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2013
Mathematical Contest in Modeling (MCM/ICM) Summary Sheet
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A Scalability-aware Network Model to Future Health Prediction

Considering the complexities of global ecosystem, some issues such as network model, the system of differential equations and policy traction in this topic are discussed, and a dynamic global network model with scalability is presented in this paper.

Firstly, by the concept and theory of data center, we build a global network recursively with dry land and water area as servers and their relationships as specific switches. Thus, we can analyze the critical nodes by the theory of graph.

Secondly, an isolated ecological competition and predation model is built to predict the seven future health measures, including population, biodiversity, amount of renewable resources, amount of non-renewable resources, pollution degree, regime stability and traffic capacity. We assume that health measures perform like organisms which compete for or prey on a shared but limited resource. The differential equations describe the rates of change of seven dependent variables. The model parameters describe death rate, interspecies competition and predator-prey which indirectly relate to different government policies.

Thirdly, the system of differential equations is introduced to the recursive network model. Then, we run the model to predict the future Earth's health, finding that interactions between each node will alter the tendency of original curve at specific moment. Results show that the tipping points will occur in 140 years. We investigate four scenarios of changes in policies affecting the global ecosystem. A basic scenario uses current health conditions; others investigate the effect of high productivity, government investment in new energy and the control of contamination on the global ecosystem.

Finally, we discuss the strengths and the weaknesses of our scalability-aware network model, and introduce how the model can be extended to the larger database via interface technology.

1 Introduction

Better predictive models will lead to better decisions in terms of protecting the natural resources future generations will rely on for quality of life and prosperity.

———*Anthony D. Barnosky*

From the Cambrian explosion to the most recent transition, Earth's biosphere has undergone at least seven state shifts in the past, each of them have brought catastrophic disasters to our biosphere, and therefore can do so in the future. Based on this concern, forecasting the biological and environmental health conditions of our planet has received an increasing attention in recent years [1]. Then decision makers can take advantage of this methodology to design effective policies to guide the future of the human societies and global ecosystem. However, a common problem is that most of current models ignore the complexities of global ecosystem such as multiple interactions, feedback loops, and impending state changes.

Several recent works addressed not only the need for scientific models but also the importance of predicting global state changes have been proposed with different methods [2] [3]. For example, [2] presents an approach in details to the detection of critical transitions and can be summed up as some critical aspects such as flickering and increased variance of fluctuation may occur before the epileptic seizures. [3] gives us a computational exploration of complex network structure and predicts the quantitative effect of a species loss on other species successfully. To the best of our knowledge, only few ongoing projects, such as *BiGCB*, have achieved an integrated analysis of historic and current data, fossil to uncover new knowledge of California ecosystem's responses to environmental change. This aspect, typically referred to as *global network model*, is still widely unexplored and there are several open issues.

Based on theory of network structure of data center, a deeper and systematic understanding is that state shifts of the small-scale components can propagate to cause a state shift of the entire system. The main issues in this topic are discussed below:

- The theory of network structure in data center and how to apply them to the ecosystem to build a dynamic global network model?
- What are the nodal entities, link properties and their attributes in model?
- How to find the critical nodes and relationships in our model?
- How to predict the Earth's future health via our model and what impacts will effective policies have on the Earth's future health?

- Further recommendations and other applications of model.

[4] shows that *BiGCB* costs up to $4,298,929, only to analyze California ecosystems systematically. Therefore, we don't expect our model can predict the future Earth's health accurately, instead we can only hope this proposed framework will contribute to developing the next generation of predictive models of the biotic response to global change.

2 Symbols and Definitions

Variable	Description
	Dynamic network model
G	dynamic network graph
N	a set of labeled nodes
L	a set of labeled links
S	state value of each node
ω_{ij}	the weight of interaction between node i and node j
ρ_t^i	the ability of transportation of node i
ρ_a^i	the ability of atmosphere circulation of node i
ρ_w^i	the ability of water circulation of node i
	Ecological competition and predation model
x_1	population of each node
x_2	the total number of biological species of each node
x_3	amount of renewable resources of each node
x_4	amount of non-renewable resources of each node
x_5	pollution degree of each node
x_6	regime stability of each node
x_7	traffic capacity of each node
d_1	human mortality of each node
d_2	biological mortality of each node
r	recovery rate of renewable resources of each node
α_i	effect of population on the other health measures
β_i	effect of the total number of biological species on the other health measures
γ_i	effect of amount of renewable resources on the other health measures
ζ_i	effect of amount of non-renewable resources on the other health measures
η_i	effect of pollution degree on the other health measures
θ_i	regime stability on the other health measures
λ_i	traffic capacity on the other health measures

3 Dynamic global network model

It is required to build a dynamic network structure to predict some aspects of Earth's health. To give a clear explanation, we first introduce data center, whose network structure coincides with the network model of the global ecosystem to some extent.

3.1 Theory of network structure in data center

The components in data center

- **Server** is a physical computer dedicated to run one or more services.
- **Switch** is a network device to connect heterogenetic servers, telecommunication circuits and other functional units.
- **Router** is a device that forwards data packets between computer networks, creating an overlay internetwork.

The network structure in data center

The network structure is the connection relation among servers, switches and routers within data center. A effective network structure contains such properties as high-bandwidth, high-availability, high reliability, and load balancing. The traditional data center network structure is a typical three-tier tree structure based on switches [5]. As shown in **Figure 1**, the network structure can be built by the following rules: Edge layer switches, aggregation layer switches and core layer switches constitute the tree nodes, servers constitute the leaf nodes, netting twines constitute the branches.

