Dynamic Supernetworks for the Co-Evolution and Emergence of Integrated Social and Economic Networks: Modeling, Analysis, Computations, Visualization, and Applications

Anna Nagurney
John F. Smith Memorial Professor

Tina Wakolbinger
Doctoral Student Associate
Virtual Center for Supernetworks
Isenberg School of Management
University of Massachusetts
Amherst, Massachusetts 01003

June Dong
Professor
School of Business
State University of New York
Oswego, New York 13126

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Agenda

- Introduction
- The framework of supernetworks
- Social networks integrated with economic networks
- Knowledge supernetworks
- Future research
- Discussion

New Era of Decision-Making

- Increasing risk and uncertainty
- Importance of dynamics and realizing a fast and sound response to evolving events
- Complex interactions among decision-makers in organizations
- Alternative and at times conflicting criteria used in decision-making
- Global reach of many decisions
- High impact of many decisions.

Network-Based New Era

- Physical networks
  - Internet
  - Transportation/logistical networks
  - Other infrastructure networks such as Energy/Power networks…

- Abstract networks
  - Knowledge networks
  - Social networks

No longer are networks independent of one another but critically linked with major questions arising regarding decision-making and appropriate management tools.

Moreover, interactions between decision-makers and individuals can be modeled as networks and decision-making processes as well!

Reality of Today's Networks

- Large-scale nature and complexity of network topology
- Congestion
- Alternative behavior of users of the network, which may lead to paradoxical phenomena

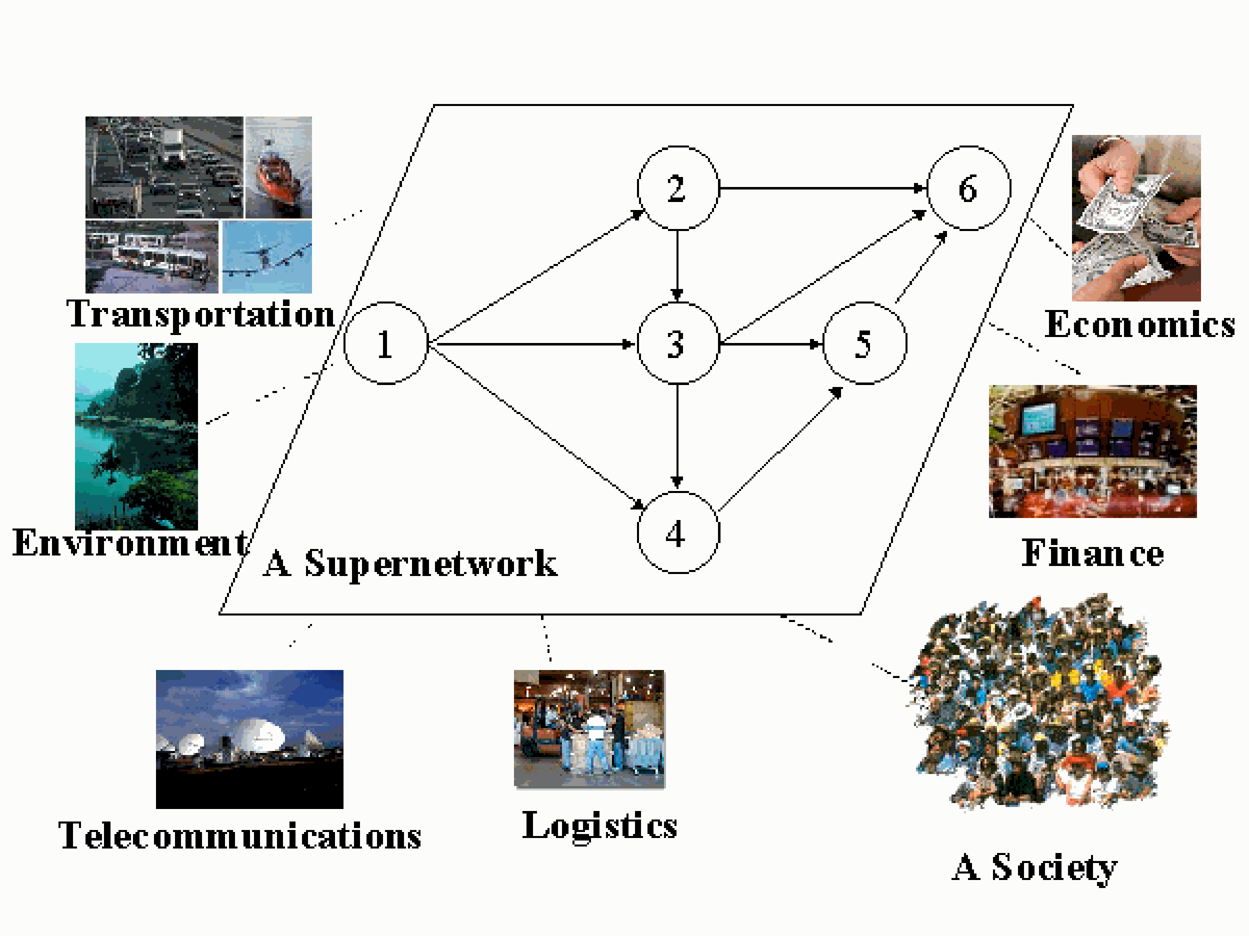
Supernetworks: A New Paradigm

- Supernetworks may be comprised of such networks as transportation, telecommunication, logistical, and/or financial networks.
- They may be multilevel as when they formalize the study of supply chain networks or multitiered as in the case of financial networks with intermediation.
- Decision-makers may be faced with multiple criteria; thus, the study of supernetworks also includes the study of multicriteria decision-making.

