spatial@ucsb
perspectives for teaching and research

Digital Earth as a Digital Twin

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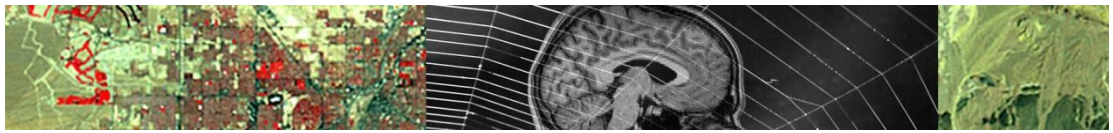


What is a digital twin?

- "A virtual representation of the real world, including physical objects, processes, relationships, and behaviors"
- "GIS is foundational for any digital twin"
  - Esri, https://www.esri.com/en-us/digital-twin/overview

What is a Digital Twin?

A digital twin is a digital replica of a living or non-living physical entity, such as a manufacturing process, medical device, piece of medical equipment, and even a person... to gain insight into present and future operational states of each physical twin. – NIH-Interagency Modeling Analysis WG (2019)

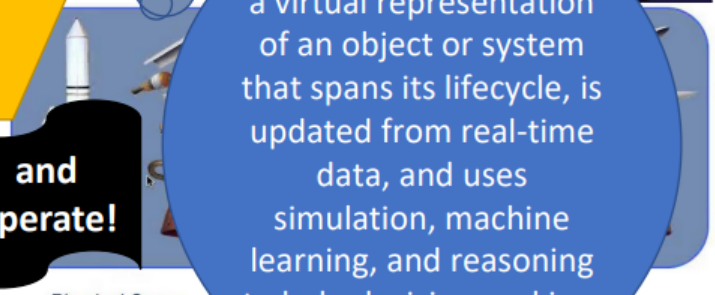
"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" – TA 11 (2010)

A digital twin is a virtual replica of an object, being, or system that can be continuously updated with data from its physical counterpart – Purdy, MIT Sloan

Digital Twin - the application of interdisciplinary modeling and simulation across the product lifecycle. – John Vickers (2021)

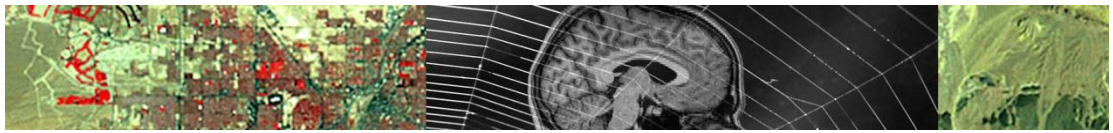
The ultimate vision for the digital twin is to create, test and build our equipment in a virtual environment. – John Vickers (2021)

A Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. – Michael Grieves and John Vickers (2002)



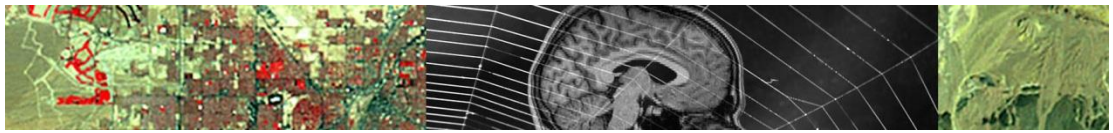
A Digital Twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help decision-making. – IBM

Danette Allen, NASA
https://ntrs.nasa.gov/api/citations/20210023699/downloads/ASME%20Digital%20Twin%20Summit%20Keynote_final.pdf



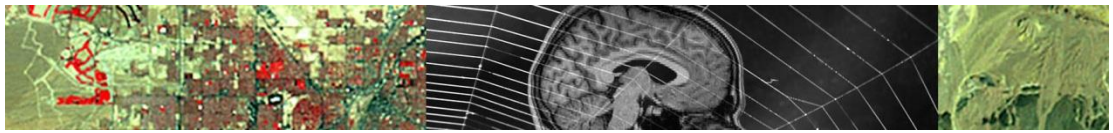
Issues with definitions

- Esri: a representation
  - including processes
  - no representation can be perfect
  - what is the purpose of the representation?
    - more than visualization?
- Replica: “fully describes…from the micro atomic level to the macro geometrical level”
  - “The map is not the territory” (Korzybski, 1933)
- A digital twin can only be fraternal
  - fraternal twins share only part of the genome
  - even identical twins are not identical



The purpose of digital twins

- Accurate simulation of a system
  - in order to evaluate what-if scenarios
  - predicting the impact of proposals
  - replicate, simulate, evaluate



The Gore speech of 1998

- "I believe we need a 'Digital Earth'. A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data."
  - http://www.zhanpingliu.org/research/terrainvis/digitalearth.pdf
  - all of the data will be of limited resolution, hence imperfect
  - no reference to processes, simulation, what-if experiments
- But travel back to the first ISDE…

Implementing Digital Earth: A Research Agenda

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Perspectives on Digital Earth

1. An immersive environment
   - “I believe we need a 'Digital Earth'. A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data.” U.S. Vice President Gore, 1/98

Spin, zoom, pan

- "fly-by" technology

Immersive environments

Head-mounted devices

Immersadesk

The "cave"

Standard computer displays

- 2D window on manipulable 3D objects
- Nick Faust, Georgia Tech
- SRI Digital Earth, Terravision
- powerful processors, 3D graphics

Research challenges

Smooth zoom

- 10km to 1m resolution
- consistent data structures
  - smooth transitions to more detailed data
  - color matches
- projections
  - orthographic for the globe
  - projected for local detail
  - Georgia State: nested azimuthal projections

Research challenges (2)