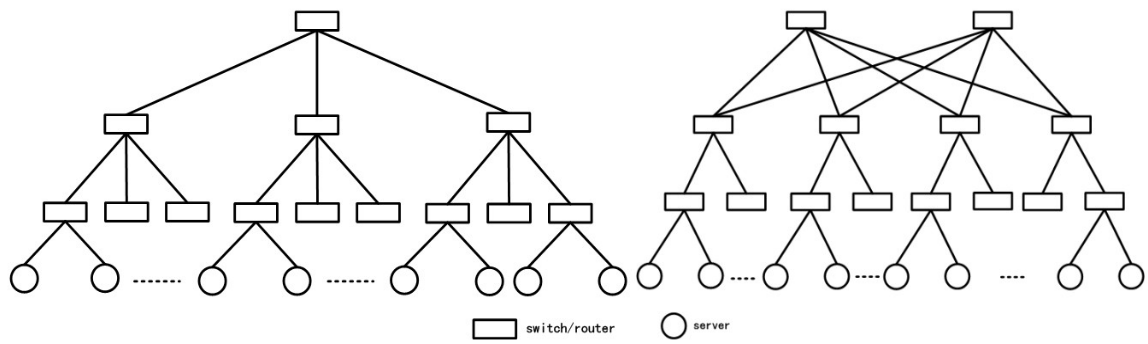

Figure 1: The two possible three-tier tree structures. The left structure has single core layer switch, while the right increases the number of core switches. It can be easily found that, on the one hand, the bandwidth of root node will become a bottleneck in this network structure, on the other hand, it is difficult to expand once the data center has been built. Some methods such as increasing the number of core layer switches can modify this situation while it cannot solve the problem of the bottleneck of root node.

The scalability of network structure in data center

With the expansion of data center, the traditional network architecture becomes a bottleneck restricting the application of data center. Therefore, DCell [6], BCube [7], Portland [8], VL2 [9] and many other new data center network architecture are proposed and deployed. They are easy to expand by the recursive building algorithm. For example, **Figure 2** presents a recursive building process for Dcell.

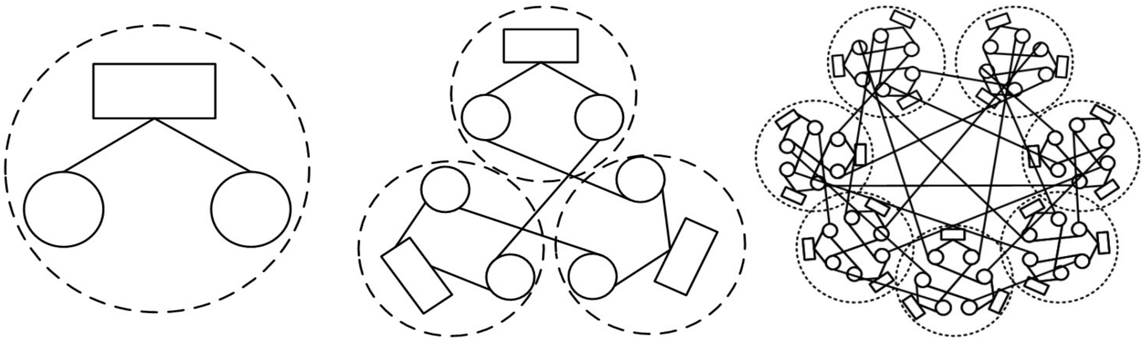

Figure 2: A *Dcell* network building process from $Dcell_0$ to $Dcell_2$ when n=2. When each $Dcell_k$ can be considered as a virtual node, these virtual nodes then form a next level network. The rectangle represents mini-switch, and the circle represents server.

Measures of network structure in data center

- **Node resources** represent each server's storage resources, computing resources and bandwidth resources.
- **Link resources** represent each link's bandwidth.
- **Traffic pattern** indicate the flowing mode of data package within data center, such as even traffic pattern and burst traffic pattern.

3.2 Elements in Dynamic Global Network Model

Health measures: population, biodiversity, amount of renewable resources and non-renewable resources, pollution degree, regime stability and traffic capacity.

Nodal entities: dry land and water area that can be nations, oceans or narrowed down to the specific city or block. Each node contains some attributes, such as population, biodiversity and above health measures.

Link properties: the different interactive relationship between different nodes, such as water circulation, atmospheric circulation and transportation.

Scientific basis is shown below: Based on the above theory of data center, it can be concluded that resources of servers occupy the entire resources within data center, while the switches only embody the connection relation between different servers. Meanwhile, in global ecosystem, most of resources such as population are concentrated in pieces of dry land and water area separately. They have multiple interactions due to their systematic complexities. Previous study indicates that, there are three principle influence ways: transportation, water circulation and atmospheric circulation [11]. Let's assume that if global ecosystem is deemed to be the data center, the separate dry land and water area will be the servers, while their multiple interactions will correspond to the different types of switches included 'transport switch','water switch' and 'atmosphere switch'.