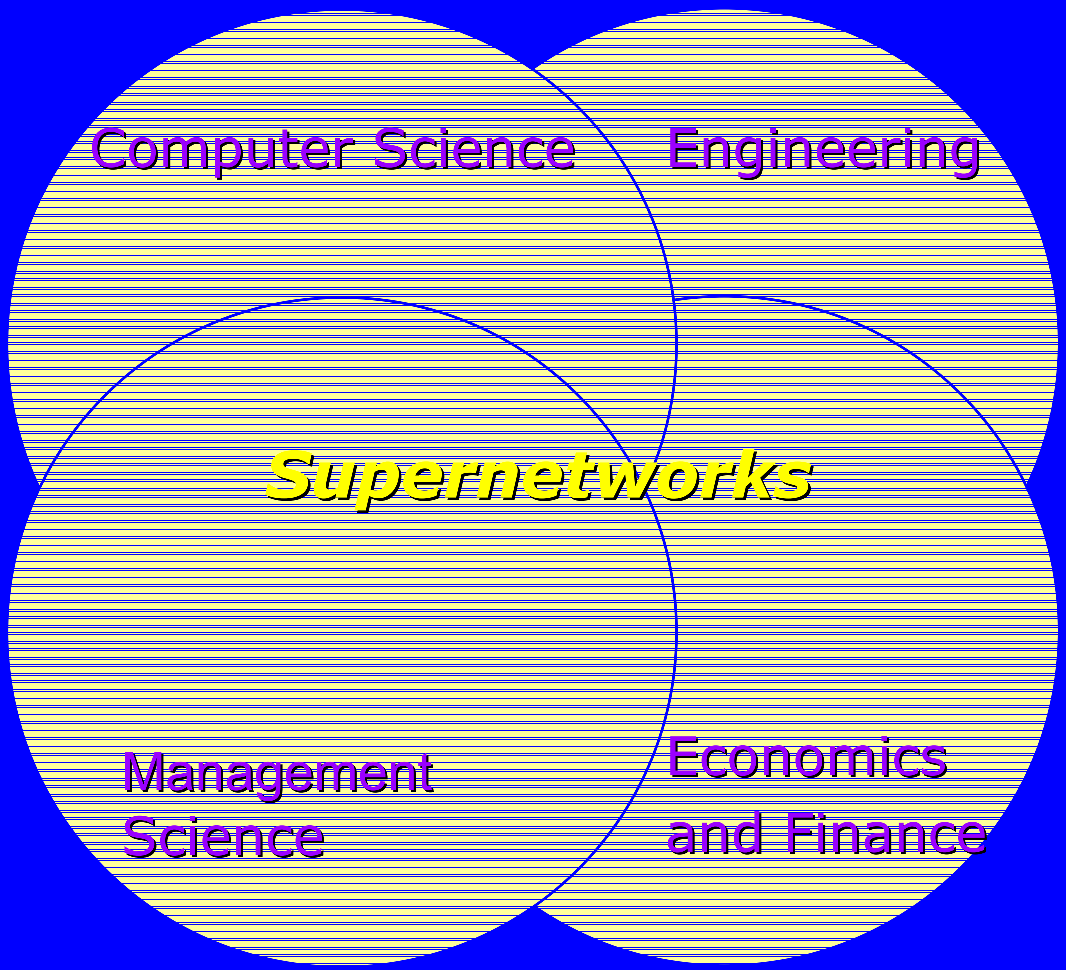
Introduction to Supernetworks

- Supernetworks: An Introduction to the Concept and its Applications with a Specific Focus on Knowledge Supernetworks
  Anna Nagurney and Tina Wakolbinger, 2004;
  see http://supernet.som.umass.edu

Supernetworks



A Multidisciplinary Approach



The Advantages of a Network Formalism

- Many present-day problems are concerned with flows (material, human, capital, informational, etc.) over space and time and, hence, ideally suited as an application domain for network theory
- Provides a graphical or visual depiction of different problems
- Helps to identify similarities and differences in distinct problems through their underlying network structure
- Enables the application of efficient network algorithms

Tools That We Have Been Using

- Network theory
- Optimization theory
- Game theory
- Variational inequality theory
- Projected dynamical systems theory (which we have been instrumental in developing)
- Network visualization tools

Applications of Supernetworks

- Telecommuting/Commuting Decision-Making
- Teleshopping/Shopping Decision-Making
- Supply Chain Networks with Electronic Commerce
- Financial Networks with Electronic Transactions
- Reverse Supply Chains with E-Cycling
- Energy Networks/Power Grids
- Knowledge and Social Networks

Role of Social Networks in Economic Transactions

Examples from the literature in the fields of

- Sociology
  - Embeddedness theory
    - Granovetter (1985)
    - Uzzi (1996)
- Economics
  - Williamson (1983)
  - Joskow (1988)
  - Crawford (1990)
  - Vickers and Waterson (1991)
  - Muthoo (1998)

Role of Social Networks in Economic Transactions (cont.)

