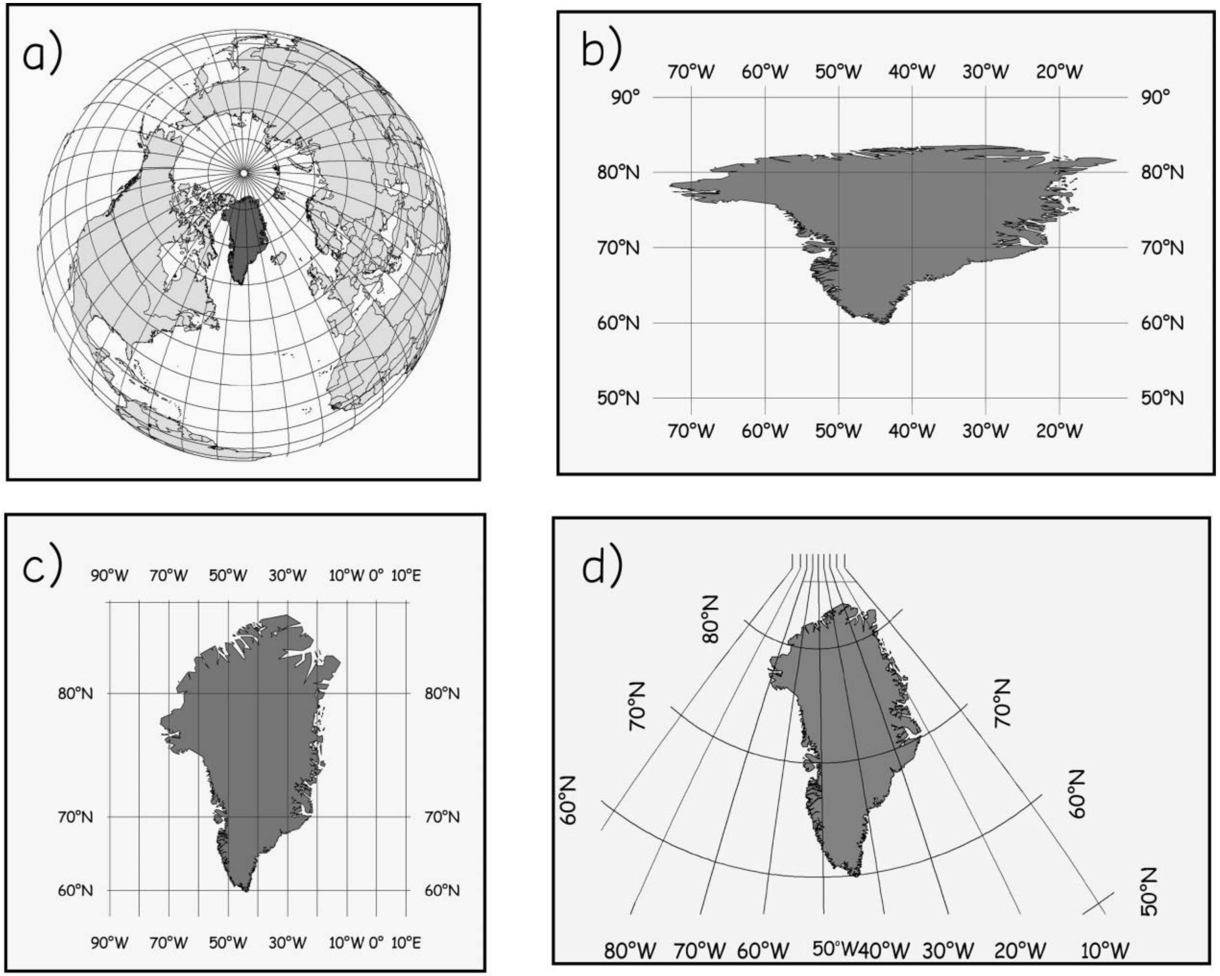
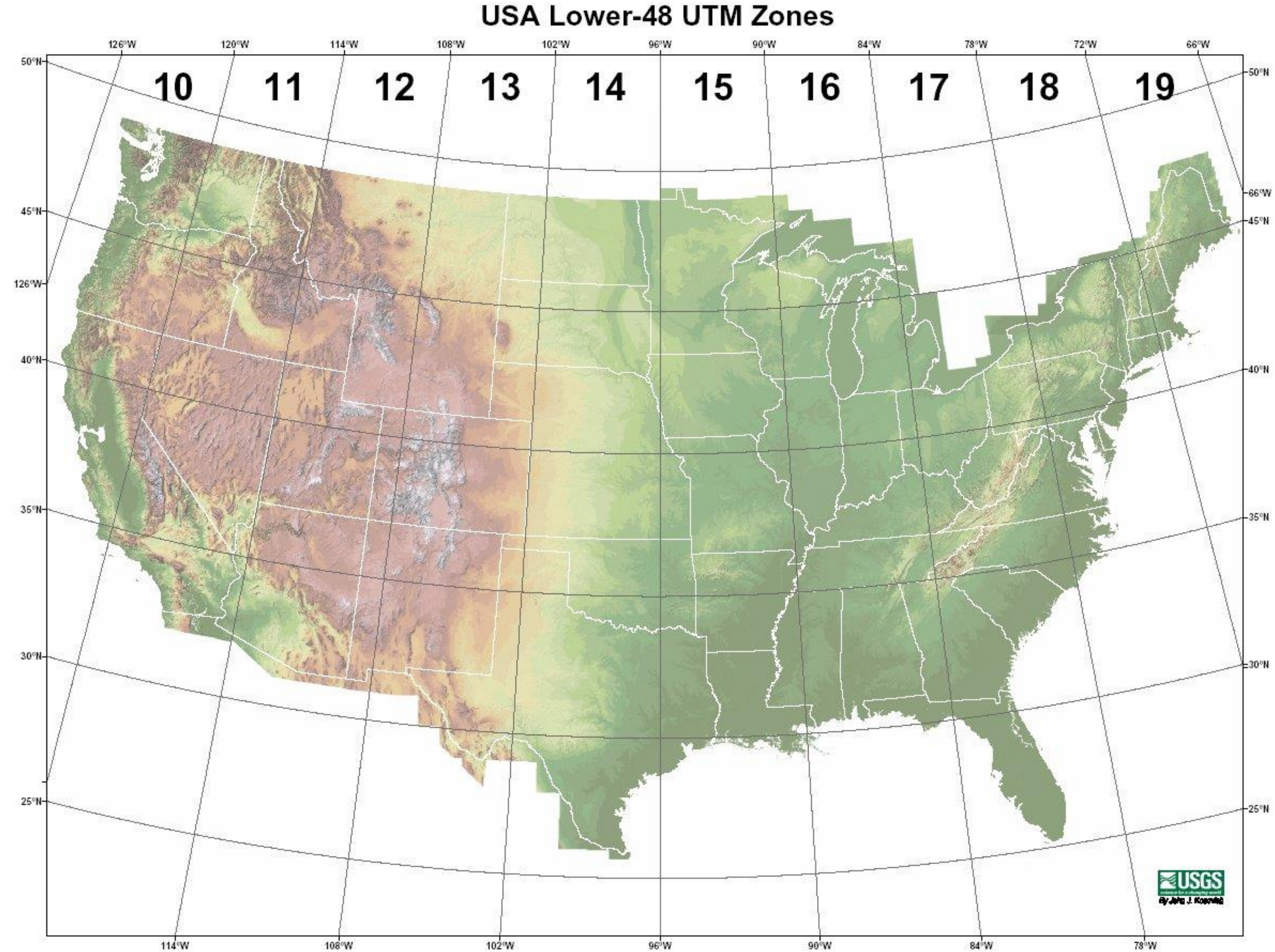



**Fig. 3-37:** Map projections can distort the shape and area of features, as illustrated with these various projections of Greenland, from (a) approximately unprojected, (b) geographic coordinates on a plane, (c) a Mercator projection, and (d) a transverse Mercator projection (Bolstad)


USA Lower-48 UTM Zones
10
11
12
13
14
15
16
17
18
19
126°W
120°W
114°W
108°W
102°W
96°W
90°W
84°W
78°W
72°W
66°W
50°N
45°N
40°N
35°N
30°N
25°N
USGS

