Connecting Dots to Locate and Intercept Terrorist Operations and Operatives

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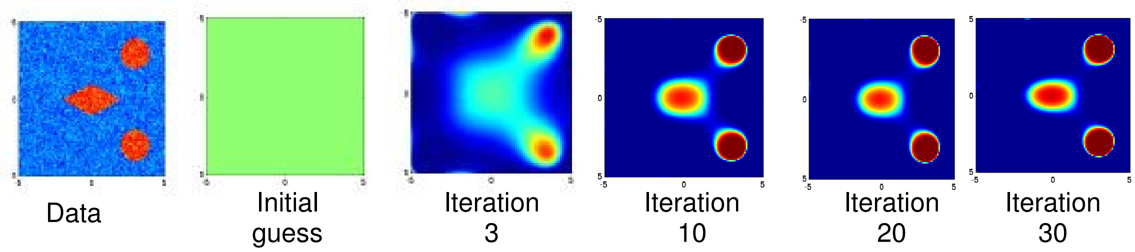
Our goal is to create a rather strange and non-classical kind of tool. It is not only for countering Jihad terrorism but may be applied to a variety of other problems where the patterns are skeletal or scantily clad at best, and often concealed under a cloak of mist. We want to build a map, inversely, from scattered and incomplete data points, analogous to the process of applying inverse methods to study acoustic or electromagnetic wave scattering in order to create an image where direct measurement is impossible for physical or other reasons. However, we are not concerned with photons or phonons as in subsurface imaging (e.g., ultrasound), but rather with relations and sets of objects that can be treated as the virtual points making up a large network. These are the dots, and the final image is not a picture but a pattern of relations that indicates something like an operational process – for example, a cooperating multi-cell terrorist plan to blow up airplanes in flight or trains in a subway system. However, there is a conceptual unity between the methods.



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The abstract inverse model may be a common core for making this new kind of map, but all the behavioral functions are different, because we are not working with Maxwell or Helmholz equations describing wave functions in a defined medium (air, glass, earth, flesh) but some initially unclear and fuzzy rules about how the elements in the relational maps, the objects that are people, cells of people, operational plans, travel itineraries, financial transactions, can occur. This is where we are, from the outset, still in a very speculative stage of thinking; perhaps by describing a few sturdy threads of investigation there emerges solid ground on which to walk.

Let me begin by making some type of analogy to the use of a survey map. We want to create a map that can be bent, folded, shaken, and otherwise warped from time to time as part of the procedure for using that map to find our way around. It is as if we were to take out an Ordnance Survey map and, instead of "reading" it by holding it in our hands, we were to mold it to the surface of the earth beneath in order to find out where we are and how to get to some destination.

This is a very different way of using maps which are customarily meant to be fixed in shape, retaining their internal geometry, and very accurate in scale. You don't bend, stretch or roll up your highway map in order to find your way from Paris to Lyon, but in this case we are aiming to have a map that can be reshaped and morphed as we move it across a variety of possible unknown terrains in the hopes that we will get a noticeably good fit and then be able to say, "Here we are and this is some kind of valley that resembles the Loire."

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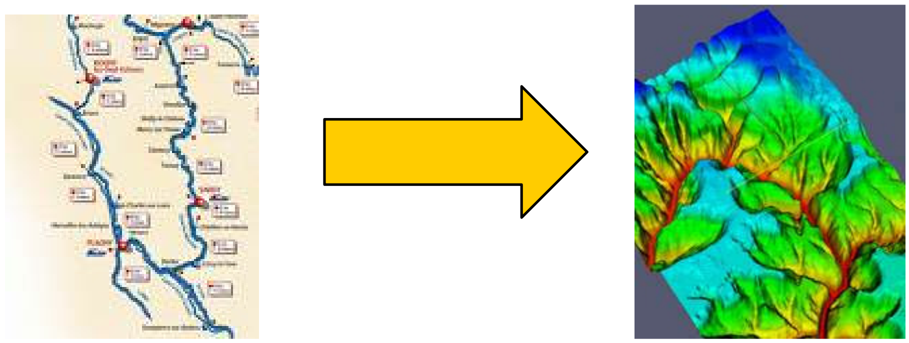