- Marketing
  - Relationship marketing
    - Ganesan (1994)
    - Bagozzi (1995)

Supernetworks Integrating Social Networks

- Dynamic Supernetworks for the Integration of Social Networks and Supply Chains with Electronic Commerce: Modeling and Analysis of Buyer-Seller Relationships with Computations
  Tina Wakolbinger and Anna Nagurney, 2004;
  to appear in Netnomics

- The Evolution and Emergence of Integrated Social and Financial Networks with Electronic Transactions: A Dynamic Supernetwork Theory for the Modeling, Analysis, and Computation of Financial Flows and Relationship Levels
  Anna Nagurney, Tina Wakolbinger, and Li Zhao, 2004;
  see http://supernet.som.umass.edu

Supernetworks Integrating Social Networks

Models explicitly consider the role that relationship levels play in other network systems.

Supernetworks Integrating Social Networks

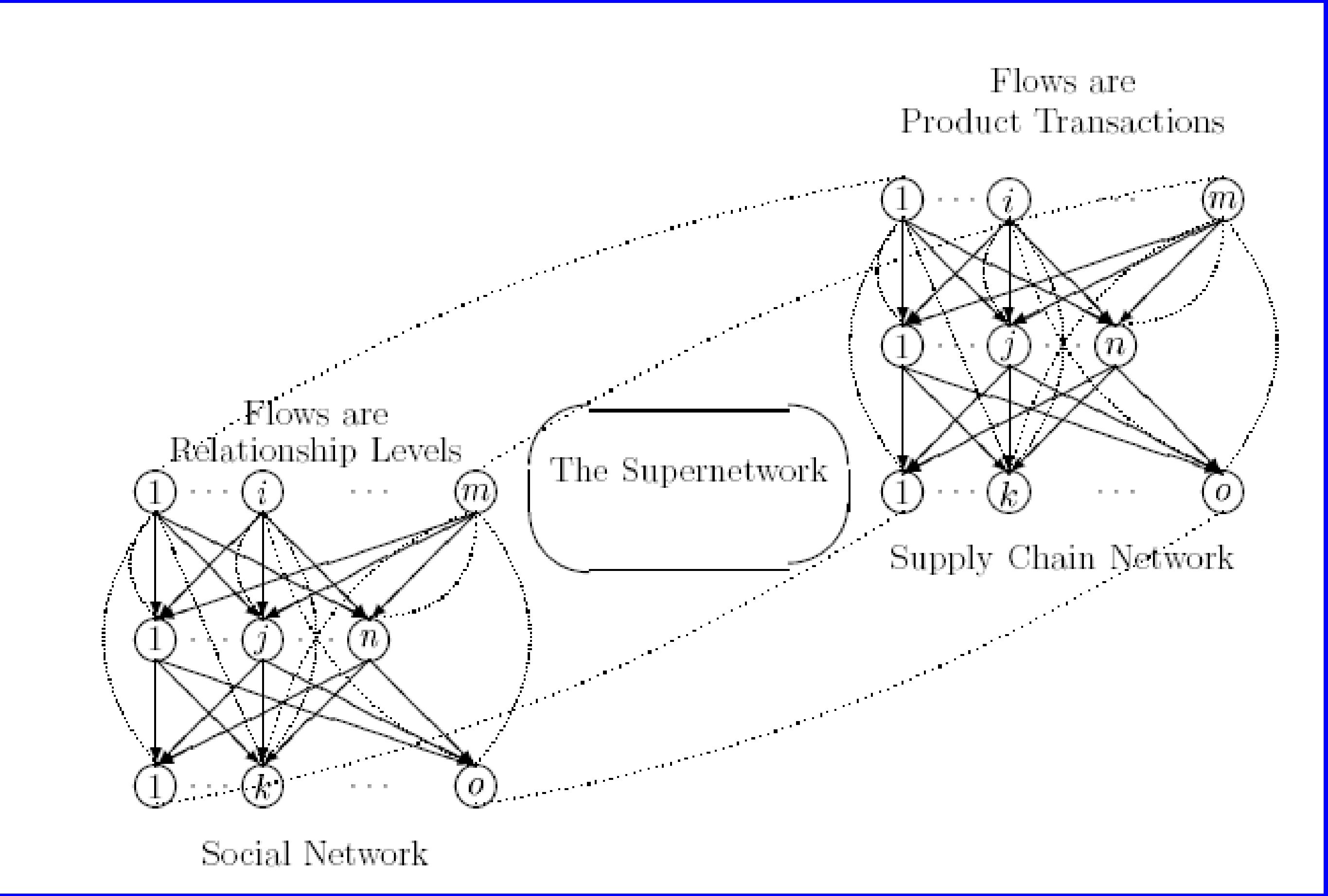
- Decision-makers in the network can decide about the relationship levels [0,1] that they want to establish.
- Establishing relationship levels incurs some costs.
- Higher relationship levels
  - Reduce transaction costs
  - Reduce risk
  - Have some additional value ("relationship value")

Supernetworks Integrating Social Networks

Dynamic evolution of

- Product transactions/financial flows and associated prices on the supply chain network/financial network with intermediation
- Relationship levels on the social network

Supernetwork Structure: Integrated Supply Chain/Social Network System



Multicriteria Decision-Makers

- Manufacturers and Retailers try to
  - Maximize profit
  - Minimize risk
  - Maximize relationship value
  - Individual weights assigned to the different criteria

Computational Procedure

We use the Euler Method to solve the Variational Inequality (VI) problems and to track the dynamic trajectories associated with the projected dynamical systems. The VI is in standard form:

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K},$$

The Euler Method

Step 0: Initialization

Set $X^0 \in \mathcal{K}$ and set $T = 0$. T is an iteration counter which may also be interpreted as a time period.