In the network structure of data center, both servers and switches are nodes. However, there will be a subtle gap if we apply them to the ecosystem. Nodes represented by the servers are actual nodes, while those represented by the switches are virtual nodes that cannot be the nodal entities in global network model. Because the former nodes contain some attributes related to the health measures, while the latter embody nothing but the multiple interactions. It might be bit of abstract, so we introduce a practical example in **Figure 3**.

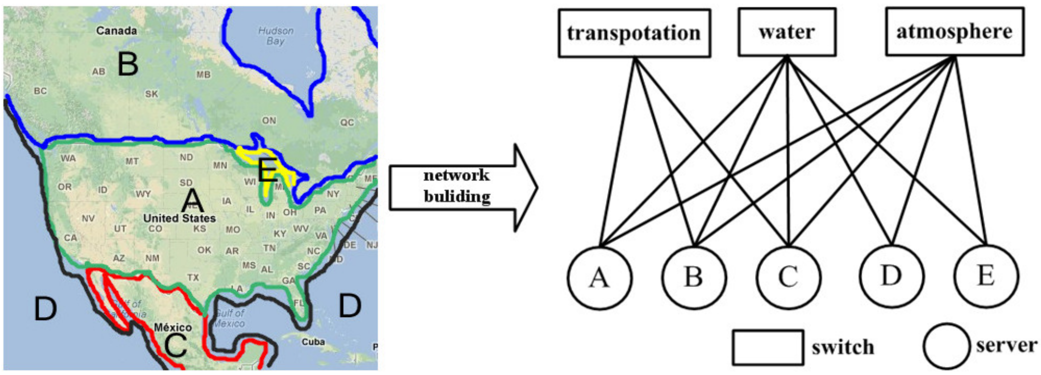

Figure 3: Some areas of North America. We regard the whole North America as a data center. The nations and water areas are servers while the transportation, water circulation and atmospheric circulation in North America are switches. Thus, it produces only five nodes. The United States and Canada can interconnect via above three ways, so we should connect node A, B to three switches. The United States and the Pacific via water and atmosphere, so we connect node A, D to water and atmosphere switches. Based on this mapping relation, the practical area can be transformed to the network model.

3.3 Global Network Model

To explicitly illustrate the process of network building, the scalability of data center should also be applied to our model. A core thought relate to this property is that a high level block is constituted from low level block (**Figure2**). In our model, a higher level of network represents a broader region. **Figure3** shows a process of local network building. We regard it as a building block to construct larger network such as the Latin America (**Figure4**). Here are the recursive building algorithm:

- *step1:* Building network for each local region.
- *step2:* Considering each network as a virtual node and analyze their multiple interactions.
- *step3:* Connecting them via three higher level switches to build a larger network based on the different interactions. If continue, goto *step1*, terminate, otherwise.

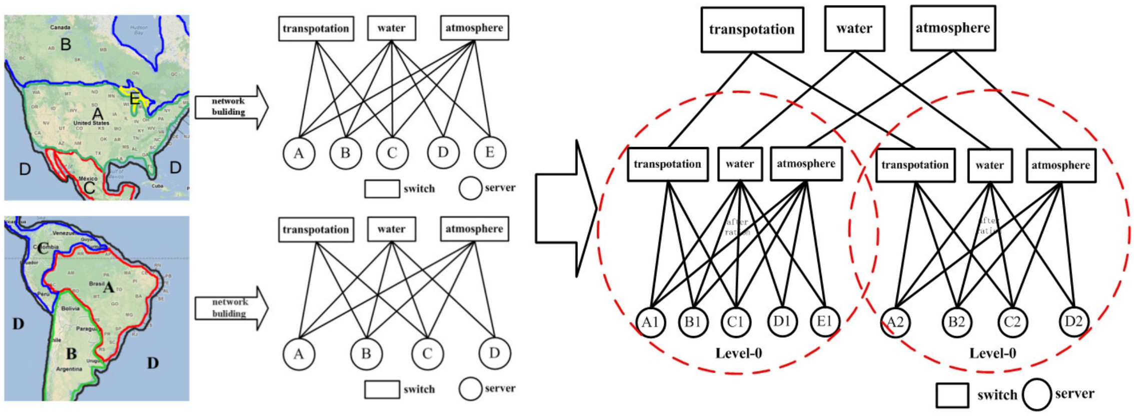

Figure 4: The recursive building process of Latin America's network from North and South America's local network. It represents the building process from $level_0$ to $level_1$.

3.4 Dynamic nature

Inspired by *state shift theory*, each node's health measure can be simplified into the value of state variable. [2] introduces a *catastrophic bifurcation theory*. When the local health conditions come into the tipping points, the local environment will come into an irreversible state which is extremely hard to survive (**Figure 5**). The state value are set between 0 and 1. When it is in the formal condition, the state value changes from 1 to the threshold continuously. When it comes into the tipping points, the state value is 0 for simplicity. After obtaining the initial value, we can iteratively adjust state value of each node to represent the dynamic change, because for a node A, its state value changes as the state value of its neighboring nodes B, C, D have changed in a network. Consider a rating system that contacting with a node of lower state value results in lower S_n, we can set up the following rating function:

$$S\left(n\right) = \left\{ \begin{array}{ll} 0, & S\left(n\right) < t_r \\ \sum_{x \in A_n} S(n)\omega_{nx}, & S\left(n\right) \geq t_r \end{array} \right. \tag{1}$$

Where A_n donates set of nodes interconnected with n_{th} node, and ω_{nx} donates the weight of interaction between n_{th} node and x_{th} node that satisfies $\sum_{x \in A_n} \omega_{nx} = 1$.

