Eigenstructure and Exergy Calculations for Superstatistical Integration of Global Transport and Urban Systems

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Abstract: In the last few years, International research group, IRG SCAFT has developed a superstatistical based integration framework in which the principle of Ever-Advancing Civilization mediates and organizes the cooperative and synchronization strategies of globally integrated transport and urban systems through the introduction of an optimally integrated network of Humanitarian Hubs and cluster merging process of local populations.

As a part of ongoing IRG research, we seek to answer two further formidable challenges encountered as we continue to develop the common integrated framework of transport and urban systems, namely the existence and nature of eigenvalues required for dimensional calculations of Humanitarian Hubs, and secondly, the social capital exergy based core logistic activities required for cluster merging processes, optimization, consistency and sustainability. Finally, and for the first time, we suggest the spiral growth pattern for the cluster merging process and Humanitarian Hub integration process as another manifestation of First Passage Time Anisotropy.

Key Words: Exergy, Eigenvalues, Humanitarian Hub

1. INTRODUCTION

Transport and social networks pose formidable integrated design challenges for transport and social experts and planners because they are complex systems that evolve in time. Recently EASTS International Research Group, IRG SCAFT (2008) and Mojarrabi et al. (2009) As a part of ongoing IRG research, developed a superstatistical based integration framework in which the principle of Ever-advancing Civilization of Universal House of Justice (2000) mediates and organizes the cooperative and synchronization strategies of globally integrated transport and Urban systems through the introduction of an optimally integrated network of Humanitarian Hubs and cluster merging process of local populations.

The basic idea behind the model offered by IRG SCAFT is the hypothesis that complex transport and social system are non-equilibrium gradient induced flow systems with
superstatistical characteristics in which their natural attraction toward their global attractor will cause advancing cycles of complex social interactions and hierarchical relations that are analogues with the concept of energy levels.

Let us briefly review the basic features of our design so far:

- We introduced the concept of clustering to account for long range interactions of the power law. We suggest these long range interactions are predominately the result of the inherent quest of individual nodes for their global attractor as a hidden treasure.

- We introduced the concept of a Humanitarian Hub as a superstatistical basis for global Integration of urban system. The center core of the Humanitarian Hub is a house of worship focusing on the oneness of religion, which suggests indivisibility.

- We showed the first passage time anisotropy of the clear time scale gradient induced flow entities is the reason beyond the progressive evolution of social networks.

A stable, non-equilibrium, gradient induced flow social system has a rich supply of energy and a highly developed internal energy processing units that ensure the dynamical evolution of the system towards a higher level of cooperation, interaction, reciprocity and integration. An important engineering question arises then how such a system obtains its energy requirements for integration processing and how this energy is processed by the system in such a way as to enable us to obtain further information regarding the next phase of its evolution and a higher level of integration order.

The paper is organized as follows: In section 1.1, we will review the application of the superstatistical method in urban systems using the concept of the Humanitarian Hub. In section 2, we will discuss the synchronization and energy processing properties of both local and clear time scale gradient networks. In section 3, we discuss the energy and exergy requirements in both local gradient induced flow systems and clear time scale gradient induced flow to discuss the growth pathways of the system. In section 4, we discuss the eigensystem of the Humanitarian Hub. In section 5, we will conclude our paper.

We refer to synchronizability as the dynamic relationship between the nodes within the network and not to some external dynamics.

In social network links are interaction between individuals (nodes). Nodes are limit-cycle oscillators.

We can define the First-Passage Time (FPT) of transport and social network as the pumping lifetime $\Gamma$ of the system. We consider the First Passage Time as the time of stable existence of the system characterized by the existence of local and global feedbacks within the system. (Ryazanov, 2004; Ryazanov and Shpyrko, 2006)

We differentiate between environmental equilibrium and dynamic equilibrium.
1.1 Superstatistical System of Transport Network

Superstatistics is a new branch of statistical mechanics pioneered by beck and Cohen (2003) and Beck (2004) suitable for modeling complex non-equilibrium systems. Mojarrabi and Mojarrabi (2005) and IRG SCAFT (2005) were the first to extend the model into the Transport network. They have described the traffic network as a non-equilibrium system in which a number of vehicles move randomly (i.e. a poissonian distribution for a reasonably large number of vehicles) through a gradient field with energy $\varepsilon_i$. There is also a second and much slower dynamic of the background, namely, the spatiotemporal fluctuation $T$ of the background. For example, drivers make mistakes and collisions may happen or roads need repairs. The net result of these fluctuations is to cause variation in nodal fitness and thereby vary the probability of connection. i.e. the resulting distribution is then a fluctuation random graph with distribution $\Pi(T)$ instead of a static random graph with distribution $\Pi_{\text{static}}(k=\text{degree})$.