Step 1: Computation

Compute X^{T+1} by solving the variational inequality problem:

$$X^{T+1} = P_{\mathcal{K}}(X^T - a_T F(X^T)),$$

where $\{a_T\}$ is a sequence of positive scalars satisfying: $\sum_{T=0}^{\infty} a_T = \infty$, $a_T \to 0$, as $T \to \infty$

and $P_{\mathcal{K}}$ is the projection of X on the set $\mathcal{K}$ defined as:

$$y = P_{\mathcal{K}} X = \arg\min_{z \in \mathcal{K}} \|X - z\|.$$

Step 2: Convergence Verification

If $\|X^{T+1} - X^T\| \leq \epsilon$, for some $\epsilon > 0$, a prespecified tolerance, then stop; else, set $T = T + 1$, and go to Step 1.

Examples 1-3: Manufacturers

- 2 manufacturers
  - Production cost functions

$$f_1(q) = 2.5q_1^2 + q_1q_2 + 2q_1, \quad f_2(q) = 2.5q_2^2 + q_1q_2 + 2q_2.$$

  - Transaction cost functions

$$c_{ij1}(q_{ij1}, h_{ij1}) = .5q_{ij1}^2 + 3.5q_{ij1} - h_{ij1}, \quad \forall i, j,$$

$$c_{ij2}(q_{ij2}, h_{ij2}) = 1.5q_{ij2}^2 + 3q_{ij2} - .5h_{ij2}, \quad \forall i, j.$$

$$c_{ik}(q_{ik}, h_{ik}) = q_{ik}^2 + 2q_{ik} - 2h_{ik}, \quad \forall i, k.$$

Examples 1-3: Retailers

- 2 retailers
  - Handling costs

$$c_1(Q^1) = .5(\sum_{i=1}^{2}\sum_{l=1}^{2} q_{i1})^2, \quad c_2(Q^1) = .5(\sum_{i=1}^{2}\sum_{l=1}^{2} q_{i2})^2.$$

  - Transaction costs

$$\hat{c}_{ijl}(q_{ijl}, h_{ijl}) = 1.5q_{ijl}^2 + 3q_{ijl}, \quad \forall i, j, l.$$

Examples 1-3: Demand Markets

- 2 demand markets
  - Demand functions

$$d_1(\rho_3) = -2\rho_{31} - 1.5\rho_{32} + 1000, \quad d_2(\rho_3) = -2\rho_{32} - 1.5\rho_{31} + 1000,$$

  - Transaction costs

$$\hat{c}_{jk}(q_{jk}, h_{jk}) = q_{jk} - h_{jk} + 5, \quad \forall j, k,$$

$$\hat{c}_{ik}(q_{ik}, h_{ik}) = q_{ik} + 1, \quad \forall i, k.$$

Examples 1-3: Relationship Functions

- Relationship value functions

$$v_{ijl}(h_{ijl}) = h_{ijl}, \quad \forall i, j, l; \quad v_{ik}(h_{ik}) = h_{ik}, \quad \forall i, k; \quad v_{jk}(h_{jk}) = h_{jk}, \quad \forall j, k.$$

- Relationship cost functions

$$b_{ijl}(h_{ijl}) = 2h_{ijl} + 1, \quad \forall i, j, l;$$

$$b_{ik}(h_{ik}) = h_{ik} + 1, \quad \forall i, k;$$

$$b_{jk}(h_{jk}) = h_{jk} + 1, \quad \forall j, k.$$

Differences between Examples

- Example 1
  - Weight for relationship value and risk functions is equal to 1.
- Example 2
  - The weight for relationship value for the two manufacturers increased from 1 to 10.
- Example 3
  - The weight for relationship value for the two manufacturers increased from 10 to 20.

Examples 1-3: Product Transactions

- Example 1

$$Q^{1*} := q^*_{111} = q^*_{121} = q^*_{211} = q^*_{221} = 3.4622; \quad q^*_{112} = q^*_{122} = q^*_{212} = q^*_{222} = 2.3914.$$

$$Q^{2*} := q^*_{11} = q^*_{12} = q^*_{21} = q^*_{22} = 13.3016.$$

$$Q^{3*} := q^*_{11} = q^*_{12} = q^*_{21} = q^*_{22} = 5.8521.$$

- Example 2

$$Q^{1*} := q^*_{111} = q^*_{121} = q^*_{211} = q^*_{221} = 3.4791; \quad q^*_{112} = q^*_{122} = q^*_{212} = q^*_{222} = 2.4027,$$

