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Dynamic Maps: Representations of Change in Geospatial Modeling and Visualization

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Representations of Change in Geospatial Modeling and Visualization

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

By
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The report of Anthony D. Turner is approved.

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This work has overrun its temporal domain, by quite a bit. My wife, Patty, and Dr. Karen Kemp have exhibited patience and forbearance in abundance. Dr. Kemp is pre-included in each of the cluster acknowledgements that follow, and Patty in all else.

Doctors Doug Flewelling, Josef Strobl, Witold Frazcek, Aileen Buckley, Mark Kumler and David Unwin, are sufficiently wise and colorful to seed my mind with the essentials of natural and computational geospace: and curious enough to let me spin some of their assignments in my direction. Each and all have advised me, in so many words, to bind the problem, define the project and get it done. I truly appreciated the point of view, but have proven hopelessly incapable of following the advice.

As the work emerged, not so much as a project, but rather as lilies on a pond, I would become stuck on an ontological pad from time to time. The people cited in the report provisioned my escapes, through vision, representation, or vocabulary. The most helpful in this regard were Doctors Michael Goodchild, the aforementioned Kemp and Ekbia, Michael Worboys, Alan MacEachren, and Troels Degn Johansson .

Over time, Euclid, Descartes, Newton, Maxwell, Tomlinson, Tobler and Dangermond have affected the major shifts in the way we apprehend and use geospace. When this work began, a single goal impelled me. While the work has meandered, and shows it, the goal remains. Jack, meet Isaac.

ABSTRACT

Dynamic Maps:
Representations of Change in Geospatial Modeling and Visualization

By
Anthony D. Turner

By coining the descriptive phrase "user-centric geographic cosmology," Goodchild (1998), challenges the geographically oriented to address GIS in the broadest imaginable context: as interlocutor between persons and geo-phenomena. This investigation responds both in a general way, and more specifically, to the representations of change in GIS modeling and visualization leading to dynamic mapping.

The investigation, consisting of a report and a series of experiments, explores and demonstrates prototype workarounds that enhance GIS capabilities by drawing upon ideas, techniques, and components from agent-based modeling and visualization software, and suggests shifts at the conceptual, methodological, and technical levels.

The workarounds and demonstrations presented here are four-dimensional visualizations, representing changes and behaviors of different types of entities such as living creatures, mobile assets, features, structures, and surfaces, using GIS, agent-based modeling and animation techniques. In a typical case, a creature begins as a point feature in GIS, becomes a mobile and interactive object in agent-based modeling, and is fleshed out to three dimensions in an animated representation. In contrast, a land surface remains much the same in all three stages. The experiments address change in location, orientation, shape, visual attributes, viewpoint, scale, and speed in applications representing predator-prey, search and destroy, sense and locate and urban sprawl. During the experiments, particular attention is paid to factors of modeling and visualization involved in engaging human sensing and cognitive abilities.

Also included, as digital appendices are:

Appendix A: University of Redlands/ESRI narrated colloquium recorded on January 9, 2007. Titled "Representation of change in GIS", it recapitulates the computational and kinetic visual aspects of this report. QuickTime, 159mb, 30 minutes)

Appendix B: Notes on the exhibits containing full motion video versions.

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1. Introduction: Uses, Shortfall and Means

> Note to the reader: If convenient, viewing the Quicktime digital ESRI colloquium attachment to this document is a good way to start. It takes about 30 minutes, but sections can be skipped, and full motion videos are the quickest way to apprehend nature of the models.

In a 2002 University of Redlands and ESRI colloquium, Michael Goodchild characterized the coming use of GIS as “augmenting our ability to interact with phenomena in real time.” In a 1999 Keynote address, he had said that increased speed of acquisition and cyber-convergence of data makes possible a “user-centric geographic cosmology” in which the user plays an active role in the outcomes of target phenomena (Goodchild, 1998). He suggested that GIS are entering a period of transition in which people will use GIS to relate to geographic phenomena in increasingly dynamic ways, and that phenomena will be represented in GIS by a more varied array of entity types than today. Many of these entities will be able to change in time. At some phase in the transition, the perceived relationship of a GIS user to a phenomenon will shift from observation and analysis to that of an interactive participant in a dynamic phenomenon; in effect, the user becomes a pilot. No claim is made here that his remarks were correctly apprehended, or that this paper accurately represents them. Nonetheless, they have been very useful.

In a second University of Redlands and ESRI colloquium in 2005, Goodchild related that GIS have undergone several paradigm transitions in reaching today’s object/relational/feature model (Goodchild, 2005). The transitions are characterized by inevitable obsolescence and gradual replacement. Exceptions and ambiguities, and their resulting workarounds, emerge and accumulate to the point that some applications become more workaround than model. He suggested that we are now in such a transition, and that two examples of the shortfall in GIS are associated with continuous entities and dynamic phenomena.

Also in 2005, in the introduction to *GIS, Spatial Analysis, and Modeling* (Maguire, Batty and Goodchild, 2005), Goodchild introduces some of the inconsistencies between GIS models and representation of continuousness and time. He suggests that “coupling with packages that are more directly attuned to the needs of modeling” is currently receiving much attention as a means to address the shortfall. The book then presents several examples of coupling in varying modeling situations.

The Goodchild citations (above) frame one of the major challenges that GIS will face over the next decade. The first asserts that users of applications of GIS will intrude into, and play a role in, dynamic phenomena. The second identifies two current GIS shortfalls as representation of continuous entities, and dynamic phenomena. The third suggests that coupling with other packages is the current means of experimentally addressing the shortfall.

This “use, shortfall, means” triad provides the framework from which this investigation launches theoretical and experimental efforts that address some issues of adding representation of temporal change and continuity to today’s GIS model.

1.1. Primary Goal Set

By means of applied research and experiment:

- In a finite time, discover as many aspects of representation of modeling and visualization of change in four dimensions (4D) as possible. Report upon and exhibit the discoveries.
- Address the issue of according the third spatial and the temporal dimension full coordinate status in classifying, modeling and visualizing both observed and simulated representations of geo-phenomena.
- Implement the ways and means of coupling, assembling, interfacing, and extending geographically oriented packages, tools, object classes and methods to form a federated geographic platform, capable of representative modeling and visualization functions leading toward user-centric geographic cosmologies.

1.2. Secondary Goals

The use of 4D visualization is itself, an integral part of this investigation process. Imagination and thought can be expressed as linear text, if the story can be linear. Other forms of expression lead to poetry, art, and cinema. Books about art (not artists) contain pictures. Without them art could not be apprehended. There are few books about the principles and practices involved in making movies because four dimensions cannot be described in one or two. This report is about 4D. 4D is used to illustrate, communicate, investigate, prototype and demonstrate to discover how helpful animation software is for education and communication of computational geographic principles and practices.

1.3. Limits

The experiments are limited to visualization, modeling, and choreographic principles implemented on a loosely coupled federated platform. Issues of data management, network distribution, and system management, performance and reliability are not addressed. Accuracy, precision and certainty are qualitatively considered, but left to chance in their realization. Data acquisition, convergence and deployment via networks are not demonstrated.

1.4. Emerging Vocabulary and Acronym: Old Words with New Loads

Time and again, a word or phrase has assumed extended meaning and become useful in, the emerging context of this investigation. A partial collection of these words appear below.

Agent: An algorithmic construct that acts on behalf of a modeler, in the stead of its real or imagined counterpart, in an autonomous fashion, with some level of proactive and/or reactive mimicry.

ABM: Agent based modeling. A programming environment and practice supporting time based simulation using agents as dynamic entities.

Apprehend: To understand through observation. Since moving creatures first appeared, they have engaged their environment with sensing organs, and acquired an ongoing "understanding" of circumstance with instinct, intuition and contemplation.

Alfred North Whitehead discriminates between apprehension and other cognitive functions joining apprehension and action into response and reaction. "Intelligence is quickness to apprehend as distinct from ability, which is capacity to act wisely on the thing apprehended" (Bartletts, 2000). In this report, apprehension is construed to mean the way humans transform either reality or a displayed visualization into signals and states amenable to downstream cognitive chambers of spatial contemplation or action.

Attend: To direct the mind or observant faculties. Here used as a cognitive control of apprehension. One must be attending to apprehend.

Chamber: Used to mean a plenum containing cognitive functions and the manner in which they work. This usage emerged with the metaphor of the "bicameral mind"(Jain, 1974). In this investigation, the notion is used to differentiate between static and kinetic visual apprehension chambers.

Choreography: The art and practice of arranging movement to deliver a message or story to an audience. Choreography is to motion as cartography is to static spatial maps where elements and symbols are so arranged. A kinetic visualization is so choreographed.

Confection: Assembly of many visual events from different times and places in a spatiotemporally coherent product: differs from snapshot, where sampling is instantaneous (Tufte, 1997).

Consilience and ***Conciliate:*** Refer to a conceptual snapping together of ontologies across disciplines to create a common groundwork of explanation (Wilson, 1998).

Domain: The dimensional extents, including time, of a phenomenon.

Dynamic: Interesting change with time, opposite of static where the change is not of interest in the domain of a phenomenon.

Geographic Federation: A confederation of model types and specific implementations that collaborate to represent and visualize entities in a phenomenon.

Happening: Occurant entities that, along with things, continuant entities, are the occupants of dynamic phenomena (Worboys, 2004).

CGI: Computer generated images or imaging. The use of 3-D computer graphics in visualizing composite entities and special effects for movies games and simulations.

Kinetic: An effect of dynamic processes used here as perceived visual change.

Lagrangian Motion: Borrowed from fluid dynamics and finite particle analysis where the forward history of each particle is determined by a set of partial differential equations. Here, it is used in a more general sense. The particles are points representing object locations. Location determiners can be sampled or computational. Their history is the stepwise track of an object location.

Mobile Objects: Real or artificial entities, not tethered to the earth's surface. Cell phones and dogs are mobile objects. Landline phones and fire hydrants are not. Mobile objects carry an identifier like Subscriber ID or dog license and they move. They occupy space, but space cannot claim them.

Pilot: One who interacts with a phenomenal domain using user-centric geographic cosmology oriented applications.

Plenum: A space-time container for entities or abstractions related by interest. The enclosure for phenomena.

Thing: Continuant entities that, along with happenings, which are occurant entities, are the occupants of dynamic phenomena (Worboys, 2004). In this scheme things can be objects or fields. When used in this special manner "things" will be italicized (*thing*).

User-centric Geographical Cosmology: An application capable of effecting dynamic computational mediation between a geographically oriented phenomenon and interested parties.

2. Background

User-centric geographic cosmologies need not adhere to our current idea of cartographic representation of three spatial and a temporal dimension. Before geography and time could be electronically represented, people made do with what they had.

2.1. The Story Tellers: Early Memorializations

In any age, storytellers constrained in technology, media, and material, elevated their craft with inspired practices.

2.1.1. Songlines: 2300 B.C.E. The Mind is the Media

Most cultures are place oriented and one travels from place to place. The landscape of Australia is so harsh as to preclude accumulating anything, or staying anywhere. Aborigines, constantly on the move, are track oriented. An old aborigine does not say he's gong to Adelaide, rather that he is going "on walkabout". Places, like Adelaide, along the track are natural resting and filling stations that sustain travelers on the track, rather than destinations.

Long before Descartes discovered orthogonal coordinates, and the Greeks happened on right triangles, aborigines mapped Australia's tracks with a system of songs. The songs played in the aborigine mind as they moved along a track (Chatwin, 1992).

Songlines are aspatial temporal memorizations of tracks, linear as tracks are linear although meandering in three spatial dimensions. They were transferred between individuals phonetically by designated story keepers. The composite waveform was blended from sequence of note, beat, pitch and tempo, evoked the environmental context as it changed along the track. In other words, the three spatial dimensions ride the temporal because a walkabout is a four dimensional, time variant, spatiotemporal, dynamic, phenomena.

Songlines are geophonic maps, not geographic. They cannot be externally visualized or expressed. They are played in the imagination, but they are not imaginary. Migrating creatures may use analogous schemes, as did the robot vehicle Stanley that drove itself to Las Vegas over the Mohave Desert in late 2005 in DARPA's Grand Challenge . It has taken five millennia to overtake the Aborigine.

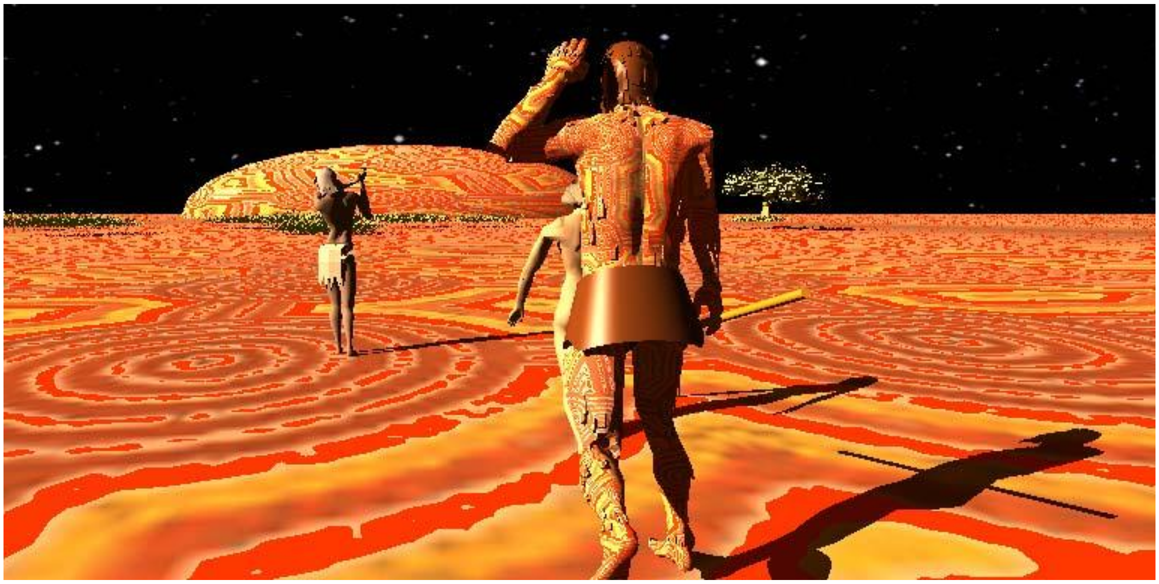


Figure 2-1: Aborigine Group on Uluru Track.

The visualization represents early man's internalization of the character and features of the land as they moved. Such memorizations likely led to transferable stories and songs.

2.1.2. Emakimono-Heiji Monogatari Emaki: Time on the X Axis

By the 12th century, the Kamakura period, Japanese artists were depicting stories on scrolls. These scrolls were often executed in continuous temporal narrative form with the same figures appearing many times against a continuous background. This method of representation was used with utmost skill and imagination.

The period saw the creation of many picture scrolls of famous battles. The best and most well known is the Heiji Monogatari Emaki, which recounts a battle between the Taira and Minamoto clans. This picture scroll is reputedly the masterpiece that best represents Kamakura painting. It appears in the figure below.

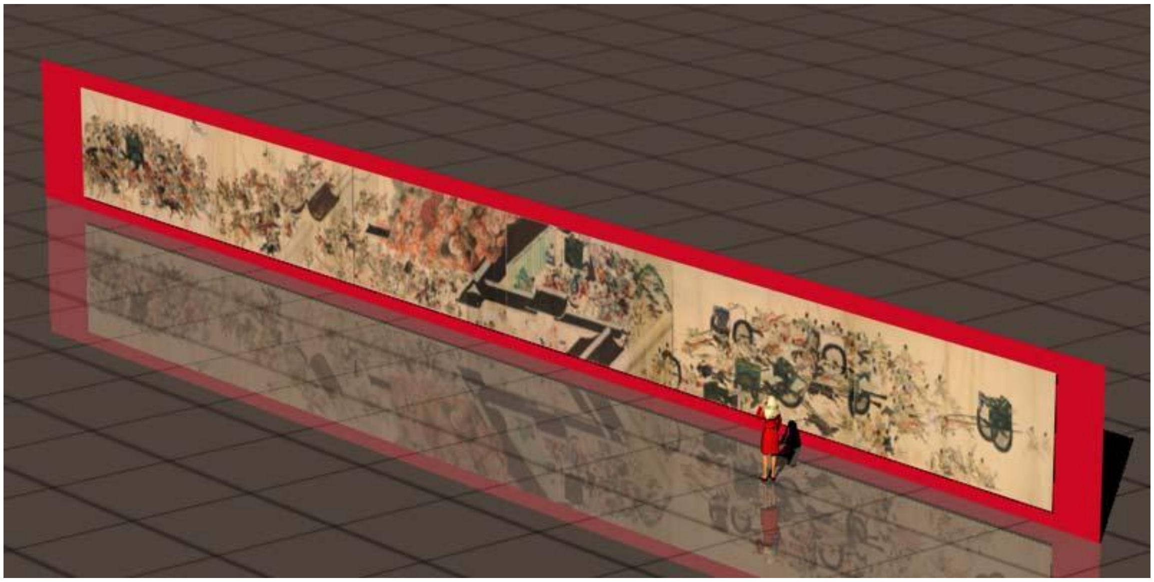


Figure 2-2: Full view of Heiji Monogatari Emaki in a Virtual Museum.

A full motion video appears in Appendix B.

Figure 2-3: Closer View of a Center Panel.

As the viewer moves from right to left the story of the battle tumbles along. The artist uses the negative X axis to carry the temporal dimension. Temporal continuity is mimicked by structures, and landforms that appear continuous across the scroll. The story flows through time without using time itself as part of the media.

2.1.3. Story Based Cartography: Napoleon's Russian Vacation - 1812

Maps represent geo-phenomena in a framework of rectangular coordinates in which entities and symbols are arranged in sensible patterns. Change can be shown by multiple state images, multi point tracks or by other means. Occurrences and causes between states may be imagined, if simple, else inspired feats of cartography are needed. Minard's often cited map of Napoleon's 1812 advance and retreat from Russia is such a feat.

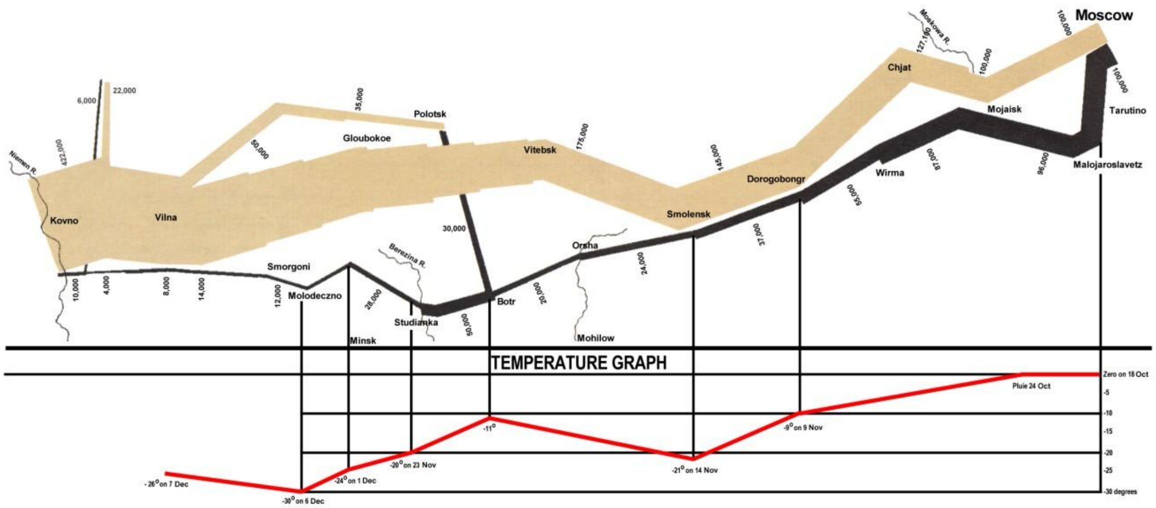


Figure 2-4: Minard's Map 1861 (From John Schneider 1998)

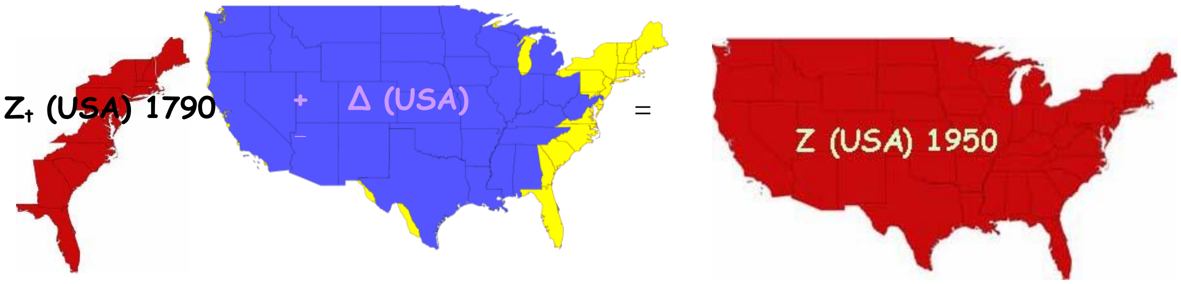
The map represents a chunk of time by treating an army as an x,y point moving first in an easterly and then a westerly direction. The army's location is shown as latitude and longitude, symbolized by a vertical line whose length represents the number of troops. Time and temperature are embraced in the lower graphic representing the return trip. The y-axis now indirectly carries troop strength, date and temperature as attributes.

2.1.4. The Mapmakers: Geographic Stories on Flat Static Surfaces

A geographic state is a confection of many individual changes that have accrued up until that time. A snapshot captures the state at an instant. A paper map may be confection or snapshot.

A later map would show a new state reflecting further accrual of the changes that occur between snapshots. Change is determined by subtracting the first snapshot from the second, or superimposing one on the other or by some other means.

For example, the underlying phenomena below are related to Territorial Expansion. The analyst could make this deduction with any two of the maps by looking at the maps and reasonably discern the change represented without the maps themselves changing.



Snapshot 1: 1790 **Delta: 1790-1950** **Snapshot 2: 1950**

Figure 2-5: USA Territorial Changes from 1790 to 1950.

In the example above, the change is 35 states or 2 million square miles in 160 years: about a state every five years or 12,000 square miles per year. So, paper maps represent change in discrete chunks. If we had a new map every year the delta would be held to one or two states.

2.2. Computational Mapping Concepts

Early computerized maps share much with paper maps. They use coordinates to tether features and fields to a location. Then, properties, attributes, and symbols are associated with feature and field. In this way, grains of ink on paper or pixels on a display are given color or symbol for visualization and a value for analysis. Location is the binding force and discriminating metric.

Tomlinson realized that digitized maps covering the same territory could be combined with location as the binding agent. Differently themed or versioned maps were brought into spatial alignment by transforming them all into the same coordinate system.

The enormous combinatorial leverage and cognitive value of many maps with different themes, now thought of as layers, helped kick start the emergence of today’s GIS. Spatial editing and the combined spatial relational data model accelerated changes to map surfaces, features, attributes and symbols.

Tobler articulated his lonely law leading to the creation of analysis tools that generated new layers derived from the old. As a result, several layers are viewed at the same time and changes can be reflected in minutes and hours. Still, maps are usually portrayed as flat and static, and they can still be printed on paper.

2.2.1. Experiments in this Report

The experiments in this report demonstrate prototype workarounds that extend and enhance GIS capabilities by drawing upon ideas, techniques and components from agent-based modeling, animation, visualization, cinema software, and solid terrain modeling. The show interactive behavior of mobile entities from dogs and hogs to electromagnetic fields on terrain.

Examples of change in location, orientation, shape, visual attributes, viewpoint, scale, and speed associated with dynamic terrain reasoning and semantics and the heuristics that emerge are presented. The models attempt properly geo-referenced agents, surfaces and features. They are presented as 4D animated movies assuming geographically oriented audiences.