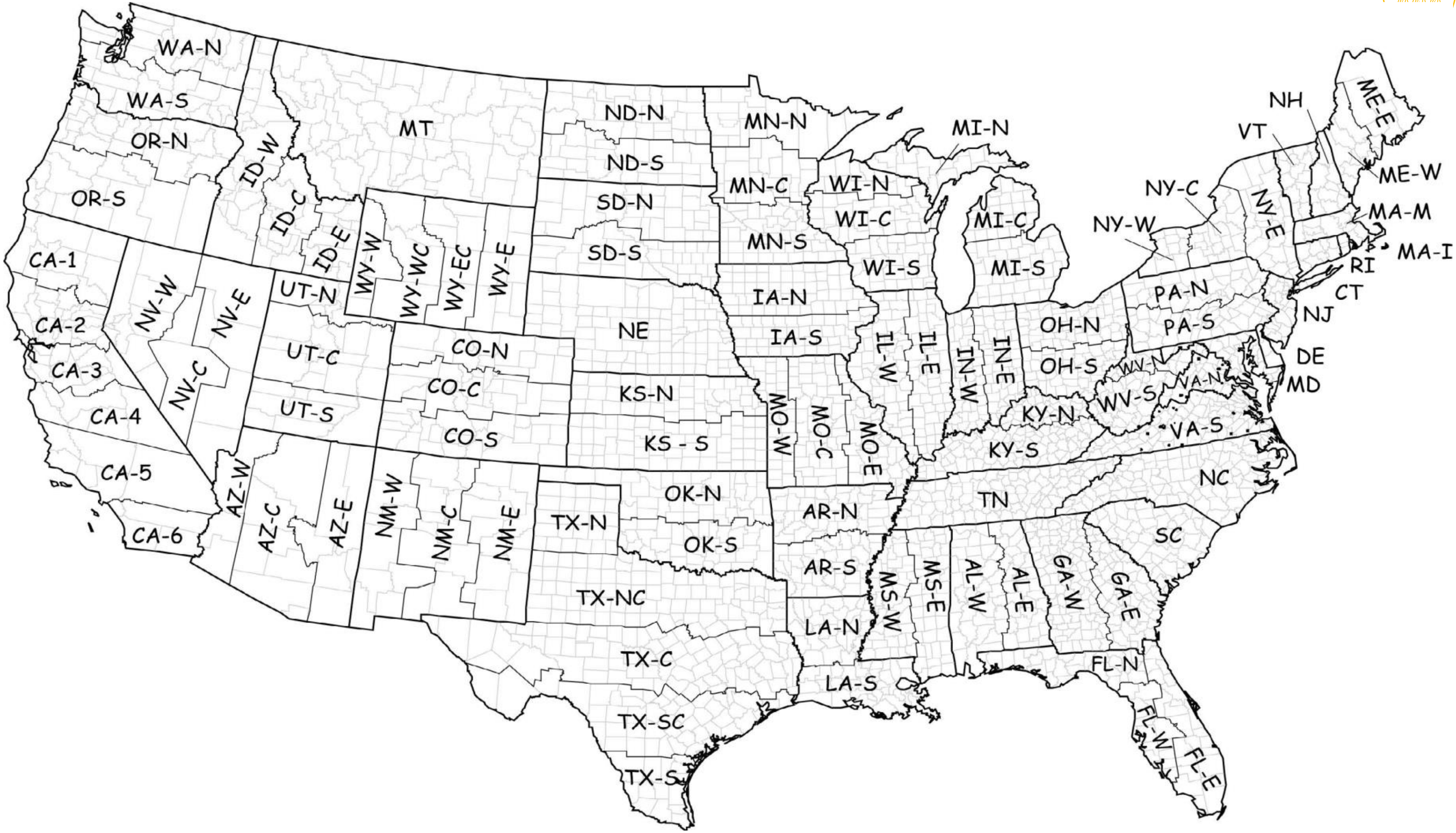



**Fig. 3-41:** State plane zone boundaries, NAD83 (Bolstad)

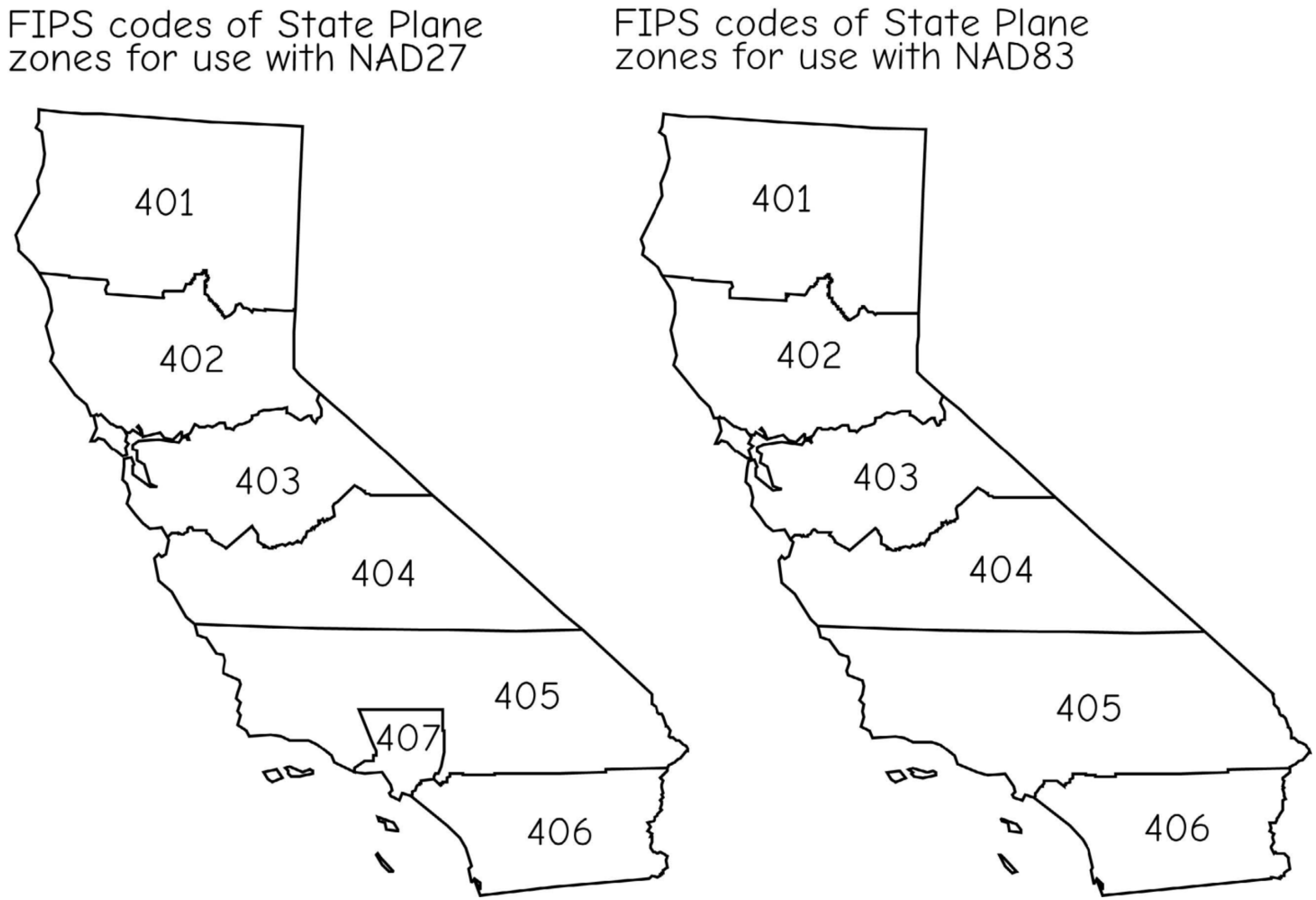
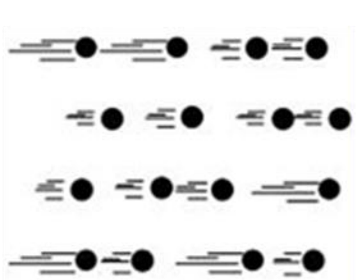
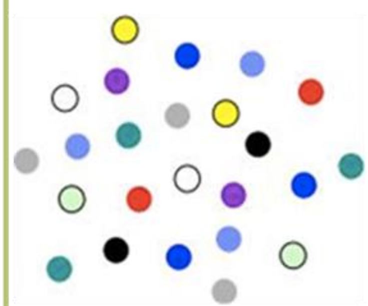



**Fig. 3-43:** State Plane coordinate system zones and FIPS codes for California based on the NAD27 and NAD83 datums. Note that zone 407 from NAD27 is incorporated into zone 405 in NAD83 (Bolstad)

