Digital Earth: Recent Technical Progress

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A grand challenge of GIS

- To create useful, comprehensive digital representations of the enormous complexity of the Earth’s surface in the limited space of a digital store, using a binary alphabet

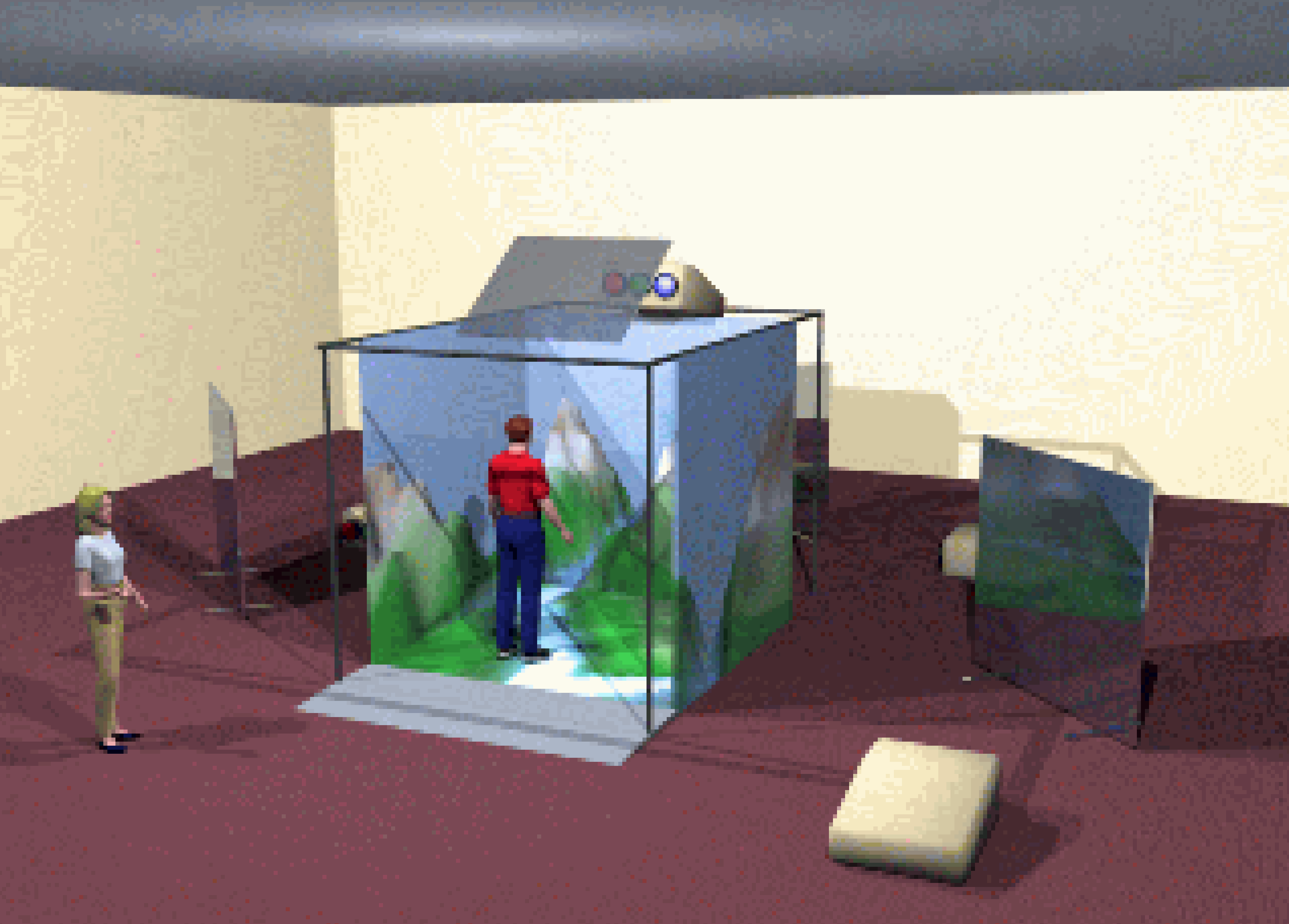
“Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a ‘magic carpet ride’ through a 3-D visualization of the terrain.”