Each iteration step is equivalent to specific time lapse. In continuous iterative process, the status of each node in the network will gradually spread to affect other nodes. By Markov property, S_n of each node will eventually reach the equilibrium after a large number of iterations.

3.5 Methodology to set Parameters

There are some parameters should be estimated in dynamic global network model:**initial state value** S_n of each node n, **the weight of interaction** ω_{ij} between node i and node j.

As for each nodes, including highly-developed transportation, strong water circulation and atmosphere circulation, are more likely to be interacted with each other, we can define

$$\omega_{ij} = \varepsilon_1 \rho_t^i \rho_t^j + \varepsilon_2 \rho_a^i \rho_a^j + \varepsilon_3 \rho_w^i \rho_w^j \tag{2}$$

where ε_i is the weight of different interactive ways. Here equalizing them for simplicity. ρ_t^i can be determined by the total traffic mileage of each node including rail, road and aviation mileage. ρ_a^i can be determined by the area of each node. ρ_w^i can be determined by the total amount of water of each node.

A simple method to estimate state value of each node is based on the percentage of cultivated area S_r [1], which can be defined:

$$S(n) = \{ \begin{array}{cc} 0, & S_r < 0.5 \\ 1 - S_r, & S_r \geq 0.5 \end{array} \tag{3}$$

3.6 Validation of Network Models

A network constituted by five nodes: U.S., Canada, China, U.K. and Brazil is considered [10] [13]. The weight of interaction are shown in **Table 1**.

Table 1: The weight of interaction between each node

ω_{ij}	U.S.	Canada	China	U.K.	Brazil
U.S.	0.72	0.11	0.05	0.02	0.10
Canada	0.11	0.69	0.12	0.08	0.10
China	0.05	0.12	0.55	0.12	0.16
U.K.	0.02	0.08	0.12	0.63	0.15
Brazil	0.10	0.10	0.16	0.15	0.49

The result is shown in the **Table 2**. Although the initial state values of five nations are different, the ultimate state values are similar.

Table 2: The result of each node in 9 iteratives

$S(n)$	1	2	3	4	5	6	7	8	9	10
U.S.	0.70	0.70	0.71	0.72	0.72	0.72	0.72	0.71	0.71	0.72
Canada	0.76	0.76	0.74	0.73	0.72	0.72	0.71	0.71	0.71	0.71
China	0.63	0.63	0.66	0.68	0.68	0.70	0.71	0.71	0.71	0.71
U.K.	0.73	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.71	0.71
Brazil	0.74	0.74	0.73	0.72	0.72	0.71	0.71	0.71	0.71	0.71

4 Ecological Competition and Predation Model in Local Ecosystem

4.1 Mathematical Model

It is required to predict the Earth's future health measure such as population, the total number of biological species and so on. However, a single state value cannot provide us an understanding of the earth's health condition in details. The ecological competition and predation model is a combination of competition and predation model, which reflects the effects of multiple species competing for or preying on a shared but limited resource. The interactions among those health measures in our network model can be extremely complex, which can be illustrated clearly by **Figure 5**.

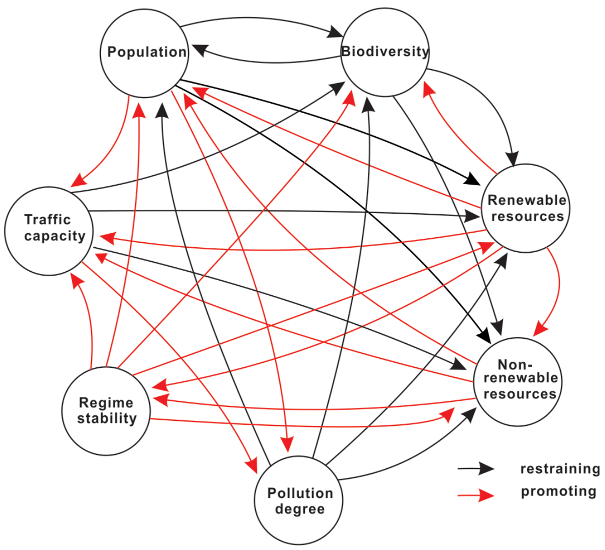

Figure 5: The interactions among seven health measures.

From the **Figure 5**, it can be concluded that different measures have different interactions. For example, the population is positively correlated to the resources while negatively related to the number of other biological species, because human and resources are predator-prey relationship while human and other species are competitive relationship. These correlations can be represented by a competitive and predatory system of ordinary differential equations(3), with initial values determined from current data [11] [12] [13] [14].

$$\begin{cases} \frac{dx_1}{dt} = x_1(-d_1 - \beta_1 x_2 + \gamma_1 x_3 + \zeta_1 x_4 - \eta_1 x_5 + \theta_1 x_6 + \lambda_1 x_7) \\ \frac{dx_2}{dt} = x_2(-d_2 - \alpha_2 x_1 + \gamma_2 x_3 + \zeta_2 x_4 - \eta_2 x_5 + \theta_2 x_6 - \lambda_2 x_7) \\ \frac{dx_3}{dt} = x_3(r - \alpha_3 x_1 - \beta_3 x_2 - \eta_3 x_5 + \theta_1 x_6 - \lambda_3 x_7) \\ \frac{dx_4}{dt} = x_4(-\alpha_4 x_1 - \beta_4 x_2 + \gamma_4 x_3 - \eta_4 x_5 + \theta_4 x_6 - \lambda_4 x_7) \\ \frac{dx_5}{dt} = x_5(\alpha_5 x_1 + \lambda_5 x_7) \\ \frac{dx_6}{dt} = x_6(\gamma_6 x_3 + \zeta_6 x_4) \\ \frac{dx_7}{dt} = x_7(\alpha_7 x_1 + \gamma_7 x_3 + \zeta_7 x_4 + \theta_7 x_6) \end{cases} \tag{4}$$