# Geospatial Value Proposition

# A world awash with geospatial big data …

| Volume | Velocity | Variety | Veracity | Value |
|---|---|---|---|---|
|  |  |  |  |  |
| Data at Rest | Data in Motion | Data in Many Forms | Data in Doubt | Data into Money |
| Terabytes to Exabytes of existing data to process | Streaming data, requiring milliseconds to seconds to respond | Structured, unstructured, text, multimedia,… | Uncertainty due to data inconsistency & incompleteness, ambiguities, latency, deception, model approximations | Business models can be associated to the data |

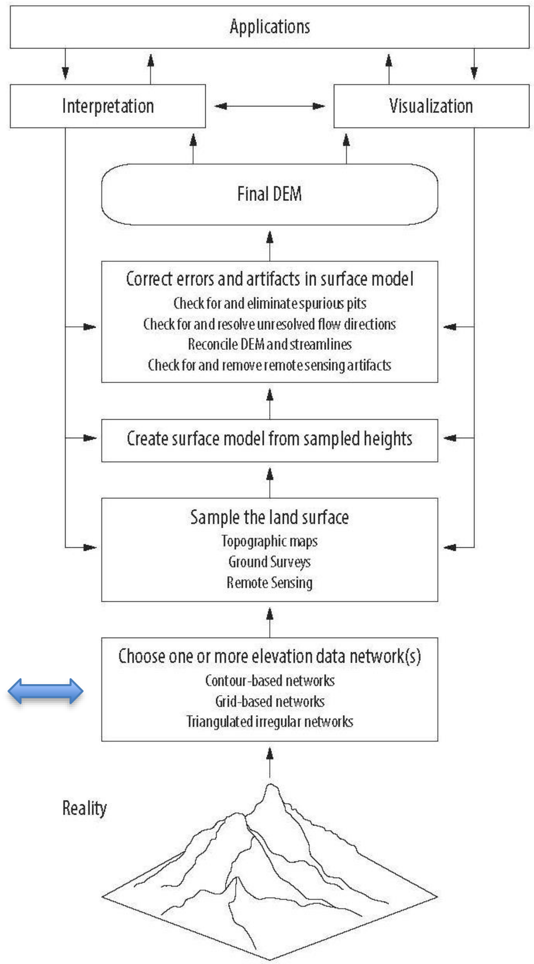
Adapted by a post of Michael Walker on 28 November 2012

# Geospatial Data Applications

## Managing Natural Resources

# Montana State University's Red Bluff Research Ranch

# Modeling soil and water resources



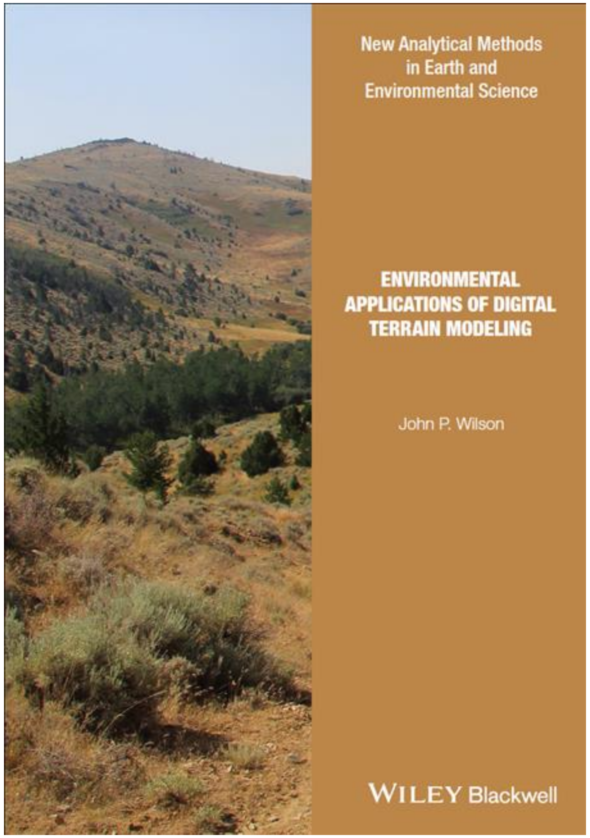

**Choice 1 or more elevation data network(s)**

Contour-based networks

Grid-based networks

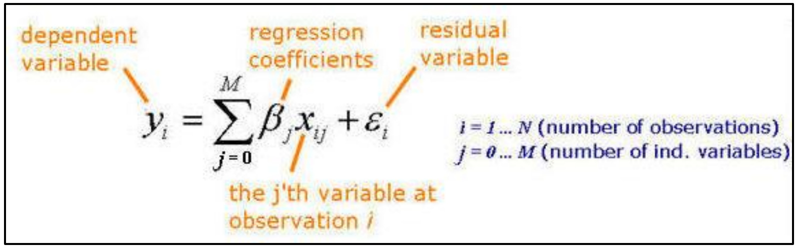
Triangulated irregular networks

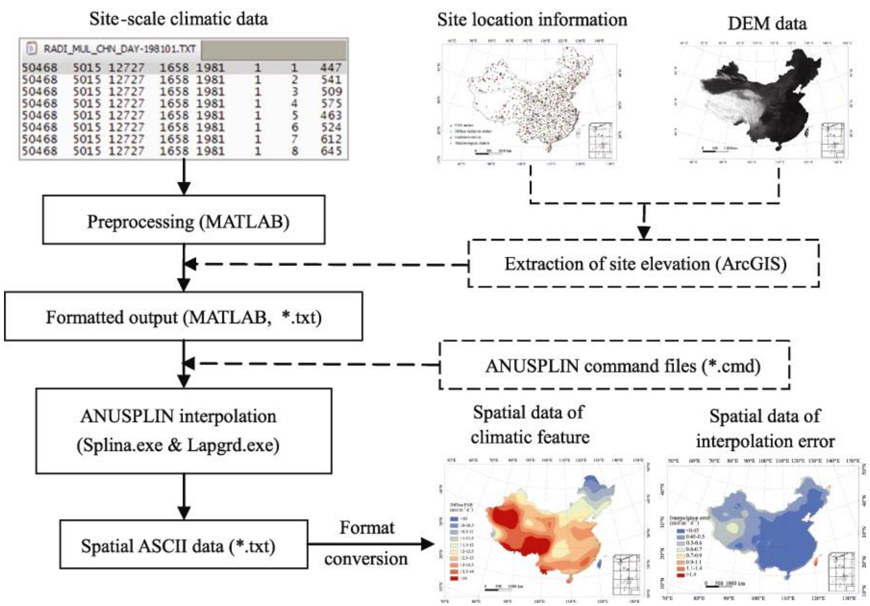
LiDAR point clouds



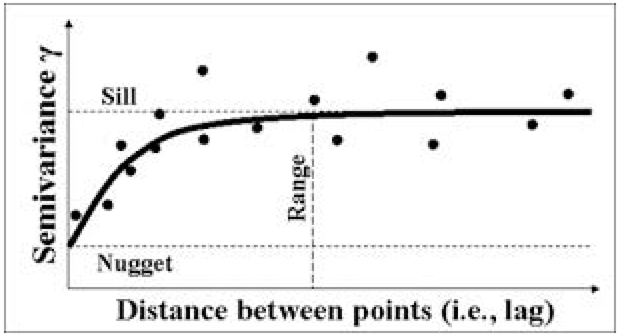
# Spatial analytics | Actionable information