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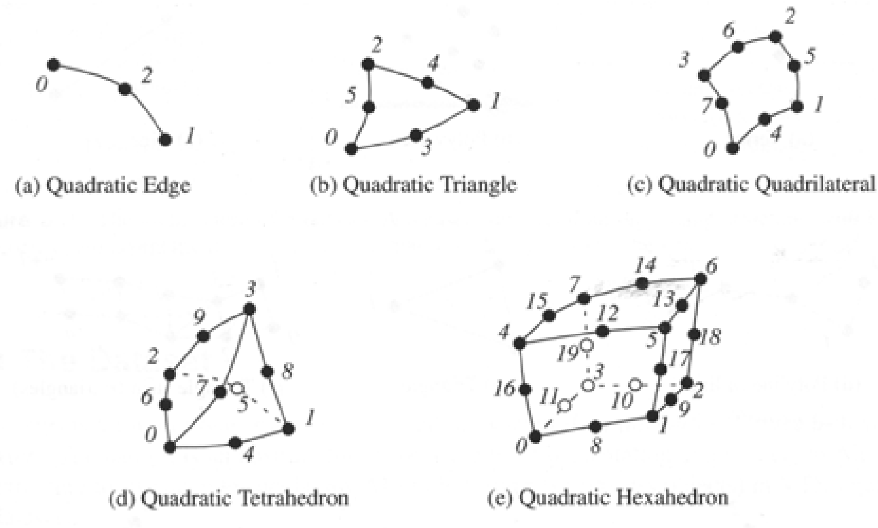
Consider this strange map not as a static map but as a deliberate and perpetual approximation. In fact, by assumption we know it will never be exact. We can eventually get it to fit with a type of terrain that we do recognize because we have either seen that terrain before or it resembles something we have seen closely enough to be worthy of saying, "Aha! we have been here before." A virtual surface, we have a topography that can serve as a guide through a terra incognito, but it is not one populated by 3D physical features. Instead there is a landscape of relations and patterns of relations between objects. The objects in the contextual space of terrorist operations may include cells, or individuals, or sensed physical concentrations of a chemical, a pathogen, a form of radiation. They may include sequences of actions that are treated as objects – for instance, a phone call after a set of internet exchanges and then followed by a trip or the mailing of a package. Ultimately in the design of the "map" we are determining what features (objects, relations) we intend to represent, and what are the scales, and the positions within a coordinate system, but it is hardly as simple as a classical map with an absolute coordinate system and fixed locations for each object in that map. From the outset we very likely do not know enough about the data coming to us, the mapmaker, from both human and sensor sources. In fact, if we did possess sufficient knowledge about the objects and relations, then most likely we would have a clear picture and not be struggling to create an adaptive and flexible representation scheme in the first place. Moreover, we have to deal with people trying to outdo and confuse the mapmakers. It is a little bit like working through an iteration process and having someone constantly juggle the numbers on a few of the parameters by unknown degrees. Are you still heading toward a convergence or you going askew?

While in this analogy with maps and the crude representations shown above we are tempted to think about 2D or 3D surfaces we are really faced with a higher dimensionality that depends upon the attributes we want to consider within these patterns. Some of these objects are collections, such as groups of agents and the processes undertaken by the agents. Part of the challenge in using ("reading") the map is that membership in different sets can change, and we are often only making estimates about the set to which a given object (actor, agent, event) should belong. We are faced with a challenge that while sharing similarity with some of the methods employed for volume separation and image recognition (e.g., digital Morse theory, isosurface extraction, Spider Web techniques), [2] there are no uniform primitives of the sort used in computerized tomography for instance. Or rather, we have not yet determined what are these primitives. They may be within reach because of the vast amount of data and conclusions about how people in small groups operate, the constraints in how processes like a terrorist operation can be conducted, but the fact remains that even when we have to some satisfaction determined that we have identified

[2] Cox, J., Karron, D. B., Ferdous, N., "Digital Morse Theory for scalar volume data" (preprint)

the n most common or most likely configurations, we know that innovations are being pursued to conceal and encrypt and to invent alternatives that will not be detected and identified.