4.2 Analysis of equilibrium

To guarantee the scientific result of each measure, the equilibrium of equations should be analyzed. Let equations $\frac{dx_i}{dt} = 0$ and solve nonlinear equations. We firstly reap a trivial solution: $x_i = 0$. Then we get a coefficient matrix A and a constant vector b, which can be formed into an augmented matrix $[A|b]$. By the rules mentioned in [16] and mathematical derivation, a relationship between solutions of equations and those coefficients are presented:

- no solution, $rank(A) \neq rank([A|b])$
- unique solution, $rank(A) = rank([A|b]) = 7$
- infinite solutions, $rank(A) = rank([A|b]) < 7$

In this model, no solution indicates that these measures cannot be stable while unique solution indicates a stable state of each measure finally. Infinite solutions is so complex that we have to utilize *Liapunov's theorem of stability* to judge the stability of each solution.

Table 3: The coefficients in the United States based on the data in 1980

i	1	2	3	4	5	6	7
α_i	0	-0.01	0.03	1.67	-0.82	1	0.01
β_i	-0.78	0	0.03	0	-0.09	0.5	0.02
γ_i	-0.03	-0.03	0	0	-0.04	-0.02	0,02
ζ_i	-1.67	0	0	0	-1.81	0.1	1.7
η_i	0.9	0	0	0	0	0	0.1
θ_i	0	0	0.07	1.71	0	0	0
λ_i	0.81	0	0.01	1.67	0	0.1	0

The data above satisfies the condition 2, which shows that the health measures in the United States will be stable in the future.

4.3 Simulation and Discussion

We solve the differential equations via the Runge-Kutta-Fehlberg method, using coefficients derived by Cash-Karp, which can produce efficient solutions without excessive round-off error [15]. This model requires a mass of data that can represent our seven health measures. Firstly, we make the following scientific assumptions to simplify our work to search data:

- Per capita fresh water possession represents amount of renewable resources.
- Oil production represents amount of non-renewable resources.
- Energy consumptions per GDP represents pollution degree
- Unemployment rate represents regime stability.
- Total traffic mileage including rail, road and aviation represents the traffic capacity

Based on the data in 1980 of the United States [10] [13] and the above assumptions, the change tendency of such health measures can be calculated in the next one thousand years.

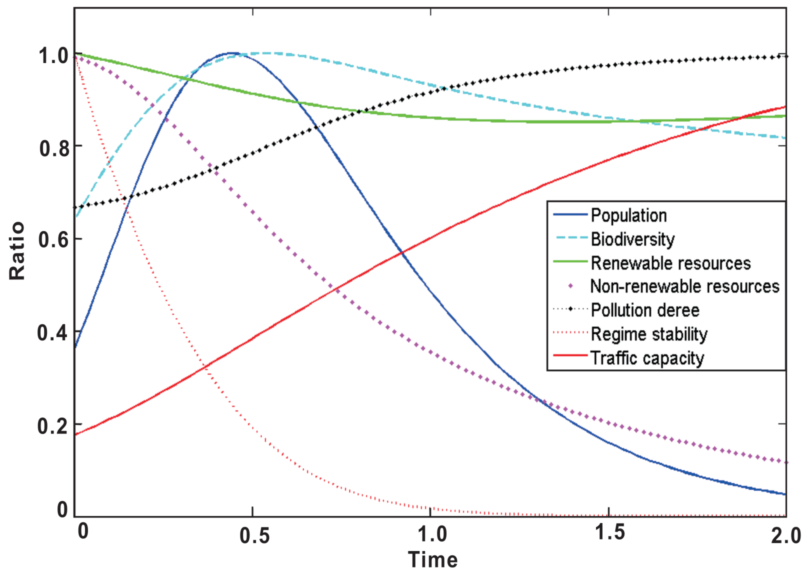

Figure 6: The interactions among seven health measures. Normalization is used in the vertical axis due to the the values of measures span several orders of magnitude.

From the **Figure 6**, the following facts can be inferred:

- Population first increases and then decreases. Because the increasing population leads to the reduction of resources and increasing of pollution which worsen the human living environment. As a result, population will decrease.
- With the growth of the human population, the resources become less and less due to consumption and pollution. As a result, other species die out gradually after a brief increase.
- Amount of non-renewable resources are gradually decreasing.
- Human activities and social turbulence lead to the soar of pollution degree.
- The regime stability decreases due to the depletion of resources and severe environment contamination.
- Transport capacity increases when population increases, slow down when population reduces.

5 Ecological Competition and Predation Model in Global Ecosystem

5.1 Mathematical Model

The ecological competition and predation model regard each node as isolated segment to study its change rule. However, global network model emphasizes that the status of each node in the network will gradually spread to affect other nodes via iterative process. The specific health measures of each node will be affected by the interactions among them, which will alter the isolated change rule at any specific moment. To obtain more accurate results, we should combine the global network model with the ecological competition and predation model, which consider not only the intrinsic change rule of each node, but also the influences from other nodes.