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
  - powerful processors, 3D graphics



Digital Earth

A very visual Earth explorer that lets Scientists – both young and old – examine information about the Earth to learn how the forces of biology and geology interact to shape our home planet.

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

Research challenges (2)

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

Research challenges (3)

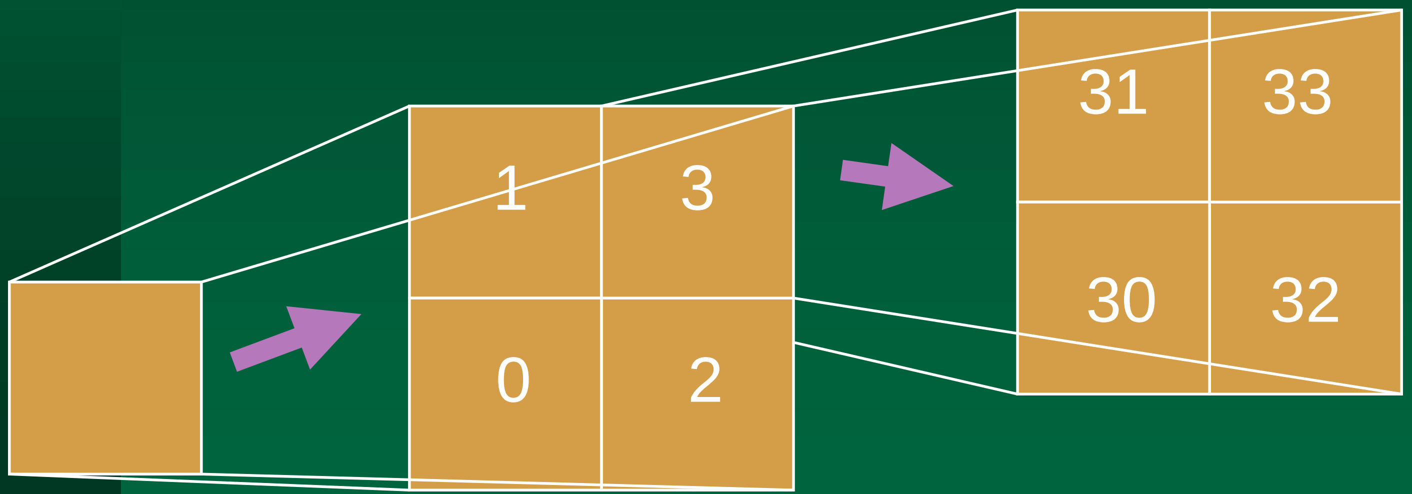
- Local data, powerful processor
  - what is deliverable via the Internet?
  - bandwidth requirements
  - local data volume
    - 10^{12} cells at 1m resolution
- Software environments
  - VRML, GeoVRML
  - Open GL
  - triangular data structures

Research challenges (4)

- Discrete global grids
  - for indexing and data representation
- QTM (Geoffrey Dutton, Spatial Effects)
  - 8 triangles at level 0
  - recursive subdivision into 4 triangles
  - address is 1 base 8 digit and n base 4 digits
  - level 20 is roughly 1m resolution