In a previous work (IRG SCAFT, 2006; Mojarrabi, 2006), we showed the poissonian transformation of $\Pi(T)$ has scale free power law characteristics. Essential for this approach is the existence of measurable finite time scale relaxation so that the system will have some time to relax to its local equilibrium shadowing its first passage time. i.e.

$$\Pi(k_i) = \int_0^\infty \Pi(T) \frac{T^k}{K!} e^{-\frac{T}{K}} dT \approx K^\gamma$$

where $\gamma$ is constant.

1.2 Superstatistical Model of Urban System

EASTS IRG SCAFT (2008) and Mojarrabi et al. (2009) extended the superstatistical model to urban systems using the concept of a “Humanitarian Hub”. In Figure 1 we can see the expansion of the superstatistical model to urban planning using the concept of the “Humanitarian Hub”. The central aqua color circle is a temple offering universal worship suggesting religious indivisibility. The yellow ellipses around the temple are the auxiliary humanitarian buildings such as for example a hospital, schools, a university, a community centre and travel centre to form the Humanitarian Hub.

These Humanitarian Hubs join together based on topological and dynamical characteristics of the gradient network to form a superstatistical integration of global integrated urban system. Humanitarian Hubs can function as a new form of conflict resolution as they promote cooperation/partnership between the nodes.

A commercial hub can be a mono-centric circle around a Humanitarian Hub or a multi-centric spread around different locations within business and housing districts. For practical purposes, it is important that the flow paths of the gradient induced flows of both commercial and Humanitarian Hubs are optimally converged in order to promote global cultural integration that humanizes. In this paper we propose Humanitarian Hubs of all major religions have similar eigenstructure with a corresponding common dimensional size eigenvalue $\lambda$ (Figure 1).
2. GRADIENT NETWORK

Gradient networks were first introduced by Toroczkai et al. (2004) A gradient network can be defined as the collection of all directed links attracted to the fittest nodes or supernodes (Mojarrabi and Vogiatzis, 2005; Mojarrabi et al., 2005). Commercial hubs (e.g. a CBD) and Humanitarian Hubs (e.g. a house of worship) are two examples of gradient network (Mojarrabi, 2006). In general, a gradient network forms due to factors such as competition or cooperation/partnership between the nodes with each factor having its own topological and dynamical field signature (IRG SCAF, 2008).

Gradient networks have a high clustering coefficient and a small world phenomenon. In social network. The small world phenomena rises due to the tendency of the individual nodes to limit the number of steps (links) in search of global attractor.

GIF entities can be classified into two groups: (1) GIF entities with low betweenness centrality (i.e. local gradient network), and (2) clear time scale GIF entities that have maximum betweenness centrality (IRG SCAF, 2006).

Gradient networks also have enhanced synchronization properties compared to other classes of scale free networks, such as BA scale free graph (Mojarrabi, 2006; IRG SCAF, 2006; Wang et al., 2007).

The dynamical route towards synchronization is different between local gradient fields and clear time scale gradient induced networks (Mojarrabi, 2006). For a local gradient network we can easily obtain synchrony by adjusting the effective weights. For clear time scale gradient induced flows, the local synchronized clusters cooperate as a result of the interplay between
their synchronization code of their corresponding gradient field entities and the environmental fluctuation field (Mojarrabi, 2006; Arenas et al., 2006). These synchronized clusters merge and grow in size as more nodes join the flow creating larger and larger community structures up to the final stage when the entire population has synchronized their phase. This process of structural formation will occur in a clear time scale from the microscale at the very early stage up to the macroscale at the end of time evolution. It prefers the direction along a trajectory originated at the center of the clear time scale gradient field (Mojarrabi et al., 2009). The efficiency of the process for the clear time scale gradient induced network depends on the form of a widespread (weak) coupling between the key nodes and whether some necessary reference points of cluster merging processes are first established.