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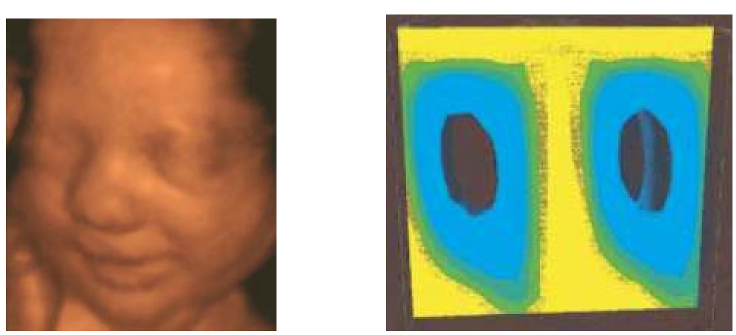
Tangible Targets Make for Better Practice

To begin with, we create a workspace that can be a tangible, malleable subject for dialogue and building an understanding by example, rather than trying to work totally in the abstract. Since we are focused upon a concrete problem of counterterrorism, we will use as a workspace a very realistic, in fact an exactly real scenario, that of CBRNE threats directed at mass transportation. We will attempt to work from the tangible real-world scenarios that have and may exist, backwards, inversely, toward the construction of a methodology for building inverse relational maps (IRMs) in the abstract which can then be used to generate massive numbers of possible fits against an ever-changing dynamic and incomplete landscape of observables and inferences. When we find likely fits of our flexible, stretchable maps to landscapes that are recorded as patterns that are with high probability close to known historical scenarios, or very well-accepted and rigorously tested models of human behavior, then we will have accomplished in the domain of terrorist modeling something that is analogous to transmitting an array of photons across a submicron wafer surface or into a dense medium and receiving a picture that resembles a known artifact like a smiling fetus or a hidden tunnel.



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We have chosen to concentrate lately upon two types of threat:

- <u>biological and natural</u> – a pandemic-potential situation such as posed by a human-transmissible H5N1 influenza virus (avian flu)

- chemical (explosive) and intentional – conventional and multi-compound liquid explosives (e.g., HMTD and TATP [3])

The threat scenarios are actually closer to each other than may appear at first or second glance. Both involve from 1..m "cells" (c_i), each consisting of 1..n of operative agents (p_i). There are indeterminate relations between the cells (R_j, defined by (c_i R c_{i+e})) and between agents who may have both intracellular (R_k, defined by (p_k R p_{k+e})) and extracellular relations (R_k, defined by ($p_{k(ci)}$ R $p_{k+e(ci)}$)). Naturally there are differences, the most obvious being in terms of control and "cybernetic" relations that govern the actions of individual agents and cells as collective wholes. Our point here is that a pandemic virus can be disseminated by a number of cells consisting of wild geese and ducks, passengers in a train or airplane or shoppers in a mall, and terrorist actions can and are disseminated by cells of terrorists and their support network (both active and passive) in the population, with some common features in the dynamical structures and relations that can exist between the cells, the agents, and the kinds of processes that can occur in such networks.

Common to both scenarios and a motivating force in our goal to achieve some type of practical modeling tools (i.e., computationally useful map generators and fitters) is the use of physical sensors, detectors, and trackers for finding and verifying the agents and the cells. Ultimately we are looking for a certain class of relation R_q that may be intracellular or extracellular but in any case it is an identifier, like a feature on a topographic map, that tells us with a strong probability value about an event in process. Distribution of infectious agents by birds, dogs or humans, or distribution of explosives – or their component sets (e.g., specific acetones, acids and peroxides); either will be a feature in the map-fitting process we are trying to abstract.

Once we can build up a set of relations such as an R_q that is discernable, and for which there is evidence of reproducibility, or shall we say, repeatability in both natural and manmade operations, then we have the beginning of some building blocks for the "internal physics" of our inverse engine. This is the equivalent to the Maxwell/Helmholz equations that govern physical wave scattering. This is what we can use to decide, when we have some "dots" on our evolving map of operations and relations detected and observed through not only sensor systems but from human intelligence and inference, how the dots can move, how they can connect. Without this basic "virtual physics" we cannot proceed. But with it, and with sufficient data (a lot of scattered points, not of light but of events including people, movement, communications, purchases, transactions), we can begin to form rough shapes in our relational space. And these rough shapes are to which we want to apply the inverse methods that have been used in optics and acoustics, such as DOT (diffusion optical tomography) and the use of level set models, so that we can see if some of the shapes resemble ones we have seen before, shapes that represent actions by a group of agents or cells, for instance, in spreading a virus or in planting bombs.