A simple method is to adjust the coefficients of the equations dynamically in accordance with the interactions. For example, at a specific moment t_k, the state value of node A change from 1 to 0.8, which represents the environmental deterioration due to the influences of other nodes, leads to the change of some coefficients. For the favorable factors on population such as resources, their coefficients should be multiplied by current state value to reduce the interaction. While the rest factors on population should be divided by current state value to emphasize the interaction.

It can be assumed that each iteration of network equalize m iterations of differential equations. Then coefficients a_{n-1} (represents above coefficients) of equations will change at time t_n, defined as

$$a_n = \begin{cases} a_{n-1}S(n), & restraining \\ \frac{a_{n-1}}{S(n)}, & promoting \end{cases} \tag{5}$$

5.2 Simulation and Discussion

Compared to the former simulation, we consider the interactions among the United States, the United Kindom , Canada, China and Brazil in addition to intrinsic change rule. And we set m to 30, **Figure 7** shows the results.

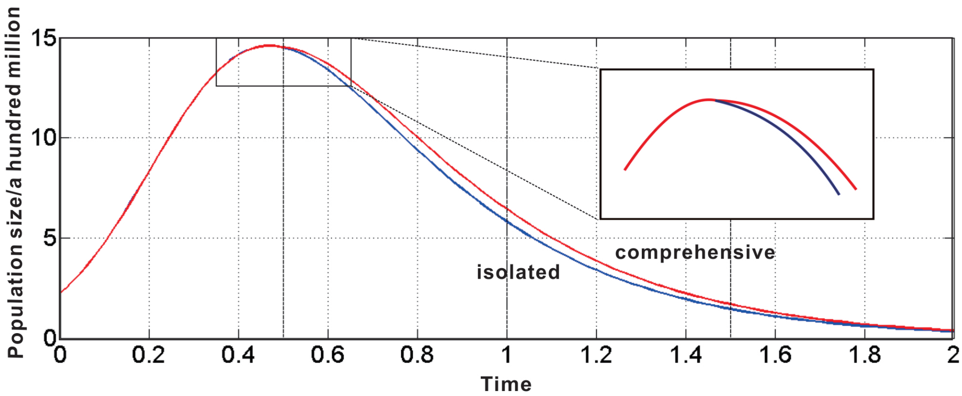

Figure 7: Demographic change in the United States in comprehensive and isolated conditions, and the difference are magnified by the right small figure.

From the **Figure 7**, the following facts can be inferred:

- Every few years, the trend of the population will change to some extent compared to the local trend.
- Interaction behaves differently at different time : enhancing or weakening the trend.

6 Critical Nodes in the Network Model

We utilize a analytical method to analyze its network topology due to a fairly complex relationship of the actual network structure and connection between each node. In a network model, a node i and its adjacent nodes can constitute a subgraph G_i. The importance of each node is positive correlated to the number of links, while negative correlated to the number of nodes in the subgraph G_i.

Thus, it can be defined as a parameter called the degree of polymerization to evaluate its importance:

$$C_i = \frac{L_i}{N_i} \tag{6}$$

Where N_i is the number of nodes in G_i, and L_i is the number of links in G_i.

The basic process of specific identification is:

- **step1:** Draw a graph G of the network topology
- **step2:** Calculate the degree of polymerization of node i
- **step3:** Define the node with the largest degree of polymerization as the critical node;
- **step4:** Remove the critical node and the connected edges. If continue, then goto **step2**, terminate, otherwise.

Here is an example using the process above.

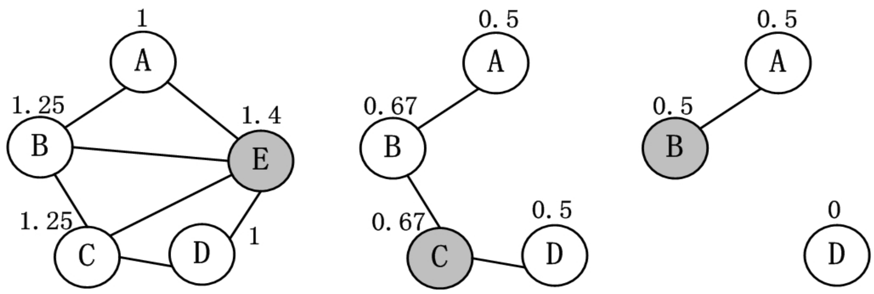

Figure 8: A graph transformed from network. Calculating the degree of polymerization of node A, B, C, D, E and defining the node E as the critical node. Removing node A and recalculating the the degree of polymerization of rest node and defining node C as critical node. Then defining node B as critical node via same process.

7 Feedback Loops in our Model

Feedback *is a process in which information about the past or the present influences the same phenomenon in the present or future* [11]. There are two types of feedback, negative feedback and positive feedback. In an ecosystem, when the ingredients change, they will inevitably lead to the corresponding change of other ingredients, whose changes will ultimately turn affect on the initial ingredients.