3. GRADIENT NETWORK ENERGY PROCESSING PROPERTIES

Energy is required for interaction (link coupling) between nodes. The interaction energy is characterized by its form and quality. The available quality of the interaction energy can be measured by a thermodynamic concept called Exergy (Wall, 2005; Dincer and Rosen, 2007). Exergy is an important thermodynamic concept that has recently been used in performance, structural and system integration engineering studies (Samali and Madadnia, 2001), (Camberos and Moorhouse, 2009) and eco-systems (Jorgensen et al., 2000). In social network it is one of the indicator of happiness and wellbeing of Individual nodes.

We define the social interaction exergy as the measured quality of the energy that is available for social community building and structural formation works and is called the “social capital exergy” $E_{in}^z$. The social capital exergy $E_{in}^z$ is a measure of the quality of the nodal interaction and is the sum of two terms:

1) Clear time scale gradient induced flow entities component that is pumping tremendous amount of energy into the Humanitarian Hub superstatistical system starting a new cycle of first passage time. The social capital exergy $E_{in}^{hub}$ is the exergy required to build the social capital resources for the Humanitarian Hubs:

$$E_{in}^{hub} = L(\omega)A(1 - \frac{T_{hub}}{T})$$

Where $L(\omega)$ is the incident illumination intensity over the area $A$ of the Humanitarian Hub and depends on the incident direction $\omega$. Sato et al. (1999) have shown that $L(\omega)$ can be estimated from the concept of cast shadows. This is the main formula of our design that can be used to derive further information about the eigenstructure of the Humanitarian Hub discussed in chapter 4. $T_{hub}$ is the environmental temperature of the hub and $T$ is the global mean temperature corresponding to the entire superstatistical system. We define the occlusion ratio as $A\frac{T_{hub}}{T}$.

2) Exergy drawn a thermodynamic reservoir needed for competitive-based interaction and also trigger-based conditional cooperation as $E_{in}^{Res}$. 

$$E_{in}^{Res}$$
Following Fiaschio and Manfida (2010), a lead paper on solar renewable energy systems, we develop a similar expression for the total exergy available as:

\[ E_{in}^Z = E_{in}^{hub} + E_{in}^{res} \]  

(3)

For an optimally stable global integration system, we are interested in the exergy that can be extracted from a given synchronized cluster within the Humanitarian Hub \( E_{out}^{hub} \). This is because a Humanitarian Hub can function as an efficient exergy storage system to compensate for the loss of exergy that occurs during the energy transfer of cluster merging processes of local populations and work done for social capital exergy based core activities.

\[ E_{out}^{hub} = N\xi_{ind}(T_{out} - T_{cluster} - T \ln \left( \frac{T_{out}}{T_{cluster}} \right) \]  

(4)

\( T_{cluster} \) is the mean average temperature of all merged clusters within the Humanitarian Hubs

\( T_{out} \) is the mean average temperature output of cluster units of the Humanitarian Hub

\( \xi_{ind} \) is the gradient action energy time which is dependent on the energy capacity of the individual nodes. It can be considered as social indicators of both the internal exergy level of the storage units and how the internal exergy processing units utilize the exergy contents in time.

\( N \) is the number of nodes attracted to a Humanitarian Hub at a given unit of time.

In addition, Exergy can also be lost from the system due to:

1) incomplete social development project work and poor implementation of reforms;  
2) incredible slow progress of social change; and  
3) spread of lethargy within internal energy processing, storage and creative units.

As time passes, the system develop complex structures and integrating organization units to increase the fitness of its individual nodes enabling them to store higher levels of exergy in order to move further away from environmental equilibrium (thermodynamic grounds), achieving a higher level of integration in order to advance in a direction marked by their clear time scale gradient induced flow entities. As the social system moves further away from its thermodynamic grounds, it exhausts most of its stored exergy by performing work and, as a result, loses its ability to progress further in their planned social progress and development. i.e. the system enter the end cycle of its first passage time (See Figure 2).