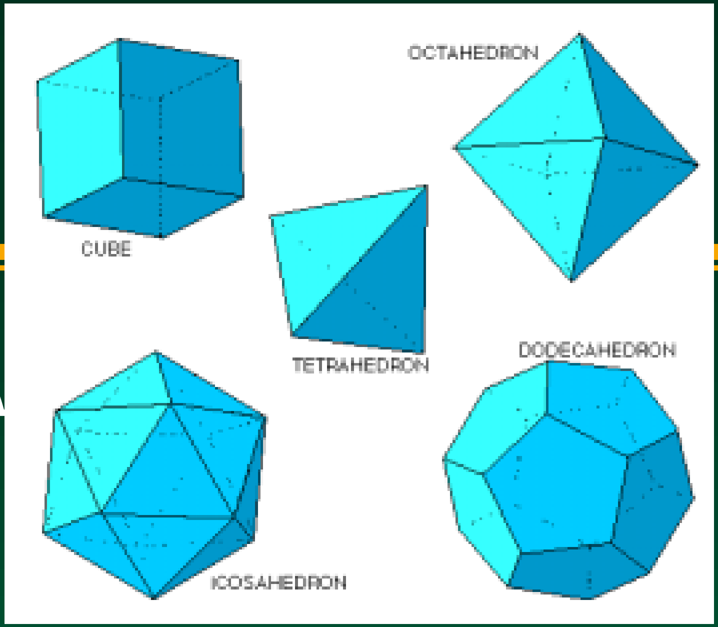
The quadtree

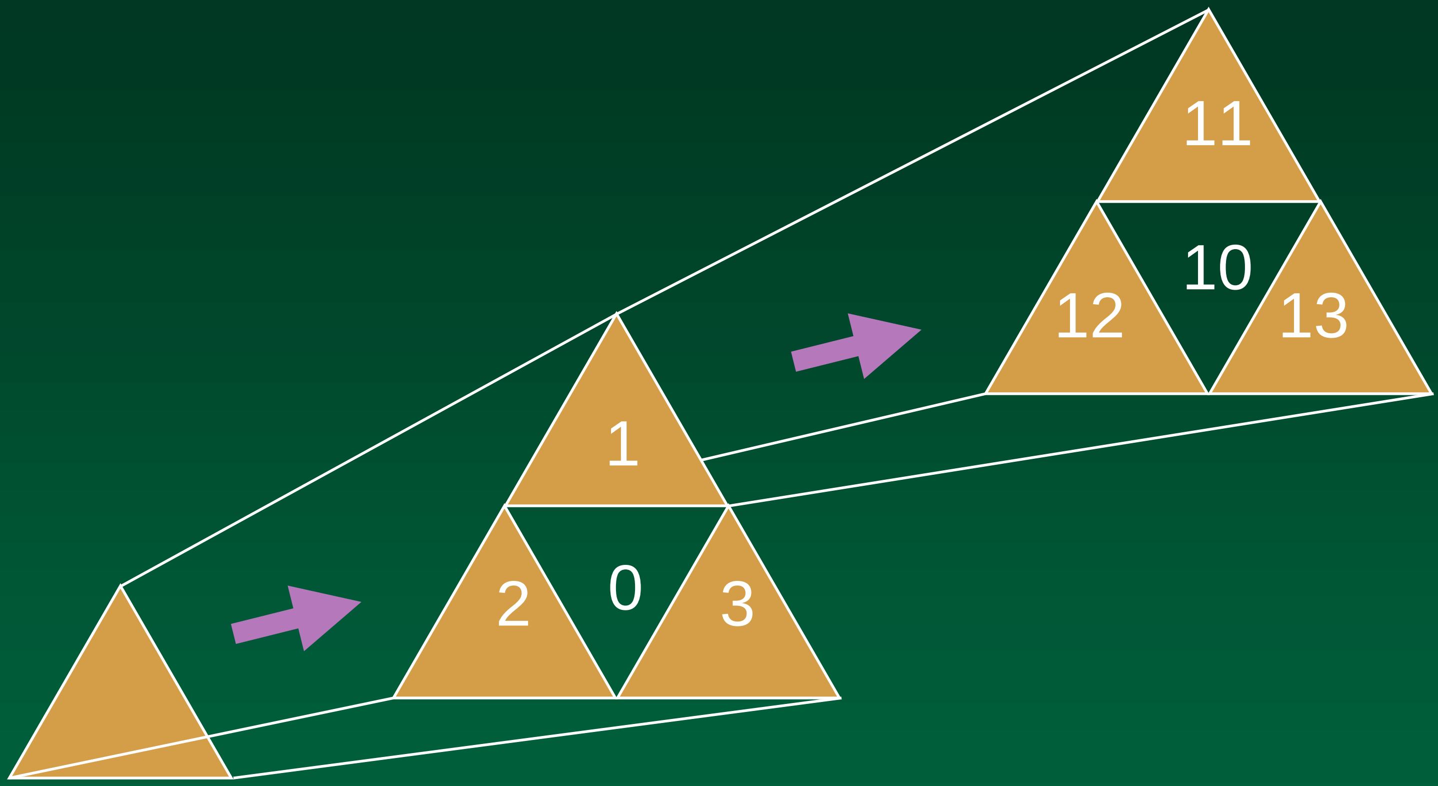
- Recursive subdivision
  - variable depth depending on local detail