In our approach we have spent an increasingly large percentage of time and effort studying how to refine and perfect the sensing side of the equation, the data collection that is essential in order to have something to put into the inverse map generation equations. This has been as necessary as it has been in ultrasound technology development, for instance, to refine crystal transducers that will can be used reliably in order that the signal processing can have worthy sense data. What has made the task of sensor design additionally complicated is that there are important issues of deployment – network design and configuration from the standpoint of where and how to use sensors such as microcantilevers or SAW (surface acoustic wave) or RPAS (reverse photoacoustic spectroscopy), and also system integration from the standpoint of using any of this

[3] hexamethylene triperoxide diamine and (tri)acetone (tri)peroxide

technology in the everyday world of human beings - air passengers, subway riders, stadium audiences, all with issues of movement, privacy, and economics entering as factors.

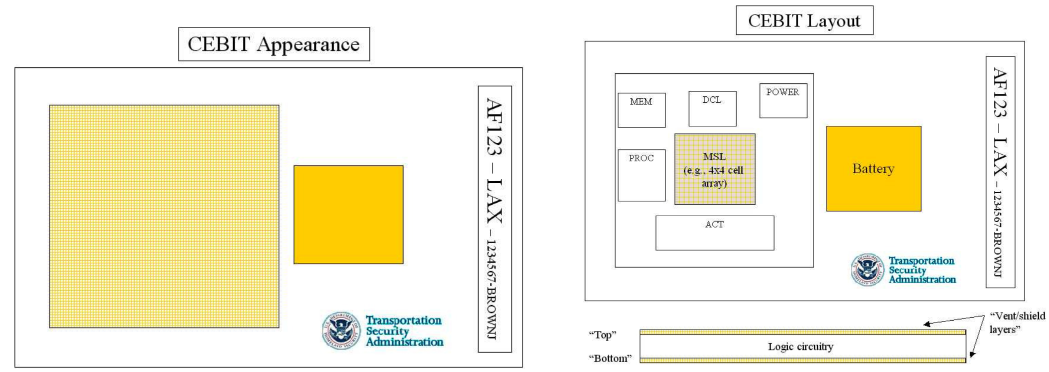
The Sensor Matrix and the Backdrop for Building Inverse Relational Maps

The recent events in the United Kingdom that could easily have led to multiple in-flight suicide terrorist attacks are indicative of the scope of threats facing the entire commercial air traffic world as well as many other modes of public transportation and assembly. The variety of novel, accessible, and concealable forms of both liquid and solid explosives (including but not limited to HMTD, TATP and more conventional TNT, RDX and PETN (C4) compounds) offers an almost irresistible opportunity for terrorists of all types and motives to create devastation in mass transportation and situations of large public gathering. The threats are not only in the highly vulnerable settings of airplanes in flight.

While many advances have been made toward development of detection technology for use in airports, the world is now more vulnerable than ever due to three principal factors: the increased numbers and motivational forces in terrorist networks worldwide,, due in significant part to the Iraq war and prolonged hostilities therein, the increased levels of sophistication and innovation among terrorists, and the increased availability of both supplies and communication tools, not the least of which is through broadband and wireless internet. The logical extension of centralized inspection systems and even measures such as the curtailment of carry-on baggage types, in the hopes of reaching a level of security that provides truly reliable security, is simply not feasible from the standpoints of engineering, technology, economics or social structures. A different approach is necessary, and such solutions exist today and can be implemented in the near future.

One pragmatic solution incorporates a particular, discrete smart card, less than the size of a credit card, that can be used to detect multiple and necessary, critical ingredients of a large variety of professional and home-made explosives, including such ingredients that are being carried or stored in advance of an attack such as on an airplane, train or bus, or inside a café or marketplace. The projected reliability of the architecture, on the basis of prior experiments and field tests, is very high, with virtually no false negatives and very low false positives because of the emphasis upon detection and tracking of not only one specific compound but a combination of agents within a specific volume of space such as a suitcase or knapsack. The ergonomics and operational cost is virtually nil and will be shown to be less disruptive in terms of passenger or crowd movement and flow of normal business, particularly at airports and mass transit terminals. The effectiveness of the system is such that it addresses the very realistic threat of liquid explosives and non-electronic control mechanisms that can be implemented within checked luggage and that today poses the same risks, even greater, than those of the carry-on threats circumvented in London and environs. The cost of each device can be low enough to allow for "use once and discard" protocols that translate into one detection device for every piece of luggage checked or carried on any plane or train, not to speak of other applications.