The peaks of these cycles are what make the dynamics of social evolution that of an ever-advancing civilization. The social system is able to obtain more information about the next phase of its evolution from the information map buried in the structural factor of the common faculties of integrated scale when the system is in its peak, corresponding to the extent of the expanding fitness of individual nodes and their exergy based creative units. This in turn results in the formation of new codes of civil laws and conducts, as well as the emergence of new additional capacities and creative possibilities in art, science and cultures (Ruhí Institute, 2005). Eventually, as the newly integrated social system exhausts its exergy contents a process of disorientation, disintegration and structural resets sets the system in motion toward a certain First Passage Time “social equilibrium reset buffer”. Around this buffer the process recurs, as a new clear time scale gradient induced flow infuses the system with new pulses of exergy to again push the system further away from the thermodynamic grounds by assimilating achievements and creative powers of past cycles into a multitude of fresh permutation pathway channels of system integration (Institute for studies in global prosperity, 2000).
It is important to note the existence of a thermodynamic link between women and in maintenance of the cycles of social progress. They carry the matrix of exergy source from one cycle of first passage time to another.

![Exergy based rhythms of progress of an ever-advancing civilization](image)

Local GIF entities and Clear time Scale GIF entities can have different energy processing units. As a result of different energy process units and synchronization pathway, they also follow different routes toward integration.

### 3.1 Energy Processing Units in Local Fields

When a local GIF network pumps its energy from the environment, it faces more difficulty in processing its exergy content (to create additional capacity) efficiently compared with that of clear time scale gradient induced flow systems, partly because of their small number of social capital exergy storage units and partly because of the nature of the unconstrained exergy source of the environmental fluctuation field.

They often strategically cooperate and coordinate with other local GIF networks with similar first passage time characteristics in order to increase their exergy contents for some period of time through mutual non-interference coupling activities. However, this increase is more likely to be an increase in the exergy storage of the combined system and often will not result in a marked increase in the efficiency of its exergy processing units.

These systems do not continue to evolve into higher integrated structures with advanced synchronization abilities and their growth is random. Their synchronisation nature is governed by the Kuramoto model (Kuramoto and Nishikawa, 1987), which is suitable for limited cycle oscillators:
\[
\frac{d\Phi}{dt} = \sigma_i + \sum_{\text{neighbours}} W_{ij} \sin(\Phi_i - \Phi_j) \tag{5}
\]

Here \(\sigma_i\) and \(\Phi_i\) are the original frequency and phase of the individual oscillators.

\(W_{ij}\) is the weight parameter of each gradient network. It depends on the fitness of nodes of the local structures \(i\) to \(\ldots N\). The bulk of the combined gradient network interacts with the background fluctuation field \(T\) within a time step \(\Delta t_h\). In general \(\Delta t_h\) is the fraction of time the fluctuation background spends in a certain state. The effective weight parameter \(\overline{W}_{ij}\) of the gradient network is then the weighted sum of all \(W_{ij}\) spent interacting with background and each other. The effective weight \(\overline{W}_{ij}\) causes a shift in the field distribution which in turn changes the balance of the exergy flow between local cluster structures. The imbalance invokes the negative feedback loops of the local GIF system that is receiving a lesser share of exergy to oppose the gradient generated by the bulk of the two systems. It is relatively easy to disentangle from such coupling activities as the cost of exergy replacement is affordable for each individual system.

A natural step in our design effort would be to plan for different coupling strategies that would enhance the synchronized response of the entire integrated system. In a previous paper (Mojarrabi et al, 2009) we discussed how local structures (exergy processing units) of GIF entities can grow into a higher structural order using the information maps coded in structural factor of the common faculty \(\omega(E)\) of the entire superstatistical system. That means

\[
\omega(E, \Gamma) = \omega(E) \omega_i(E, \Gamma) \tag{6}
\]

where \(\omega_i(E, \Gamma)\) is the structural factor of the local field in the state of dynamic weight assignment equilibrium with environment or other local fields.

This merging would allow for the local structural factor of common faculty to measure the transitional times between its key nodes and their synchronized feedback response (to external and possibly internal fluctuation field) more efficiently and therefore both increase and optimize its exergy flow.