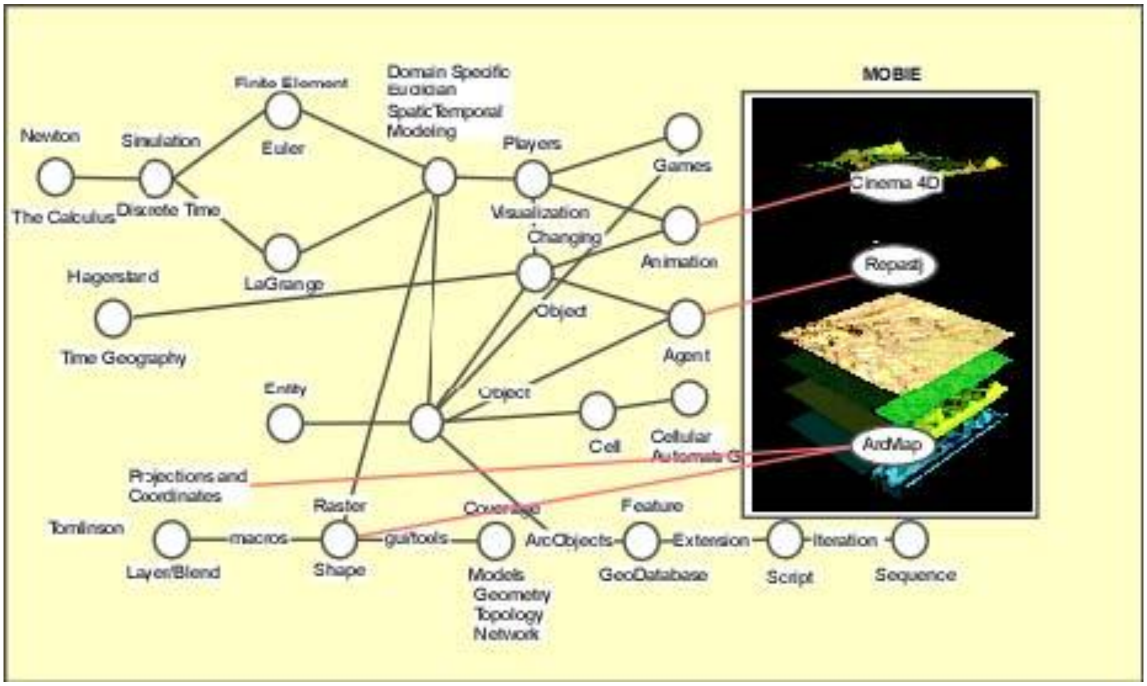


Figure 2-6: Genealogy

GIS transitions, are shown from left to right, across the bottom, programming models are in the middle and other application models are situated at the top. An application platform, crafted in this investigation and called MObIE (Mobile Objects Interactive Environment) appears at center right. MObIE’s GIS elements (shapes, raster layers, projections and coordinates indicated by red connectors) are dated earlier in GIS evolution, before they became specialized by the models. To these are added agents, spaces, and schedulers from agent based modeling, and media players and compound objects from animation. While the components are all objects, they come from different object class library structures. Today, they cannot be combined in a single system image, but they can exchange services through various kinds of coupling. It is the reason that they are coupled, rather than integrated.

GIS are capable of modeling and visualizing fields as surfaces in 2D + z: where z is an attribute. There can be only one occurrence of ‘z’ value for each X, Y in a theme, so it is not a true spatial dimension. The z value can be used to visualize time in addition to surfaces. In the figure below, each surface is visualized as 2D + z at time t. The sequence of surfaces has occurred over time in the + Z direction.

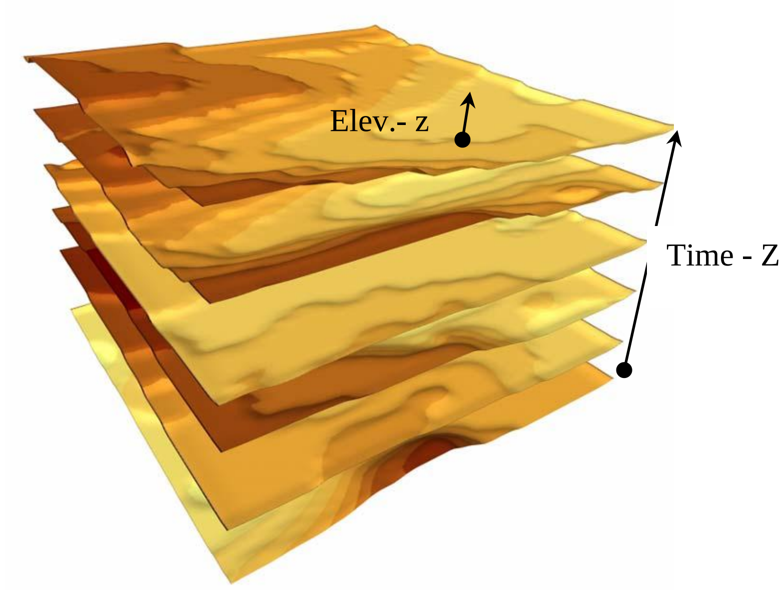


Figure 2-7: Temporal Field Value Sequences.

In a similar way, tracks are visualized below as Hagerstrand time geographies.

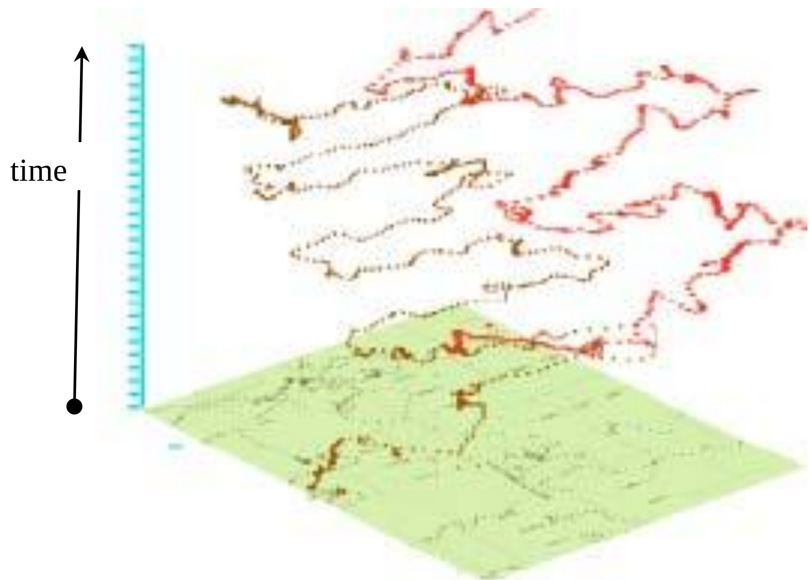


Figure 2-8: Hagerstrand Time Geography.

Here, two dog tracks rise from the desert floor. The camera angle can be changed in this type of visualization. Using multiple views, it can be visually determined if the tracks come close to one another in space-time, possibly a useful discovery when analyzing animal behavior.

By 1967, Hagerstrand envisioned individuals as moving through geography with time in the vertical axis. (Hagerstrand, 1967). At about the same time, Tomlinson devised digital layering and blending within reconciled projected coordinate systems, the spatial GIS seed model.

The ensuing forty years do not appear to have unified the Hagerstrand and Tomlinson models. Most temporal research addresses the inclusion of time in the data model for the purpose of query, and assembly of maps. Little attention is paid to human time, the sensory real-time in which we observe, apprehend and react to things that are 'happening' (Worboys, 2004). Time is considered as data, rather than human dimension, giving rise to Goodchild's call to user-centrism. Peuquet (1995) observes that time and space exhibit important differences that do not comply with the neat addition of dimensions, and Kemp (1997) notes, "In order to fully integrate the two we need to add dynamics and continuity to our understanding of spatial data and spatial interaction and functionality to the environmental models". While practitioners and researchers alike are on a quest for a consiliated model, they have only unearthed patches of the grail, and give rise to Goodchilds's observation of the prevalence of coupling rather than integrated approaches.

2.2.2. Waldo Tobler and Transitional Geography

In 1970 Waldo Tobler recast five cellular automata transitional models into geographic context. These models, listed below, are the basis for most of today's GIS mainline raster operations and analysis.

Using positional notation, let g^{t}_{ij} be the state of any cell value type at location i,j at time t**.** Let $g^{t+\Delta t}_{ij}$ be the state at this location at some other time. One primitive classification of cell based models is then as follows:

(I) The *independent* model: $g^{t+\Delta t}_{ij}$ is a random variable in no way related to g^{t}_{ij}.
(II) The functionally *dependent* model. The state at location i,j at time t + Δt depends on the previous state at that location,

$$\mathbf{g^{t+\Delta t}_{ij} = F\,(\,g^{t}_{ij}\,).}$$

(III) The *historical* model. The state at position i, j at t + Δt depends on several previous states at that location:

$$\mathbf{g^{t+\Delta t}_{ij} = F\,(\,g^{t}_{ij},\, g^{t-\Delta t}_{ij},\, g^{t-2\Delta t}_{ij},\, \ldots, g^{t-k\Delta t}_{ij}\,).}$$

(IV) The *multivariate* model. The state at location i, j is dependent on several other variables at that location:

$$\mathbf{g^{t+\Delta t}_{ij} = F\,(\,u^{t}_{ij},\, v^{t}_{ij}, w^{t}_{ij}, \ldots z^{t}_{ij}\,).}$$

(V) The *geographical* model. The state at location i, j is dependent on the states at other (neighboring) locations:

$$\mathbf{g^{t+\Delta tij} = F\,(\,g^{t}_{i\forall p,\, j\forall q}\,).}$$

At the time, Tobler cautioned, ceterus parabus, that many of the factors, including automata location, shape and size, transition function and neighborhood had best not vary across space and time.

MCA, and Geographic Automata Systems emerged with subsequent relaxation of these stationarities, and faster computers. The cellular automata evolution set the stage for many forms of urban growth and epidemiology simulations.

In time, cells became agents able to express themselves spatially (change in location, shape and size) as well as in attribution. The resulting modeling environments support the choreography of dynamic behavior of individual living and artificial entities in geographically oriented applications. These applications are most fully evolved in the military concept of "battlespace" with names like rules of engagement, terrain reasoning, and situation awareness; but they also appear in non military contexts like predator prey, tracking, search and rescue, traffic, and situation response. Today's object oriented platforms increasingly support these new environments.

Over the same time period, computerized cinematography has evolved from Godzilla to Lord of the Rings and games from Pong to Battle for Middle Earth. However, the transition from cell to agent to character to avatar crosses segmented disciplines, and there aren't many conspicuously geo-referenced action movies or games, nor are there many kinetic maps. The gap isn't so much technical as professional.

2.3. GIS Modeling

The GIS feature relational model uses difference between states to represent change. GIS' natural resistance to time and change is an effect of its enforcement of the substantial spatial relationships between geographical features. Much of the modeling supports the geographic, geometric, topologic, and network consistency of huge amounts of geographic data. Coupled with the relative lack of volatility of features on earth's surface, the balance has favored a dependence on variations of static spatial representation.

The GIS shortfall with regard to representing change is partly conceptual, partly methodological, and partly technical. Conceptually, it derives from the epistemological view of representations as static and passive reflections of a given reality. Methodologically, it is an effect of the cartographical view of change as the difference between snapshots, rather than the continual accrual of change from state to state. Technically, it has emerged with the technical origins and transitions of GIS, which utilize sequences of tools to apply changes within static collections according to the rules and constraints of geometric, topological, network and relational models rather than dynamic scenes or situations governed by natural law and individual animate pursuit. Three facets of GIS models illustrate GIS' spatial embrace. One is its unit of work, the second the degree to which it supports time, and the third, its view of process.

2.3.1. Unit of Work

GIS, while extendable via workarounds, are stretched thin as temporal and spatial granularity move toward continuity. The GIS unit of work, and record, and its natural level of aggregation, modeling and visualization is the layer or theme. GIS tools that change features in a layer build new layers. Intra and interlayer constraints representing earthbound spatial feature relationships made this a necessity, or close to it.

However, real change occurs an entity at a time, rather than a theme at a time. The GIS model is ineffective where change is of this hyper-transactional form.

In the GIS base model, features in a layer are knit together by geometry and network, and layers by topology. They can be further linked by application rules, some of which are enforced manually. Implementing the transaction model is difficult in GIS. It is possible to make new maps as changes occur, but the process of representing and reconciling a single change is similar to that of making an entire new map layer and map.

On the other hand, change can be detected by revisiting the same domain at a later time and comparing. A theme can be a single point, so the movement of a point can be detected. If another theme, such as a fire, has emerged, the domain can be rebuilt, reassembled or re-rendered as a new extent and set of themes. Movement of a point symbol or the changing extent of a fire anywhere on the globe can be modeled and visualized. Iterative geo-processing will move some dynamic modeling and visualization from workaround to under the GIS cover.

2.3.2. Support of Time

Today, ArcMap is essentially atemporal. There are hundreds of tools in its toolbox. None of them are temporal. Nor is any temporal function cited in the ArcGIS 9.1 Desktop Functionality Matrix on ESRI's Web site. Time and change can be represented using the data model, the geo-processing model or extensions to ArcObjects. Whether such uses are considered applications or workarounds is unclear. In either case, they are not straightforward.

On the other hand, ArcScene, ArcGlobe and ArcGIS Explorer explore ways that the spatial model can be extended to represent movement of either an observer or target. The approach is to use dynamic layer refresh function. Much is achieved relative to added complexity. Time will tell how much room is left.

2.3.3. Concept of Process

Dynamic phenomena contain many types and instances of changing entities. As time passes, not only the entities change; our interests also change. As we see, apprehend, sort out, contemplate and react, the many entities are cut to few: the lioness picks one of a million wildebeest. As time goes by, and the time for action approaches, individual creatures, localized features, and current happenings prevail. The concept of scale is not just spatial. It is temporal and individual. Geo-processing addresses some aspects of process. However, the steps in a GIS model are still GIS paradigm steps.

2.3.4. Shortfall in Other Models

In pointing out the GIS shortfall, that it is sublimely spatial has been underplayed. Life on earth has been, is, and will be, preoccupied with the location of one thing related to another. Thousands of schemes have emerged, some innate, some artificial, forming a locational tower of Babel. Without reconciliation, location could not be communicated. GIS morph most schemes into the same X,Y map space as a matter of course. Locational information accrues computationally across horizontal extent and vertical layers, and the total value grows exponentially, as in networks.

Other modeling systems spatially begin and end with x,y and add Z,T. In a way, they are spatiotemporal without being realistically spatial. They use space, so long as it is properly arranged for them. As a result, there are two kinds of systems to consider: GIS and not-GIS. GIS excels at X,Y and envelopes z and t with limited success. The other models excel at modeling three-dimensional change, but only in basic engineering coordinates.

2.4. Real-time Change Oriented Technology

Many new GPS based applications acquire point locations of self-identifying mobile objects such as cell phones. Other applications acquire sample data at stationary waypoints, using Radio Frequency Identification Devices, human observation, remote sensing and imaging, or other forms of instrumentation. The result is an ever expanding plethora of real time location data from multiple sources that moves over networks to applications as identity/point location pairs or image sequences of changing continuous fields. Further, GPS, coupled with ubiquitous atomic clock signaling, is emerging as a reliable location determination standard. Space-time location is becoming more precise and inexpensive in the real world.

The return loop is also accelerating, the usage of networks carrying telematic and voice protocols and commands back into the phenomenon. Several examples of Jack Bauer's (the television series "24") imagined world are already a reality.

Rapid improvement in video display resolution and refresh rates coupled with processor speed and visualization algorithms enable television-like bandwidth to be generated on the fly by application programs. The visual bandwidth can carry motion and other change along with the usual visual spatial clues like perspective, occlusion, and light and shadow. Visual bandwidth is information bandwidth.

2.5. Emerging Applications

The use of GI Science in modeling, visualizing and responding to dynamic situations is increasing. Today, the most numerous applications are military and intelligence, but scientific, logistics, urban growth, computer gaming and CGI based cinema examples are emerging.

Terrain reasoning is an emerging military application. In-vehicle navigation is nearing ubiquitous deployment. Other emerging application domains include disaster response, logistics and transport, and wildlife management. In most cases, these entail real phenomena and real users.

Smart bombs are guided in the moment by algorithmic target scenarios rather than human users. They respond to real phenomena, their location relative to the target, with a virtual user.

Games use imaginary phenomena played by real users. Simulations are imaginary versions of real phenomena created by real users.

Multiple classes can combine in an application and applications themselves can be, and are often, combined. Cruise missiles have stored within them, maps of terrain that they compare with real terrain. Mars rovers are controlled in the short term by their own pursuits, but are controlled by human commands over longer periods.

The variation in dynamic situations is infinite as are the ways and means of addressing them. However, fundamental themes cross through a good portion of them. Terms like "terrain reasoning", "situation awareness" and "time dominance" now have technology behind them, albeit limited. Regardless of the configuration, the application inter-locates between phenomena and pilot by means of intermediate representations of changing objects and fields.

2.5.1. Changing Objects

Software objects can represent creatures, including humans, acting according to their own pursuits in natural phenomena. They may be simple or compound with multiple components able to change in different ways, such as the flapping wings of a bird or rotating turret of a tank.

Mobile objects represent the lead entities in many dynamic geographic phenomena. Those involving creatures, beasts or humans, or smart assets include, but are in no way limited to: browse-and-feed, search-and-rescue, predator-and-prey, disaster evacuation, crisis response, detect and evade, species migration, search-and-destroy, search-and-capture, search-and-mate, find-and-alert, perimeter guard and defend, hide-and-seek, and roundup-and-herd, traffic, logistics, and location based services. Mobile assets have a similar menu.

2.5.2. Changing Fields

An ontologically pristine field is a “function on a domain which is a subset of space-time” (Kemp, 1998). Few pristine fields appear in GIS: that is unless a domain is allowed to be an irregular bounding object or plenum, and the function is allowed to be unknowable. Nonetheless, modeling operations can be, and are, performed on pseudo continuous fields.

2.5.3. Means to Implement

Representation of change in the entities contained in a phenomenon is a-many-splendored-thing. Change can appear in a simple property, or in complex behavior of a living creature. Change occurs on an inactive stage, but the scene is visualized in all of its kinetic vitality using the stage as spatial reference. Different phases of change in the same entity may need different models from time to time. Behaviors can consist of pursuit, constraint, natural law, man’s law, environmental and ecological factors, and uncertainty blended in a bouillabaisse class recipe. Here, the recipe is a particular confederation of model types and specific implementations that collaborate to represent entities in a phenomenon.

The confederation has components and exhibits behaviors as follows:

- Platform: Geographic Framework, Agent Based Level Modeling, Animation and Visualization
- Model types : Difference, Accrual, Agent Based and Dynamic Simulation
- Entities: Creatures, Assets, Tracks, Surfaces, Features, Observations
- Kinds of change: Lagrangian, Eulerian, Rotation, Morphing, Property
- Dimensions: 2D, 2D + z, 2D + z + t, 3D, 3D + t, 4D
- Kinetic Classes and Methods: Random, Newton, Terrain, Interaction, Scent, Line of Sight

3. Toward User-Centric Geographic Cosmologies

Nature and our imagination are both players of phenomena. All other representations are artificial, approximate and intermediate. A phenomenon may originate in nature and migrate to the imagination by cognitive processes, or originate in the imagination and migrate to nature by action. Things do not stop there.

3.1. The Nature of Representation

Nature and imagination become interactive, and assimilate one another: a single phenomenon, playing out in two places.

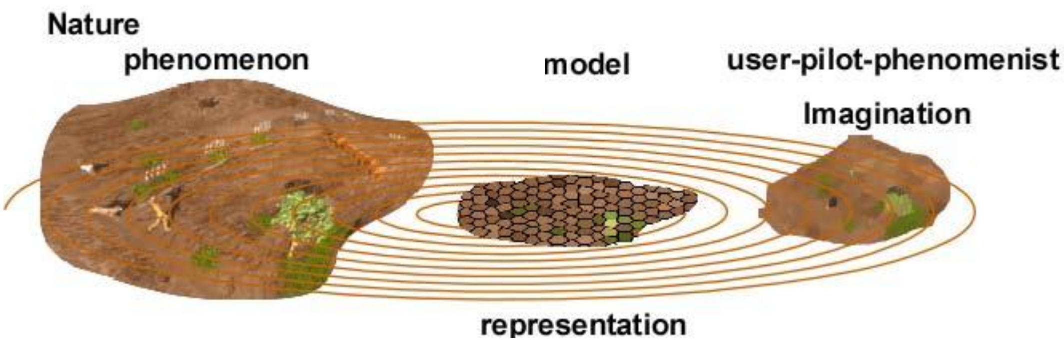


Figure 3-1: Phenomenon, Model and Pilot

A phenomenon may originate in nature and migrate to the imagination by cognitive processes, or originate in the imagination and migrate to nature by action. Things do not stop there. Nature and imagination become interactive, and assimilate one another: a single phenomenon, playing out in two places.

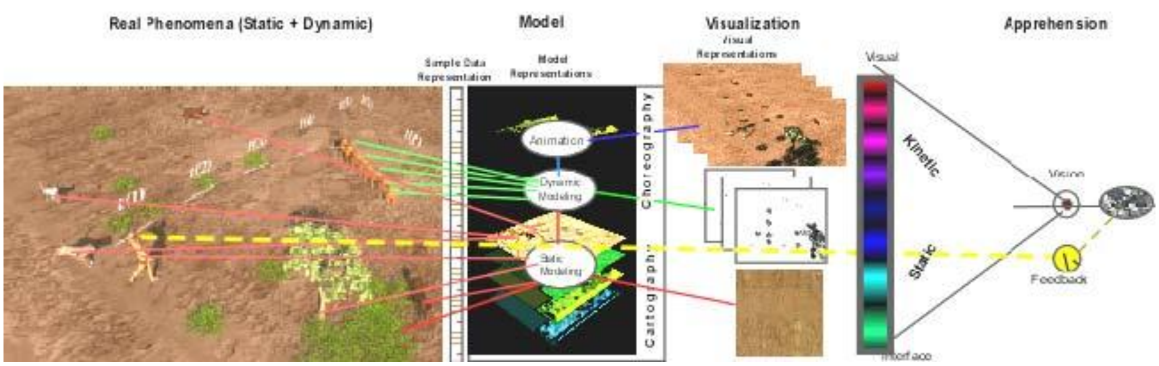


Figure 3-2: Coupled Model and Visualizations.

Phenomena can pass through intermediate artificial representations in the process of communication between nature and imagination. Photographs, maps and computational models are examples of intermediate representations of natural phenomena. Plans, designs and models are examples of intermediate representations of imagined phenomena. No representation can exactly preserve the original in any way. However, life is directed by pursuit, not preservation. When viewed as pursuit, it is possible for a system of intermediate representations to improve upon nature or imagination in some ways.

3.2. Phenomena in the Imagination

The human visual system is somehow implicated in all incarnations of GIS There is a close link between GIS and cognitive science. — GIS scientific models might draw upon human vision for insights (Mark et al. 1999, Peuquet 2002), GIS products should be amenable to human visual capabilities (Mennis et al. 2000), and GIS technologies will benefit from both of the above (Egenhofer et al. 1999). Despite the close link, however, research in this area is in its infancy. More importantly, to the extent that there is research, the incorporation of its findings in GIS products is problematic.

3.2.1. Visual Apprehension

Apprehending one's environment is neither temporally or spatially continuous at the visual sensory level. Time is discretized into steps by the sampling rate of the organs of vision. Each step produces a snapshot of reality in the moment. In humans the rate is ten to twenty per second. We are, of course, largely unaware that visual sense works frame by frame much like a camera (Churchland, 1995).

Space is discretized by rods and cones in the retina. These are unevenly distributed, but otherwise the incoming image can be said to be photonically pixilated. Space is also sampled into apprehensible objects or field segments that are tagged with some form of an identity as attention is drawn to, focused upon them and retained over time (Pylyshyn, 1998). However, we are conscious of the oceans and waves as continuous in space and time. The mind smoothes sensual chop.

Only poets come close to expressing the importance of apprehension. In the following quotations, Whitehead gently bifurcates the mind; then Godwin reunifies and extends it. "Intelligence is quickness to apprehend as distinct from ability, which is capacity to act wisely on the thing apprehended" (Alfred North Whitehead). "There must be room for the imagination to exercise its powers; we must conceive and apprehend a thousand things which we do not actually witness" (William Godwin).

User-centric geographic cosmologies had best attend to matters of human visual apprehension. After all, it is the market.

3.2.2. Chambers of the Mind

Human vision appears to differentiate between types of visual apprehension. More specifically it appears to see things that change differently from things that do not and things that vary continuously from shapes and objects. Many creatures freeze so as not to be detected.

Jaynes (1978) suggests that a "differentiated bicameral" mind is explanatory of primal metaphor. Shlain (1991) describes chambers as "one side holistic and contemplative and the other specific and anticipating". The left brain is said to be artistic and spatial, the right iterative and temporal. "One side uses long term memory and feed back networks and the other short term memory and feed forward." (Churchland, 1995). These do not cite visual differentiation, but introduce the idea of a 'cameral' or chamber that serves as a cognitive plenum containing circuitry performing a particular, albeit fuzzy, cognitive meta-function.