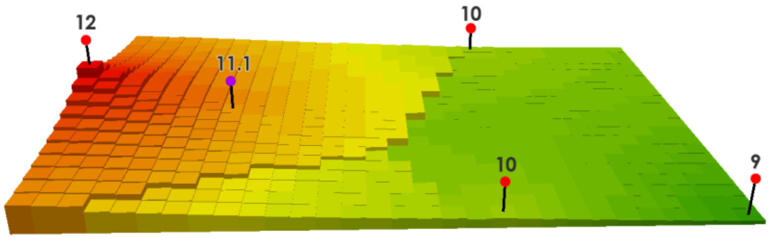
**Geographically weighted regression**



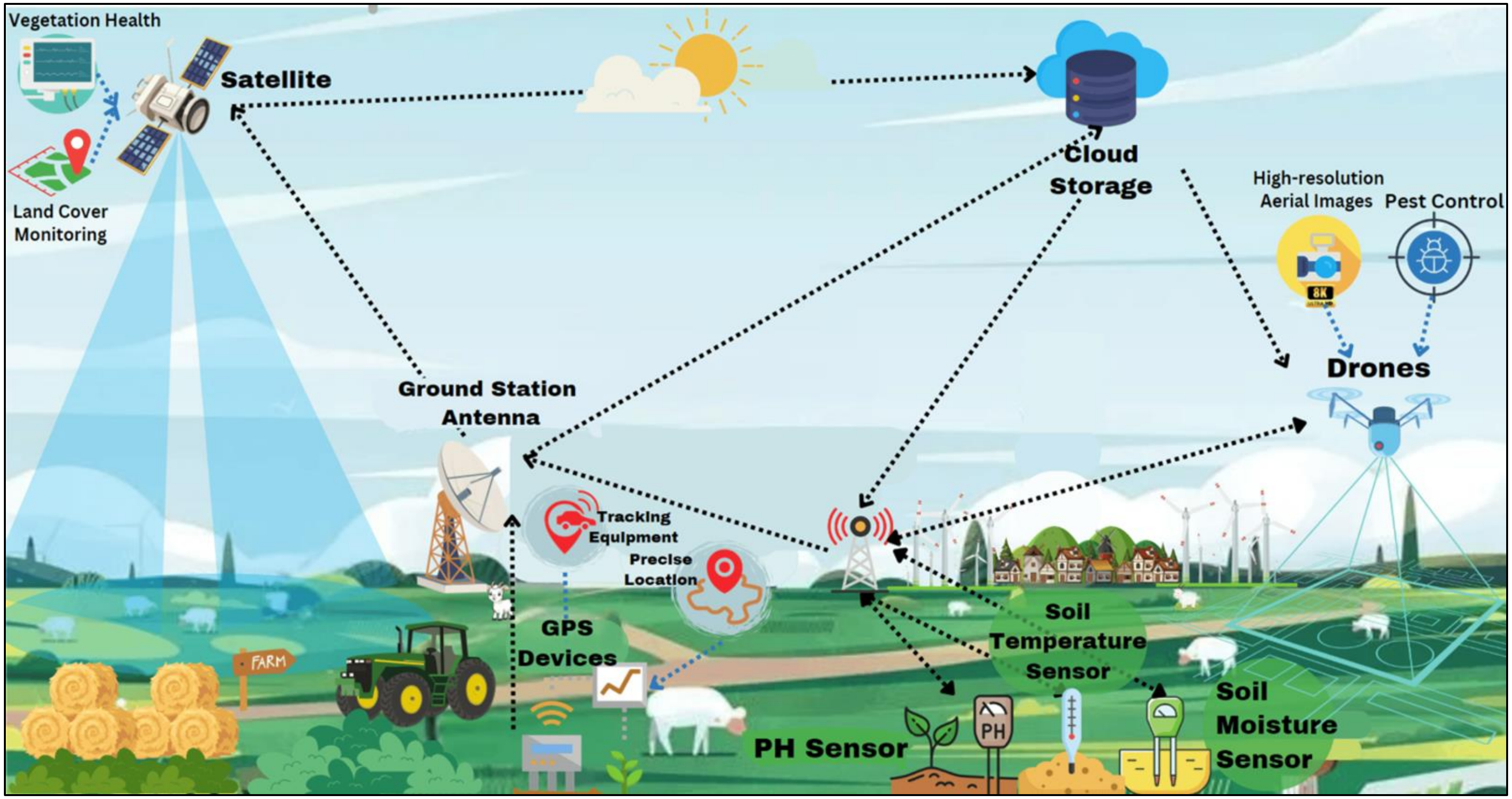

Thin plate splines




Kriging

# Precision farming …

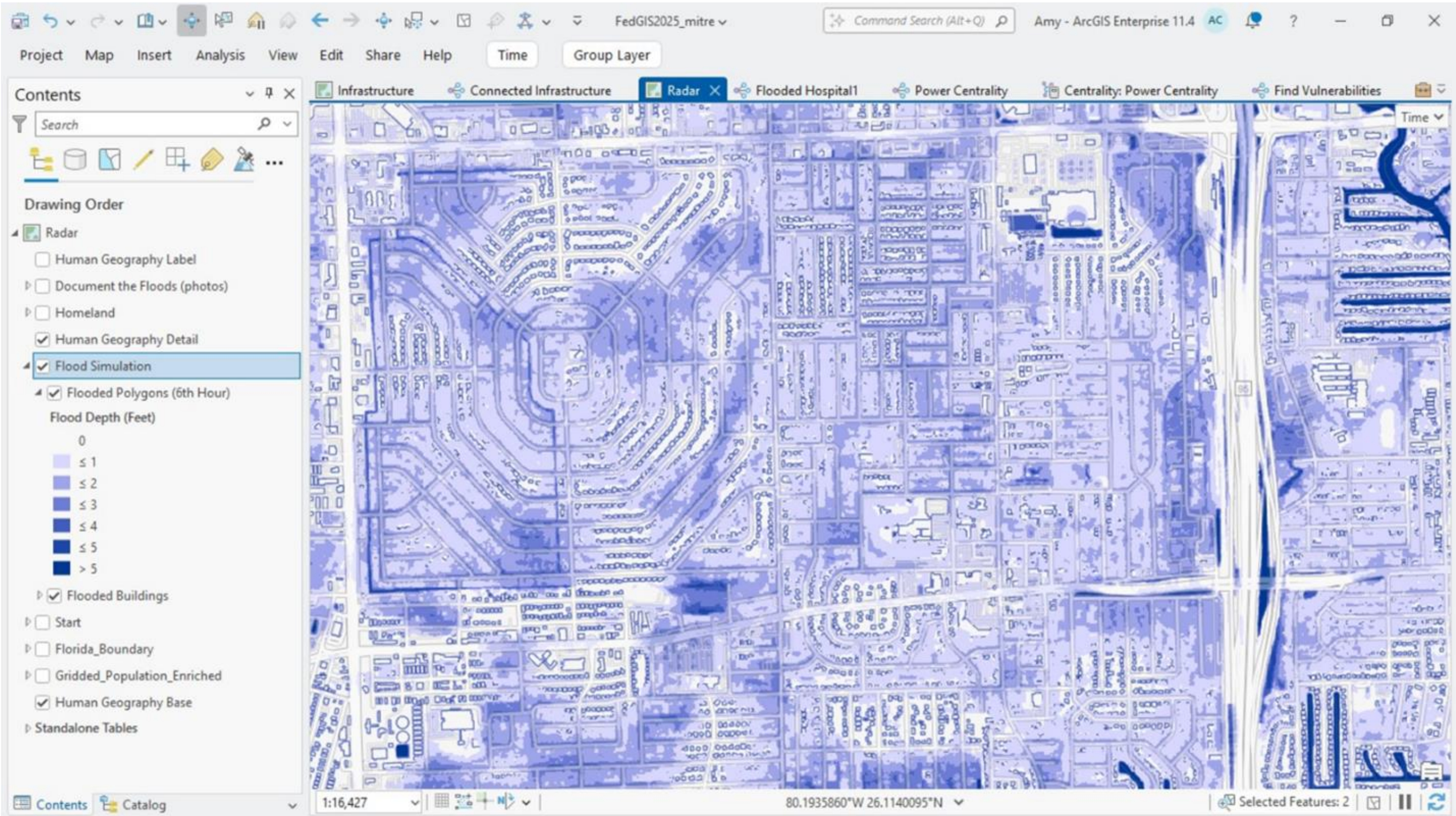



**Geospatial technologies in agriculture (GIS, GPS, IoT) is revolutionizing farming by optimizing planting, water management, crop monitoring, and more, leading to increased yields, less soil and water degradation and reduced costs**