The figures below provide simplified views of the CEBIT (JEDI) architecture. Deployed in large numbers, this offers not only the diversifiable, adaptive, "platform/target-independent" sensing and data collection capability needed to address today's and tomorrow's problems of terrorist innovation. More importantly from the standpoint of incident prevention and circumvention, this type of sensing and data collection allows us to proceed with the type of inverse method based processing that can yield maps of processes and agent networks in operation.



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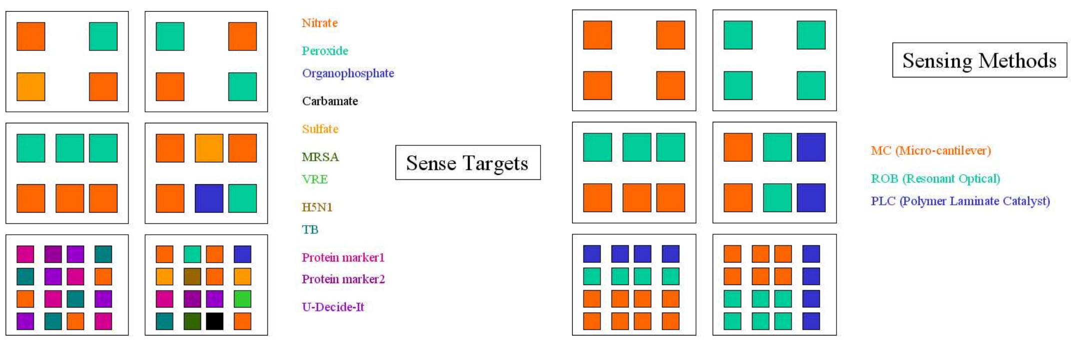

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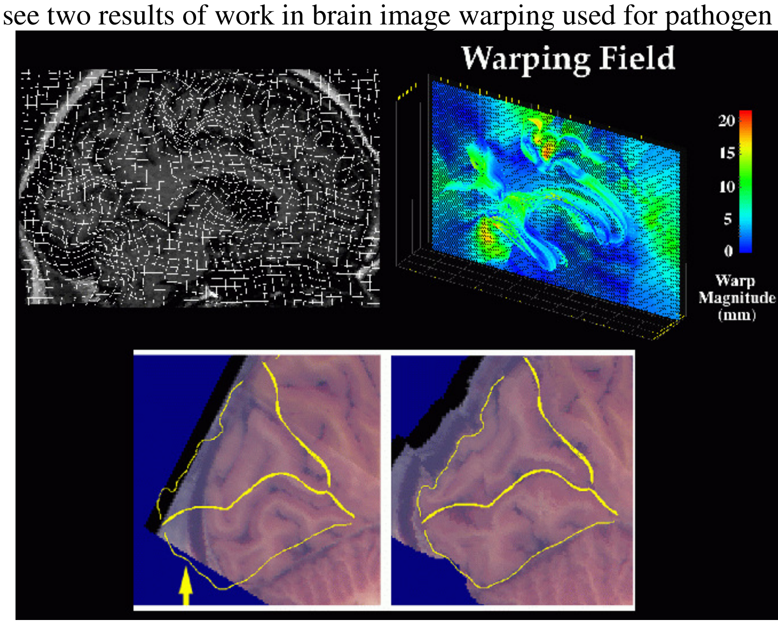
Connecting the Dots to Make a Moldable Map

In the medical imaging world, especially that of MRI and PET for cancer imaging tasks such as are required by intensity modulated radiation therapy, there has been a vast amount of progress from which we believe those working on countering a different form of cancer can learn and re-use. Below we see two results of work in brain image warping used for pathogen detection.