Grids on the globe

- Impossible to tile a curv
squares
- Five Platonic solids
  - tetrahedron: 4 triangles
  - cube: 6 squares
  - octahedron: 8 triangles
  - dodecahedron: 12 pentagons
  - icosahedron: 20 triangles





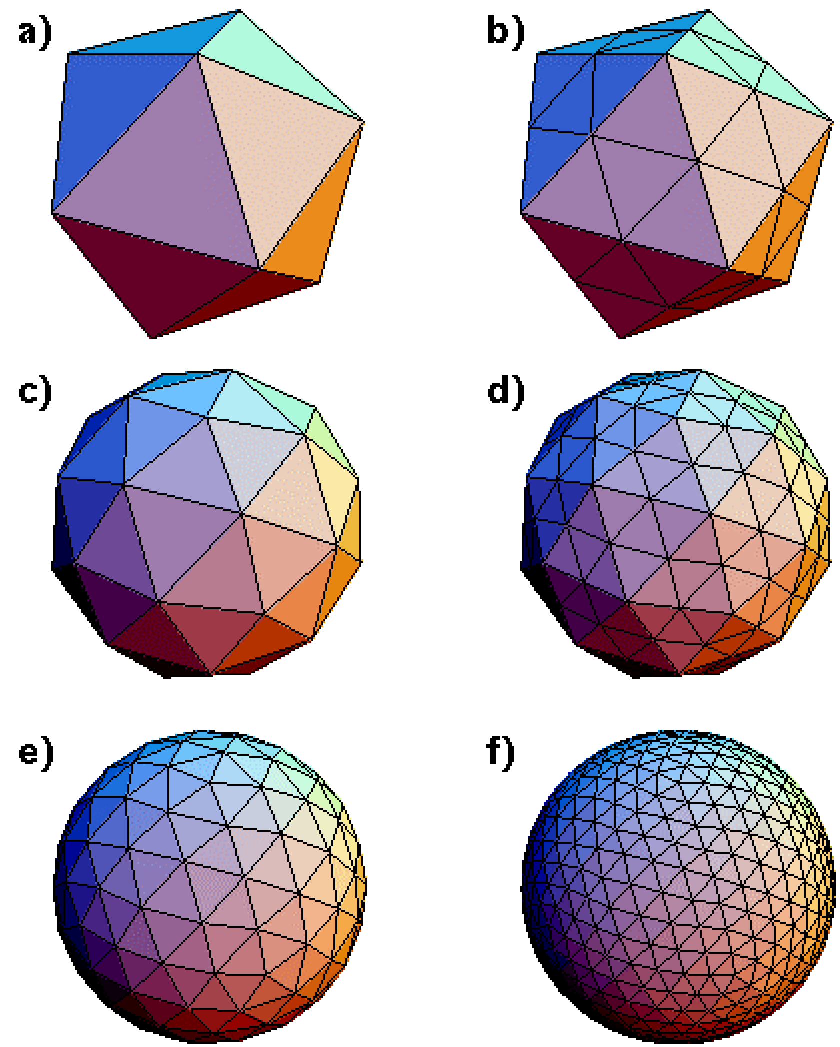
Octahedron: 1 base 8 digit plus unlimited base 4 digits

Discrete global grid based on the Icosahedron (20 triangles, 1:4 recursive subdivision)

Ross Heikes and David Randall, Colorado State University

Construction of a simple Icosahedral grid

a) Suppose we have an icosahedron inscribed inside of a unit sphere.
b) Bisecting each edge forms 30 new vertices, and partitions each equilateral face into four pieces.
c) Project the new vertices onto the unit sphere.
d) Bisect and partition again.
e) Project again.
f) And so on.... The result is a sequence of polyhedrons that increasingly approximate the sphere.