# Geospatial Data Applications

## Protecting Human Life and Critical Infrastructure During Natural Disasters

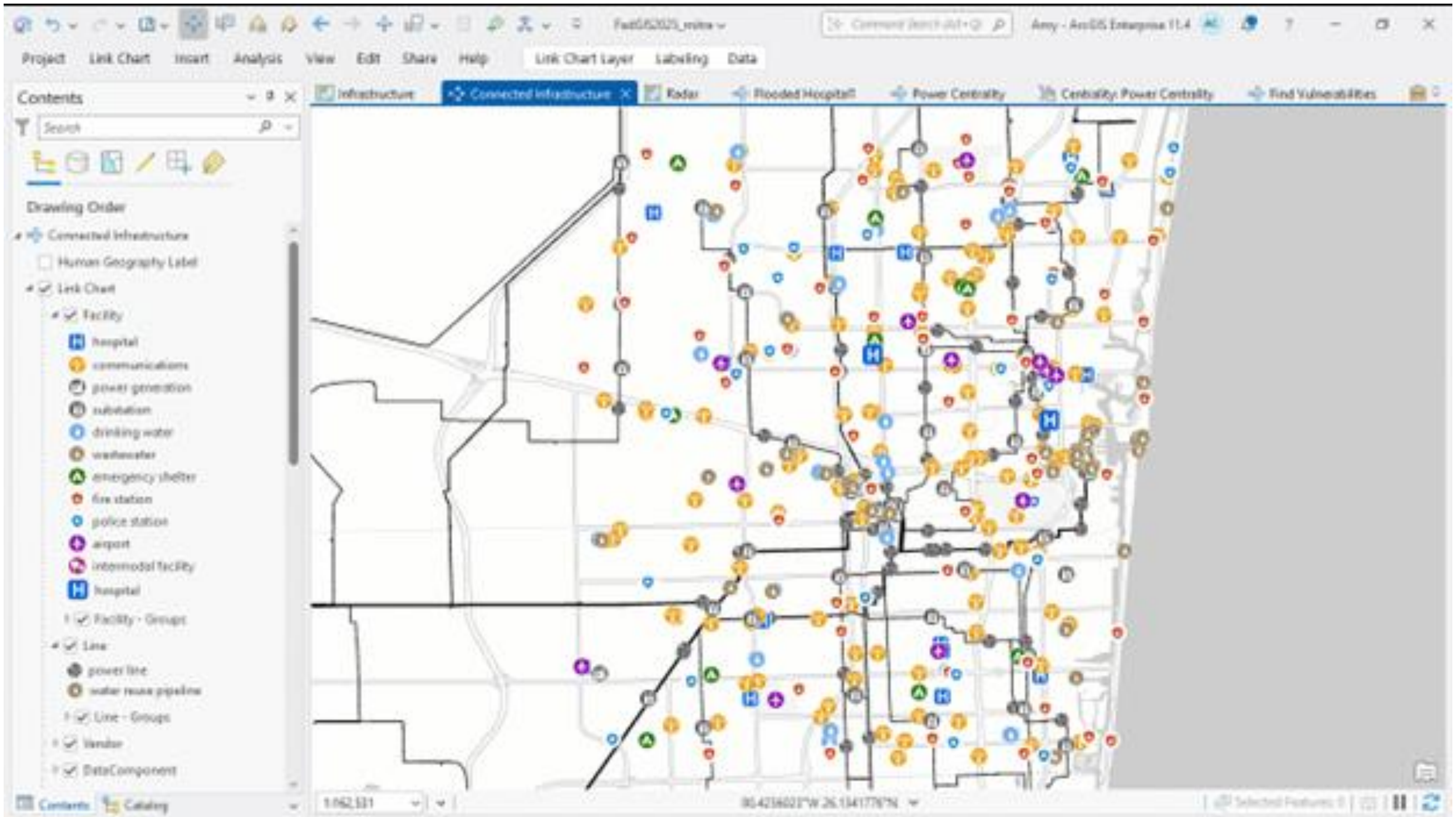
# **MITRE** Uses ArcGIS Knowledge To Analyze Critical Infrastructure Dependencies




This ArcGIS Pro layer shows simulated flood water in Fort Lauderdale. The simulation is based on 25 inches of rain falling over 24 hours, similar to the historic rainfall on April 12, 2023. The deeper blues show deeper water.

https://www.esri.com/arcgis-blog/products/arcgis-knowledge/public-safety/mitre-uses-arcgis-knowledge-to-analyze-critical-infrastructure-dependencies

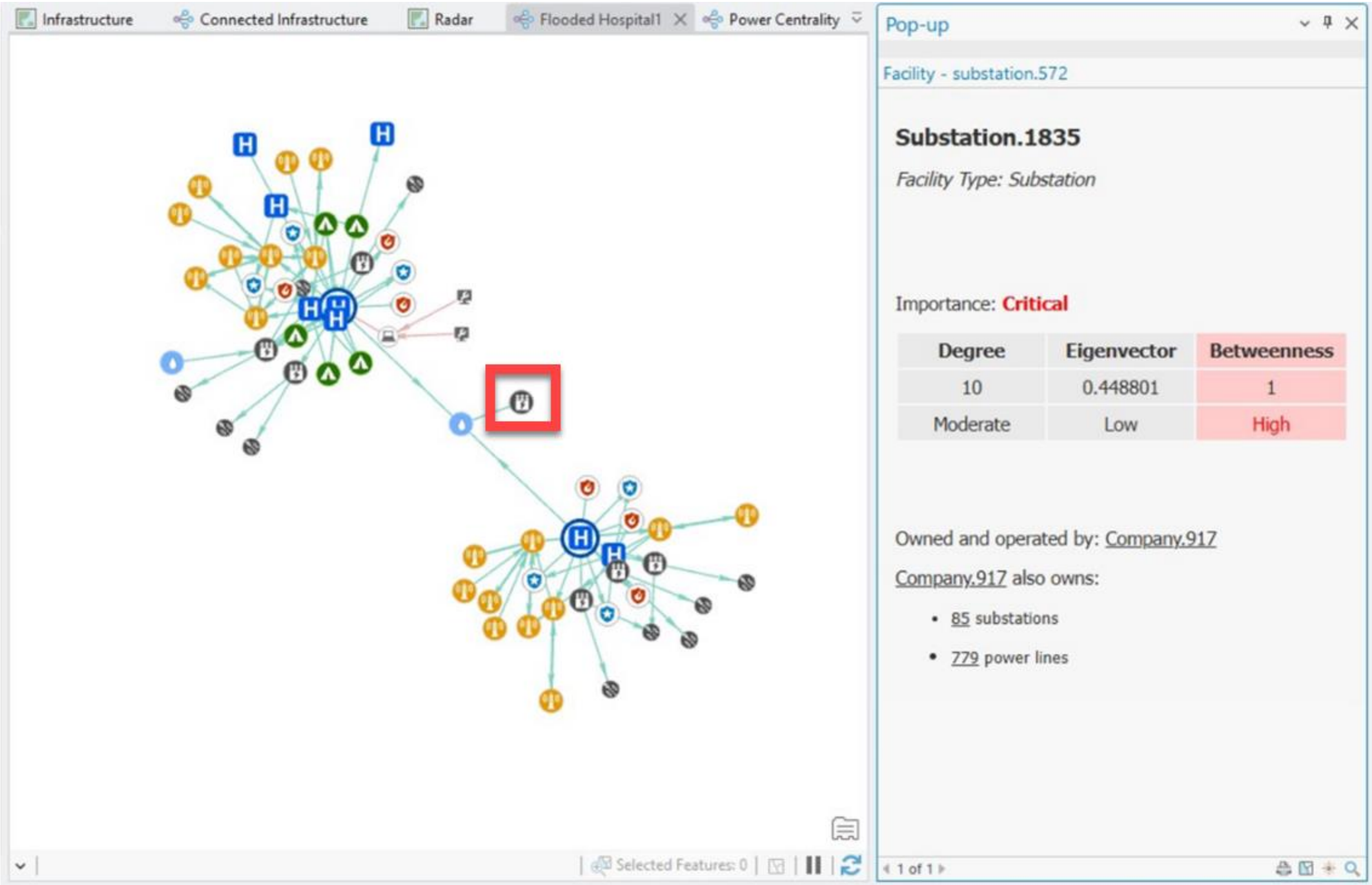
# MITRE Uses ArcGIS Knowledge …




Infrastructure facilities drawn as separate map layers vs. infrastructure drawn as connected entities in a knowledge graph

https://www.esri.com/arcgis-blog/products/arcgis-knowledge/public-safety/mitre-uses-arcgis-knowledge-to-analyze-critical-infrastructure-dependencies