Accordingly, it can be shown the minimum free energy \(E(T_0)\) required to put the local system into gear for superstatistical integration is dependent on the temperature of fluctuation field and energy of a local cluster \(E_{\text{out}}^x\):

\[
E(T_0) \approx \frac{\int_0^{\infty} \Pi(\beta) \beta E_{\text{out}}^x d\beta}{\int_0^{\infty} \Pi(\beta) \beta d\beta} \tag{7}
\]

where \(\Pi(\beta)\) is the probability density of the fluctuation field and \(\beta\) is the inverse temperature (Beck, 2010).

In clear time scale GIF networks, this energy is pumped from the central core node. However, when a gradient induced flow local structures receives a flow of energy from their clear time
scale GIF entity, it to do work within the fitness limit of its exergy processing units of their populated clusters in order to put the system into gear to move forward. The work will generate internal flows, causing an increase in social capital activities required for core logistical activities within the Humanitarian Hubs. This would move the system further away from the equilibrium but in a predestined direction determined by anisotropy of first passage time which is now coded into the synchronization growth process of the newly merging clusters.

As a note of caution, it is plausible that the noise from the environment end coding up the structural factor of the local field, creating disorientation defects in their evolution pathways in the early phase of growth, even further degrades its exergy contents than before.

To solve this, we introduce the exergy support units we call “Accompanying units” to regularly update a complete survey of the population within the cluster and identify the newly joined cluster elements that can be pinned as either shifted or disoriented from the orientation pathways of an ever-advancing civilization. The newly joined local structures and their “Accompany” wind through dislocated joints, adjusting the exergy flow according to the capacity level of local nodes sufficient enough to shift the local system blocks into higher gear in order to successfully orient the synchronized interactions between the newly arrived populations toward the global attractor (in a way that matches the shape of the local neighborhood community’s own background transitions and interactions). However, each new orientation mimics the previous successfully oriented synchronized cluster in the oscillator phase space. This means this new synchronized cluster settles into an appropriate phase location within the phase space of the entire integrated superstatistical framework. In this way, one can choose an angle \( \Phi \) that determines the orientations of each cluster from the axis directed toward the central point attractor. Such a settling down process propagates from the center. This would map a spiral growth model. The spiral growth offers three advantages:

Firstly, it will enhance the status of low class, minority nodes and disadvantages as the growth is sustaining through a multiplication of social capital based core logistic activities by the exergy processing units indigenous to the neighborhood itself.

Secondly, when the forward loop becomes weaker, spirals can cause (commensurate with the expanding capacity of individual key nodes) the feedback loop to become stronger causing a marked increase in transparency.

Thirdly, it keeps the fluctuation noise away from the core due to the role of the “Accompanying Unit”. It is due to the third reason that the creations of highly efficient and trained “Accompanying Units” constitute an important exergy based core activity for policy makers interested in large scale integration systems. An important source for building “Accompanying Units” is through Non- Government Organization resources (NGO).

To validate the spiral growth model of clear time scale gradient induced flow networks, we intend to measure the homokinetic growth plateau of their first passage time. This requires a detailed analysis that would be the subject of future IRG SCAFT work.
4. HUMANITARIAN HUB EIGENSYSTEM

Consider a global gradient scale free flow system as a non-equilibrium gradient state in which its universal tendency toward its global attractor drives its evolution (Figure 3). We divide the entire system into a large number of local structures called cells, each of which has been reached into the dynamic weight assignment with its environment and neighboring cells after certain time. Within each of these cells, there are a number of highly populated clusters, each of which has oriented toward the center Humanitarian Hub. An individual node moves through the different clusters with different temperatures in search of a global attractor. In our model, The traveller or seeker from the entire available directional pathway toward the global attractor will chose those pathways that maximising his/her exergy storage and minimising his/her exergy waste. Accompany units form the companionship for the traveller within a distance X in initial phase of the journey. Accompany Units are not referral or reference peer group units.

![Figure 3 The dynamics of nodal search for its global attractor](image)

We can deduce information about the maximum spatial dimension of a Humanitarian Hub in travel time units from incident illumination intensity $L(\omega)$ in equation 2 and the concept of cast shadow.