7.1 Feedback Loops in Network Model

The network structure can be converted into the form of directed graph by the weight of interaction between each node. If the graph is not a tree (connected graph without simple cycles is a tree), there must be a cycle to form the feedback loop. For example, North America's network is converted to the following forms (**Figure 9**). There are many cycles such as A, B, C. When state shift occurs in node A, the state of node B will be influenced by the node A after first iteration. Then the state of node C will be influenced by the node B after second iteration. At last, the influence is returned to node A after third iteration.

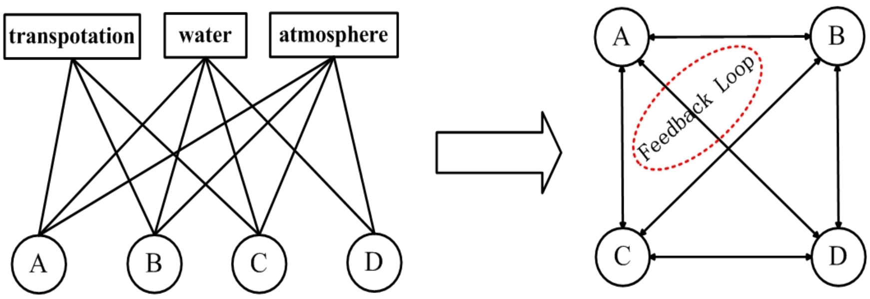

Figure 9: Feedback loop in the network of the North America.

7.2 Feedback loops in Ecological Competition and Predation Model

In ecological competition and predation model, various health measures interacting with each other constitute a network structure (**Figure 5**). It is convenient to find cycles to form feedback loop. A simple example, the increasing of population will lead to a reduction of resources, while the reduction of resources inhibits the increase of the population. It's a negative feedback loop that guarantees the equilibrium of ecosystem after finite time.

8 Predictive Results

We predict the Earth's future health measures only considering the interactions among the United States, the United Kindom , Canada, China and Brazil. To study the impact of the different policies on future health measures, we propose firstly some scenarios that are global policies. For simplicity, here are some assumptions:

- The Earth's health measures are the average of health measures of above five nations.

- The tipping point is where the population is twice as much as the current population.
- The 1 unit represents 30 years in horizontal axis that is derived by the rule of proportion.

8.1 Scenarios

Basic Scenario

As for a base case, we presume government don't design any policies to protect global ecosystem. Results are given in **Figure 10**. After 140 years, population increases to twice as much as the current population. It might be a tipping points for global ecosystem.

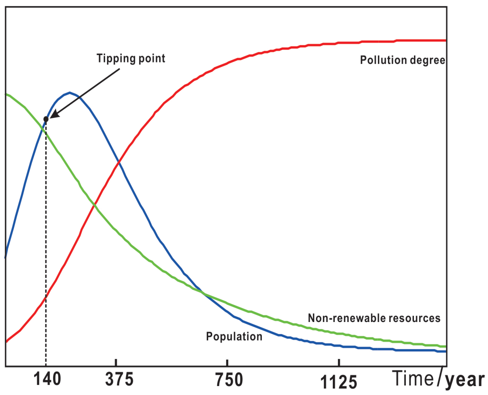

Figure 10: Population,non-renewable resources and pollution degree curve in base Scenario.

Scenario 1:Increasing Productivity

The increase in productivity will permit a reduction of energy consumption per capita. It can be represented by the change of coefficients:

- Increasing γ_1, γ_2 and ζ_1, ζ_2, which represents the increasing supporting ability of resources.
- Decreasing α_3, α_4, which represents the reducing energy consumption per capita.
- Increasing γ_7 and ζ_7, which represents the increasing productivity for infrastructure construction.

Results are given in **Figure 11**; The consumption rate of non-renewable resources decrease, and the death rate of population also decrease after the peak. After 253 years, population increases to twice as much as the current population. This policy would move the tipping points forward 113 years with respect to the base scenarios.

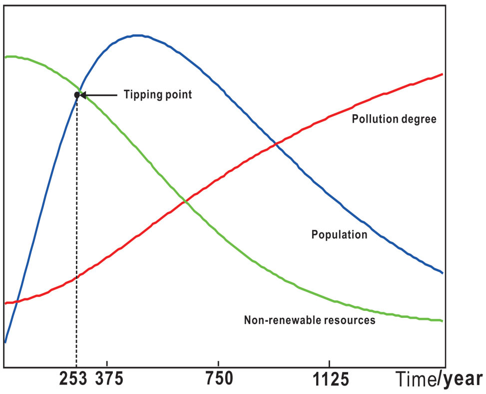

Figure 11: Population,non-renewable resources and pollution degree curve in Scenario 1.

Scenario 2: Heavy Investment in the Development of New Energy

The increasing investment in new energy will permit a larger potential of renewable resources . It can be represented by the change of coefficients:

- Increasing γ_1, γ_2 , which represents the increasing supporting ability of new energy.
- Decreasing α_4, which represents the reducing renewable resources consumption per capita because of new energy.
- Increasing γ_6 and γ_7, which represents the increasing ability of new energy for infrastructure construction.

Results are given in **Figure 12**; The consumption rate of non-renewable resources decrease obviously. After 188 years, population increases to twice as much as the current population. This policy would move the tipping points forward 48 years with respect to the base scenarios.