# MITRE Uses ArcGIS Knowledge …

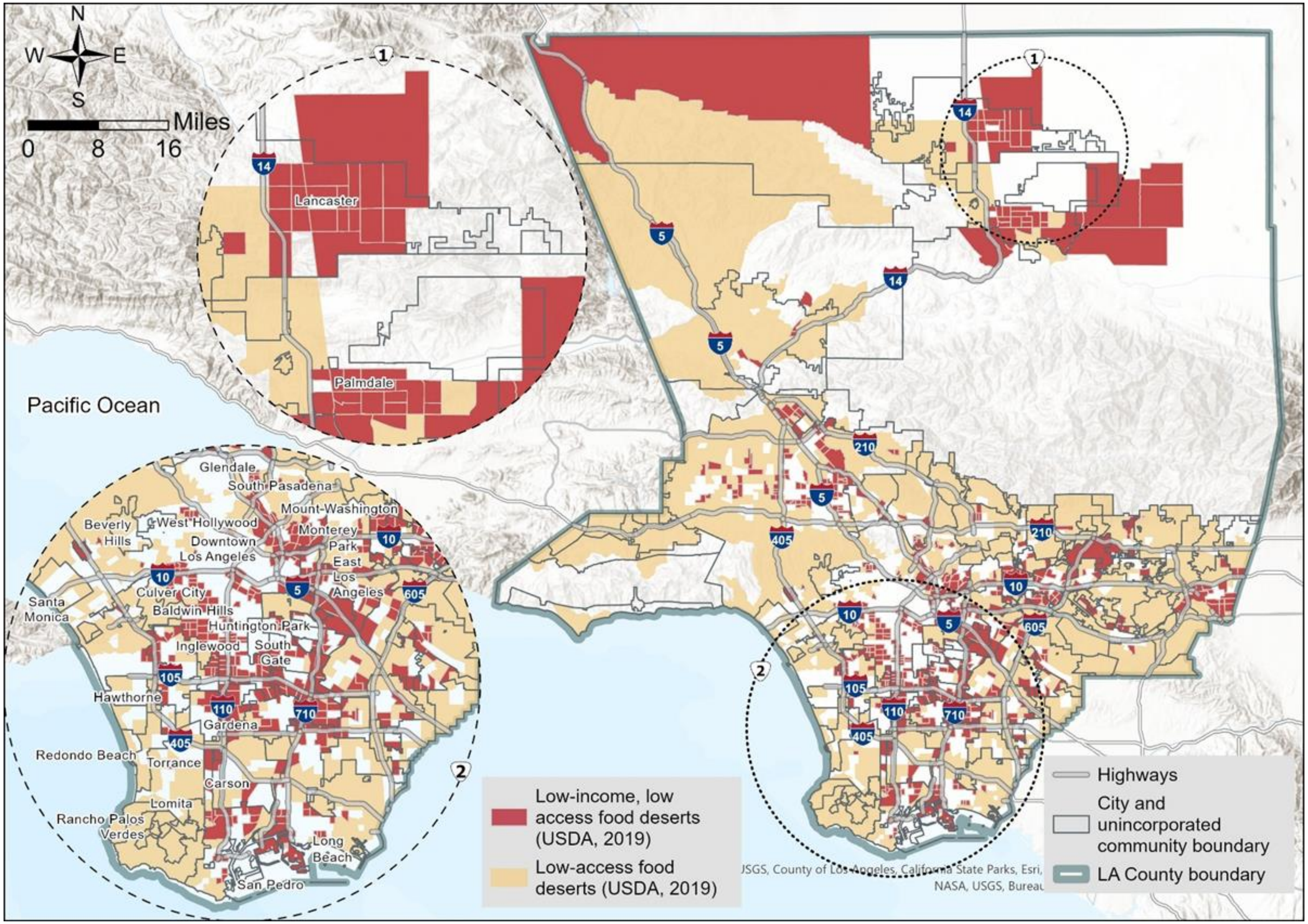



This link chart depicts the critical infrastructure facilities that two key hospitals depend on. Graph analysis tools help to quickly reveal the most critical dependencies based on the entire system of systems.

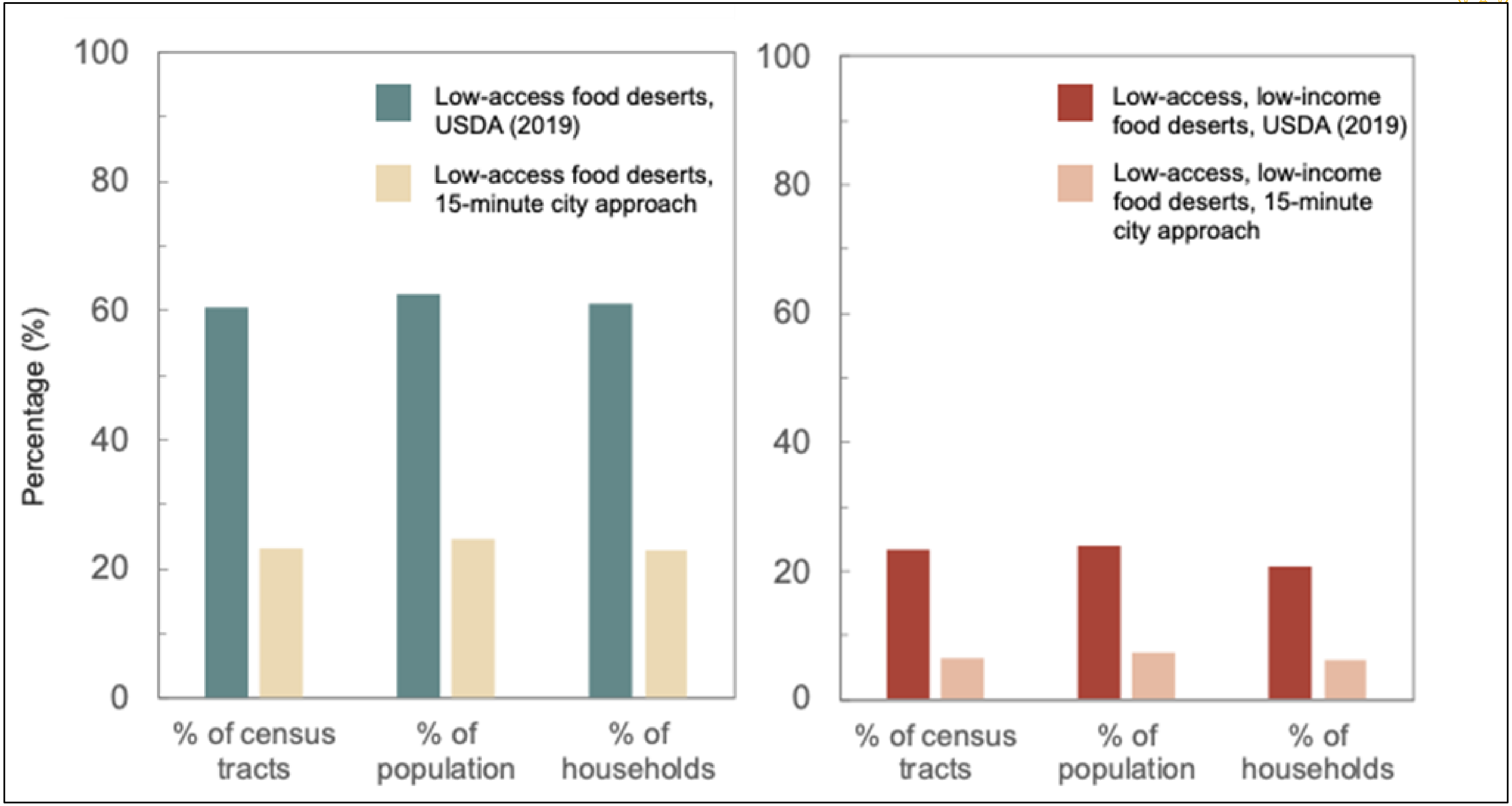
https://www.esri.com/arcgis-blog/products/arcgis-knowledge/public-safety/mitre-uses-arcgis-knowledge-to-analyze-critical-infrastructure-dependencies

# Geospatial Data Applications

## Tackling Food and Nutrition Security in Specific Neighborhoods




Census tracts identified by the USDA (2019) as food deserts in LA County: 1409 are “low access,” and 545 tracts are “low access and low income” out of 2344 total census tracts