Comparison of Criteria for the Assessment of Global Grids

Criteria in Goodchild (1994)	Criteria in Kimerling et al. (1999) (Goodchild's Numbers given in parentheses)
1. Each area contains one point	Areal cells constitute a complete tiling of the globe, exhaustively covering the globe without overlapping. (3,7)
2. Areas are equal in size	Areal cells have equal areas. This minimizes the confounding effects of area variation in analysis, and provides equal probabilities for sampling designs. (2)
3. Areas exhaustively cover the domain	Areal cells have the same topology (same number of edges and vertices). (9, 14)
4. Areas are equal in shape	Areal cells have the same shape. ideally a regular spherical polygon with edges that are great circles. (4)
5. Points form a hierarchy preserving some property for m < n points	Areal cells are compact. (10)
6. Areas form a hierarchy preserving some property for m < n areas	Edges of cells are straight in a projection. (8)
7. The domain is the globe (sphere, spheroid)	The midpoint of an arc connecting two adjacent cells coincides with the midpoint of the edge between the two cells.
8. Edges of areas are straight on some projection	The points and areal cells of the various resolution grids which constitute the grid system form a hierarchy which displays a high degree of regularity. (5,6)
9. Areas have the same number of edges	A single areal cell contains only one grid reference point.(1)
10. Areas are compact	Grid reference points are maximally central within areal cells. (11)
11. Points are maximally central within areas	Grid reference points are equidistant from their neighbors. (12)
12. Points are equidistant	Grid reference points and areal cells display regularities and other properties which allow them to be addressed in an efficient manner.
13. Edges are areas of equal length	The grid system has a simple relationship to latitude and longitude.
14. Addresses of points and areas are regular and reflect other properties	The grid system contains grids of any arbitrary defined spatial resolution. (5,6)

Imagery courtesy of WorldSat Intl. Inc.

GeoFusion

Imagery courtesy of WorldSat Intl. Inc.

GeoFusion

Perspectives on Digital Earth

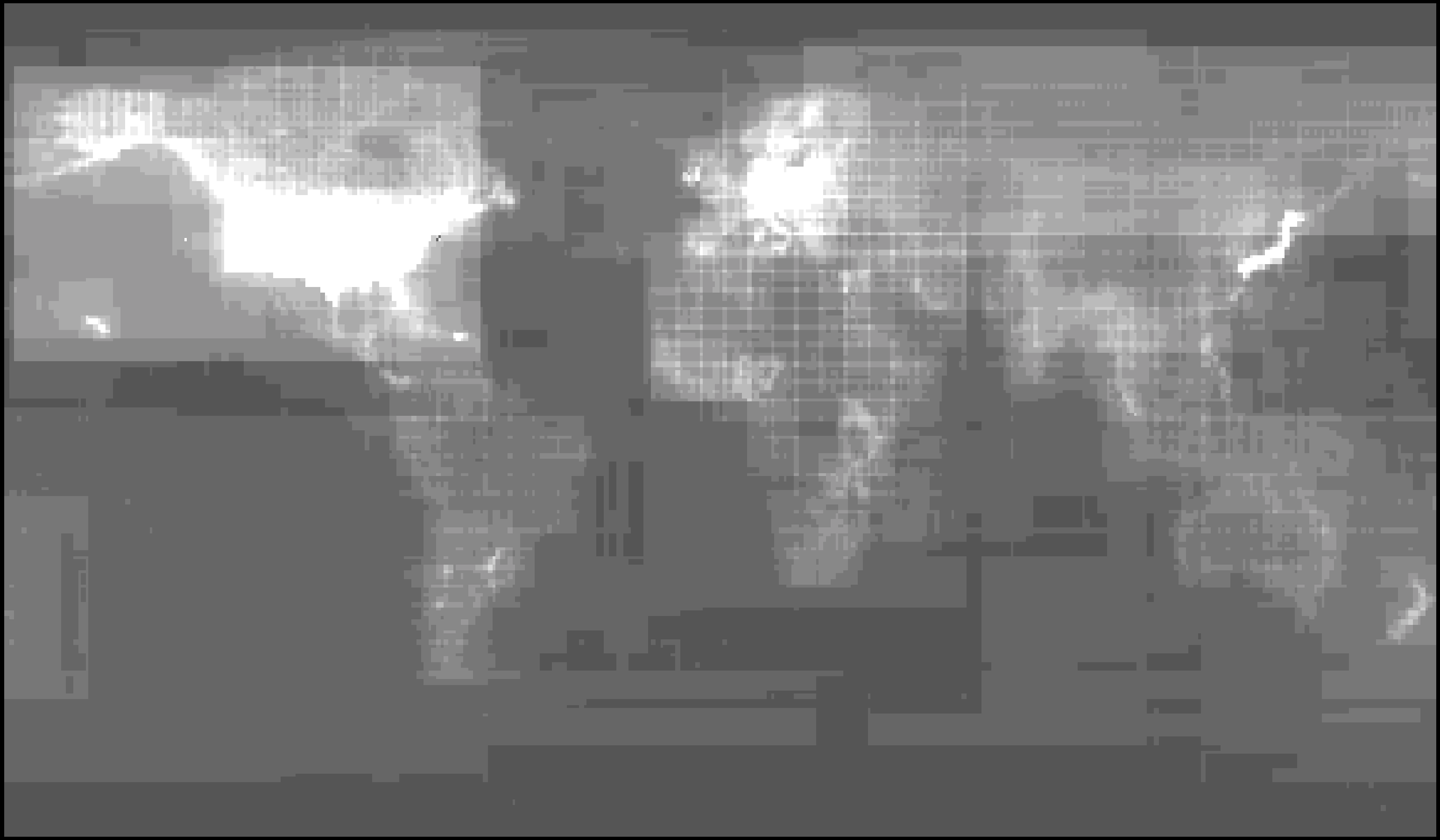
- 2. A metaphor for organizing information
- The geolibrary
  - a library that is searchable by geographic location
  - "what have you got about *there*?"
  - physically impossible but feasible in a digital world