$$Q^{2*} := q^*_{11} = q^*_{12} = q^*_{21} = q^*_{22} = 13.2790.$$

- Example 3

$$Q^{1*} := q^*_{111} = q^*_{121} = q^*_{211} = q^*_{221} = 3.4904; \quad q^*_{112} = q^*_{122} = q^*_{212} = q^*_{222} = 2.4102;$$

$$Q^{2*} := q^*_{11} = q^*_{12} = q^*_{21} = q^*_{22} = 13.2790,$$

$$Q^{3*} := q^*_{11} = q^*_{21} = q^*_{21} = q^*_{22} = 5.8696.$$

Examples 1-3: Prices

- Example 1

$$\epsilon_1^* = \epsilon_2^* = 263.9186,$$

$$\rho_{31}^* = \rho_{32}^* = 274.7686.$$

- Example 2

$$\epsilon_1^* = \epsilon_2^* = 264.1087,$$

$$\rho_{31}^* = \rho_{32}^* = 274.7666.$$

- Example 3

$$\epsilon_1^* = \epsilon_2^* = 264.2347$$

$$\rho_{31}^* = \rho_{32}^* = 274.7649.$$

Examples 1-3: Relationship Levels

- Example 1

$$h^*_{ij1} = h^*_{jk} = h^*_{ik} = 0, \forall i, j, k \qquad h^*_{ij2} = 1 \quad \forall i, j$$

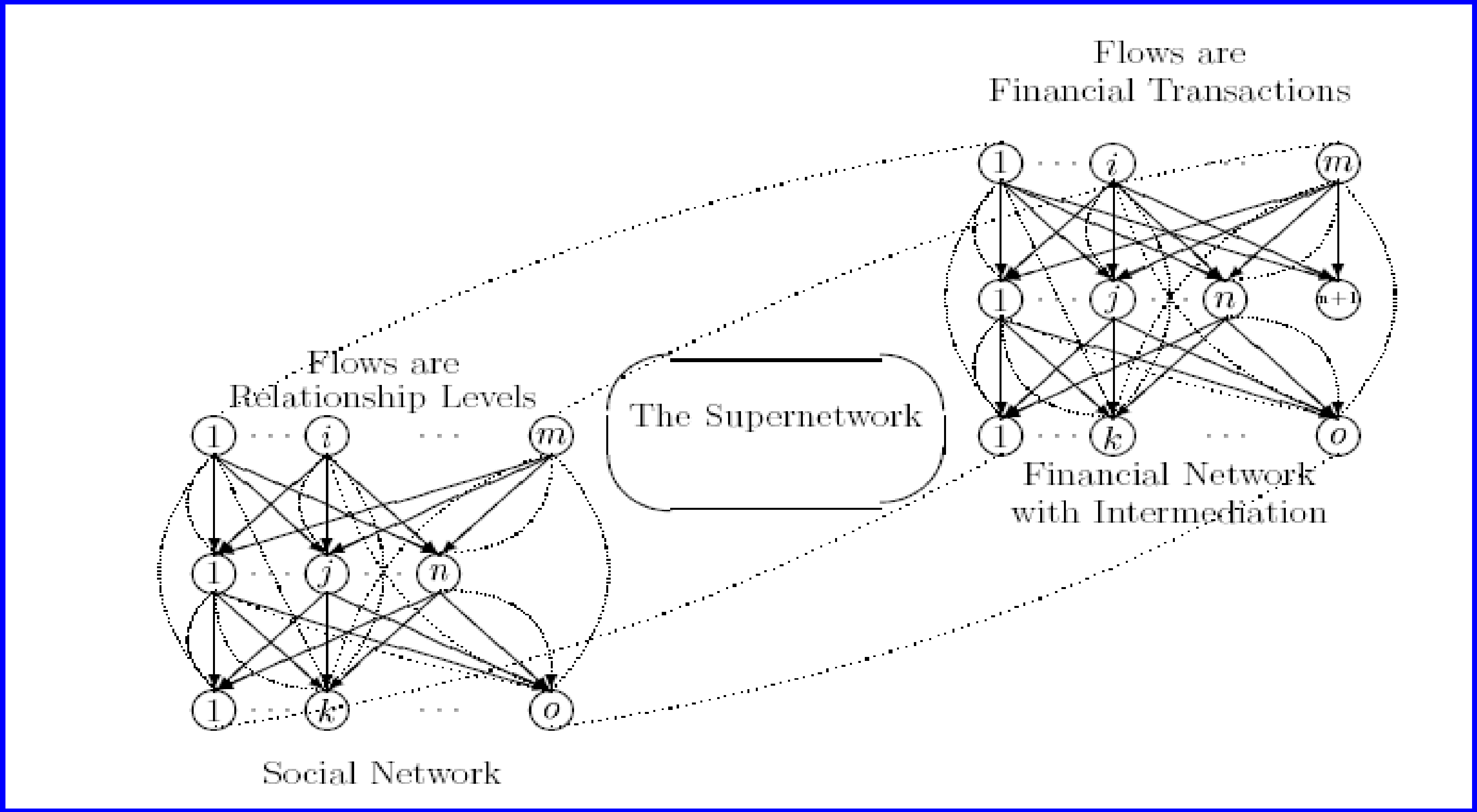
- Example 2

$$h^*_{ijl} = 1, \quad \forall i, j, l; \quad h^*_{jk} = .2179, \quad \forall j, k; \quad h^*_{ik} = 0, \quad \forall i, k.$$