Morgan (1996) opens the possibility that static and kinetic entities are cognitively differentiated. “Where the image is kinetic and sequential, as in film or video, in contrast to static and contemplative, as in unprojected photography or text, the pattern of receivership functions differently. The subject is apprehended in such a way that it becomes difficult to move beyond the visual seduction of the image and thereby to grasp its structural implications. This is because the seduction offers a immediate sensation while repressing an inert sedative desire. On a more conscious level, perception leads to cognition through a synaptical set of occurrences. Simply put, the kinetic image makes the conceptual basis of the image more directly inaccessible.”

MacEachren (1995) supports the notion in the following: “Our ability to attend to moving objects can be thought of as the ability to focus on position in space time. If the position of an object changes over time it is difficult not to attend to it.”

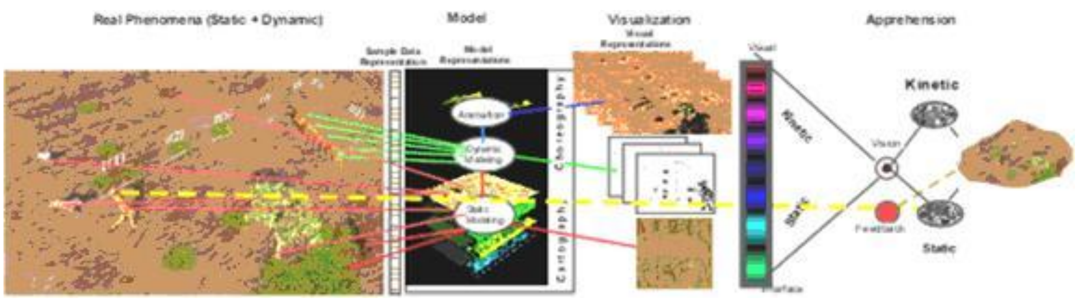


Figure 3-3 Bicameral Apprehension.

Everything is the same as before, except the visual is bifurcated into static and kinetic chambers. Both then feed forward into the imagination. Heretofore, “kinetic” has appeared without explanation. It is used in here in a particular way. These suggest that visual apprehension is multi-cameral. Static and kinetic, are one of the bifurcations and the two chambers have different requirements and roles in the cognitive scheme of things. The kinetic chamber feeds forward to response and reaction and the static chamber to contemplation and analysis. In other words, kinetic trumps static.

3.3. Proto-Ontology of Phenomena

Phenomena exist in the eye and imagination of the beholder. The cosmos envelops everything that exists, known, unknown, or even unsuspected. A phenomenon forms within the cosmos, when something about it is interesting to someone. Someone has to have an interest. That is it. The cosmos does not care about particular subset of entities.

3.3.1. The Cosmos-Entities and Their Behavior

A falling apple can be interesting: as can a tornado, migration of wildebeests, light, plate tectonics, decay of cesium atoms or distribution of rainfall across Brazil. The possibilities are infinite.

The entities in a phenomenon all change with time and in space. Human visual and cognitive abilities are incapable of apprehending, modeling or representing all the entities, much less their behavior.

Choreography is the art and practice of arranging movement to deliver information to an audience. Here, it is extended to arranging all kinds of change. Choreography is to kinetic information as cartography is to the messages in traditional maps.

Plays, ballet and puppet shows were first to choreograph kinetic information to represent change. With the emergence of cinema and video, kinetic information was recorded as movie and cartoon. Video displays connected to computers enabled visualization of computational artifacts. While the word originated in the theatre, newer uses appear in the military as in choreography of maneuver, in computer games, and on the Web as choreography of services.

3.3.2. Kinetic-Change Over Time

In physics, the word “kinetic” means “dynamic” absent consideration of energy, force and mass. The kinetic representation of the equation ‘F=ma’ is simply ‘a’. Force and mass are at play in real dynamic phenomena, but the sense of vision, by itself, does not detect them. What you see is what you get. The cause is left to contemplation. The laws apply to movement, rotation and deformation and, with a bit more of a stretch, to changes in color and other visible attributes. Computational visualization has to carry the kinetic load, but not the dynamic.

In real world dynamic phenomena, some things are too big or too small, too fast or too slow, too erratic or intermittent, too consistent or temporary, too dull or too bright, too numerous or cluttered, too erratic or regular, too few or too many, too close or too far, to be seen and apprehended. Our sense, apprehension, and contemplation of changing things have developed with a complex set of metrics and fuzzy logic. If things fall outside of certain ranges, we do not attend to them. These metrics have to be considered in visualization.

To become kinetic, a visualization has to represent change as if it were visually apprehended in reality. It has to change “before your very eyes”. Visualized change must be kinetic, even when the real phenomenon is not. Metrics include change rate, sample rate, time step size, frame rate, temporal scale, temporal extent, spatial resolution, spatial scale, spatial extent, and object size. Some of these metrics are familiar from Cartography. Even these take on a different role when things are changing.

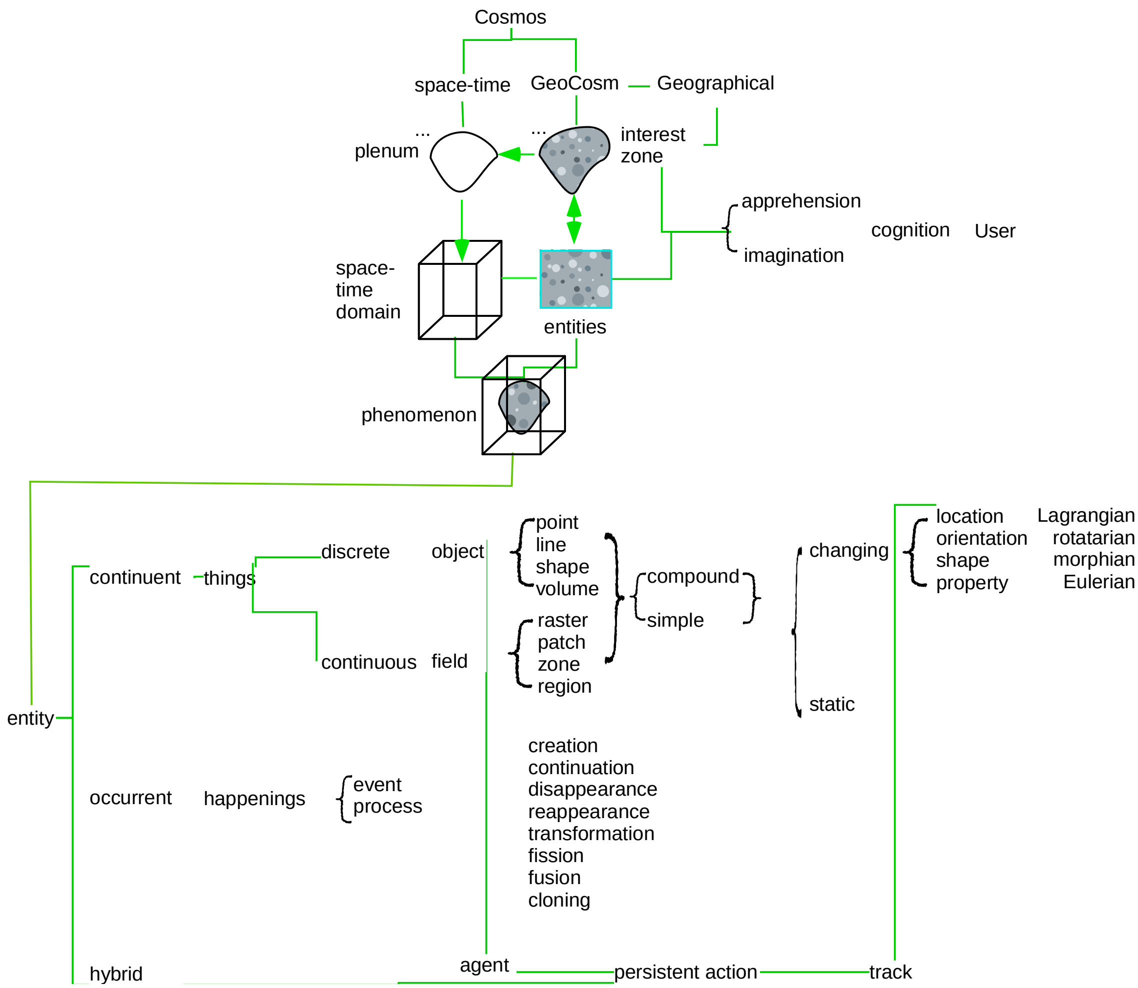


Figure 3-4: Cosmic Breakdown.

This diagram in concert with some tables that follow represents a hybrid taxonomy, class structure, and use case of a phenomenon.

3.3.3. Space-Time, Plenum, and Domain

A Phenomenon is enveloped by an ontological plenum, in this case a space-time surface containing all its entities. In turn, the entities are contained in a space-time domain, and referenced by 4D coordinates.

3.3.4. Entities

Phenomena are populated by entities. Worboys (2004) asserts that there are two kinds of phenomenal entities, continuant *thing*s and occurant happenings.

3.3.5. Things

Things are continuous or discrete, and changing or static. Familiar classification ambiguity and hybridization issues ensue, particularly in GIS. Continuous and discrete is a matter of judgment and context in dynamic phenomena. Is a flock of geese a continuous function of goose density per cubic meter vs. distance and heading from the lead goose? Is it a set of individual geese each with a location at its center of mass? Is the continuous distribution contained within an object located by its center of volume? Is a flock object a container for individual goose objects? Is the flock a triangulated or rectangulated volume represented by its centroid location: or a point by itself?

Changing vs. static is a also matter of judgment and context. Everything changes, but, is the change of interest in the domain? Tectonic Plate movement is not of interest during a goose migration while the geese are. The flock is moving relative to the earth's surface. The geese are moving within the flock. If the origin of the domain is the lead goose, the flock is static but the geese are changing their location, or the flock could be moving with each goose static within the flock. If the pattern of geese within the flock is a continuous function, the values at each element might change. Each goose has a set of wings that move relative to the goose.

GIS deals with *things*: continuous and discrete, field and object, raster and vector, surface and feature. There are fields of objects, such as a flock, and object fields. All have edges, boundaries or faces; some have patches, zones or regions. All of these kinds of *things* are constructed of points, lines and polygons or perhaps, rasters, cells, or voxels, edges and nodes that are things themselves. All of these things can come in one, two or three spatial dimensions. Each thing can have spatial properties or attributes. If these *things* are static, there is no need of time in the spatial model. There is change over space but not over time. Dogs do not run, and octopi do not change color. So, what is to choreograph? The GIS universe is wondrous but lifeless.

3.3.6. Happenings

Happenings contain events, processes, and actions (Worboys, 2004). As with *thing*s, there are hybrid, complex and compound happenings that make classification complicated. For example: mobile agents are said to exhibit persistent action expressed as tracks that are more or less continuous, but punctuated by measured or calculated points.

The classification of happenings is as context dependent as is that of *things*. Events emerge from phenomena at points along the time line. They may result from actions or processes. Processes have duration. Actions may persist as do processes or occur as events.

3.3.7. Types of Change

Objects and fields do not just change. They can change in some ways, not in others. For example, cells do not change location, because they <u>are</u> locations. However, the value h a cell can change because a cell also represents a discrete chunk of area able to held by a attribute values. Points, on the other hand can change location, but are of zero dimensions, unable to carry non-spatial values. They do carry identity, which can be symbolized. Identity does not change: however its attributes can.

The following types of change have been considered in this investigation. They are then spread against entity types in Figure 17. The selection is arguable at multiple levels. It is used as a guideline for the experiments rather than proposed as a classification.

Lagrangian: Change in Location

The Lagrangian perspective tracks the changing location of arbitrarily small particles through space and therefore is a description of movement where object locations are represented by a true spatial point: for example, a centroid or the point at the object's coordinate origin.

Rotarian: Change in Orientation

Change in Orientation Expressed as heading, pitch and roll.

Morphian: Change in Structure

Lines, polylines, polygons, vector surfaces and volumetric shapes or structures are built of vertices. Movement of any of the points, excepting the one that represents location, changes shape and, perhaps, derivative metric properties like length, area or volume, but not necessarily location unless location is derived from the subordinate points.

Eulerian: Change in Property

The Eulerian view describes the processes that influence properties (e.g., temperature) at fixed locations, and thus is a description of change. This kind of change is the basis of cellular automata, and finite element analysis, and changes in feature attributes in GIS.

Table 3-1: Entity/change table.

Blank = not possible or uncertain, X = imaginable and worth a try.

Change type SpatialEntity \	Lagrangian		Rotarian	Morphian		Euler
	appear disappear	Move in x,y,z	Move in h,p,r	Internal Structure	Shape/ size	Properties, attributes
Raster Based						
Raster, cell, grid						X
Surface (z attribute)		X				X
Field, Patch, zone, region					X	X
Object Based						
Edge, Border					X	X
GIS Features, Networks	GIS only	GIS only			GIS Only	X
Topologies, TINs						
Shapes	X	X	X		X	X
Mobile Point	X	X				
Mobile Volume	X	X	X		X	X
Compound	X	X	X	X	X	X
Object Field	X	X	X	X	X	X
Objects Container	X	X	X		X	X
Camera		X	X		X	Focal Length

The scheme is not normalized and has inconsistencies. Some classes are fundamental and some specific to an implementation. The form of the same thing in reality changes in its representation from ArcMap to RePast to Cinema4D. In a typical case, a creature begins as a layer point in GIS, becomes mobile and interactive in agent-based modeling, and is fleshed out to three dimensions in an animation environment. In contrast, a terrain surface remains much the same in all three stages.

Eulerian and Lagrangian are borrowed from fluid dynamics (Brown, Riolo, Robinson, North and Rand, 2005). These changes suffice for particles or grid points assumed to be of arbitrarily small size, but not for volume objects, the locations of which are represented by calculated points such as a centroid or center of gravity, or some point on the surface.

Many processes in the real world could be reasonably described as Eulerian, Lagrangian or morphian. For example, magma flow can be described as morphian edge change if the edge is modeled as a polygon. On the other hand, at each raster location of the terrain several properties change, affecting an Eulerian change. Another possibility is that an edge is the interface between objects that is modeled as Lagrangian movement, but visualized and apprehended as Eulerian.

The ambiguity between alternative models of change can be extended to nearly all geospatial processes, and the choice of which approach to take for representing any given process is made on the basis of both cognitive and practical considerations.

3.4. Dimensions of Change

A map can be visualized in spatial and temporal dimensions as shown below. The lower case z indicates that elevation is represented as attribute rather than dimension. The lowercase t means that time is represented in the visualization, but has to be deduced rather than apprehended. The upper case T means that time is fully represented, but change may not be readily apprehended due to inadequate choreography. The k subscript indicates that change is kinetic and apprehensible.

Time is at once similar and dissimilar to space. It is perceived as either discrete as in “a minute”, or continuous as in the variable t. It can have nominal (Christmas), ordinal (Jan, Feb), interval (Date) or ratio (lap time) values. It flows in only one direction but can have positive or negative values. Since time has one dimension it can contain points called events, multi-point sequences called tracks, or chunks called intervals.

Table 3-2: Spatiotemporal dimensions of map visualizations.

	Plane	Surface	Volume
Spatial Temporal behavior	2D = X,Y plane	2 1/2 D = X,Y + z = attribute surface	3D - X, Y, Z volume
0 static	X,Y	X,Y + z	X,Y,Z
t multiple snapshot	X,Y + t	X,Y + z + t	X,Y,Z + t
T animated sequence	X,Y + T	X,Y + z + T	X,Y,Z + T
T_{k-} animated sequence in kinetic range	X,Y + T_k	X,Y + z + T_k	X,Y,Z + T_k = 4D

3.5. Cartography and Choreography

Cartographers address dynamic phenomena as a confection or sequence of states. The change on the map or between maps can then be analyzed and inferred by a user, a sort of pseudo reverse kinetic cartography. The primary visual message is carried by the map and transition is an analytical or intuitive derivative. Napoleon advances on, and retreats from, Moscow on a single map, or Detroit grows on a sequence of maps. Change is perceived as collective symbol or pattern on the land itself and recorded in data models.

On the other hand, choreographers imagine the transitions of individuals in combination with other individuals. Position is a necessary physical and visual byproduct, and the stage a platform. In a ballet or computer game, individual and combined (not collective) motion carries the message. The model is artistic and algorithmic taking real form as a dance or battle maneuver or computational form as an animation or simulation.

As the uses of GIS extend beyond data-analysis to situation-response and signal-reaction, not only does representation change, but so does the fundamental nature of apprehension and interaction by the user, which shifts increasingly from analytic to kinetic while the required expertise shifts to a balance of cartography and choreography.

GIS transitions, are shown from left to right, across the bottom, programming models are in the middle and other application models are situated at the top. An application platform, crafted in this investigation and called MObIE (Mobile Objects Interactive Environment) appears at center right. MObIE's GIS elements (shapes, raster layers, projections and coordinates indicated by red connectors) are dated earlier in GIS evolution, before they became specialized by the models. To these are added agents, spaces, and schedulers from agent based modeling, and media players and compound objects from animation. While the components are all objects, they come from different object class library structures. Today, they cannot be combined in a single system image, but they can exchange services through various kinds of coupling. It is the reason that they are coupled, rather than integrated.

4. Assembling a Geographic Federation

A recently published book on modeling and GIS asserts that, "Extending GIS from 2D to true 3D and 4D (x,y,z and t [time]) remains a challenge" (Maguire et al. 2005: p. 450). The authors sum up their findings in this respect in the following way:

"What, in fact, is going to be required is not one way of putting together different software and models and GIS representations but a generic framework for GIS, spatial analysis, and modeling which users can adopt to the many kinds of problems and applications discussed in this book, and in the next decade this is sure to be forthcoming."

Representation of change in the entities contained in a phenomenon is a many splendored thing. Change can appear in a simple property, or in complex behavior of a living creature. Change occurs on an inactive stage, but the scene is visualized in all of its kinetic vitality using the stage as spatial reference. Different phases of change in the same entity may need different models from time to time. Behaviors can consist of pursuit, constraint, natural law, man's law, environmental and ecological factors, and uncertainty blended in a bouillabaisse class recipe. Here, the coupling is a confederation of model types and specific implementations that collaborate to represent entities in a phenomenon.

4.1. Methodology –Discovery through Problem Solving

Where the target is in uncharted territory and of unknown extent, traditional project methodology is ill suited to the problem. Discovery, during an experiment, alters the terrain and inspires another experiment. Where repetitive discoveries are the dominant events in a process, all else is in flux. The effort is a spiral of heuristic, experiment and discovery, yielding new heuristics. This investigation had three experiment tracks with this spiral form:

- Platform: Prior to the experiments, there was no platform. Along the way Cinema 4D, ArcMap, Excel, Stella, and RePast were incorporated.
- Applied Research: Starting with heuristic. 4D mapping principles from the prototypes, and 4D systems principles from the platform were assimilated as they emerged.
- Proof of Principle Prototype: Prototypes begot principle used to imagine prototype to verify principle. The illustrations and Kinetic Exhibits were products.

As time went by, an iterative poly-spiral pattern emerged.

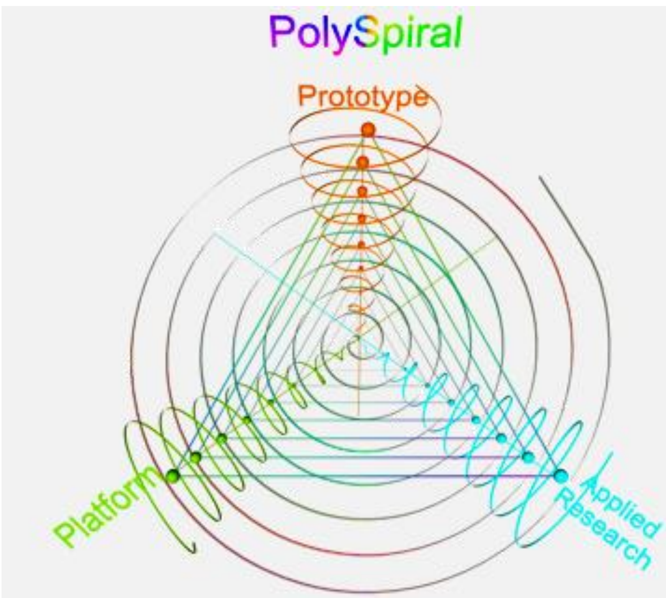


Figure 4-1: Heuristic-Experiment-Discovery Principle.

The three interacting dimensions (platform, prototype and principle) cannot interact without time. When time operates, each dimension can support tracks, in this case spirals. In the fanciful portrayal, each dimension begins at the origin and spirals outward. Each loop of a spiral represents an experiment for that dimension. (The spiral is also called iterative refinement, prototyping or protocycling in project parlance.) Experience, assimilation, insight and reusable apparatus and code, created in one experiment, serves as direction and resource for the next, also called a learning curve in project parlance. They interact at intervals. For example, a prototyping experiment creates input for the next, and either suggests or requires changes to the platform and more applied research, and formulates incremental principle and insight. On the other hand, a platform experiment can either verify existing capability or reveal new possibilities relative to 4D Maps. These suggest new prototype experiments and add new principles and insight. Each principle experiment uses existing principles, research and platform apparatus to discover or test new ones.

The three dimensions and their spirals did not proceed in lockstep. They were synchronized by discovery.

The proof of concept prototypes usually began as visualization on real terrain and extended to modeling as a result of insight assimilated by visualization.

Platform: MObIE-Mobile Object Interactive Environment

The platform does not provide a generic framework for GIS, but it suggests the nature of the potential contributing components to such a framework. It is the result of the integration of GIS, agent-based simulation, and four-dimensional visualization software such as Cinema 4D.

The platform utilizing the contributions of these components emerged during this investigation. It contains three functional levels; each occupied by a software assembly and loosely connected by import export interface.

4.2. Platform Composition

ArcMap, RePast and Cinema 4D were selected as MObIE's main components.

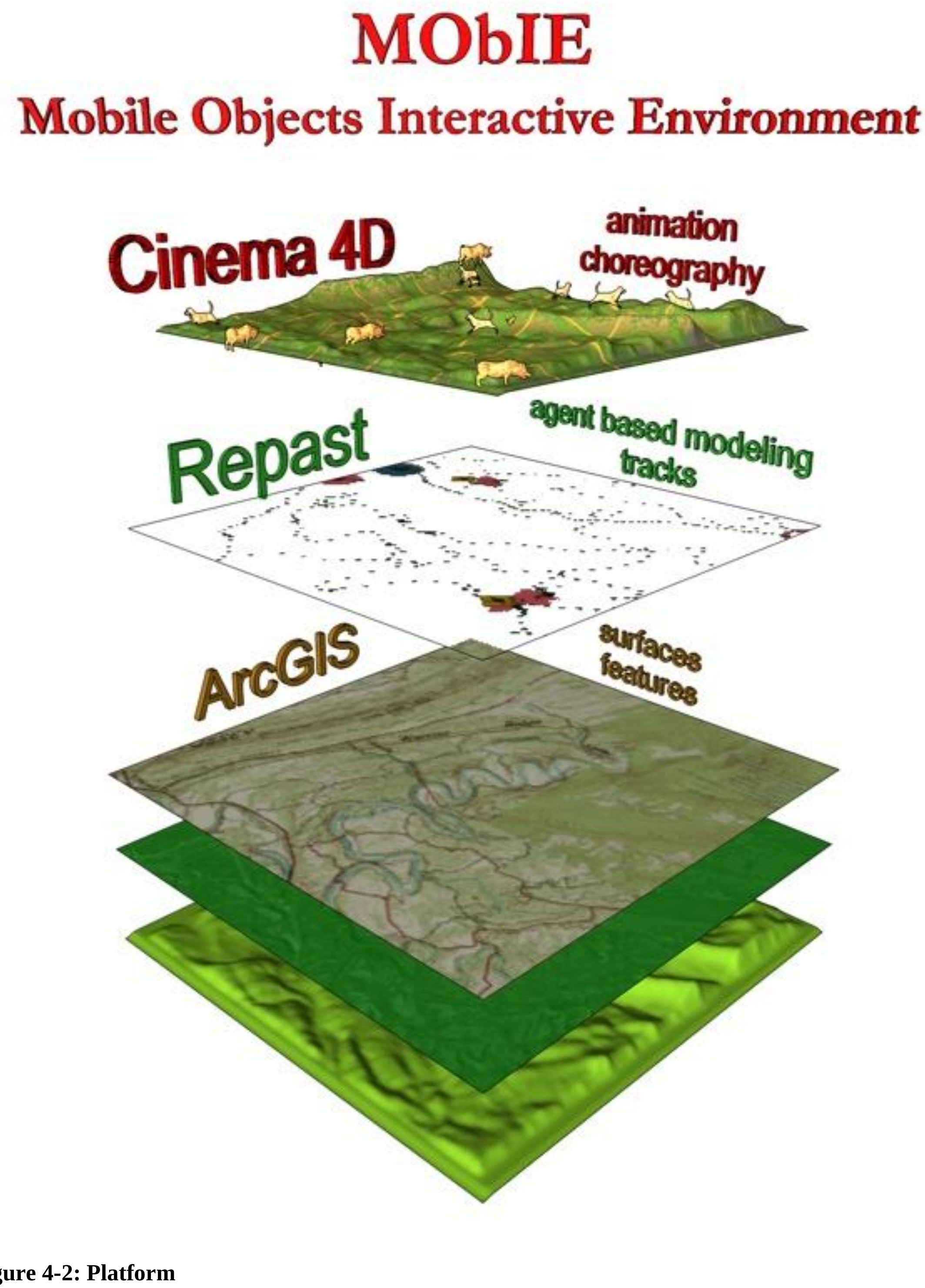


Figure 4-2: Platform

The simplest set of functions required to properly represent many kinds of change in space time could be aggregated by coupling the three products. A partial reckoning follows. MObIE utilizes the strong points of each technology to fashion a presentation used to communicate dynamic aspects of entities in a geographic phenomenon.