Visualization

- renderable data
- non-renderable data
  - iconic representation indicating presence
  - symbolic representation
- user-centered views
  - reduce resolution in periphery
  - avatar

A dynamic Digital Earth

Simulations of past and future conditions

A library of simulation models

- applied to local conditions represented by data

A tool with enormous educational value

PCRaster demonstrations

- University of Utrecht, Peter Burrough

The demo illustrates:

- A simplified model of normal faults and landform before uplift
- Reaction of landform to gradual vertical displacement along the parallel normal faults
- Erosion and deposition as a result of vertical movements (red is erosion - blue is deposition)
- Emergent behaviour of rivers leading to development of braided streams

tectonics

Research challenges

- Data structures and modeling
  - no finite difference models on the curved surface of the planet
  - finite element models based on triangles?
  - object-based models
- Describing models
  - metadata
  - libraries of models

Research challenges (2)

- Software environments
  - PCRaster
- Calibration, verification, accuracy
- Integration across domains
  - coupling models
  - distinct ontologies

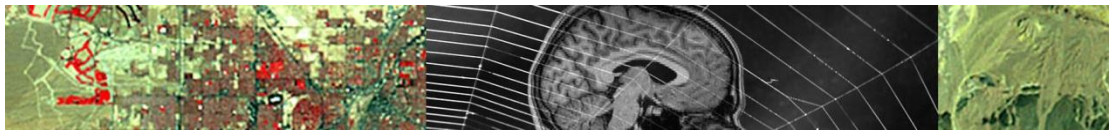
Summary: four perspectives

An immersive environment

A metaphor for information organization

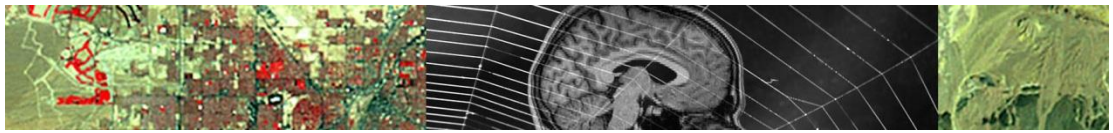
A distributed database transparent to the user

A representation of the planet's dynamics



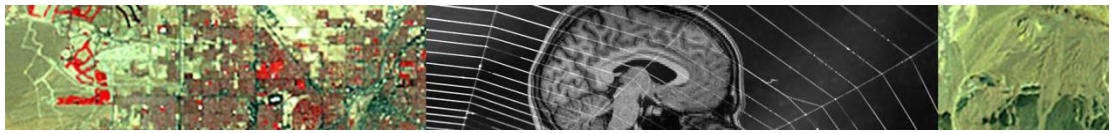
Is a digital twin distinctive?

- Does it have distinct principles?
  - or is it just more of?
    - finer resolution
    - more accurate process models
    - more layers and variables
  - compare “big data”
    - bigger than small data?
    - too big to handle?
- Is there a threshold that merits the term “digital twin”?
  - of data resolution, functionality, accuracy…?



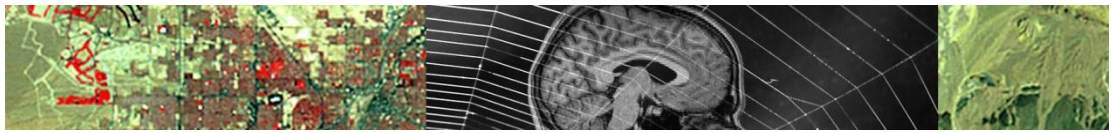
The uncertainty problem

- How to visualize uncertainty?
  - are spatial resolutions already finer than those of the human eye?
- How to incorporate uncertainty into predictions?
  - uncertainty will come from:
    - data
    - the process of integrating or fusing data
    - simulation models
    - the means of communicating or presenting the data



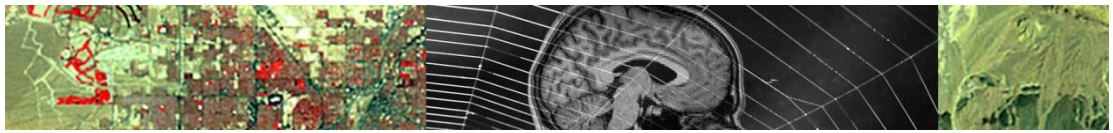
Dealing with uncertainty

- To ignore it is unethical
- Fitness for use
  - is the level of uncertainty acceptable for my particular use case?
  - must digital twins be tied to particular use cases
    - and never repurposed?
- Propagate uncertainty into predictions
  - using methods of sensitivity analysis
  - using simulation



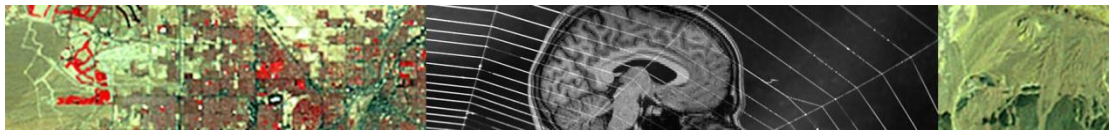
Some ethical issues

- Uncertainty
- The potential for misinformation
  - deep fakes
  - false inferences
- Privacy
  - of individuals
- Lack of transparency
  - proprietary (black box) software
  - provenance of data



The missing pieces

- Data fusion and integration
- Interoperability of process models
- Search for data and process models
- Integration of digital twins
- Education
  - what are the principles?
  - lack of software for demonstration



Some takeaways

- There is abundant and rapidly growing interest across industry and academia
- To date there has been little interest in academic GIScience
- The imperfect nature of all digital twins raises issues
  - there are no standards for what can be claimed to be a digital twin
- There are strong links between digital twins and Digital Earth