- Example 3
  - Like example 2 except for

$$h^*_{jk} = .3700, \quad \forall j, k.$$

Supernetwork Structure: Integrated Financial/Social Network System

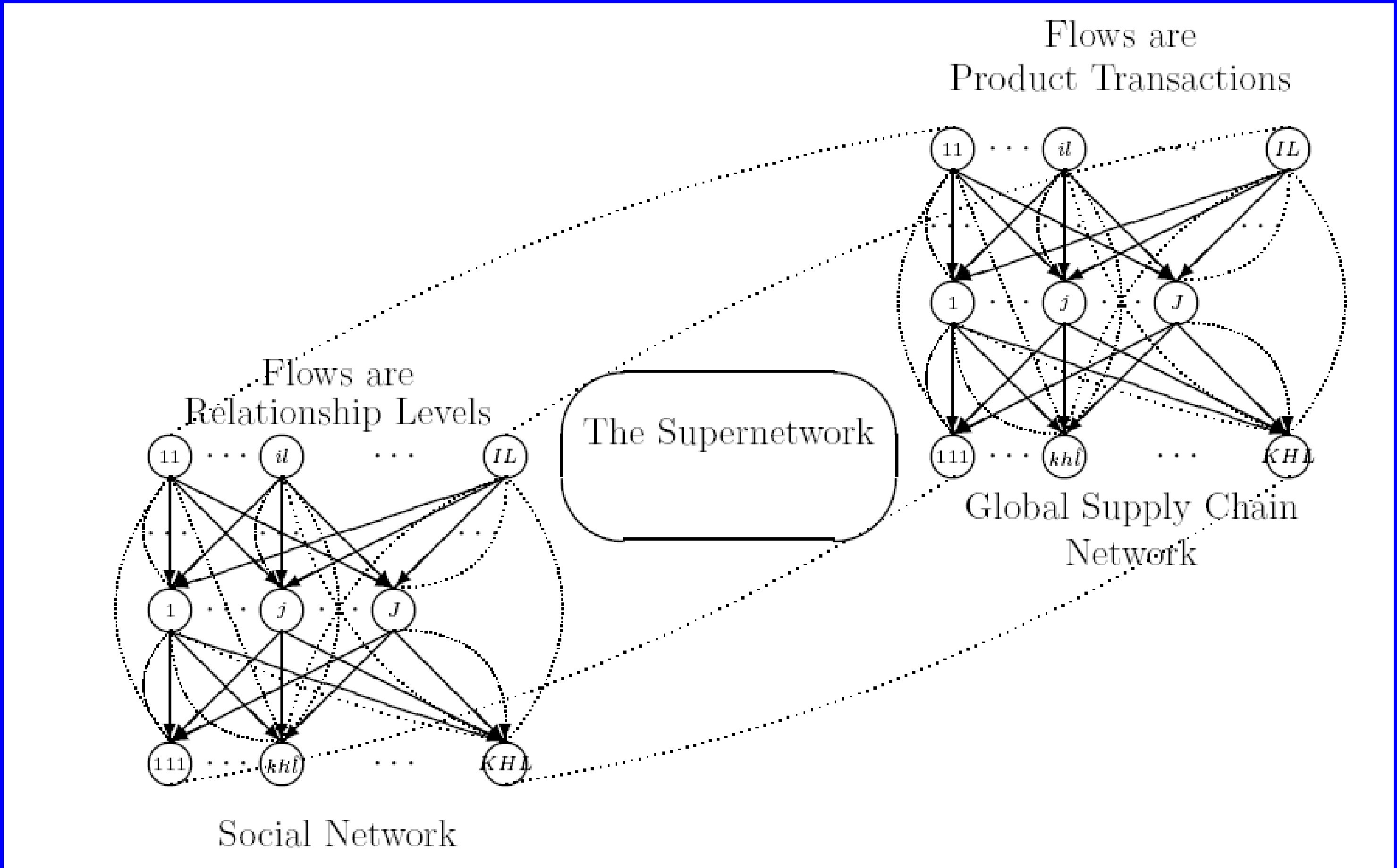


Extensions to Global Applications

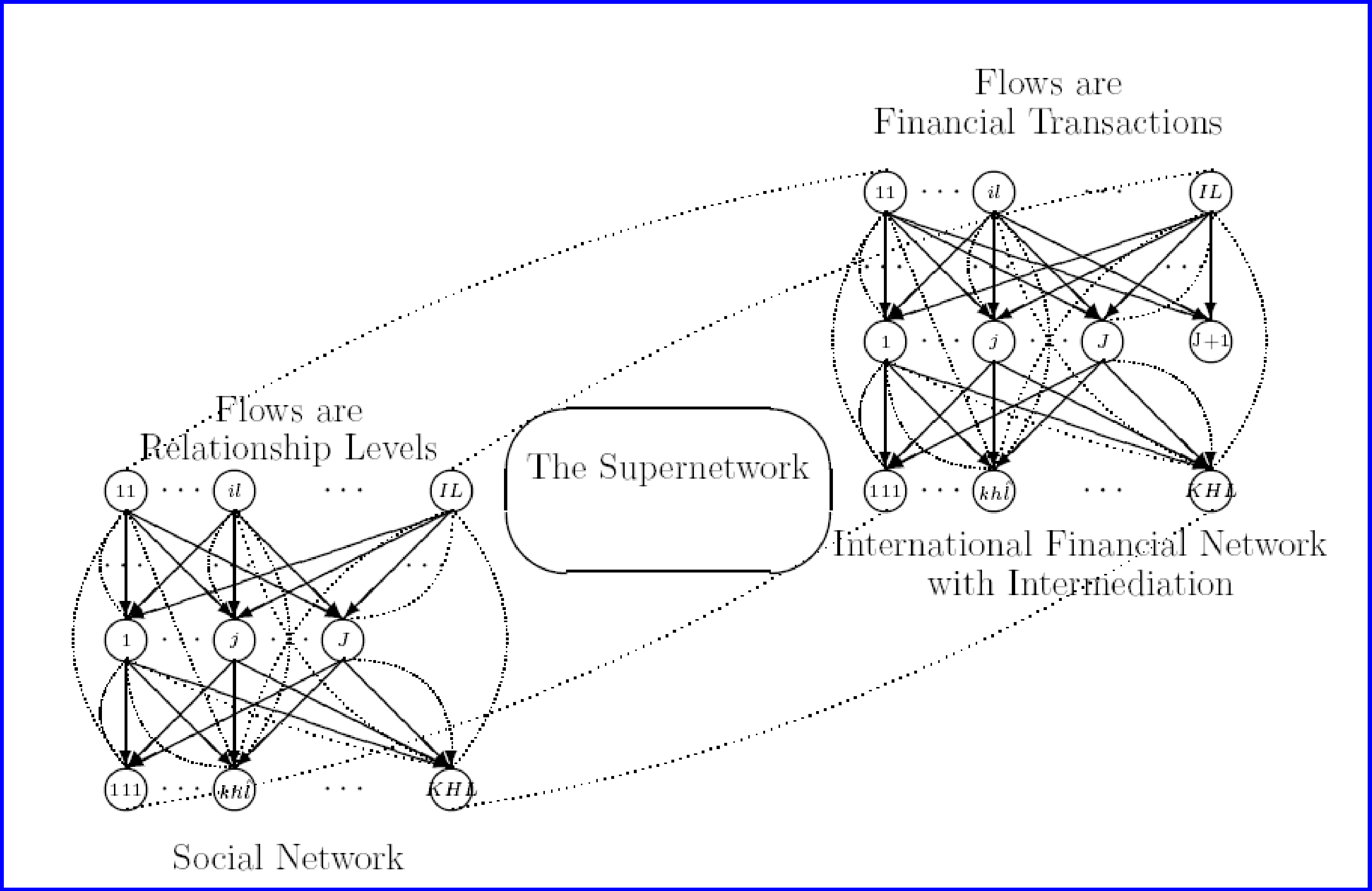
- Financial Engineering of the Integration of Global Supply Chain Networks and Social Networks with Risk Management
  Jose M. Cruz, Anna Nagurney, and Tina Wakolbinger; see http://supernet.som.umass.edu

- The Co-Evolution and Emergence of Integrated International Financial Networks and Social Networks: Theory, Analysis, and Computations
  Anna Nagurney, Jose M. Cruz, and Tina Wakolbinger; see http://supernet.som.umass.edu

Supernetwork Structure: Integrated Global Supply Chain/Social Network System



Supernetwork Structure: Integrated Global Financial/Social Network System



Multicriteria Decision-Makers

- Agents with sources of funds and intermediaries try to
  - Maximize net revenue
  - Minimize risk
  - Maximize relationship value
  - Individual weights assigned to the different criteria

Interactions among decision-makers in different organizations (producers, intermediaries, consumers)

↓

Single knowledge producing organization to provide greater refinements

The Knowledge Supernetwork Model

The knowledge supernetwork model helps decision-makers determine how to best use their resources to most efficiently produce the knowledge products.

This research is forthcoming in **Mathematical and Computer Modelling** (paper co-authored by Nagurney and Dong).

The Knowledge Supernetwork Model

- Can support decision-makers that try
  - To determine the optimal allocation of resources
  - To schedule the activities.

- Captures the alternatives available of a graphical format and by providing
  - The optimal allocation of activities as well as resources
  - Their dynamic development
  - Possible alternatives
  - Their related benefits and costs.

Knowledge Production

- Knowledge production can be described as a process "by which standard resources, which are available in open markets … are used and combined within the organizational context … in order to produce" (Ciborra and Andreu (2001)) explicit knowledge goods that are of measurable value to certain target customers

Special Characteristics of Knowledge Products

- Nonrival consumption (Liebowitz)
  - Special demand situation
  - Problem of copies
- Quality depends on organizational and individual knowledge
- Standardization of production is more difficult or even impossible

Previous Knowledge Network Models

- Karlqvist and Lundqvist (1972)
- Andersson and Karlqvist (1976)
- Batten, Kobayashi, and Andersson (1989)
- Beckmann (1993, 1994)
- Kobayashi (1995)
- Nagurney (1999)