- X,Y - dimensions in accordance with GIS standards of projections and coordinates. ArcMap excels.
- Z - A dimension rather than an attribute. Cinema4D.
- T - A dimension rather than an attribute. Cinema4D and Repast.
- C - Application of rules and enforcement of constraints to geographic collections. ArcMap's geometry, topology and network models.
- I - Persistent action by individual things. RePast and Cinema4D.
- A - Interaction among things. RePast.
- V – Visualization in four dimensions.

Together, the selected components, combined by coupling in MObIE address these requirements. A symbolized shorthand, albeit subjective, appears below.

ArcMap = (X,Y,z,t)* (C*i*), (i i,j), (a(i,j),(j,k)) ,v) = X,Y, z,t, C,i, a,v

Repast = (x,y,z,T)* (c*i*), (Ii,j), (A(i,j),(j,k)),V) = = x ,y ,z, T,c,I,A,V

Cinema4D =(x,y,Z,T)* ((c*i*), (Ii,j), (a(i,j),(j,k)),V) = = x, y, Z,T,c,I, a,V

MObIE = GIS+Repast +Cinema4D = ______________

(X,Y,Z,T)* (C*i*), (Ii,j), (A(i,j),(j,k)),V) = X,Y,Z,T,C,I,A,V

4.2.1. Cinema 4D Animation:

Surfaces, sampled and generated tracks are imported as needed from either ArcMap or Repast. Tracks are projected onto surfaces. Mobile Objects are aligned to the tracks. These form the skeleton of a 4D Map. Then, animation, and cartographic and choreographic principles are applied.

4.2.2. RePast Agent Based Modeling

RePast, dramatically extends cellular automata because everything is an object. Even an entity that is a raster in Arc is converted to an object in a matrix of objects in a 2D Space metaphor. These objects are identified by matrix position and accessible by the agents. They are not dispatched directly by the scheduler. However, they can be indirectly dispatched via an agent.

Agents differ only in that they have an ID that is not based on position, and are dispatched by the scheduler. With enough time, any object can be programmed with any imaginable behavior in relation to any other object.

It profoundly changes the modeler's perspective from GIS' digital layer blending paradigm. During a step move in a simulation, each agent of each type makes its own decisions, taking into account any information, and using any method available within the model. The rules used to make those decisions are set down by a modeler.

However, that does not change the perspective that each agent is an independent identified entity. Each step is the model sum of the change effects of the interacting decisions of all agents. While the modeler sets the stage and casts the parts, he does not control the outcomes of running a model.

An agent may be simple or compound. It can contain subagents that share the agent's properties of independence within the agent, or it can be another type of model with determined relationships among its parts. A type of agent might be a tank consisting of moving parts. Once a tank has maneuvered into position, it may arrange its parts in order to fire with accuracy. Another type might be a swarm containing agent bees. The swarm may change position or direction the each bee agent would arrange itself within the swarm. Clusters of agent types may represent differing domains of a problem. Ships navigate according to schedules, nature and ports; ports schedule slips, ship and receive cargo, manage reconfigurations; on the land side, trains and trucks do similar jobs. Any of these nouns and aggregation, or disassembly thereof, could be an agent type, or not. It is up to modeler: a blessing or a curse?

As a major component of MObIE RePast reads in as much of the ArcMap framework data as it requires. The raster layers become RePast object Spaces, and the sampled tracks become point Arrays. Action is incorporated into the model with agent behaviors governed either by programmed rules or input samples for movement on each step. Any rule can use any piece of information at the action level: for example, the absolute or relative location and attributes of other agents, and the elevation or slope at any location. The resulting tracks are recorded as ASCII point files.

4.2.3. ArcMap Framework:

The coordinate system is set by ArcMap. The other components have no natural capacity to re-project or transform geographic coordinates. ArcMap assembles the geographic layers including terrain, infrastructure, measured track point layers and derivatives and transformations thereof, normalizes their coordinate systems and exports the kit as ASCII versions of the layers for RePast.

4.3. Function and Data Flow

MObIE consists of three components, used to build a modeling facility for a geo referencing framework, agent based modeling, and object animation. The result is a loosely coupled feed forward assembly, not a system. Modeling can begin in any of the three components. A run of any of the three results in data or visualization. The curved arrows indicate data type and flow. Visualization appears in the outer ring for apprehension by modelers and analysts if the model is to be refined, and users if it is to be applied. Several iterations of the same component or sequences of components can be run. Visualization levels in the outer ring are associated with the component that produces them.

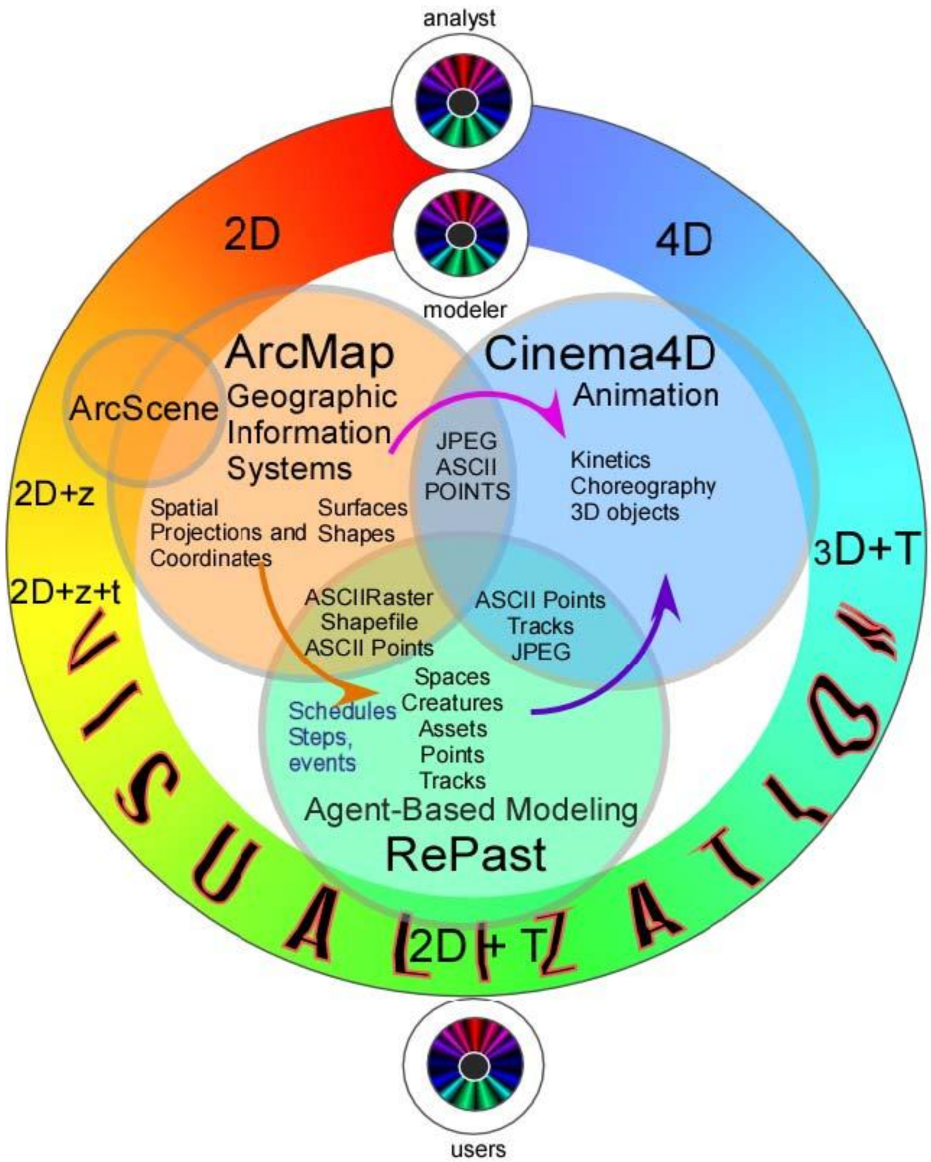


Figure 4-3: MObIE Process Flow.

4.3.1. Development Environment

The particular software packages used here are, respectively, ArcMap, Repast, Stella, and Cinema 4D. Both Repast and Stella are useful in exploring system behaviors, but there are certain differences in how this happens. In using Stella, one typically thinks in terms of aggregate quantities (Resnick, 1999). For example, to model an ecosystem with dogs and tortoises, one specifies the parameters affecting their respective populations, and Stella generates the evolution of these populations with time. Repast, by contrast, is a single-agent model — it focuses on individual creatures, rather than overall populations. To model the same ecosystem one specifies how each individual dog tortoise behaves. Repast can then display the creatures interacting with one another. The overall behavior arises out of the interactions among individual creatures. Entity types must be implemented in each model type and the metric assumptions reconciled. This is best explained by example. ASCII point files can be imported and exported by most modeling programs and used for tracks if required. ASCII, JPEGs, and TIF raster files are exchanged as surfaces. Shape files are recognized by some programs, in this case ArcMap and ReRast, but not Cinema 4D. Shape files have rules about shapes, but not about a concert of shapes, as do Features. GIS Features were not used in the experiments. Surprisingly QuickTime and AVI movies can be created by ArcMap and RePast and used as valuable input by Cinema4D.

4.3.2. ArcMap

3D feature layers, better terrain visualization, dynamically linked charts and iterative geo-processing will be delivered in ArcGIS. Coupled with Geodatadase and Web models, ArcGIS is indispensable for enterprise level applications. However, the extensions do not reform the underlying spatial model. There is simply no good reason to build a dimensional treatment of time on a model where the level of transaction consistency is a layer. ArcMap, by itself, appears to be a reformation away from being spatiotemporal.

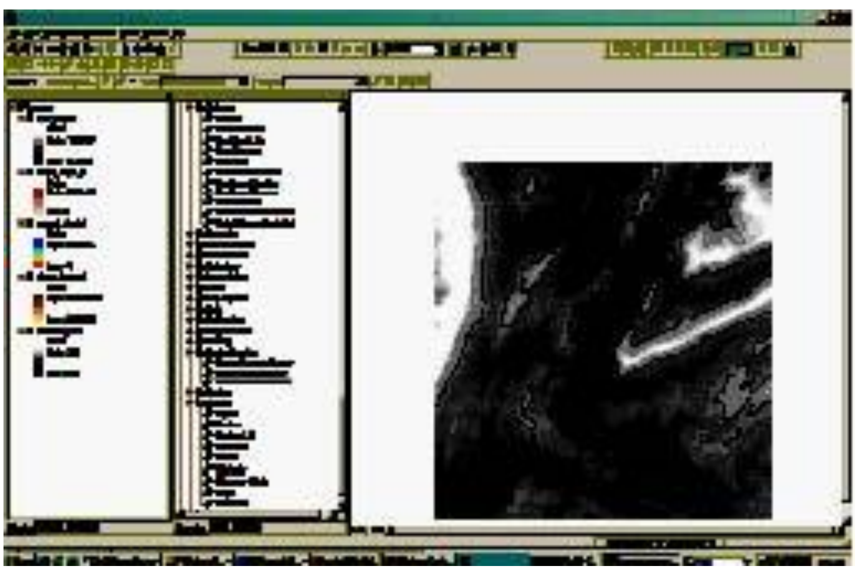


Figure 4-4: ArcMap GUI.

4.3.3. Agent Based Modeling in RePast

Repast comes in two flavors. One is RepastJ, a pure Java class implementation with the following kinds of classes:

- schedulers, timelines, events and other temporal entities
- two dimensional spaces containing static objects
- agents, changing objects dispatched by the scheduler that interact amongst themselves other types of agents and static objects
- two dimensional visualization

- import export of data types necessary to support interoperation .
- run time player
- and, for which, the programmer chooses any Java programming IDE.

The other is RePastPy which comes with a limited Python IDE as a programmer's front end. I used RepastJ and BlueJ, an elegant Java IDE with no frills and no limits for my purposes. I used Google desktop to search the RePast Java classes, including source code, and my own classes. The only thing I had to do to make BlueJ work with RePast was include the RePast class libraries in BlueJ's classpath. The rest is pure Java.

Today, RePast can use its own display, export the tracks and display for use by Cinema 4D or the tracks for use in ArcScene.

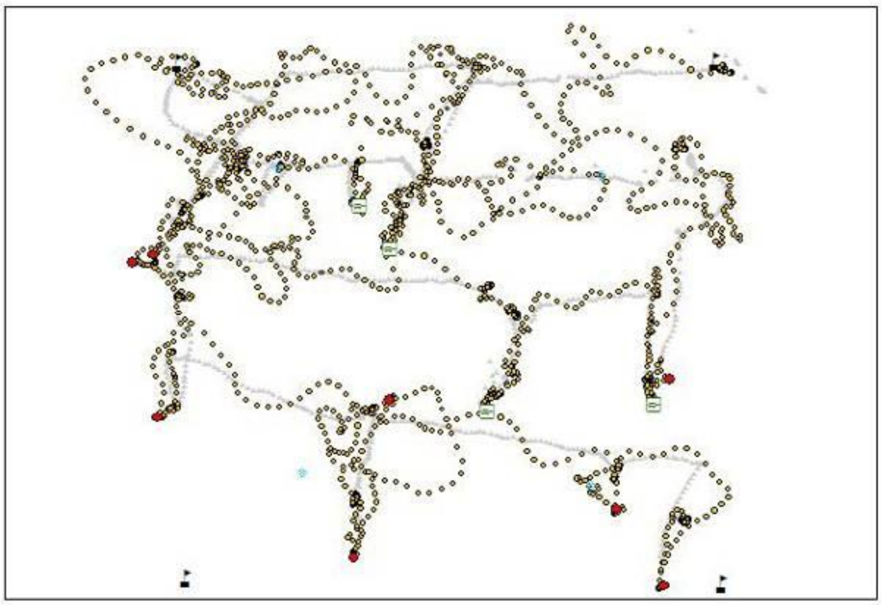


Figure 4-5: BlueJ IDE and RePastJ Runtime GUI.

The background panel shows BlueJ Java source code for the pursuer agent. The center panel shows the BlueJ class structure and tester. The right side lists RePast application parameters that can be changed at run time and the top strip contains Repast runtime controls.

4.3.4. Cinema 4D Animation and Visualization

In this investigation, a model emerges from RePast as an ArcMap surface/projection framework, and point sequences constituting agent tracks.

Cinema 4D, as shipped, can import the surfaces and tracks into its x, y, z, t space. 3D objects are set upon and aligned with the tracks and the tracks projected onto the surface. 4D cartographic effects are added, and a choreographic timeline model devised. Cameras and lighting are set. The objects are set in motion under the control of the timeline model. As a model runs according to its timeline, frames are rendered and captured sequentially. The frames are then assembled into a QuickTime or AVI movie.

All elements of Cinema 4D are properly object based. All have recursive six dimension (Laplacian and Rotarian) coordinate systems; one references to the model itself and the other the object that contains them. All objects inherit methods of translation, rotation, and scaling and attribute of position and orientation within any of the recursive x, y, z, t coordinate systems.

Cinema 4D provides unexpectedly rich dynamic spatial function in this investigation. Some of the experiments used Cinema 4D alone for dynamic modeling, animation and visualization. In others either RePast generated or ArcGIS projected track points were imported, and the rest modeled in Cinema 4D. Among the most useful functions are: projection of a track onto a surface, alignment of a mobile object with its track, and the control of temporal and spatial metrics to effect kinetic visualization.

The elements in a Cinema 4D visualization may be textured. Surface textures can be applied in a geo-registered manner although some precision is lost. For example, an image of land cover, a grid or road map can be laid on the terrain. Cartographic spatial metrics, extent, scale, resolution, and elevation exaggeration are all controllable within Cinema 4D's native x,y,z and heading, pitch, bank coordinate systems. Coordinates systems are cascadable and every object has its own that applies to its contained objects. For example, two separate RePast models, one of a storm and another of typical behavior of elements within a storm can be unified by making the element object part of a storm object in Cinema4D.

Cinema 4D modeling is essentially limited to animation and visualization. Mobile objects do not interact beyond visual clues of intersection and occlusion. Once started, visualization executes in pure playback. Real-time data cannot be imported.

4.3.5. Stella

Stella models excel for a range of simulation types. The graphic development environment and types of output make them effective for dynamic modeling of single tracks shown below. Stella is used frequently for GIS dynamic modeling. It is moderately priced from High Performance Systems. The figure below shows the Stella GUI. The GUI is the model.

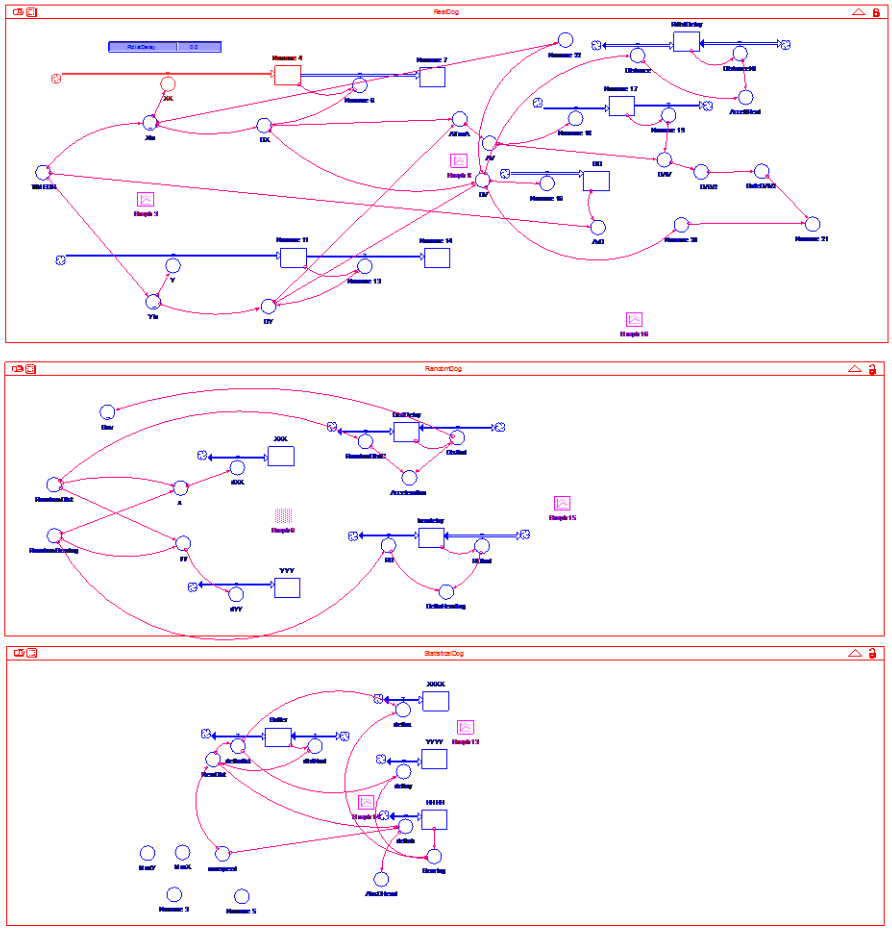


Figure 4-6: Stella GUI – Reference, Derivative and Newtonian models.

4.3.6. Combinations and Bridges

If RePast and Cinema 4D are used in tandem, limited 4D interactive mobile object applications can be modeled and visualized. At this time, the connection is limited to feature attributes and shape files. Workarounds are possible by using geo-processing. Cinema 4D, ArcGIS and Repast are implemented on object class structures. ArcObjects are Microsoft COM, Repast is pure Java, and Cinema 4D is C++. All three are programmatically extensible. RePast is naturally so, and Cinema 4D and ArcGIS can be extended, albeit in specialized ways, in object oriented languages.

The table below spreads import export files types of program components. Most of the experiments were fashioned using either ASCII raster or Jpegs for surfaces, and ASCII points.

Table 4-1: Import/Export.

Package	Raster	Shape	Feature	Object	Matrix
ArcGIS					
ArcScene					
Tracking Analyst	Grid, ASCII raster, JPEG	Shapefiles	feature class, shapefile, ASCII points	3DS	tbl
ArcGlobe					
ArcGIS Explorer					
Google Earth		KML features, shapefiles	KML features, shapefiles	3DS	tbl
RePast	Grid, ASCII, raster, JPEG		ASCH points		tbl
Cinema4D	JPEG, DEM		ASCH points	3DS	

4.3.7. Common Principles and Practices

Tracks

The tracks of mobile objects moving in time over terrain form the keystone of most exhibits in this investigation. Unlike roads and paths, static things that look similar, tracks are essentially spatiotemporal, a hybrid of thing and happening, of points or events, or figments for that matter. It depends on viewpoint. The dog has a position, at this time, or, at this time, a dog reached this position. Typically, a track is formed by extension from the present point to the next. They are thus iterative derivatives or differentials of motion. The difference between two track-points positions is more useful in analysis than either position.

Here, a track consists of a time sequence of two or three-dimensional spatial points. They can be measured, simulated or a mix of both. Tracks differ slightly depending on the applications that display them. Figure 5-7 is a GPS point location map displayed by ArcMap -Tracking Analyst (TA) followed by the same track in Cinema 4D.

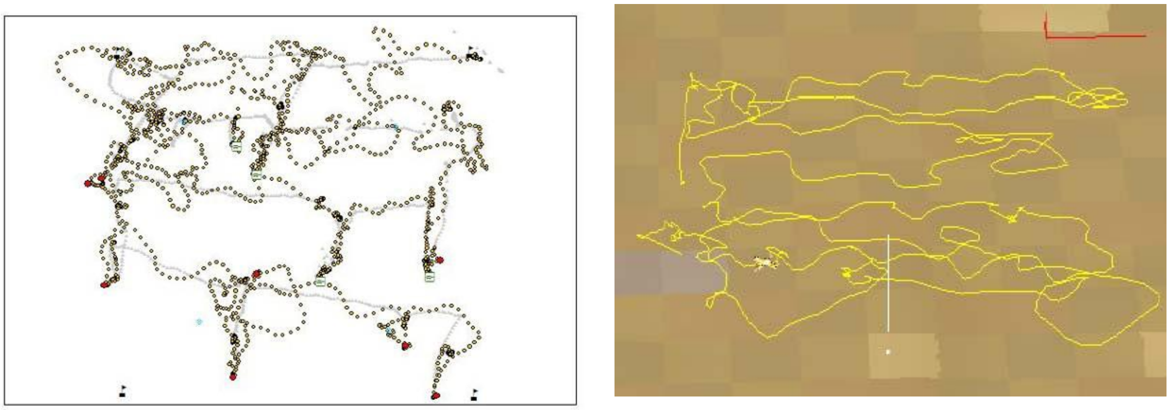


Figure 4-7: Agent Analyst point layer and Cinema4D spline.

There are equal time periods between each point. GPS samples and simulation generated tracks tend to have this quality.

Recorded RePast tracks are ASCII Point Files. After a little adjustment with WordPad they are imported as Cinema 4D splines. The splines have an elevation for each point that corresponds to elevations (y values) at locations on the relief. However the vertical scale can be changed for the relief. Cinema 4D has a tool that projects splines onto surfaces.

Terrain

Terrain is a surface represented by a number of raster based image or special elevation formats. Terrain and tracks must be referenced in consistent coordinates. If 4D visualization software used projected and coordinate spaces other than the rectangular kind, this investigation wouldn't have been as challenged.