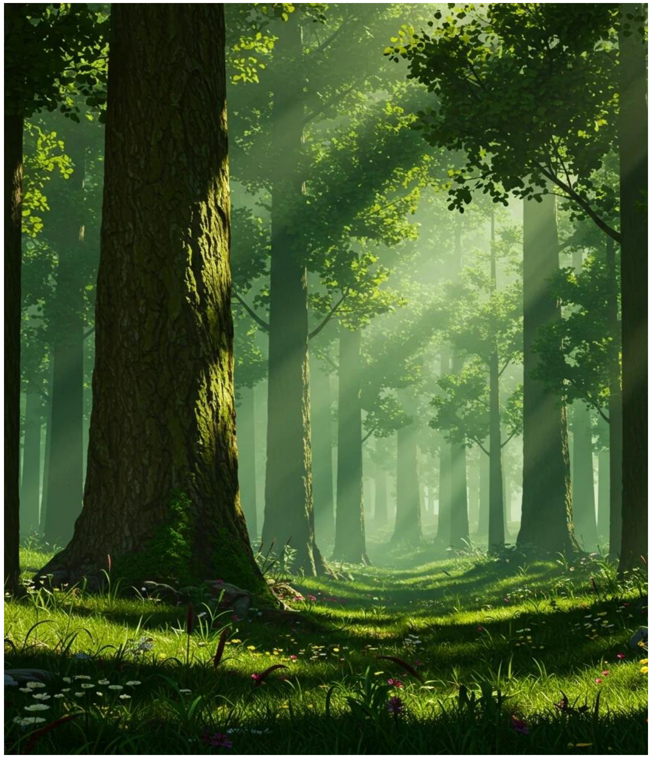

Comparisons showing food desert census tracts using the USDA (2019) and the 15-minute city approaches

# Geospatial Data Applications

## Using Trees to Mitigate Rising Temperatures

# Mapping urban tree canopy at scale

- The open-source U-NET segmentation and YOLOv9e object detection models were combined, optimized, and used to map urban tree canopy
- Various technical advances have led to significant gains in small-object detection tasks, such as identifying trees in aerial imagery
- A series of experiments were conducted to show how these models can be used to depict the tree canopy extent in previously unseen areas without retraining