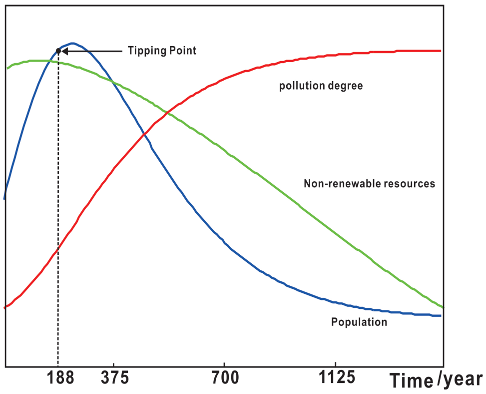

Figure 12: Population,non-renewable resources and pollution degree curve in Scenario 2.

Scenario 3: Controlling Contamination

The control of contamination will protect ecosystem including resources, other biological species and humanity themselves. It can be represented by the change of coefficients:

- Decreasing $\eta_1, \eta_2, \eta_3, \eta_4$, which represents the more healthy environment is more likely to live.

Results are given in **Figure 13**; The pollution degree has slowed and decrease after one thousand year. After 197 years, population increases to twice as much as the current population. This policy would move the tipping points forward 57 years with respect to the base scenarios.

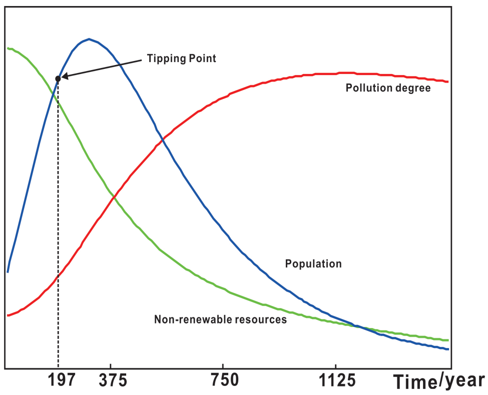

Figure 13: Population,non-renewable resources and pollution degree curve in Scenario 3.

Scenario 4: Best Cases

For a best-case scenario for health measures, we combine Scenarios 1 and 2 with less pollution. This case would produce a equilibrium after 260 years (**Figure 14**).

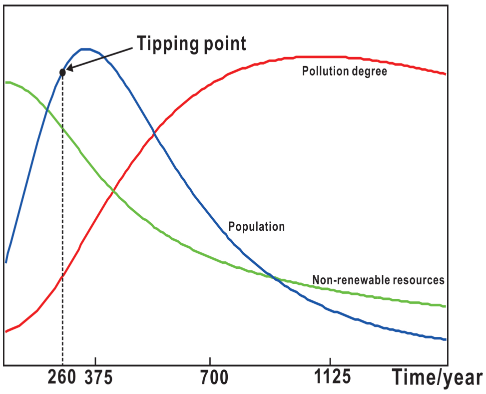

Figure 14: Population,non-renewable resources and pollution degree curve in best Scenario.

8.2 Impacts on Earth's health by Local Policies

Local policies have potential impacts on global ecosystem. We can study this phenomenon by our network model.

We assume that Canada design a new policy, corresponded with the Scenario 1, in 2013. Then predict the Earth's future health measures. Results are given in **Figure 15**; After 171 years, population increases to twice as much as the current population.This local policy would move the tipping points forward 31 years with respect to the base scenarios.

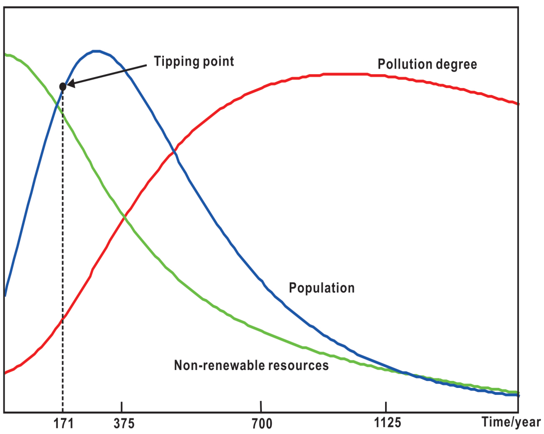

Figure 15: Demographic change in global and local conditions in the United States.

8.3 Proposals to Government

Based on the Scenarios above, we have three proposals to the government of each nation:

- Adopting a global policy instead of local policy.
- Improving productivity as soon as possible.
- If conditions permit, combining improving productivity with the control of environment contamination to prolong the arrival time of tipping points

9 The Strength and Weakness

Strength

- The dynamic global network model innovatively applies the theory and concept of data center to Global ecosystem. It can be used and deployed in a wide range from a block to a nation because of its scalability.
- The dynamic global network model considers not only the intrinsic change rule based on the ecological competition and predation model, but also the multiple interactions, feedback loops based on the network model. As a result, the prediction of future Earth's health is more scientific.
- The network model guarantees a convenient way to detect critical nodes and relationships by means of graphic theory.

Weakness

- The dynamic global network model requires a mass of data to predict accurately, which is impossible in such a short time.
- In the dynamic global network model, there are many parameters to be determined. We set some parameters artificially due to lack of related data.

10 Application in large database

Inspired by *PBIE* in *BiGCB* [4], we further enhance the applicability of the model in the worldwide by interface technology. Using the high-scalability of this model, we can build the global network from the block, city, state and nation to global recursively. Then, the only thing we should do is to design **a user interface**, which enable rapid access, visualization, and analysis of the local environmental health. It will also allow users to import their own data, which is a critical process to develop the next generation of predictive models of the biotic response to global change.

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