For example, Cinema 4D can directly import DEMs and show them as rectangulated 2D + z surfaces.   They are effectively visualized in UTM but, once imported, addressing is rectangular. On the other hand, GPS measured tracks or and USGS maps, recorded in lat/long, are both imported and visualized as rectangular. GIS are necessary to get things in spatial order.

An objective of the investigation is kinetic 4D visualization with consistent georeferencing. Using a process, similar to the one on the following page, served to bring terrain related data into a degree of spatial consistency.

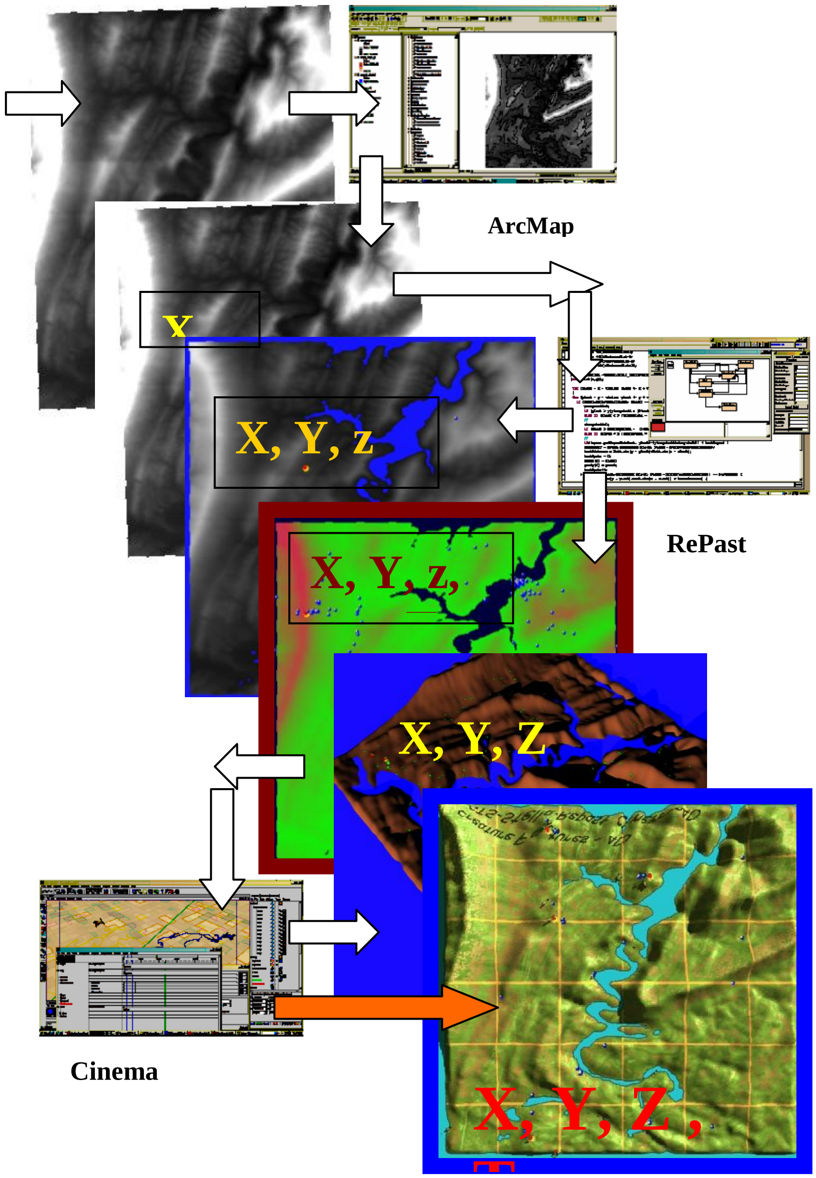


Figure 4-8 Terrain

ArcMap was used to re-project UTM 17N to lat/long NAD 27, and export them as either ASCII raster or Jpeg. The raster layer was exported by ArcMap as ASCII, and input to Repast, where it became an array (about 500X500) of Integer elevation objects ranging from 280 to 1700 feet. Each elevation object is programmatically available. The elevation was used to shade the map. ArcMap derivatives of elevation, for example, slope and aspect could have been added in a similar way. The Repast image of terrain in Figure is output as a JPEG file, and input into Cinema 4D as a relief object.

Lat. Long. NAD 27 USGS con and aerial photography were partially rectified by hand trial and error in Cinema4D. At this stage the terrain still has the same extent as when exported from ArcMap. However, Cinema 4D thinks it's a 500X500 rectangulated surface, subject to its own manipulations that include nothing of projection or other GIS rules. This was a loose procedure at best, but better than the alternatives.

Mobile Objects

Some Cinema 4D mobile objects are portrayed below. The gimble at top center represents their capacity to move in six dimensions, or change size in three dimensions. Objects are textured with raster fields, which can be dynamic and projected. So, Eulerian change can be represented on the surface of any object including the terrain. An object may consist of nested federated objects. Each acts partly independently of its parent and partly independently. A bee can flap its wings; a tank can rotate its turret, a swarm can roil. An object can have imbedded behaviors. A hog can exfoliate skin cells, or a tank can fire rounds, that are themselves objects. There are additional animation effects playing the roll of cartographic and symbolizing tools in mapping.

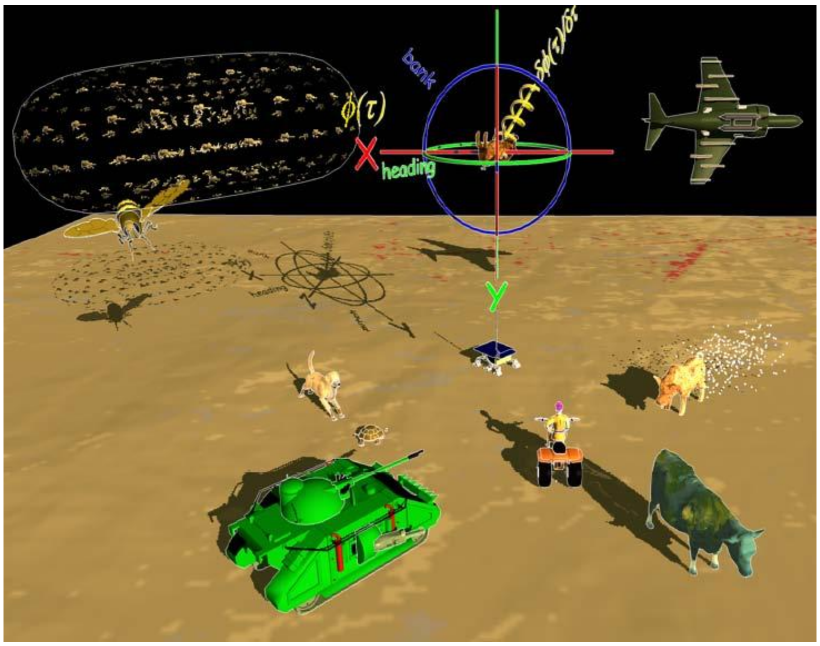


Figure 4-9: Mobile objects in Cinema4D.

Figure 4-10: Tomlinson Principle applied to 4D models.

Tomlinson’s principle is that two map layers may be spatially blended, if their objects and fields are referenced in the same x, y coordinate system. Cinema 4D models can be blended in four dimensions if their objects, fields, and behaviors reference the same 4D coordinate system. Above, the two lower models are blended in the upper model.

4.4. Modeling Agent Interaction and Display

An agent is associated with each mobile object of interest in a model. Dog agents and hog agents of one instance of a model are represented in the Cinema 4D visualization below. The model is staged on terrain. The terrain is actually a Space object containing an object for each cell in the terrain matrix. In this instance, terrain objects contain simple Integer objects representing elevation and color properties. During each RePast simulated time step, each agent has an opportunity to change position, or any of its other properties, or the open properties of any other object in the model. To make decisions, an agent may invoke any of the methods on any of the agents or space objects in the model, including other agents or the cells of the terrain.

Below, it is the turn of the hog on the upper left hill. That hog, let us call him Bob, can programmatically "see" everything in the model, the dogs, hogs and every cell of terrain. Bob makes decisions and then acts. The bottom of the figure contains the code that Bob uses. Any of Bob's separate actions can be recorded and Bob can have multiple tracks. Perhaps one of them is Bob's x, y, z position over time. After Bob, each of the rest of the agents has a turn. Bob's position track continues to build until RePast's run is done. Bob's recorded track can be imported into Cinema 4D as a spline.

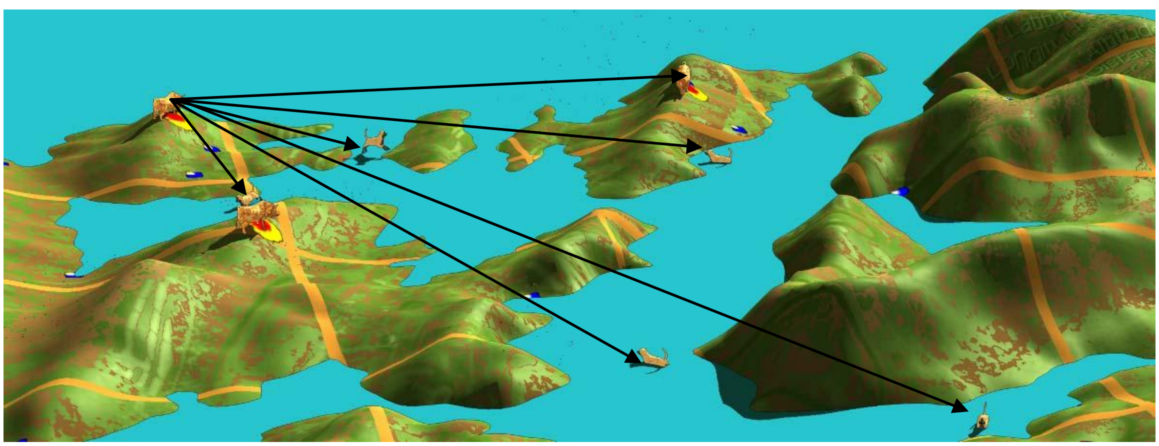


Figure 4-11: A hog's view.

```
public void moveToBestSpot()

        {int bestPlace = 0;

           int xLook, yLook;

         yLook = y;

           for (xLook = x - vision; xLook <= x + vision; xLook++)

           {for (yLook = y - vision; yLook <= y + vision; yLook++) {

            if (model.getAgentAt(xLook, yLook) != null&&xLook!=x&&yLook!=y){
```

```
bestSpots=0;
 bestPlace=10000;
     bestDistance=1;
     goodx[bestSpots]=xLook+2*(x-xLook);
     goody[bestSpots]=yLook+2*(y-yLook);
     bestSpots++;   }
 if (model.getAgentAt(xLook, yLook) == null){
   if ((space.getPlaceAt(xLook, yLook)) > bestPlace)
   {bestPlace = space.getPlaceAt(xLook, yLook);
     bestDistance = Math.abs(x - xLook)+Math.abs(y - yLook);
     bestSpots = 0;
     goodx[0] = xLook;
     goody[0] = yLook;
     bestSpots++;}
   else{ if ((space.getPlaceAt(xLook, yLook)) == bestPlace)
   {if (Math.abs(x - xLook)+Math.abs(x - xLook) > bestDistance)
     {bestDistance = Math.abs(x - xLook)+Math.abs(x - xLook);
       bestSpots = 0;
       goodx[0] = xLook;
       goody[0] = yLook;
       bestSpots++;}
     else if (Math.abs(x - xLook)+Math.abs(x - xLook) == bestDistance)
     goodx[bestSpots] = xLook;
       goody[bestSpots] = yLook bestSpots++;}};
```

Figure 4-12: JavaCode for predator-prey interaction.

The visual results appear in a RePast Display. In this case, dog are blue dots and hogs are red dots. The terrain elevation values are programmed. Each time step in the simulation can be displayed, recorded and made into a movie that can speed up or slow down the action. The quality of visualization, kinetic or static at this stage is good enough to judge the quality of the model that produced it. As a result, the model can be iteratively refined without going any further.

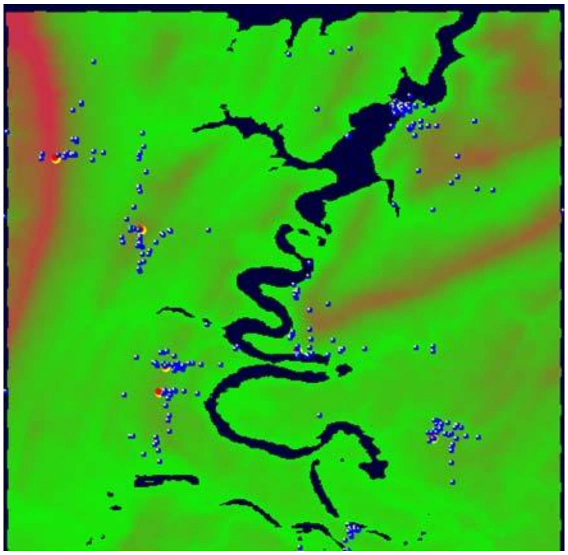


Figure 4-13: RePast display.

4.5. Animation, Choreography, and Visualization

On the way to 4D visualization, mobile objects on terrain can be represented as:

- 2D symbols on 2D terrain in RePast image displays
- 2D +t RePast symbols on 2D terrain in RePast rendered QuickTime movies
- 3D objects on 3D terrain in Cinema 4D image displays
- 3D + t objects on 3D terrain in Cinema 4D rendered QuickTime movies
- 4D objects on 4D terrain in choreographed Cinema 4D rendered QuickTime movies

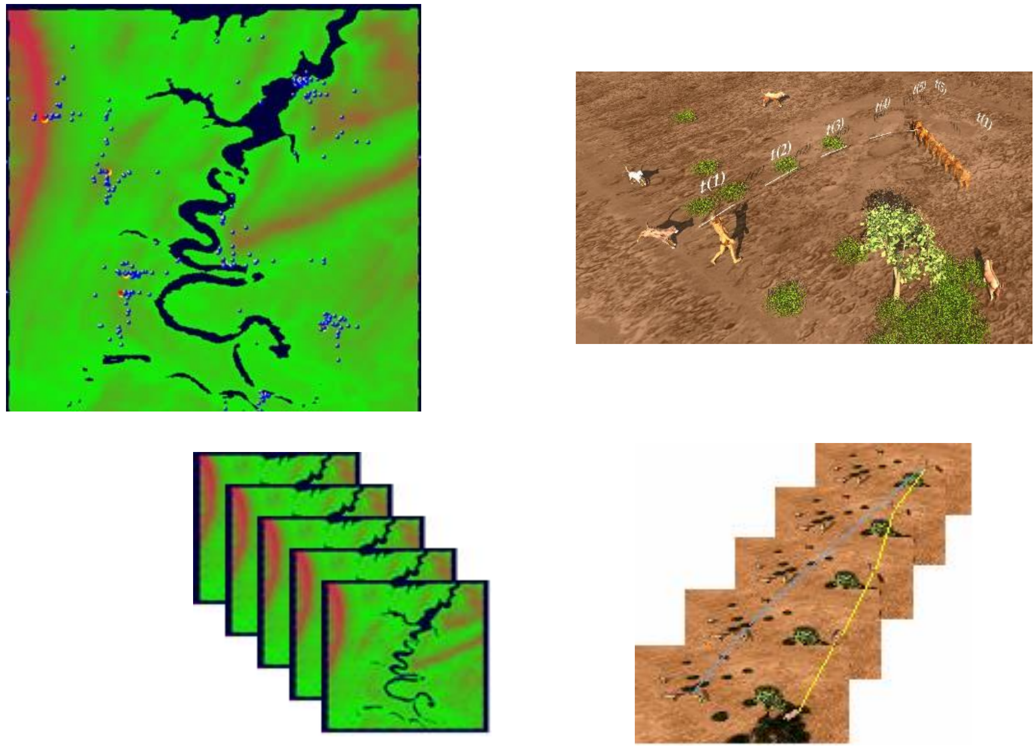


Figure 4-14: Mobile objects on terrain in RePast, Cinema4D, and QuickTime.

A sequence of static frames appears as five static maps. A close look will reveal that each is a little different from its predecessor and successor. You could pull out your calipers and measure the change. Were the positions connected in they would be tracks, a spatiotemporal construct and could be analyzed to represent the same entities and happenings in the actual phenomenon.

Animation

RePast is used to model basic behavior for animation: which might be sufficient. Cinema 4D is used to replace dot symbols with 3D objects, set tracks upon terrain, set the objects on the tracks, align objects along tracks, and control movement along the tracks.

Three alternatives are used to project 2D tracks onto a 2 ½ D surface to affect the appearance of terrain following. One is an ArcMap tool that pulls z-values from surfaces into point features. The second is modeled in RePast: the other by a Cinema 4D structural function. On balance Cinema 4D is easier to work with, once tracks, and terrain are co-rectified. Associating a track to a mobile object in Cinema 4D makes an object/track combination that is spatiotemporal. Initially, its temporal points are spread evenly across the temporal extent of the animation. Subsequently, the duration of a spline may be changed or any of its points moved in time.

Two dogs and a hog appear below. When the animation runs, the hog, and the dogs, move from point to point each animation time step.   During movement, an object's z axis is oriented along its spine to so as to appear to be following the track.

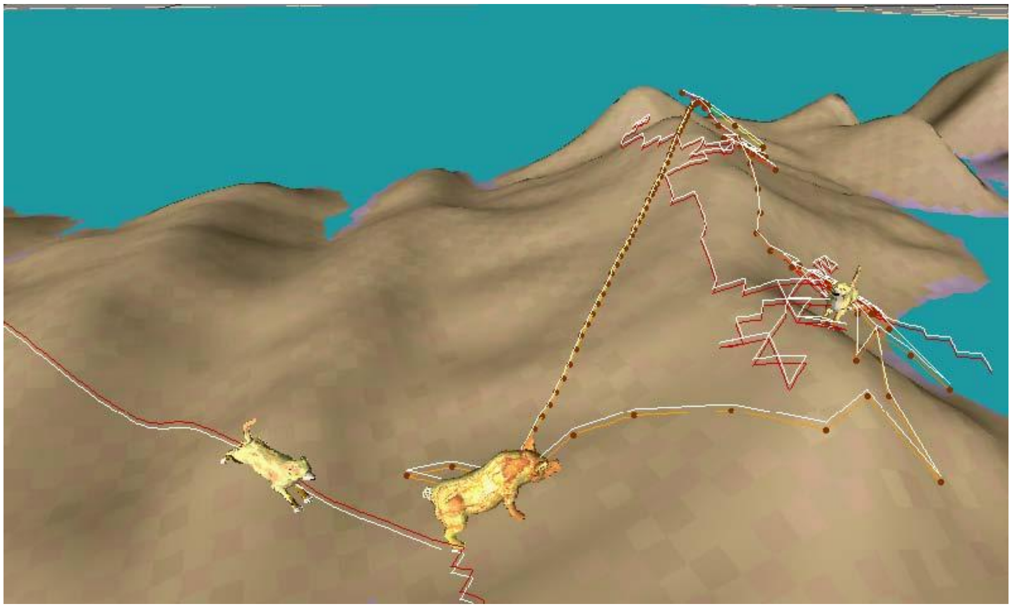


Figure 4-15: Model objects on simulated tracks.

4.6. Empirical and Simulation Based Modeling

States are connected by, in, and over time. The following two proto-equations underlie two different models of relationships between states.

4.6.1. The Observed State Difference Model

$\Delta Z_{t,t+1} = Z_{t+1} - Z_{t}$ *for each t*

If a state ***(Z)*** is observed and somehow recorded with perfect precision, accuracy and certainty at time **t,** and then again, at ***t+1,*** the change is simply the difference between them. Nothing need be known about the processes, events, or inputs causing the difference. All one has to do is observe the two states. Future states and states intermediate between the two are not addressed. Apprehension of the causes of change, based on the difference, can be inferred, calculated, analyzed, or visually apprehended, but is external to the model.

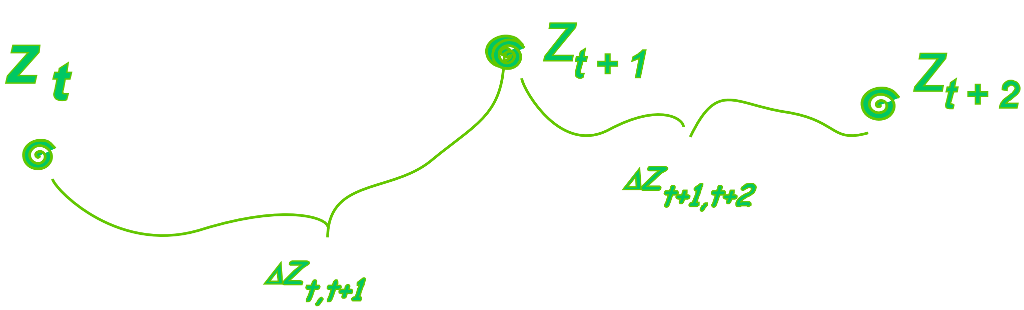


Figure 4-16: Difference model.

4.6.2. The Change Accrual Model:

$Zt+1 = f(Zt, It)$ *for each t*

where Zt is the domain state at time t, It is the set of inputs driving change, and f is the process that effects change. Here nature is changing from state to state continuously, driven by processes and inputs. If the processes and inputs are known perfectly, the model can proceed from the big bang to the Sun's collapse without the bother of observation of a real state. This is the model used in simulation to compute a future or intermediate state. Observed state can be used, but is not necessary.

The equation is incredibly compressed. To become a model, it has to be expanded for each entity type and instance, and for all of the forces that will influence change, expressed as functions, and all of the inputs that might join those entities and forces. These individual changes can be accrued and confected for each period to constitute a new state.

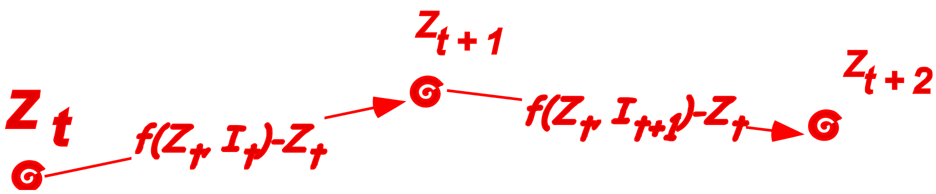


Figure 4-17: Accrual model.

The beginning location at point Zt is known as are the functions that act on Zt. The functions and inputs define a vector that points to Zt+1 and so on to Zt+2. In this version of the model Zt+1 is not necessary to get to Zt+2.

4.6.3. Combinations, Blends and Hybrids

Both models only approximate reality. They are computationally forced to use discrete sample times and time steps in simulation. In that sense they approach reality only as the time period approaches zero. One model is seldom used alone.

Dead Reckoning

For example, before the perfection of the seagoing clock, ships could only acquire longitude while within sight of land. These observations were plotted and the distances and bearings between them determined. From the differences a ship's pilot could analyze and make estimates of their progress into short term future, in effect supplementing observation and distance with a bit of change and accrual. Once out of sight of land, the crew let out a line tied to a drag anchor with a knot every mile or so. The knots were counted over a known time. Using compass headings and knowledge of currents and wind drift, they calculated a vector and added it to the last location. This was called dead reckoning, the first form of inertial guidance.

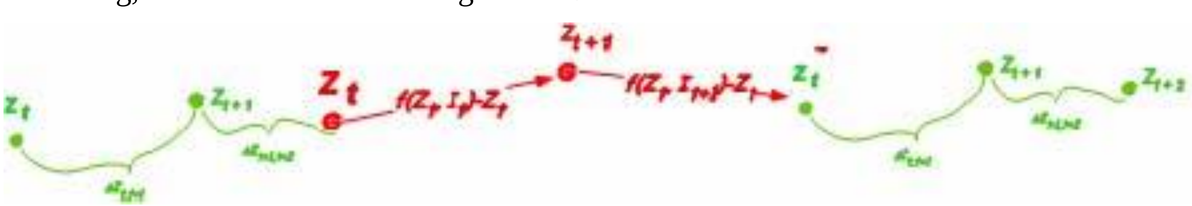


Figure 4-18: Combined difference and accrual models

Unfortunately, accrual models accrue error. With no observations to verify position, ships could get way off course. If land was finally sighted, and the observation was reliable, position was adjusted. The adjustment could be used to improve the quality of the dead reckoning model. However, suppose the observation is less reliable than dead reckoning: as in the time that America was mistaken for India. In such a case, it could be that the observation should be called into question.