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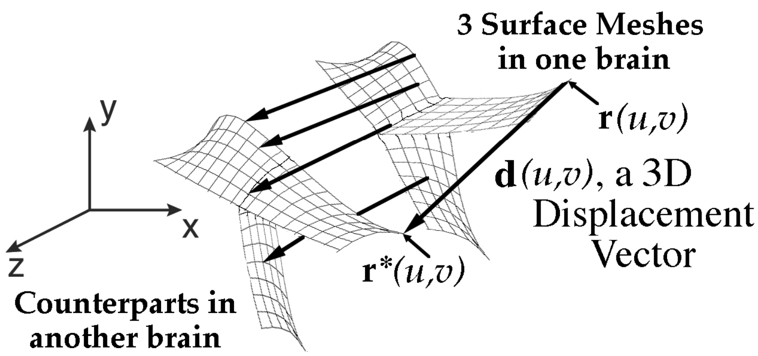
SURFACE MATCHING



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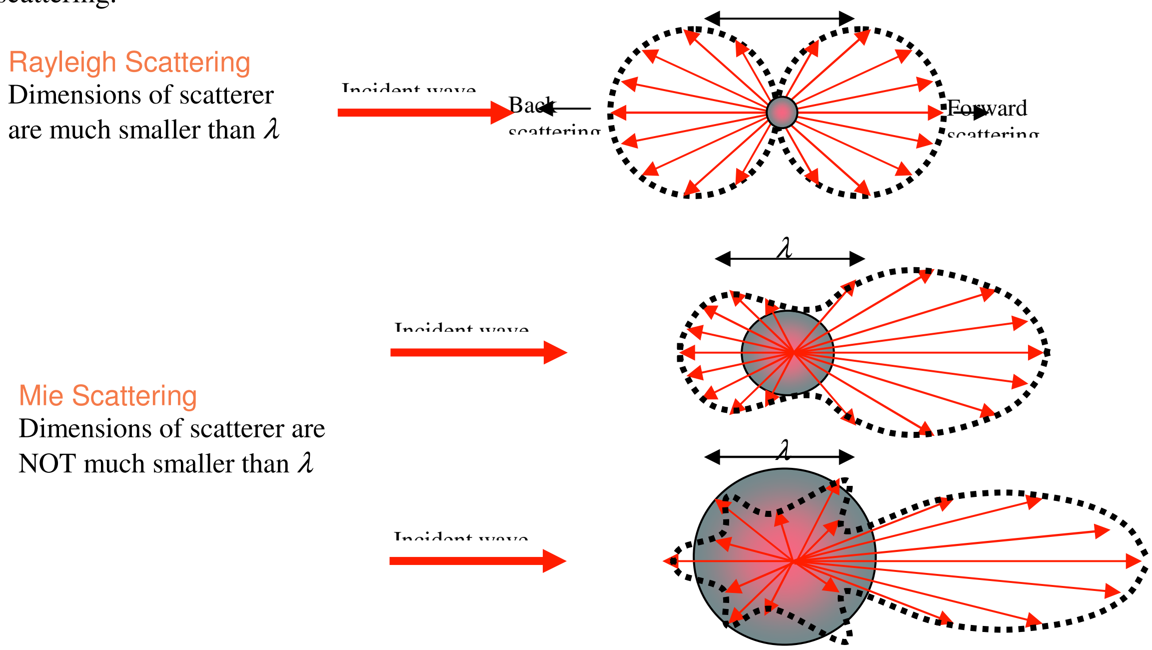
We are dealing also with surfaces and complexes that may be treated, for computational purposes, like volumetric regions. For this, DOT (diffusion optical tomography) has evolved from some basic principles of level sets and iteration that reverses “shrinkwraps” around a true object. In the imaging case the object is something three-dimensional, onto or about which there has been wave scattering.



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In our evolutionary relational maps, the objects are multi-dimensional, or they may be reducible to three dimensions artificially, but we may still be possible to apply level set iteration concepts. In the past, the concern has been interior, boundary and exterior sets and evolving the level set over time. Miller [4] has introduced the concept of polynomial parametric level sets (PaLS) in order to identify some characteristic function spanning the regions of interest for which all points (x, y) satisfy a relationship (e.g., p(x,y) < 0) and thus everything can be reduced to being in terms of a small set of parameters in a:

[4] see refs. [-]

$$
\begin{aligned}
p(x,y) = {} & a_0 + a_1 x + a_2 y + \\
& a_3 x^2 + a_4 xy + a_5 y^2 + \\
& a_6 x^3 + a_7 x^2 y + a_8 xy^2 + a_9 y^3 + \cdots \\
\equiv {} & B(x,y)a
\end{aligned}
$$