The irradiance $E(x, B)$ is related to incident illumination intensity $L(\omega)$ through equation

$$E(x, B) = \int_{-\pi/2}^{\pi/2} L(w)V(x, w, B)dw$$

The first step is to derive a formula for visibility $V(x, w, B)$ in order to reduce it into an
eigensystem.

1) We parameterize $V(x, w, B)$ as $V(\alpha, w, B)$,

2) Ramamoorthi et al. (2004) has shown a single image with complex illumination is a simple convolution between the incident illumination intensity $L(\omega)$ and Heaviside or unit step function donated as $L \otimes H$ i.e.

$$ E(u) = \int_{-\infty}^{\infty} L(w) H(u-w) dw = L \otimes H $$

(9)

In Fourier domain we will have:

$$ E_f = \sqrt{\pi} L_f H_f $$

(10)

where $L_f$ are the Fourier illumination coefficients and $H_f$ are the Fourier Heaviside Coefficients. The above equation corresponds to the illumination of many sources that is related to the orientation of different synchronized clusters within a given cells. Intuitively, this suggests the eigenfunctions will be standard sine and cosine functions.

But we need eigenvalues to further describe Humanitarian Hub eigensystem. Now we suggest the case of complex illumination in Figure 4.a can also be applied to the case of eigenfunction derived from single moving directional illumination source in Figure 4.b that corresponds to the case of cast shadow of the rising sun. Our approach is similar to the work of Ramamoorthi (2002) and Ramamoorthi and Hanrahan (2001).

We will use a Singular Value Decomposition (SVD) technique. The SVD theorem states:

Let's $A_{np} = U_{mm} S_{np} V_{pp}^T$

(11)

Where the columns of U are left singular values

$S$ is the matrix with only its diagonal elements are non-zero. These diagonal elements are called singular values of $A$. $V$ has rows that are right singular values.

Calculating SVD consists of finding the eigenvalues and eigenvectors of $AA^T$ and $A^TA$.

Now, for a fixed $\beta$, the visibility matrix $V(x, w, B)$ becomes $V(x, w)$. $V(x, w)$ is a matrix with its rows corresponding to geographic unit of the cluster location and columns corresponding to illumination direction $\omega$. We need to compute eigenvalues of $V^T V$.

Figure 4.a Mathematical basis of the cast shadow. It corresponds to illumination from many source of light. Figure 4.b Corresponds to illumination from the same source of light.
4.1 Eigenvalue Spectrum
A detailed discussion of the eigenvalues has been provided in Ramamoorthi and Hanrahan (2001) and Ramamoorthi et al. (2005). However a complete mathematical description of the set of energy spectrum eigenvector and their characteristic shadowing decay rates (Eigenvalues) is complicated and is omitted here.

Eigenvalues tend to cluster together further confirming the inherent characteristics of the Humanitarian Hubs are that of cooperation and synchronization (IRG SCAFT, 2008; Mojarrabi, 2009). The eigenvalues decay as 1/k corresponding to unit step size function. The eigenvalue $\lambda = 1$ corresponds to the case of maximum shadowing. It signals the case of total misdirection of the synchronized clusters in their cooperative based orientation pathways (corresponding to maximum travel time) within the cell (see Figure 3).

The degree of shadowing is related to the occlusion ratio $A \frac{T_{hub}}{T}$ in Equation 2. Now if we let

$$A \frac{T_{hub}}{T} = 1$$

then the temperature of the Humanitarian Hub would be the same as the entire superstatistical region area. That is the reason why $\lambda = 1$ is the maximum possible dimension (in travel time unit) of the Humanitarian Hub.

5. CONCLUSION
This paper introduced two further basic steps with a completely new and objective approach in the development of a superstatistical framework for a globally integrated of transport and social system.
Firstly, we introduced the concept of exergy as a new tool for analysis of optimal growth pathways of integrated social systems based on the concept of Humanitarian Hub. Secondly, for the first time, we presented the eigenvalue $\lambda = 1$ for the maximum travel time size of the Humanitarian Hubs. The existence of at least one eigenvalue suggests Humanitarian Hubs may have a common set of essential characteristics that are clearly worthy of further research attention.

Taken together, from the accumulating research publication work obtained, we are gaining more confidence that our superstatistical approach is the correct framework to develop a globally integrated transport and urban system.

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