User-centric geographical cosmologies, as a class, will use difference models, accrual models and all manner of combinations, blends and hybrids to represent past, present and future change. Our powers of sense, cognition, and action are similarly provisioned.

They must also be able to improve themselves, or at least be easily improved, as we are by experience. For example, observations used to improve the functions in the accrual model, or the functions in the accrual model used to extend the observation model to prediction and interpolation.

Without any measurements, constraints, natural law, familiarity, or a million other kinds of clues the creature could be anywhere with equal likelihood, a lost soul in a random 4D cosmos of possible spatiotemporal positions. Direct visual observations and sampled measurements are kinds of clues, good ones to be sure, but there are many other kinds and cognitive tools with which to use them.   We gather clues continuously, sort them out, and store them for the time they are needed. As a situation involving our interests arises, the clues are pulled out and assembled to sculpt a sub-cosmic past-present-future shape that distinguishes the more likely from the less. Like that of a sculptor, the process is likely to be spatially interesting and iterative.

Most of the time, observation and measurement are mixed with the other kinds of clues. There are exceptions: Einstein’s mind experiments were pure calculation while getting hit in head with a rock comes close to pure observation. Most phenomena are arranged between. Cognitively, we have no general problem with apprehending the mix.

Computational systems have yet to approach our general cognitive ability to use mixed clues as they are needed. However, specialized uses are numerous. For example, high-end vehicle navigation systems use both GPS and inertial guidance subsystems. So long as GPS signals are received, they are used. In large buildings, and urban or natural canyons, GPS signal can be lost. Inertial guidance is used from the last GPS signal acquired. Upon signal reacquisition, GPS resumes the primary function.

$\Delta Z_{t,t+1} = Z_{t+1} - Z_t$ *for each t* $Zt+1 = f(Zt, It)$ *for each t* $\Delta Z_{t,t+1} = Z_{t+1} - Z_t$

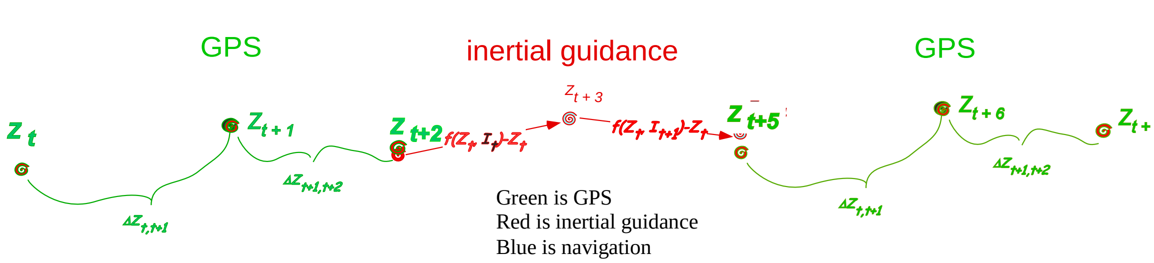


Figure 4-19: Vehicle Navigation.

High-end vehicle navigation systems use both GPS and inertial guidance subsystems. In large buildings, and urban or natural canyons, GPS signal can be lost. Inertial guidance is used from the last GPS signal acquired. Upon signal reacquisition, GPS resumes the primary function.

Avionics

High-speed navigational avionics use three models. Dynamic navigation projects forward to determine to determine where a craft should be at a future point in time. GPS periodically observes current position by observation, and inertial guidance accrues position using laser-gyros and accelerometers. The models are temporally synchronized, but their positioning cycles differ. GPS takes about a second to calculate a position, while inertial guidance recalculates every 1/64th of a second. Navigational checkpoints vary widely, but assume every 10 seconds for illustration.

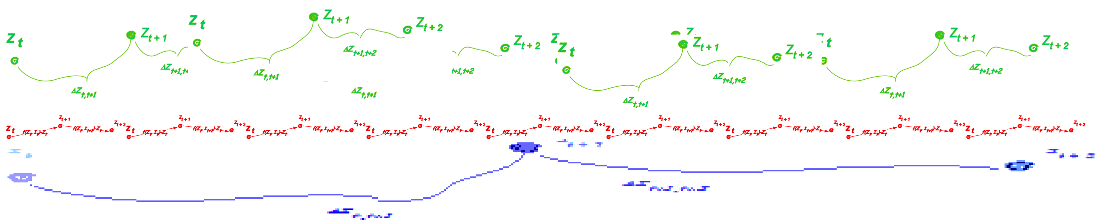


Figure 4-20: Hybrid Position Model.

These models are all input to a master model that determines positional differences and either resolves them or takes action to effect a resolution.

Geographic Science

Hybrid models in the geographic sciences use many technologies and computational schemes. Suppose we are tracking a wolf pack. The leaders have radio collars. For a time, pack location is available, but the pack moves out of range for a long period. So, where are they? We know that they are on the earth's surface in rough terrain. In the past, they have never moved more than six miles in a day, or more than two miles from water, unless in active pursuit of large game. We have digital topographical maps and a study of land cover, and elk and deer grazing patterns. When the radio signal goes away, we still have clues and computational tools to use. Streams can be buffered and terrain slope and aspect derived with ArcMap. Terrain following, line of sight and predator game interaction have been programmed using agent based modeling. Of course, a single radio signal based location would trump all these. On the other hand, the pack may be in range, but we want to predict where it will go, and we cannot measure the future. Going a bit further, we might not have any measurement capability at all, and the model would be pure computational speculation.

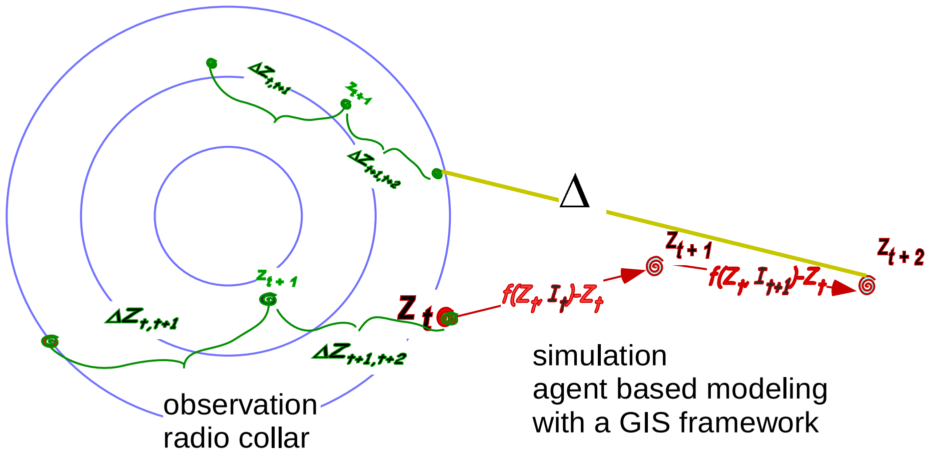


Figure 4-21: Wolf pack, off track.

When the pack returns within radio range, it is likely that it will not be where the simulation claims. The difference (Δ) is both error and an opportunity to improve the simulation. Dead reckoning and inertial guidance are reset by a direct observation and can be autocorrected for consistent difference effects: for example, a time linear error: perhaps caused by drift or gravitational anomaly.

A model consists of a computational federation of differential, accrual and other model types interacting in a manner that mediates and reconciles observable reality and human knowledge, insight, and imagination. A hybrid model is capable of mimicry of phenomenon entities, and of adaptation and refinement with experience. Below, a model arrangement is shown in relationship to a user-centric geographical cosmology.

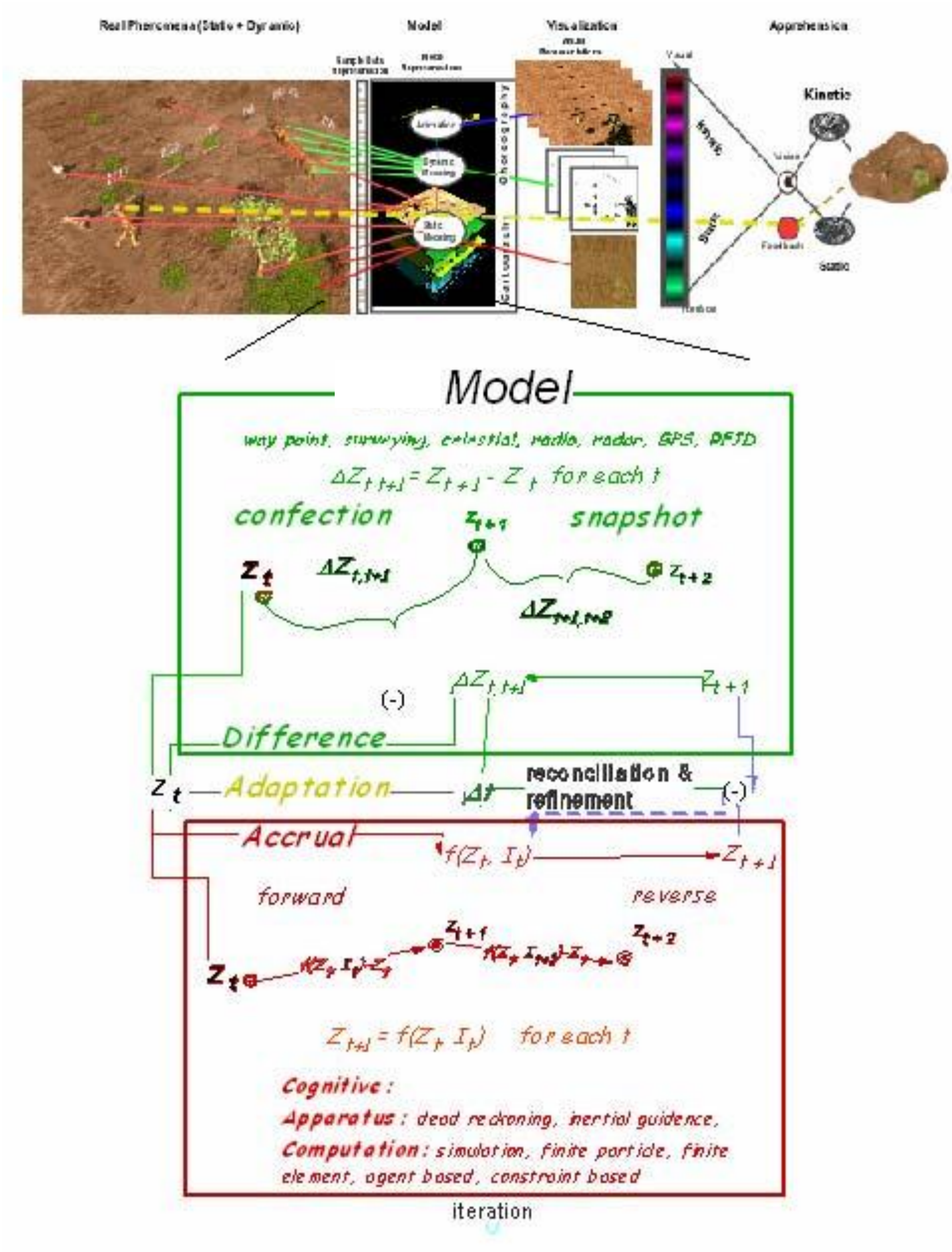


Figure 4-22: A hybrid modeling arrangement.

The green box shows difference model Z state plumbing in three forms, along with means of measuring entity states. The red box shows accrual model, δZ state plumbing, in three forms, along with ways of implementation. The red and green models exchange information. For example, the red model might control some the measurement activity of the green model, or; the differences in a value acquired by measurement and that computed for the same value by a simulation, might be used to refine or adapt the simulation itself.

Measured tracking data is straightforward to represent in its original x, y form. ArcMap, RePast, and Cinema 4D can all import ASCII points; so can Excel and Stella. Once the data is computationally accessible, x, y can be used to calculate Δ x, and Δ y. From there a velocity, direction vector for each step is easy to calculate, as is acceleration and change in heading. The x, y track is translated to a difference model of the track.

Below a canine track is translated to a scatter plot of change in velocity vs. change in heading. The second track is that of the dog's handler.

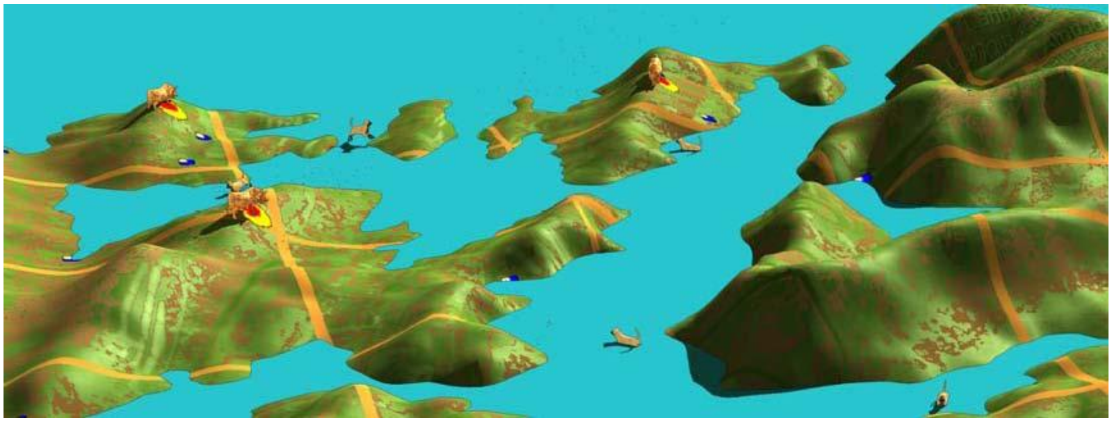


Figure 4-23: A derivative of velocity and direction.

Clues

The above shows a bit about how the dog behaved, but not why. To figure that out, we have to combine the clues known so far.

In real life, the dog was in trials to determine their ability to find-and-alert on desert tortoises. The terrain was flat and an acre in extent. The raw track data shows that the dog was generally influenced by its handler and stayed within the trial acre. Based on experience with dogs, dogs on sight move rapidly in a straight line; dogs on scent move at moderate speed with differential headings (change of direction); and dogs on bay-up have low velocity and high differential heading. The dog apparently used both scent and sight. The derivative scatter plot shows a possible upper limit on combined change in heading and velocity indication, indicating a Newtonian effect, and clustering, which is likely around repeated patterns. This dog is visualized in 4D in Kinetic Exhibit 5. The visualization, while far from finished, shows "bay-up" behavior on contact, and apparent repeated patterns.

The observed clues combine with speculation in heuristic form:

- When you do not know anything, check to see if the phenomenon is random.
- Anything with mass has to obey Newton.
- Land creatures stay very close the surface and follow terrain.
- Creatures are motivated by innate pursuit tempered by acquired discipline.
- Creatures interact by means of their senses.

A useful accrual based simulation would confect clues and speculation, and mimic observation in some way, perhaps visually, or even by a statistical measure. Here, we explore such a confection. The entities of interest are tracks carved by creatures in pursuit of the desert tortoise and then, the feral hog.

4.6.4. Comprehensive Model

A comprehensive model of animal behavior should consider as many parameters as needed to explain the behavior. GIS have limited capabilities in generating this kind of model, both for conceptual and technical reasons. Conceptually, an agent-based modeling approach provides the right framework for generating integrated models by embedding objects in their environments. Technically, current 4D visualization software provides useful insights, and visualization techniques to work around current limits in GIS and database technologies.

4.6.5. A Small Step Toward Hybrid Modeling

This exploration uses agent and dynamic modeling of canine movement, beginning with GPS referenced track data obtained in a tortoise recovery project in the Mojave Desert (Redlands Institute, 2003). An iterative approach to model development is used, where the model is refined in successive stages, adding new causal elements in every step, and comparing the result to information in the reference track.

Reference Track

We start with a model that visualizes the reference tracking data.

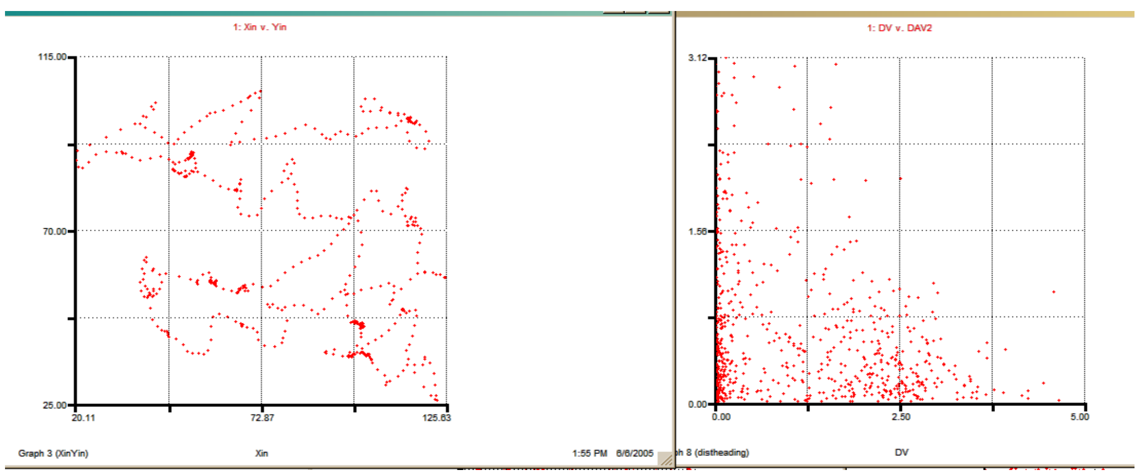


Figure 4-24: Scatter plot of Measured track and Δv/ Δηraḍ̃

GPS single dog track shown first as an x-y position (left) then as a differential scatter plot of the change in velocity vs. change in heading (radians)Δϖ/ Δη) for each time step in the track. The differential plot shows a full range of heading changes at low speeds, which diminishes with higher speeds suggesting that clues to the nature of different aspects of canine behavior can be found in the clusters.

Random Derivative Model

The first accrual model is Random Derivative that simulates creature incremental step movement as random with a speed limit. The simplest model of simulated dog behavior is one that would generate a random-walk track of the dog's movement. The only constraint in this model is that the dog moves with a maximum velocity of 5 meters per second. Each incremental move is extracted from normal distributions centered around 0-2.5-5 km/sec and -180 0 +180 degrees. The change in the output of the model is then visually compared with the reference track in order to test the hypothesis that dog's movements are somewhat random. Visually, output of the model (left panel) breaks down when we look at the respective scatter graphs (right panels). The model fails to capture the statistical pattern that seems to exist in the observed data.

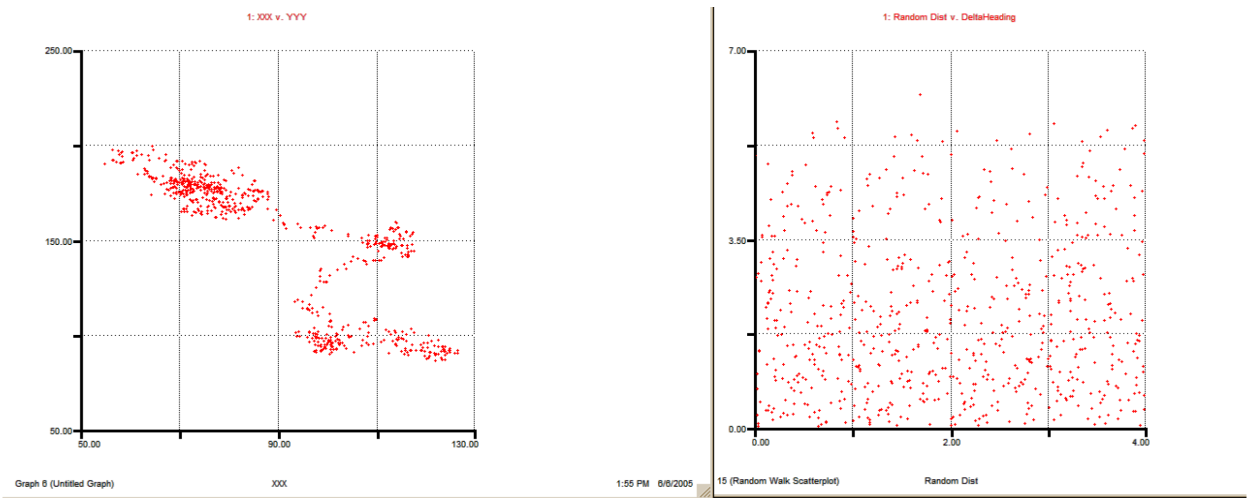


Figure 4-25: Stella scatter plot of random track and Δv/Δη(rad).

Note that there is some similarity in the position plot (left). The dog stays in the same territorial extent as the real dog. On the other hand, the differential plot is random, as one might expect. Some similarity between the two is suggested. This suggests that dog's behavior has a random component, but we need to refine the model to judge the relationship.

The Newtonian Model

Next, a Newtonian model that provides a better approximation by incorporating Newtonian rules about changes in velocity and direction.

Creatures are not random-walkers with unconstrained capabilities and an unlimited repertoire of movements. They have bodies with physical properties that both allow and constrain their movements. For example, the friction between feet and the ground is an important contributing factor in animal and human locomotion. On the other hand, the same friction makes it impossible for them to move at speeds higher than a certain limit. As another example, a dog can change its heading angle (direction of motion) at rates that depend on its speed and vice versa. The Newtonian model refines the random model by incorporating these physical constraints into account. Specifically, it takes account of the fact that the speed and heading at any given moment is a function of speed in the previous moment. These basic modifications to the model generate an output much more similar to the observed data in both the track and the statistical representation.

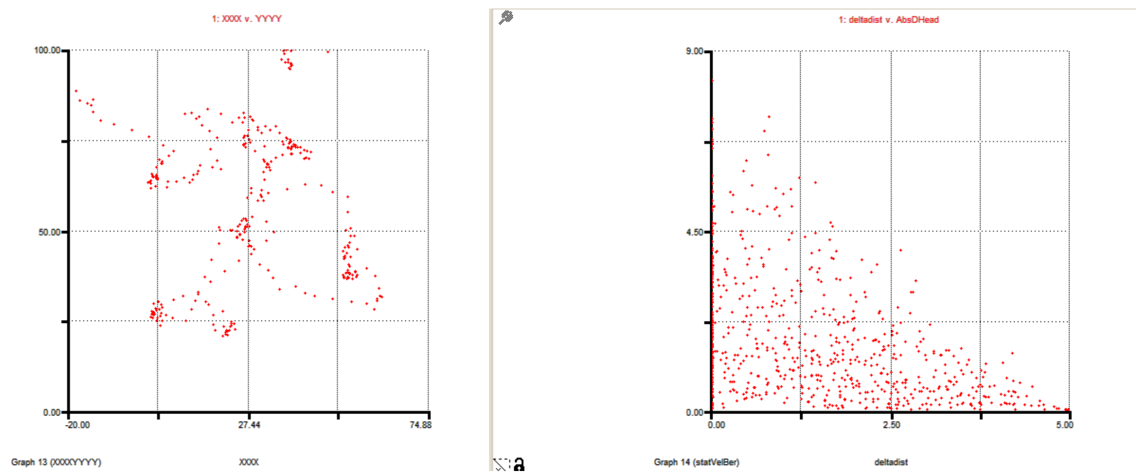


Figure 4-26: Stella Scatter Plot of Newtonian track and $\Delta v/\Delta\eta$(rad).

Newtonian constraints were added to random walk and the track started to look more like the reference track. The derivative scatter plot assumed the general shape of the reference track, but lacked clustering, probably because no imaginary tortoises were present.

4.7. Terrain, Interaction and Pursuit

Creatures function in diverse environments with various features such as temperatures, wind directions, and other features such as rivers, barriers, and fires. However, nothing is as ubiquitous as terrain and gravity. Movement over terrain occurs with pursuit, even if it is only grazing. Certain pursuits, such as find-and–alert and predator-prey, involve interaction with other creatures. Creatures are cognitive agents. That is, they perceive their environment and behave according to the impinging stimuli and the goals that they pursue at any given moment, and these affect their movements. Much observable creature behavior implements some form of pursuit. That is certainly true for dogs.

Interactive pursuit over terrain suggested a change of platform component and the scene itself. Terrain is difficult to model in Stella because it does not implement programmatic arrays and subscripting. Additionally, the dog trials were on flat ground, and the tortoises were stationary. So switches were made: Stella to RePast agent based modeling: the Las Vegas desert to the Raystown River gorge in South Central Pennsylvania: find-and–alert to predator–prey: and stationary tortoises to mobile hogs. Consequently, scale and extent changed. These trade-offs made the reference tracks unusable, and visual apprehension became the only judge of result quality.