# Study workflow …

Tree Crown Annotations
Boyle Heights, CA

Tree Crown Annotations
City Terrace, CA

**Step 1: Data Preparation**

Model Selection
U-NET Segmentation
YOLO Detection

Model Optimization
Model Hyperparameters
Training Data Size

**Step 2: Model Development**

NAIP CIR Imagery
Boyle Heights, CA

Model Metrics
Precision, Recall
F1-Score, Dice

Model Outputs
U-NET - Segmentation Masks
YOLO - Bounding-box Shapefiles

**Step 3: Quantitative Performance Evaluation**

NAIP CIR Imagery
City Terrace, CA

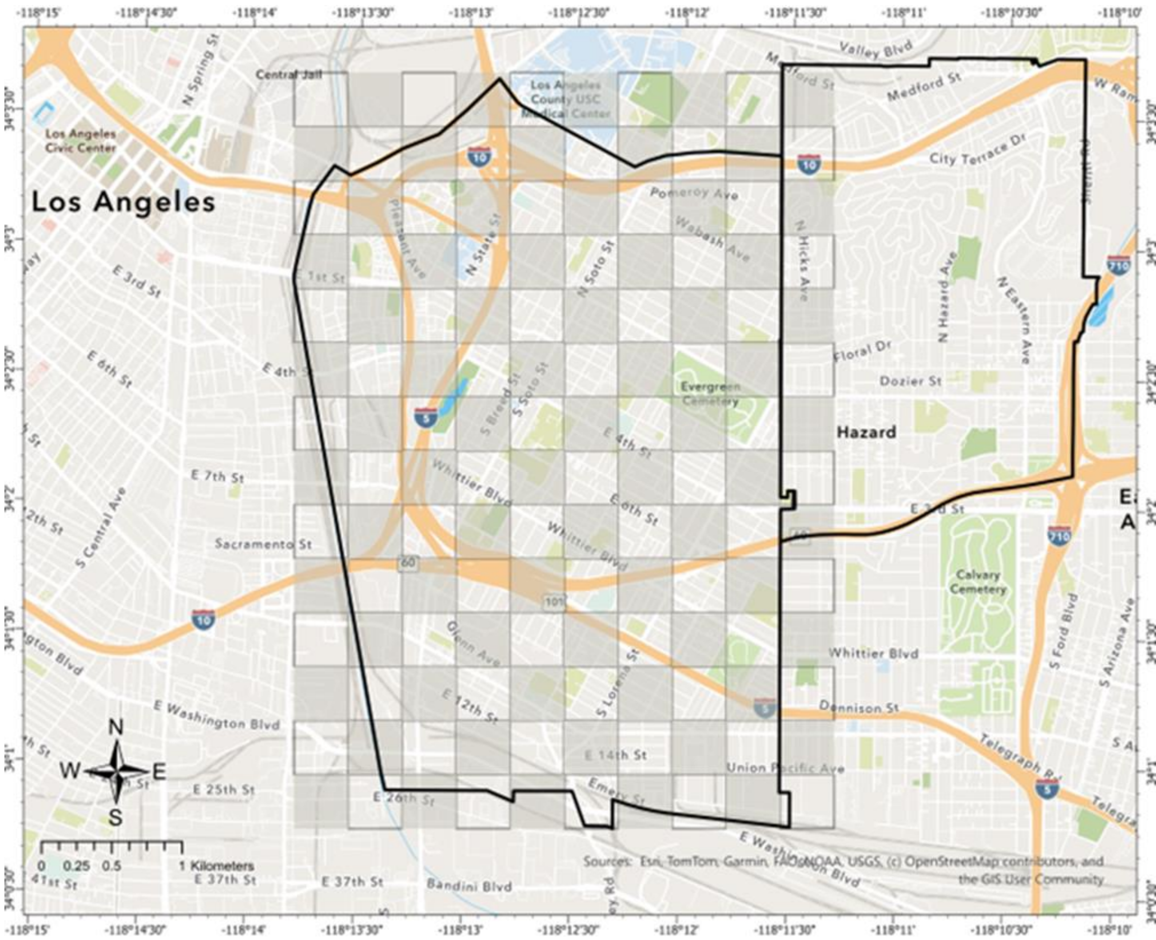
NAIP CIR Imagery
San Francisco, CA

NAIP CIR Imagery
Phoenix, AZ

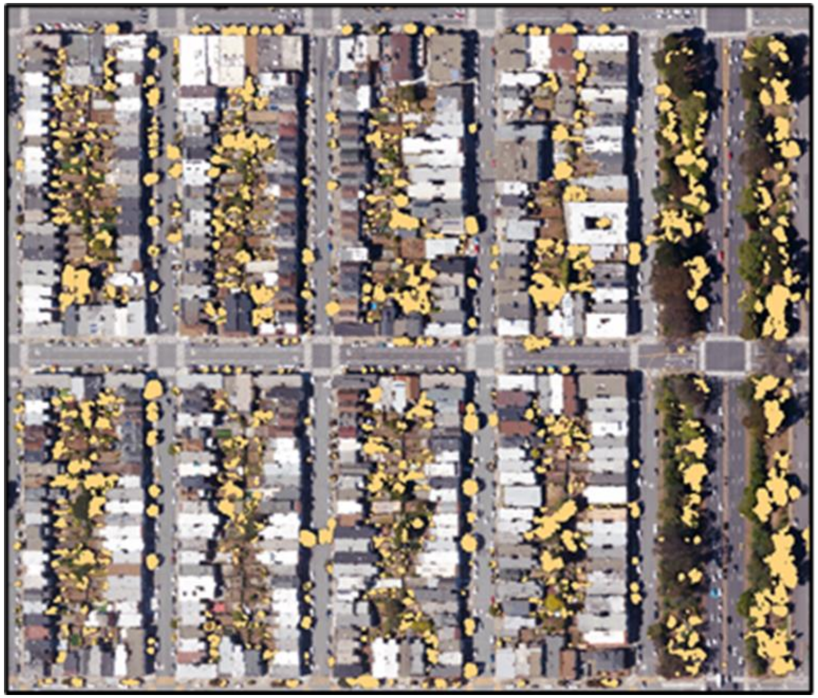
**Step 4: Model Transferability Tests**

# Manually labeled tree crowns …


Boyle Heights and City Terrace

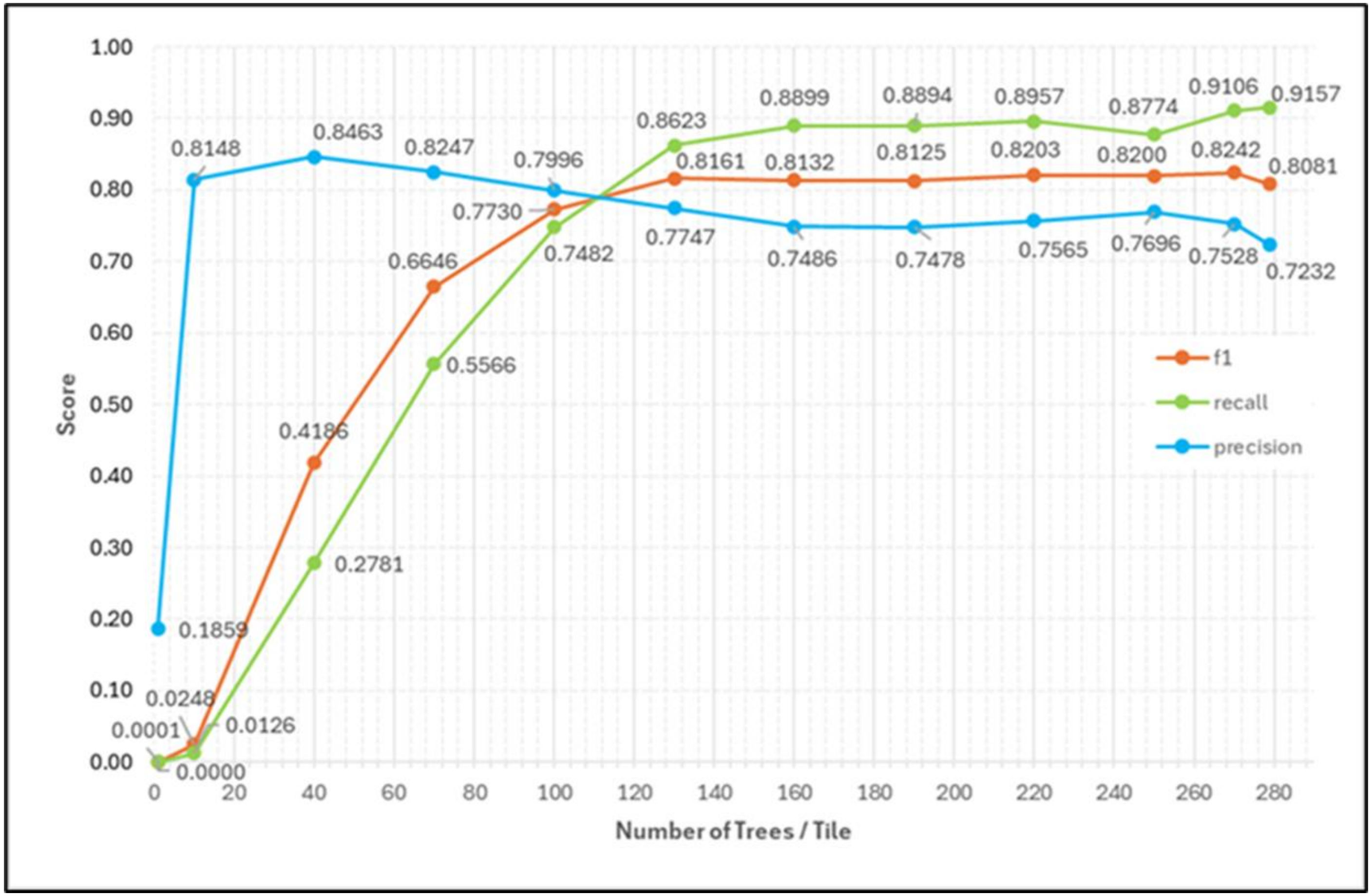


# Data augmentation and overlap …



The San Francisco, CA model, trained without data augmentation and overlap, on the left failed to segment the dense urban tree areas, particularly along continuous rows of street trees, leading to substantial under-segmentation (orange overlay) and the model trained with both data augmentation and 50% overlap on the right produced more complete and accurate segmentation in high-density canopy areas, with improved coverage and boundary continuity (green overlay)

# Tree numbers and model performance




The variation in model performance with increasing numbers of trees per tile

# Major takeaways …

- The deployment of this deep learning framework and publicly available imagery achieve performance comparable to models trained on costly lidar and commercial satellite data
- This workflow provides a standardized, bottom-up framework that bridges the gap between complex deep learning techniques and the practical needs of urban foresters, and empowers local stakeholders to create accurate, affordable, and timely urban tree inventories and foster data-driven decision-making to support the sustainable management of vital tree canopy in a warming world

# Closing Comments

# Spatial connects everything ...

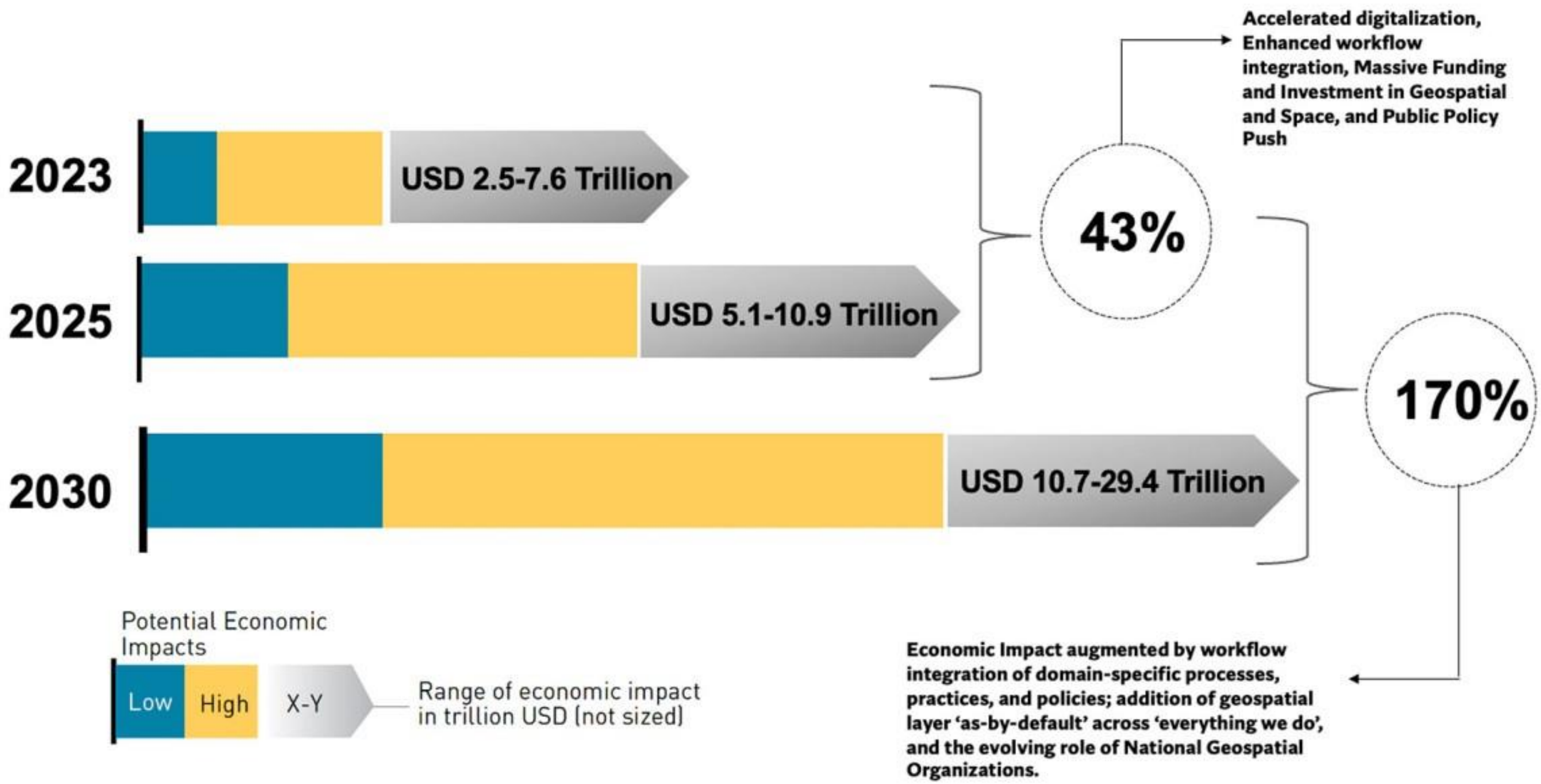

Source: GW Consulting Analysis

# Spatial connects the local to the global

Night light images paint accurate picture of China GDP

Barcelona's car-free 'superblocks' could save hundreds of lives

# Geospatial Technologies' Direct Economic Impact to Rise by Almost 290 Percent Between 2023 - 2030




Source: GW Consulting Analysis

# Questions

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**http://dornsife.usc.edu/spatial**