Extended Kalman Filters have been thus far showing promise – ultimately this is a nonlinear least squares type of problem. One possibility may be something like the following, where there are three basic elements – the data term, some form of spatial regularization, and some type of temporal dynamics, such as a random walk, to enable a smoother and faster iteration through a series of deformations until there is a common "core" that can be resolved to be the most stable object.

$$\hat{a}(n) = \arg\min_{a(n)} \left\| y(n) - Kf\left(a(n)\right) \right\|_2^2 + \lambda_1 \left\| f\left(a(n)\right) \right\|_2^2 + \lambda_2 \left\| a(n) - \hat{a}(n-1) \right\|_2^2$$

In our case the final goal of the iteration is not to obtain a final blob image that is the "true object" in 3D space, a clean artifact-free image of a tissue region, a mineral deposit, or a wafer surface feature. Instead the final goal for each iteration is a refinement and isolation of an object that represents a collection of relations R_j and R_k between cells and agents respectively, from which certain relations are of type R_q, namely, critical because of resemblance to relations that have been known from past analysis to either preview or infer certain consequences (outbreaks of disease, terrorist attacks).

The outcome at this point is an outcome from a long train of events that start with the planning and planting of arrays and networks of sensors and observation processes, be they mobile or static, automated or human-operated. This brings us back to the world of CEBIT (JEDI) and the devices we have been designing for luggage inspection, for metro stations, for airport waiting halls, for auditoriums. However, we are actually in something of a circular process. The placement and organization of such a sensor network, the Deployment for Observation, is the explicit starting point for how masses of data begin to be collected, that in turn build up the scattering points, which define the corpus of relations that we want to refine and see in clear focus. But that planning and deployment depends upon having some idea about what is the landscape for possible operations, terrorist or natural in origin, that can occur, that need to occur, in order for the critical events to even be possible. So we must have a prior outline to begin with. We must have a map initially, even a crude one, with which to start sketching and folding our new map, our Inverse relational Map.

And here is where we see the connection with lattices and order sets (posets) and also models such as reflexive theory. All that we have been talking about concerns a way to work with surfaces and shapes that represent the flow of information that is scattered and disjointed, either through lack of comprehensive collection, or intentional disruption and disinformation, or simply noise and error, and we must have some guidelines, some schematic, some type of structure to use for knowing what to expect, what to look for, what to give diminished regard. The outcomes from using both of these techniques can produce better formulations about not only set membership and the hierarchy of control within a given set (cell) but also rules and constraints on the types of relations that may exist among members in a cell and between cells or among members of different cells.

All of these restrictive forms of information are filters that affect the range of variety we can face in terms of the relations R that will make up, or bundle themselves into, virtual objects that become topographical features of our strange inverse mapping world. The result, hopefully, is a reduction in the computation complexity that must be dealt with in the iterative diffusion-attraction "fitting" process. The outcome of an lattice-theoretic model could possibly yield indicators of what may be the most likely set memberships for both cells and relational bundles (composites of actions, transactions, real-world processes). The outcome of a reflexive theoretic analysis could refine these set memberships further, particularly those of relations that can or cannot likely fit together in certain spatio-temporal or cell-to-cell combinations. The next level of analysis is where the IRM-theoretic techniques we have been speculating about can apply, in order to yield in the end a deformable, flexible map that can not only offer correspondences with the real world as it has been but illuminations about what is yet to come, in time enough to do something about it constructively.

Credits (images)
(1) courtesy of Eric Miller, Northeastern University
(2) (left) http://www.worldwide-river-cruise.com/assets/maps/vale-de-loire-large.jpg,
(right) http://www.discoverourearth.org/student/topography/index.html
(3) public source unknown
(4) (right) Anacostia tunnels image created by diffusion optical tomography, courtesy of Eric Miller, Northeastern University
(5) author
(6) author
(7, 8) Paul Thompson, Brain image warping and pathogen detection, http://www.loni.ucla.edu/%7Ethompson/detailed_warp.html
(9) K. Thomenius & B. Roysam, Introduction to Subsurface Sensing and Imaging Systems, GE Global Research. ECSE-4963

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