The experiment group portrays predator-prey interactions with two agent types: dogs and hogs: effecting and displaying persistent behavioral rules on each step. The scene is repeated below.

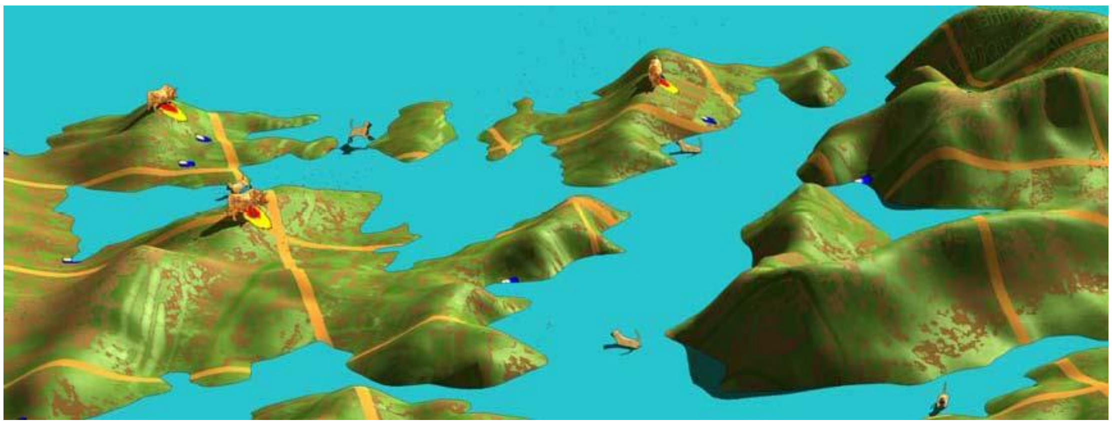


Figure 4-27: Model environment

A Repast interactive predator-prey model on Raystown terrain produced both dog and hog tracks, shown below as 2D and 3D, and 4D the Kinetic Exhibits of Group 3. The model rules were minimal. For example, the model did not use line of sight or scent for the dogs to locate hogs.

MODEL RULES:

Canine, for each dog:

> **Avoid position overlap with other dogs**
>
> **Find the closest Hog in Euclidian space.**
>
> **Move through adjacent cells toward the Hog over easiest terrain, slowing to 1/3 if in the water.**
>
> **Increase hill climbing energy on closure with the Hog.**

Porcine, each hog:

> **Follow terrain to high ground.**
>
> **Move away from close Dogs but prefer high ground if it is available.**

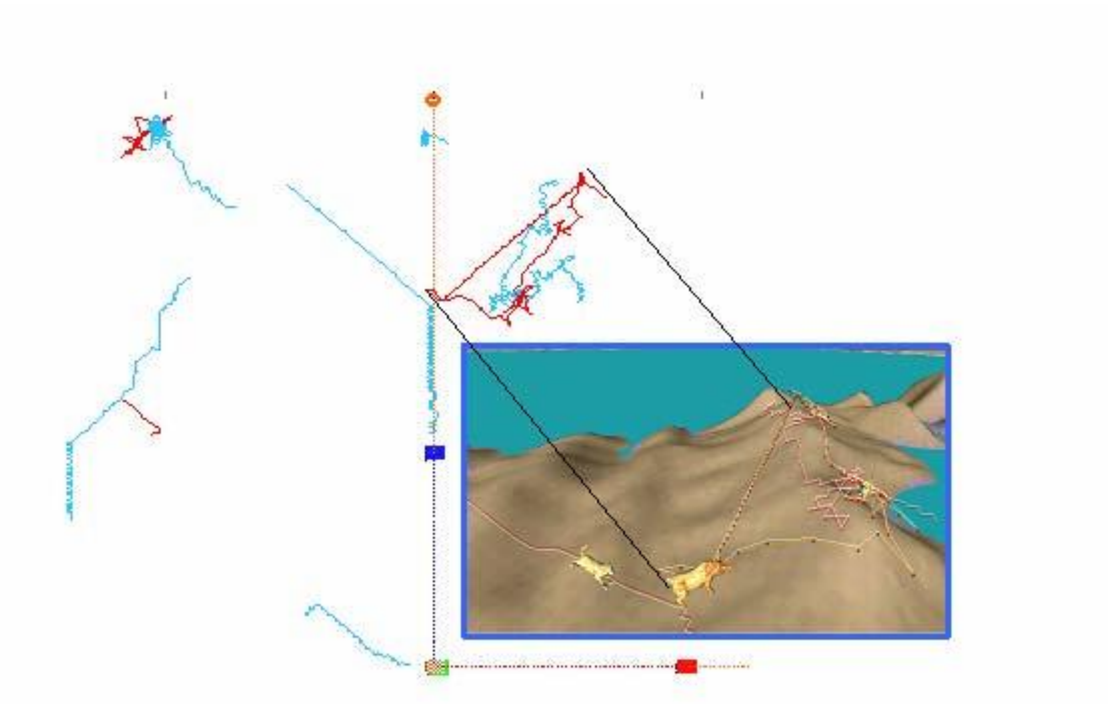


Figure 4-28: RePast drama on Raystown.

The resulting tracks and movement in the exhibits appear plausible, although the choreography could be much improved. The hogs move toward higher ground and the dogs move toward the hogs. Within these pursuits, both followed terrain. When engaged the hog tried to evade the dog, and the dog attempted to bay-up the hog.

4.8. The Sensory Model: Line of Sight and Scent Cone

The first figure below visualizes a dog's interaction with a tortoise scent cone. It captures some of what is known about the way dogs pursue by nose. All of the entities shown (tortoise, scent molecules, dog, dog track, bushes and surface) are objects. In addition, for the first time there is a "happening" entity: the wind that propels the scent molecules.

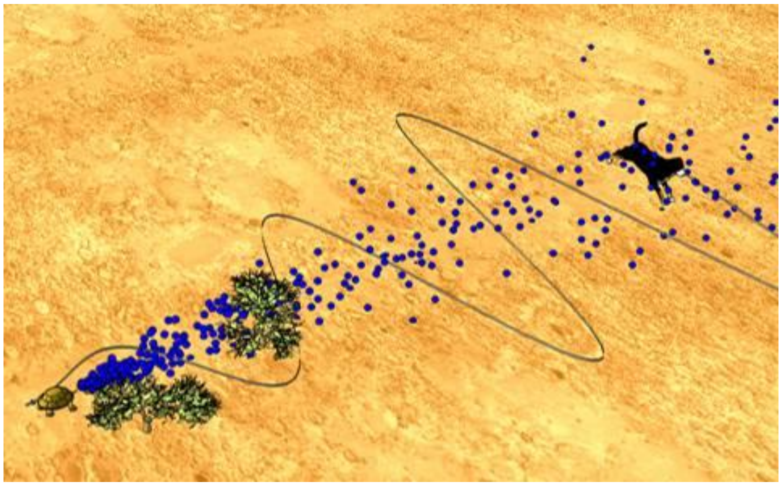


Figure 4-29: Tortoise scent cone.

Dogs have fifty times as many olfactory receptors as humans. Each is about a hundred times as discriminating. The dog brain apprehends scent like we do vision. A dog on air scent apprehends direction in a number of complementary ways. Smell works on molecules. Even a resting tortoise sloughs off thousands of skin cells per second. Some are picked up by air currents and disperse in a scent cone. Once in a scent cone, dogs seek to move toward its source by testing for the for the differential counts at the cone edges, and turning back to higher airborne cell density always pressing, but not moving directly, upwind. This produces a zig-zag pattern.

If a tortoise were suspended under a balloon at a thousand feet in a steady wind, the cone might actually be conical and very slim. However, chaos and turbulence would still cause some dispersion. A flying dog, once in such a scent cone, could easily follow it by seeing higher cell density.

No such luck: close to ground, cone cells move with their immediately local nano-winds. In turn the wind's molecules are driven along their immediate local nano-pressure gradients, caused, in part, by immediately local temperature gradients resulting in one of the most gentle of object collections, the scent cone; a phenomena so gossamer that only canines can put one to good use.

Some molecules are deposited and accumulate on vegetation or ground especially in moist conditions. There they accumulate over time, perhaps a stronger and less whimsical trail   A dog on ground scent snuffs the ground disturbing and lifting the scent to sniff level.

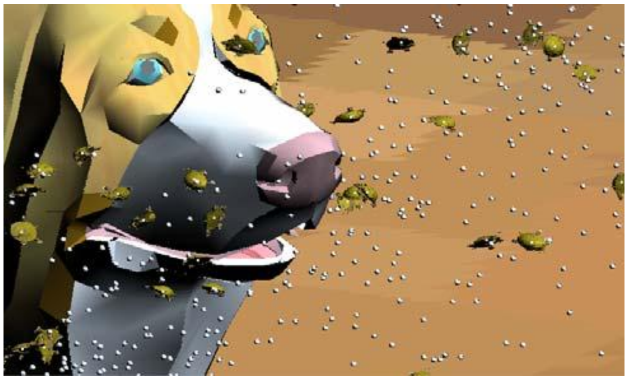


Figure 4-30: The nose knows.

The canine nose is moist inside and out. Molecules are ingested and adhere inside the passages and, especially, in the side flaps that flank them. The flaps are spread and molecules are collected. The flaps are then pinched shut as the sample is read then spread again for the molecules to be cleared. In this manner samples can taken at a rate faster than respiration. Once sampled, the tortoise molecules are apprehended in a manner as complex as the one in which we sort out colors.

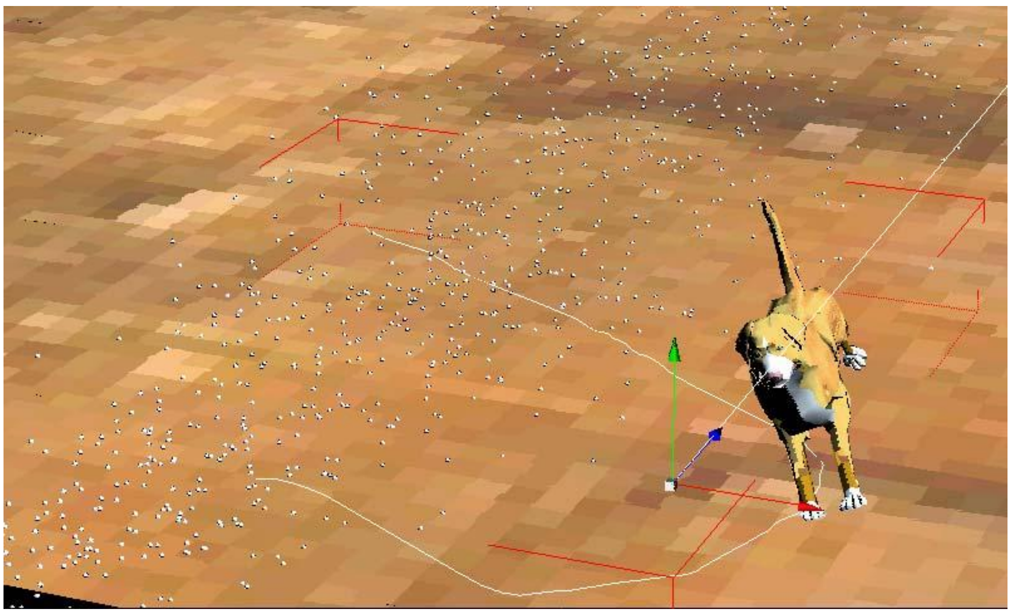


Figure 4-31: Visualization of dog, track and scent cone.

It is clear that scent cone visualization is far ahead of scent cone agent based modeling. Neither comes close to that needed for a dog agent to interact with a scent cone agent. First, we would need micro- and nano-climate models: then skin cell exfoliation models and canine olfactory models, and then…. Maybe, at some time in the future, we will stand on the shoulders of giants. Scent has probably been modeled as a continuous function of wind speed and direction and distance. We can at least do as well.

Figure 4-32: Line-of-sight visualization.

Line-of-sight is a straight line in three dimensions. The line, in this case passes through the eye of the ATV driver and a point on the tank. The tank is not in sight of the ATV because the line also passes through the ridge at a point between.

In a model, the line of sight, anchored by tank and ATV, would be systematically sampled for its x, y and z values at the sample points. The z value will be either below or above the terrain surface at x, y. If, after the vector has been sampled over its length between the two agents, no sample point is below the surface, there is a line of sight between point elements of the agents. That might be enough for some applications.

On the other hand agents can have dimensions and hence a cross section perpendicular to line of sight. Line of sight becomes a shaped cone of sight. Beyond that, line of sight, in a navigation context becomes remaining out of sight or in sight.

Cameras emulate vision in Cinema 4D as they do in all visualization software and in reality. They do line of sight as a matter of course. If I can see a target in terrain, I have line of sight. Virtual cameras were placed in both the virtual reconnaissance ATV and the virtual tank. The visualization was run twice: once with the ATV camera on and then with the tank camera on. The results appear in the two figures below and in the Kinetic Exhibits.

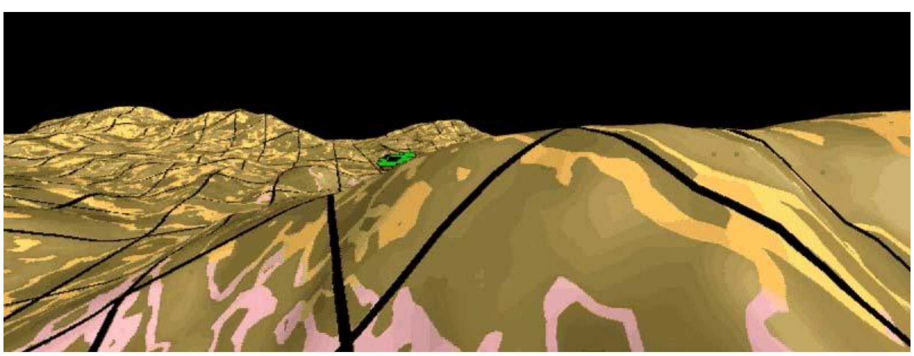


Figure 4-33: ATV line-of-sight.

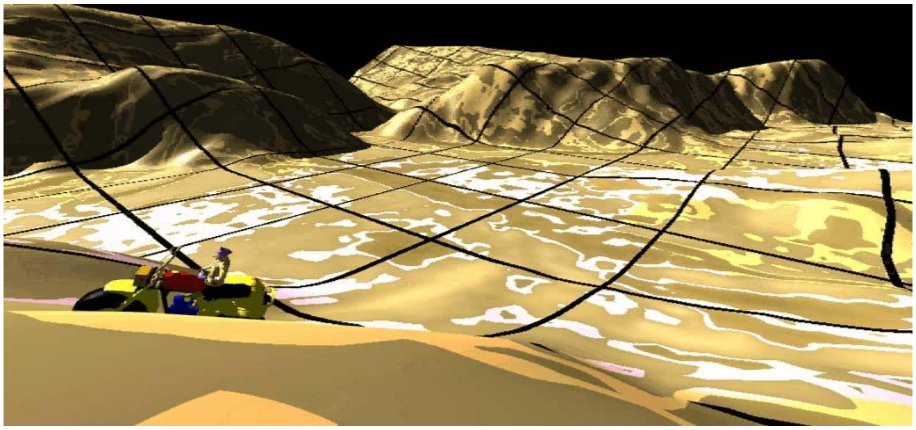


Figure 4-34: Tank line-of-sight.

Table 4-2: Several models have been modeled and visualized.

Model or Method	External Source	Model Type	Modeling Program	Visualization
Reference	**GPS Points**	**Differential**	**Stella**	**Cinema 4D**
Random Difference		**Accrual**	**Stella**	**Cinema 4D**
Newton		**Accrual**	**Stella**	**Cinema 4D**
Terrain and Pursuit		**Accrual**	**Repast**	**Cinema 4D**
Scent Cone		**On the Fly**		**Cinema 4D**
Line of Sight		**On the Fly**	**(Repast)**	**Cinema 4D**

The Scent Cone and Line-of-Sight methods differ from the models above in that they do not directly affect an accruing property. The distinction depends on choices about object programming structure. The essence is best explained by an example specific to agent based modeling and these experiments.

The accrued property in these models is (x, y) location. In each simulated time step, each agent, hog and dog, or tank and ATV, gets a computational shot at calculating their next move. They make the move by changing their own location. That new location becomes the base location for the following move. Location accrues as the sum of previous moves.

Line-of-Sight, if added to the model, is an input to the decision. The hog on the upper left can either see, or not see, other agents, and use that information in the decision, but it does not change any properties, on itself or on other agents. The same sequence would happen on the next step.

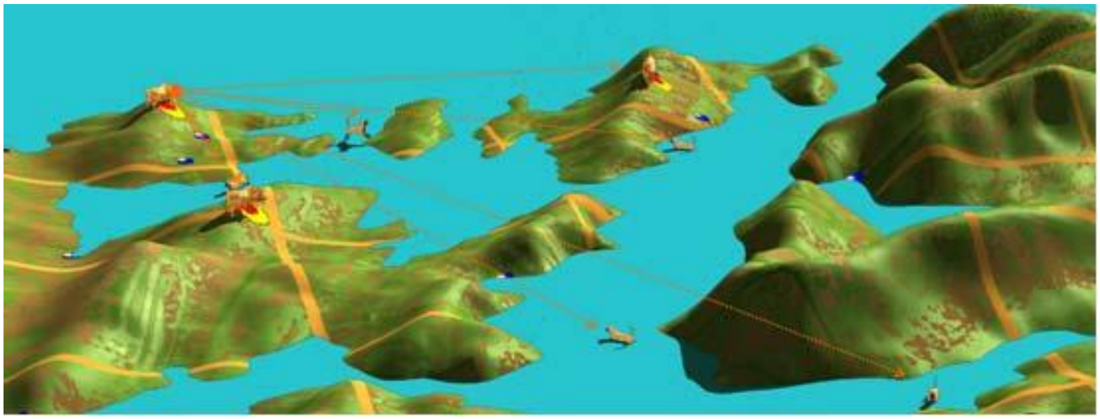


Figure 4-35: Line-of-sight on-the-fly.

These experiments have modeled and visualized several individual functions applied to creature and asset movement. It remains for these, and others to be used in concert. A general idea of a comprehensive model appears below. It reflects several qualities that haven't been explored in depth. For example, both the Next Move function and a GPS observation can change an agent's location. If they are different, how are they synchronized and reconciled?

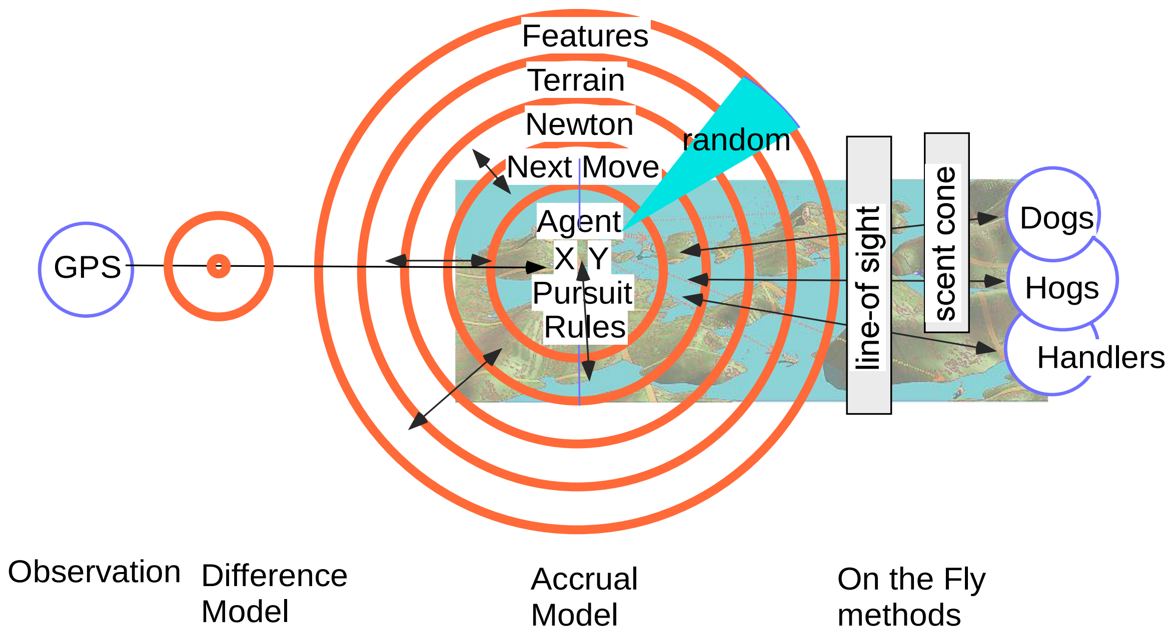


Figure 4-36: A Geographic federation.

5. Creature Features and Assets in Action: The Kinetic Exhibits

The Kinetic Exhibits accompany this report in digital form in Appendix B in a word document, entitled "Kinetic Exhibit 0booklet.doc", containing embedded .avi movies containing notes on, and movie versions of the exhibits. Each runs from fifteen seconds to a minute or so.

Experiments began using with GPS tracking data, recorded during canine find and alert trials conducted by the Redlands Institute. The trials tested the ability of dogs, trained to alert, but not catch, on find, to discover Desert Tortoises. A trial was first visualized as a static image in Cinema 4D. It appeared somewhat realistic. I discovered that I could bring dog GPS tracks through ArcMap and Excel and import them as splines in Cinema 4D. Temporally tuning the visualization produced mimicry of realistic motion. I used ArcMap to co-register a DEM of the terrain and the GPS tracks as unprojected lat/long, exported them and imported them into Cinema 4D as surface and spline. I then discovered two ways to project the spline onto a surface. As hoped, there was information in the motion the dogs clearly behaved according to their changing spatial relationship to the tortoises. Attempts to model that canine behavior followed, and through the effort a five level iterative residual scheme emerged. A cycle began as a notion that an application could be prototypically modeled and visualized followed by solving its associated new problems.

The solutions became both new problems and suggestions of new applications and lead to modeling and visualizations representing battlespace, The process was, in effect, a cyclical hack. It was confirmation that significant discovery can occur anywhere in an experiment cycle in any of the experiment types. Then discovery drives the process. This approach stands at the opposite end of the spectrum from the waterfall method, as continuous stands far from discrete with a slippery slope between. I offer only this investigation in its support, but hope that it indicates that some efforts are actually of this nature and would be drowned in a waterfallian structure.

5.1. Introduction

These experiments demonstrate prototype workarounds that extend and enhance GIS capabilities by drawing upon ideas, techniques and components from agent-based modeling, animation, visualization, cinema software, and solid terrain modeling. They show interactive behavior of mobile entities from dogs and hogs to electromagnetic fields on terrain.

Examples of change in location, orientation, shape, visual attributes, viewpoint, scale, and speed associated with dynamic terrain reasoning and semantics and the heuristics that emerge are presented. The models attempt properly geo-referenced agents, surfaces and features. They are presented as 4D animated movies assuming geographically oriented audiences.

The first group of five exhibits is a sample of matters, means, metrics, and parameters associated with animation of things. They illustrate the communication leverage in using elementary animation and kinetic visualization to represent and explain physical change. In three minutes, we walk through time on a Japanese Manimono scroll, look at dogs dimensionally, observe a bovine version of Lagrangian, Eulerian, Rotational, and Morphian change, apprehend a lava field advancing ever so slowly in visual contention with a slightly faster tortoise, and watch as dog moves hog out of cover, and over terrain into Newtonian spear range.

A second group of two exhibits uses actual data and combines simulation with animation to model the visualizations. The first shows tortoise find and alert dogs moving over terrain on GPS measured tracks. Canine behavior is clearly influenced by several factors. The second experiment converts the measured dog track into differences in velocity and heading. Using the original track as a reference, random and Newtonian accrual models use Stella simulation to mimic canine behavior with the intent of unifying the differential and accrual models at the visual level.

The next group of five exhibits introduces Agent Based Modeling (ABM) to model animal interaction in a predator prey application. A combination of (ABM) and animation effects dogs and hogs navigating on actual terrain, and then zeros in on a single encounter. The behavior is credible even at this elementary level of modeling. More importantly the visualization suggested improvements to the model.

The next two exhibits examined scent cones as an element of animal behavior. As before, the first step was to animate and visualize the interaction of airborne skin cells and dogs to apprehend the phenomena. Then a crude approximation of a scent cone was modeled and added to the behavior model which was then played on terrain.

The application was changed to search-and-destroy in the next two exhibits. Dogs and hogs became surveillance vehicles and tanks with slightly different models, scale was changed, terrain became desert. Again the behavior was credible and a new model line of sight feature was animated.