Goals of Knowledge Supernetworks

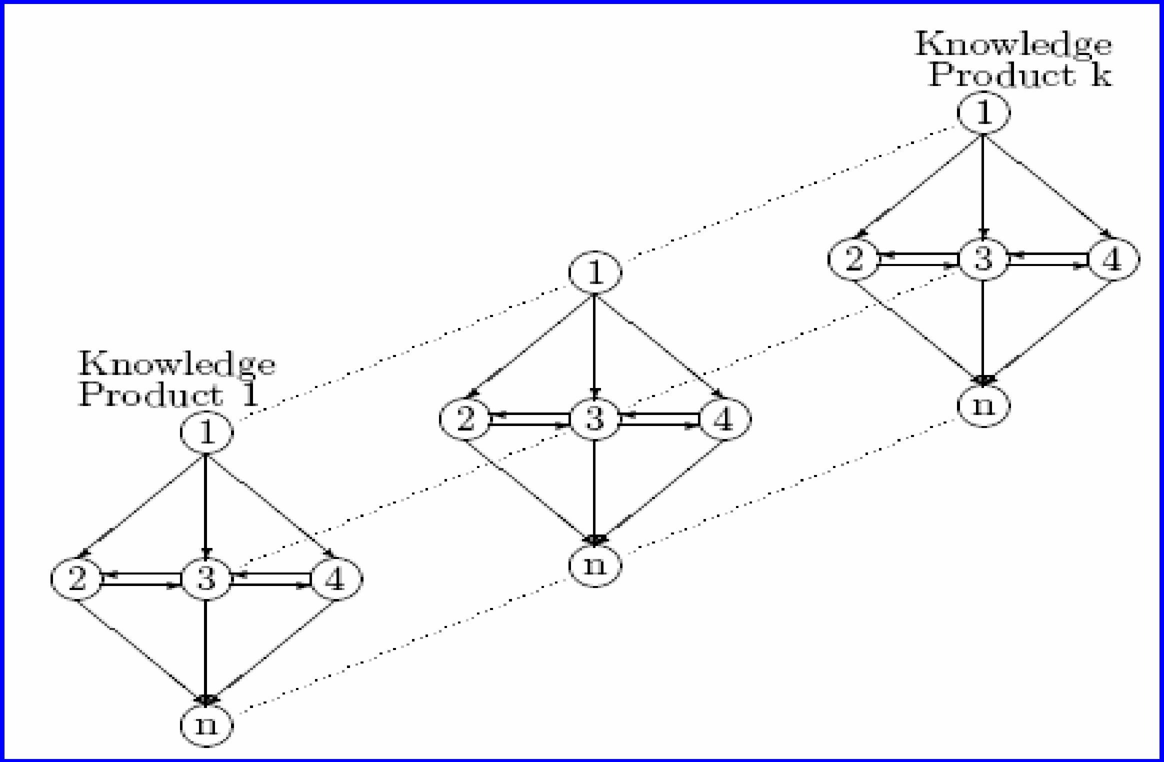
- To capture graphical format
- To provide alternatives
- To determine the optimal allocation of resources
- To schedule the activities

The Knowledge Supernetwork Model

- Network G = [N, L]
  - N notes
  - L directed links
    - Physical links
    - Abstract links
      - Associated with a factor of production or activity required for knowledge production
    - A path corresponds to a production process

    - Origin/Destination (O/D) pairs
  - An O/D pair corresponds to the beginning and the end of knowledge production

The Knowledge Supernetwork



The Multicriteria Decision-Making Problem

The decision-maker seeks to

$$\text{Minimize} \quad Z(\phi_1(f), \phi_2(f), \ldots \phi_H(f))$$

subject to

$$f \in \mathcal{K}.$$

Criteria Examples:

- Total (production) cost
- Total (production) time
- Total risk
- Total quality

Modeling Extensions

- Elastic Demand Model with Known Price Functions
- Elastic Demand Model with Known Demand Functions

Applications of the Knowledge Supernetwork Model

- News organizations
- Multinational research corporations
- Global financial institutions
- Intelligence agencies

Application to a News Organization (Eg. CNN)

- A knowledge organization
  - Produces knowledge
  - Disseminates knowledge
  - Its product is in the form of processed information or knowledge

Application to a News Organization (Eg. CNN)

- An O/D pair
  - News programs
- Products
  - News segments
- Demand for each product
  - Minutes
- Links
  - Activities that are needed to produce the news segment

Application to a Global Financial Institution

- O/D pairs
  - Clients
- Demands
  - Financial products
- Links
  - Transaction links (physical or electronic)

What Do We Gain from the Model?

- Incorporate various related elements (networks) into the supernetwork structure

- View problems in a systematic way to see the whole picture

- Incorporate multiple criteria into the decision-making process to capture the sometimes conflicting issues.

What Do We Gain from the Model?

- The model provides us with the optimal allocation of activities and the allocation of resources.

- It also will allow us to see the dynamic of the changes in reaching the optimal solution.

Future Directions

- Integration of social networks with knowledge networks
- Develop visualization software package
- Empirical study if data is available
- Incorporate risk and uncertainty into the models

The full text of the papers can be found under Downloadable Articles at:

http://supernet.som.umass.edu

Eugene M. Isenberg School of Management

Virtual Center for Supernetworks

Thank you!

Eugene M. Isenberg School of Management

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