Organizing information by location

- Information with a geographic footprint
- Organizational metaphors
  - the desktop, office, workbench
  - the surface of the Earth

Research challenges

- Defining footprints
  - fuzzy, vernacular
- Mapping between georeferencing methods
  - the gazetteer
- Search over a distributed archive
  - search engines
  - object-level metadata (OLM)
  - collection-level metadata (CLM)



CLM of the Alexandria Digital Library

Research challenges (2)

- Approaches to CLM
  - by data type
    - *ortho.mit.edu*
  - by area of the globe
    - SRI's Digital Earth, IBM's WorldBoard
  - the one stop shop
    - *www.geodata.gov*
  - a new generation of search engines
    - identifying footprints

Perspectives on Digital Earth

- 3. The Mother of All Databases (MOADB)
- A distributed collection of knowledge about the Earth
  - transparent to the user
  - accessible through geolibrary mechanisms
  - supported by consistent protocols

Perspectives on Digital Earth

- 4. A collection of knowledge about the Earth's dynamics
  - the processes that create and modify the landscape
- Dynamics or statics?
  - most GIS data are cross-sectional time-slices
    - providing facts
  - understanding of the Earth must focus on processes

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
  - University of Utrecht, Peter Burrough

Research in Metadata for Computer Models

Models available over the Web
Model research and articles
Metadata & Cataloging: Examples, Ideas & Articles

Meetings
Interviews
Readings

Reporting Model 'Fitness of Use' or 'Validation' in Metadata
Comparison chart for Model Metadata
An Easier Method for Metadata Collection
Creating a Computer Model Metadata Standard

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link to Geography 5, Fall 2000

Is Digital Earth feasible?

- 500,000,000 sq km
  - 5 million at 10km resolution
  - 500,000,000,000,000 at 1m resolution

[illegible]

The LS ratio

- Computer screen - 1000
- Digital camera - 1500
- Remotely sensed scene - 3000
- Paper map - 5000
- Dimensionless
- $Log_{10}L/S$ in range 3-4
- Human eye - 10,000

So where do we stand?

- Basic data structures and algorithms
  - using somewhat enhanced graphics capabilities
- Support from remote servers
  - with fraction of T1 bandwidth
- Cartographic research
  - how to render abstract variables
  - how to render 3D
- Institutional change
  - vertical integration of data supply
  - infrastructure for sharing models