To this point, the things that changed were 3D objects. The next exhibit begins the process of changing polygon borders. In this case, Phoenix eats its suburbs on two and three dimensional surfaces.

5.2. Exhibit Summaries

Tables 5-1 through 5- 4 summarize types of change, dimensionality of entities, and software components of the federation.

Table 5-1 Types of Change.

\ Change type	Lagrangian		Rotarian	Morphian		Euler
Spatial Entity \	**appear disappear**	**Move in x,y,z**	**Move in h,p,r**	**Internal Structure**	**Shape/ size**	**Properties, attributes**
Raster Based						
Raster, cell, grid						X
Surface (z attribute)		X				X
Field, Patch, zone, region					X	X
Object Based						
Edge, Border					X	X
GIS Features, Networks Topologies, TINs	GIS only	GIS only			GIS Only	X
Shapes	X	X	X		X	X
Mobile Point	X	X				
Mobile Object	X	X	X		X	X
Compound	X	X	X	X	X	X
Object Field	X	X	X	X	X	X
Container of Objects	X	X	X		X	X
Camera		X	X		X	Focal Length

There are seventeen orange cells representing a type of change exhibited in this report. White X cells are possible but not exhibited. Grey cells do not make spatiotemporal sense.

Table 5-2: Dimensionality of Entities.

Spatial Dimension Temporal Visualization	2D = X,Y plane	2 1/2 D = X,Y + z = attribute surface	3D - X, Y, Z volume
0 static	X,Y	X,Y + z	X,Y,Z
t multiple snapshot	X,Y + t	X,Y + z + t	X,Y,Z + t
T animated sequence	X,Y + T	X,Y + z + T	X,Y,Z + T
T_{k-} animated sequence in kinetic range	X,Y + T_k	X,Y + z + T_k	X,Y,Z + T_k = 4D

Dimensionality ranges from 2D to 4D in 12 spatial and temporal combinations. Combinations used in this report are orange.

Table 5-3: Components Used.

Framework	Modeling	Animation	Visualization	Exhibits
		Cinema 4D	**Cinema 4D**	**0,1,2,3,4,11,16**
ArcMap		**Cinema 4D**	**Cinema 4D**	**5**
ArcMap		**Cinema 4D**	**Cinema 4D**	**6**
	Stella	**Cinema 4D**	**Cinema 4D**	**7**
	RePast		**RePast**	**8**
	RePast	**Cinema 4D**	**Cinema 4D**	**9**
ArcMap	**RePast**		**Cinema 4D**	**10**
ArcMap	**RePast**	**Cinema 4D**	**Cinema 4D**	**12,13,14,15,17**
ArcMap			**Cinema 4D**	**18**
Alternative Possible	**Combinations**			
ArcMap	**Stella**	**Cinema4D**	**Cinema 4D**	
	RePast	**Maya**	**RePast**	
	CellularAtomata		**ArcMap**	
	Finite Part/Elem		**ArcScene**	
			ArcExplorer	
			Google	

Data coupled systems in some ways similar to MObIE can be built by using a candidate from each of the four columns; some with more trouble than others.

Table 5-4: Geographic Federation.

Framework & Stage	Observation and Action	Animation & Choreography	Visualization
ArcGIS	Agent Based Modeling - Repast		RePast
	Dynamic Modeling -Stella		ArcMap ArcScene ArcExplorer
			Google
		Cinema4D	Cinema 4D
		3DS MAX ,Studio MAX ,Lightwave	3DS MAX ,Studio MAX ,Lightwave
	CellularAtomata – NetLogo		CellularAtomata – NetLogo
	Complex systems-Swarm		Complex systems-Swarm
	Maya	Maya	Maya
	Finite Element		
	Finite Particle		
	Computer Game Platform	Computer Game Platform	Computer Game Platform
	Massive	Massive	Massive

The top row arrows indicate flow of data types among platform component types. Smaller arrows, below, indicate flow among specific components used in the experiments. Alternative components appear as red.

5.3. Relationships among the Exhibits

In the figure immediately below, the experiments run inside the outer rim. They are grouped and colored according to their function, and the main component used in their implementation. As shown with connecting lines, some experiments feed forward to others.

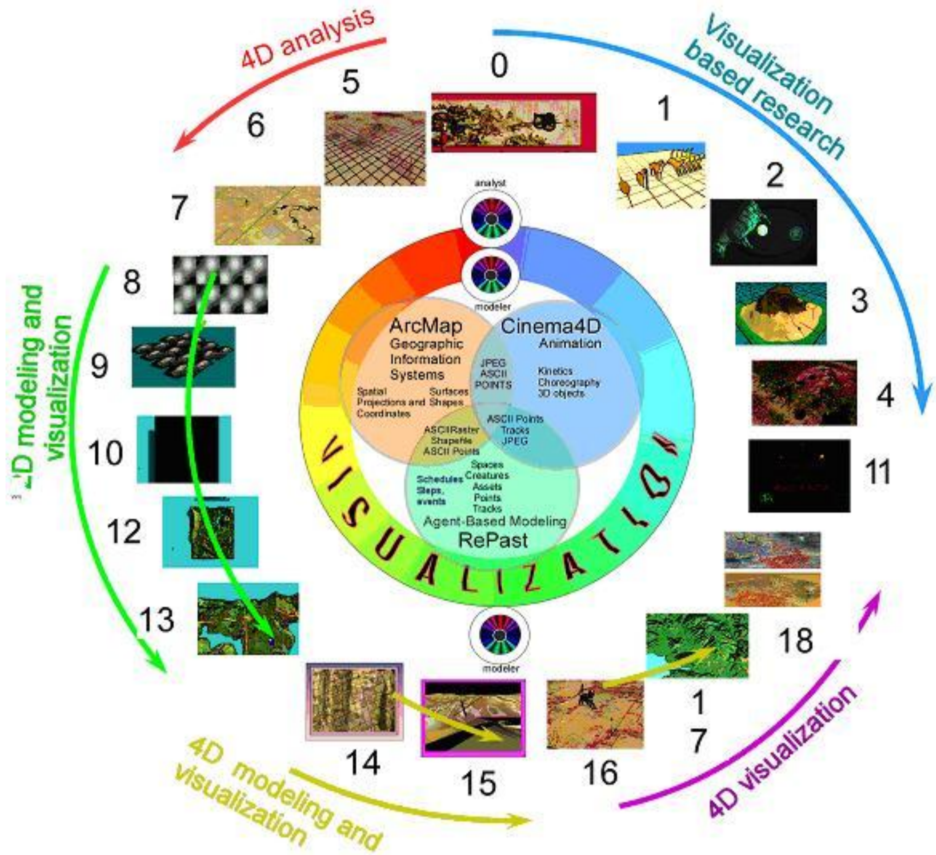


Figure 5-1: Exhibit Relationships

6. Summary: Means, Discoveries, Shortfall

This report has considered uses, shortfall and means as they relate to the representation of change in user-centric geographic cosmologies. In the long run, value is predicated on use. Many investigations set out to discover ways to move the current state of things toward intended uses by characterizing the shortfall and discovering means to bridge it.

6.1 The Primary Goal: Toward User-Centric Geographic Cosmologies

Here, the tool has been a test bed, itself experimental, and a set of experiments in which natural or imagined change is mimicked by computational means. Change representation is a small step; There are many more to make.

The means to address them are lurking in today's technology. So, this conclusion begins with the means discovered in the investigation, re-characterizes the shortfall in that light, and suggests possible means to bridge it.

6.1.1. Ways and Means

The principal new area of investigation is the application of persistent agent action, coupled with the means to choreograph and visualize the result in a properly geo-referenced framework.

- X,Y - X and Y dimensions in accordance with GIS standards of projections and coordinates. ArcMap excels.
- Z - Z as a dimension rather than an attribute. Cinema4D
- C - Application of rules and enforcement of constraints to geographic collections. ArcMap's geometry, topology and network models.
- I - Persistent action by individual things. RePast and Cinema4D
- A - Interaction among things. RePast

Together, the selected components, combined by coupling in MObIE address these requirements. Symbolized shorthand, albeit subjective, appears below.

GIS = (X,Y,z,t)* ((C*i*), (i i,j), (a(i,j),(j,k))) = X,Y,z,t, C,i, a
Repast = (x,y,z,T)* ((c*i*), (Ii,j), (A(i,j),(j,k))) = x ,y ,z, T,c,I,A
Cinema4D =(x,y,Z,T)* ((c*i*), (Ii,j), (a(i,j),(j,k))) = = x, y, Z,T,c,I, a
MObIE = GIS+Repast +Cinema4D =
(X,Y,Z,T)* ((C*i*), (Ii,j), (A(i,j),(j,k))) = X,Y,Z,T,C,I,A

MObIE had sufficient functionality to show that change occurring in geographic phenomena could be computationally represented in models and visualization. The kinds of change emerged partly from feedback from the experiments themselves, and partly from applied research.

6.1.2. Alternatives

The components and methods used in this federation have functional and market competitors stretching from massive game engines to partial differential equations, and from Pixar to Google. Those referenced below are but a small sample.

Cinema4D

Cinema4D has close CGI animation and visualization competitors: 3DMax, StudioMax, and Lightwave for example. Beyond that, advanced programs begin to take on modeling and simulation functions. Maya implements collision detection and Newtonian object behavior and interaction. Computer games use kinesics for intra-character movement and use player or multi-player input in real time. Some of the characters are avatars. Cockpit simulators incorporate representations of real environments and situations. In general however this genre is not connected to external data sources, other than that of the player's or pilot's, during the simulation or game. Military combat and vehicle navigation systems are, but the quality of visualization is reduced.

RePast

There is a close relationship between agent based modeling and work on cellular automata, complexity theory, finite element and particle analysis, event driven and real time systems, and object oriented systems in general. All are used to model and visualize dynamic phenomena with a mixture of discrete, individually identified objects representing real world objects and fine grained object arrays that represent real world continua. Algorithms fashioned, and programs written in one model can cross over to different application domains, with a bit of translation.

ArcMap

ArcMap has few close rivals at the geodatabase feature class geometric model level. The representations and models are proprietary, and the dues required to match thirty five years of house-to-house fighting are high. Most experimentation and research involves extension or workaround of ArcObjects with new tools or geoprocessing scripts. However, at the shapefile level, Geographic Exploration Systems combined with GPS portend a new face of GIS where the Geo in Geographic is the global Geo, with one unified electromagnetic computational coordinate system. By various means shape files, raster surfaces, images, points, polygons, tracks, and three-dimensional objects can be visualized on these global platforms. They accept the kinds of data that RePast and Cinema4D model, record and export.

6.1.3. Discovery

Tobler's Transitional Geography

In 1970 Waldo Tobler recast five existing cellular automata (CA) transitional models into geographic context. These models combined with Tobler's first law are the basis for most of today's GIS mainline raster operations and analysis.

At the time, because of computing power, or lack thereof, Tobler cautioned, ceterus parabus, that many of the factors, including automata location, shape and size, transition function and neighborhood had best not vary across space and time.

MultiCellular Automata, and Geographic Automata Systems emerged with subsequent relaxation of these stationarities, and faster computers. The cellular automata evolution set the stage for many forms of urban growth and epidemiology simulations. Today, agent based and other forms of dynamic modeling have removed nearly all of Tobler's constraints opening limitless application of geographic principles. Still, these are best understood as combinations and extensions of Tobler's equations.

Tomlinson's Principle

Tomlinson's principle is that two map layers may be spatially blended, if their objects and fields are referenced in the same x, y coordinate system. Cinema 4D models can be blended in four dimensions if their objects, fields, and behaviors reference the same 4D coordinate system. Above, the two lower models are blended in the upper model. The Cosmos is the model. Nobody, no thing, and no happening escapes space-time; there are no holes or overlaps in nature.

In this investigation, temporal reconciliation was not automatic. On the other hand, it wasn't difficult. ArcMap has no temporal dimension. Both RePast and Cinema4D were used in such a way that they only had to share the idea of a time step or tic. Spatiotemporal entities such as tracks were translated easily between environments. Translation by means of visualization to vision, kinetic apprehension and cognition entailed temporal scaling other straightforward metric choreography. In Cinema4D, one 4D model, no matter how rich, could be added to another as simply as adding another layer to a map: importing, or by copy and paste or: so long as they make the same space time assumptions. RePast requires that components of an added model be programmatically registered with a common scheduler.

Entity Classification – Phenomena

A conceptual representation evolved. It is, by no means, a proper classification taxonomy or ontology, but does position changing things relative to happenings and phenomena. Changing things are continuants. They persist in time. Continuants are entities, as are occurrents know as happenings. Entities are contained in a domain. In turn, the domain exists in a plenum created as a matter of interest in the imaginations of humans. The domain has four dimensions in space time. The phenomena play out in the real domain and the imaginary plenum.

6.1.4. Shortfall - Further Work

Extending modeling and visualization to four dimensions has a great deal to contribute to representation, apprehending, and reasoning about the dynamic world. However, the work here is a nano-step. Further work, follow up and new, is suggested.

- Synthesize difference (measured sample or observation) and accrual (dead reckoning or simulation) models. Adjust models in real time using dead reckoning
- Support or accommodation of GIS feature geometry. Within MObIE, point shapes, raster surfaces, textures and covers, tracks, simple and compound volumes and a single polygonal shape were used. Only tracks, surfaces and covers were shared between programs. Shape and raster files, and attribute tables are represented by RePast Java classes. There is no RePast class support for modern GIS feature geometry and other models. An assertion of this report is that, in a user-centric

geographic cosmology context, ArcGIS both benefit if they cooperate. In the long term, cooperating on features is better than cooperating on shapes.

- Conceptual application domain framework. Development of a framework in which models of specific domains can be recognized and developed. Computationally combining change and geography is not exactly new in nature, but it is recent in GIS. GIS has addressed the issue incrementally. Adding an agent model would be a big application enabling step. Business development and marketing depend on ways to connect potential uses with products and services, and vice versa. A framework would shape that process and the first stage of fitting specific application type to the model.
- Point and track ontology.
- Entity/change ontology.
- Increased temporal sophistication. RePast and Cinema 4D have facilities to express many of Worboys' occurrent entities within a continuent model. It is possible that RePast could be transformed into an occurrent model with continuant entities. Nature is both at once. Time will tell. The experiments used a step clock and tracks to generate persistent action: no events, processes, intervals and so on. New occurent oriented experiments can be conducted.
- Refinement of the principles of choreography. Principles of choreography will need to be introduced to represent levels of kinetic detail at which representations can be best apprehended and manipulated.
- Connection, integration and interoperation. Important connections have not been addressed in this report: for example, with other simulators, active databases and networks.
- Performance and scalability. The devil is in the details, and the matter is in the metrics.
- Simulation and measurement synthesis. Combine snapshot and continuous change are by filling the inter snapshot intervals with simulation.

6.2. Secondary Goals

The use of visualization in the experiments is, perhaps, more important than the resulting full motion video exhibits. It was the gist of proof of concept, requirements, design, prototyping, refinement, and production and product. The report merely provides context.

6.2.1. Uses of 2, 3, and 4D Visualization

I began the investigation with a heuristic, ***"Render unto 4D, that which is 4D"*** and ended using visualization to think about things in addition to making them visible. Visualization is both cause and effect. Most of the experiments began as an imaginary visualization. I would then fabricate an animated visual prototype in Cinema4D. I determined what inputs and modeling could produce visualization closer to the phenomena, and then refine it. Visualization was used to discover and illustrate principles used to prototype the next 4D applications. Time and again, words or snapshots were ineffective in describing a 4D principle. Without using 4D visualization, this investigation would have taken more time, and produced little value.

6.2.2. Presentation and Communication

Classification, vocabulary, and the kinetic exhibits are codependent. Viewing the kinetic exhibits alone without narration fails to associate visual apprehension with underlying principle or the words that go along with the images. Reading the report without viewing the exhibits doesn’t blend the visual into the proto-ontology. Neither, by itself is strong enough to meet the goals of the effort. Used together in presentation they have proven to be very effective.

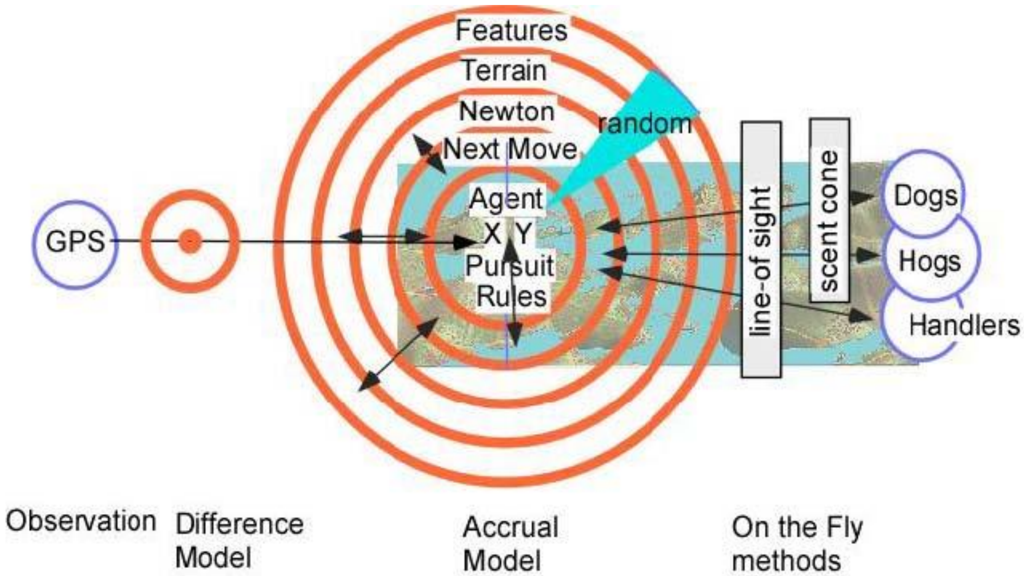
6.2.3. Heuristic, Experiment, and Discovery

This investigation was predicated upon four heuristics,

- “To cross a river you must feel for the next rock.” Deng Xiaoping.
- There is a large segment of a geographic message that cannot be apprehended using static data, algorithms and media.
- Consider 4D Maps to be an extension of 2D maps.
- 4D matters are best expressed in 4D.

7. Conclusion

Representation of change in the entities contained in a phenomenon is a many splendored thing. Change can appear in a simple property, or in complex behavior of a living creature. Change occurs on a stage, held inactive, and visualized in all of its kinetic vitality using the stage as spatial reference. Different phases of change in the same entity may need different models from time to time. Behaviors can consist of pursuit, constraint, natural law, man’s law, environmental and ecological factors, and uncertainty blended in a bouillabaisse class recipe. In an imaginary model of canine tracking as in Figure 7-1, multiple types of packages, models, classes, methods and visualizations would have to be federated



Platform: ArcMap, Repast, Cinema 4D,Stella,
Model types: Difference, Accrual, Observation, Agent
Entities: Things, Creatures, Assets, Tracks, Surfaces
Methods: Random, Newton, Terrain, Interaction, Scent, Line of Sight

Figure 7-1: Geographic Federation for Tracking.

On the other hand, this kind of model is adaptable to other close relatives. This report explored a minor subset of geographic federations in non-rigorous ways. No changes were made to the platform components. Multiple factors helped a lot in the process. ArcMap is a great workbench for surfaces, and projections, and there is a way to get them over to RePast. RePast comes with essential classes for building dynamic geographic models including tracking, and there a way to get tracks over to Cinema 4D. Once a basic model works well enough to produce feedback, incremental refinement is straightforward, if you know what the refinement is supposed to do. Layers can be blended, agent model classes added, and 4D animations combined, so long as the projection and coordinate system is consistent. At this prototypal level, the technical obstacles are subsumed by application related issues, that is, “What are you trying to represent?” Real applications and systems leading to user-centric geographic cosmologies will be much different in this regard.

Sifting out a consistent vocabulary and classification scheme for entities and functions was harder than a consistent coordinate system. While scientific modeling, animated films, computer games, Object Oriented Programming, CAD, GIS, ABM and GGI overlap ontologically and computationally, they use different words and spins for the same things. In effect, this “cultural” gap has, to a surprising degree, hindered the consilience of these technological and marketing domains.

Nonetheless, even at this level, some real value adding applications are probably within reach of this sort of federated system. Each platform component used here worked flawlessly. As always, the trick is to discover the applications, and funding.

REFERENCES

Bova, B. (2001). *The story of light*. Naperville, IL: Sourcebooks, Inc.

Brown, D. G., Riolo, R., Robinson, D. T., North, M., & Rand, W. (2005). Spatial process and data models: Toward integration of agent-based models and gis. *Journal of Geographical Systems, 7*(1), 25-47.

Chatwin, B. (1987). *The songlines*. New York: Viking Penguin.

Churchland, P. M. (1995). *The engine of reason, the seat of the soul*. Cambridge: Massachusetts Institute of Technology.

Egenhofer, M. J., Glasgow, J., Gunther, O., Herring, J. R., Peuquet, D. J. (1999). Progress in computational methods for representing geographical concepts. *International Journal of Geographical Information Science, 13*(8), 775-796.

Goodchild, M. (1998). *Rediscovering the World Through GIS: Prospects for a Second Age of Geographical Discovery*. Keynote paper presented at the ESRI GIS PlaNET '98 Conference, Lisbon, Portugal, September 9th - 11th.

Jaynes, J. (1978). The origin of consciousness in the breakdown of the bicameral mind.

Johansson, T. D. (2000). *Visualization in cybergeography: Reconsidering cartography's concept of visualization in current user-centric cybergeographic cosmologies* (No. 17). London: Center for Advanced Spatial Analysis (CASA).

Kemp, K. K. (1997a). Fields as a framework for integrating gis and environmental process models. Part 1: Representing spatial continuity. *Transactions of GIS, 1*(3), 219-234.

Kemp, K. K. (1998, September 17-19th). *Towards an ontology of fields.* Paper presented at the Third International Conference on GeoComputation, Bristol, UK.

Maguire, D. J., Batty, M., & Goodchild, M. F. (Eds.). (2005). *Gis, spatial analysis, and modeling*. Redlands, CA: ESRI Press.

Mark, D. M., Freska, C., Hirtle, S. C., Lloyd, R. and Tversky, B. (1999). Cognitive models of geographical space. *International Journal of Geographical Information Science, 13*(8), 747-774.

McEachren. (1995). How maps work. *The Guilford Press,* 425-438.

Mennis, J. L., Peuquet, D. J., Quian, L. (1999). A conceptual framework for incorporating cognitive principles into geographical database representation. *International Journal of Geographical Information Science, 14*(6), 501-520.

Morgan R. C., (1996). Inside the visible, Internet access, http://www.lot.at/EXTENS/selichar/engl/visible.htm

Peuquet, D. J. (2000). *Representations of space and time*. New York: Guilford.

Peuquet, D. J., Duan, Niu. (1995). An event-based spatio-temporal data model for geographic information systems. *International Journal of Geographical Information Science, 9*(1), 7-24.

Resnick, M. (1999). *Turtles, termites, and traffic jams: Explorations in massively parallel microworlds*. Cambridge, MA: MIT Press.

Shlain, L. (1991). *Art & physics*. New York: William Morrow & Co.

Tobler, Waldo (1979). "A Transformational View of Cartography", *The American* Tobler, Waldo (1979).*Cartographer*, VI, 2 (1979); 101-106.

Tobler, Waldo (1979)."Cellular Geography", in S. Gale, G. Olsson, eds., *Philosophy in Geography,* Riedel, Dortrecht, pp. 379-386.

Tufte, E. R. (1983). *The visual display of quantitative information*. Cheshire, CT: Graphics Press.

Tufte, E. R. (1997). *Visual explanations: Images and quantities, evidence and narrative*. Cheshire, CT: Graphics Press.

Wentz, E., Campbell, A.F., Houston, R. (2003). A comparison of two methods to create tracks of moving objects: Linear weighted distance and contrained random walk. *International Journal of Geographical Information Science, 17*(7), 623-645.

Wilson, E. O. (1998). *Consilience: The unity of knowledge*. New York: Alfred A. Knopf.

Worboys. (2004). Event-oriented approaches to geographic phenomena. *International Journal of Geographical Information Science, 19*(1), 1-28.

8. Digital Appendices

8.1. Appendix A

Quicktime movie of a University of Redlands/ESRI narrated colloquium recorded on January 9, 2007. Titled “Representation of change in GIS”, it recapitulates the computational and kinetic visual aspects of this report. Colloqium_Tony_Turner .mov

8.2. Appendix B:

Word document with embedded .avi movies entitled “Kinetic Exhibit 0booklet.doc” containing notes on, and movie versions of the exhibits.