Supernetworks: The Why, The How, and Applications

Anna Nagurney

John F. Smith Memorial Professor

Dept. of Finance and Operations Management

Isenberg School of Management

University of Massachusetts at Amherst

Eugene M. Isenberg School of Management

The Virtual Center for Supernetworks
http://supernet.som.umass.edu

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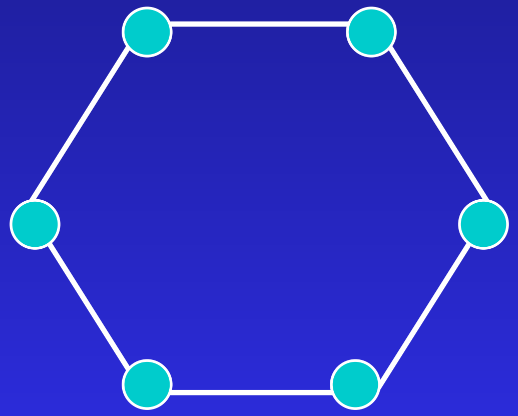
Network problems also arise in ***surprising and fascinating*** ways for problems, which at first glance and on the surface, may not appear to involve networks at all. Hence, ***the study of networks is not limited to only physical networks*** but also to *abstract* networks in which nodes do not coincide to locations in space.

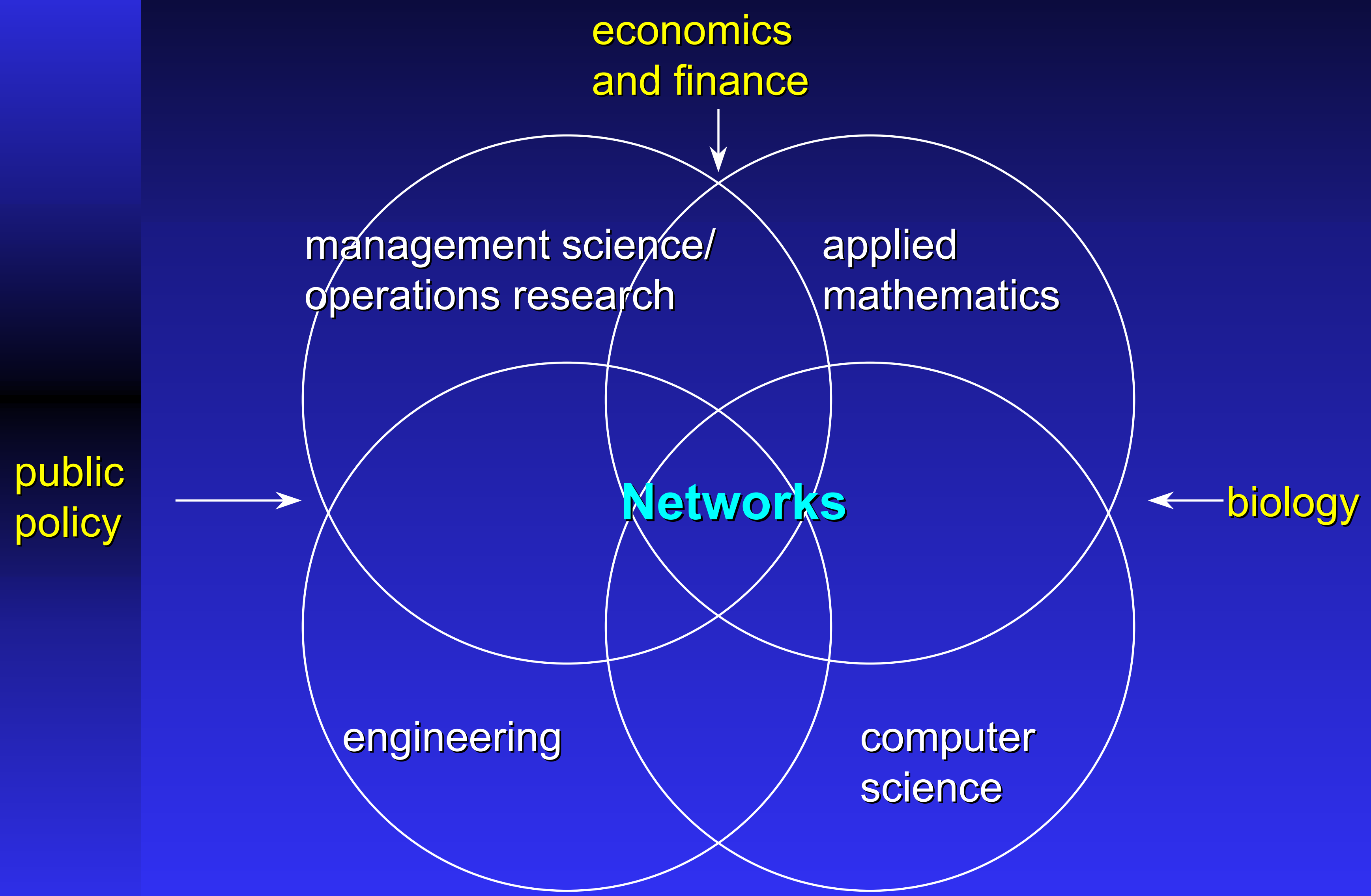
In fact, **Quesnay** in 1758 in his ***Tableau Economique*** introduced an abstract network in the form of a graph to depict the **circular flow of financial funds** in an economy.



The advantages of a scientific 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;
- allows for the study of disparate problems through a unifying methodology.


economics
and finance
management science/
operations research
applied
mathematics
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policy
Networks
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computer
science

Interdisciplinary Impact of Networks

Networks

Finance and Economics

- Interregional Trade
- General Equilibrium
- Industrial Organization
- Portfolio Optimization
- Flow of Funds Accounting

Engineering

- Energy
- Manufacturing
- Telecommunications
- Transportation

Sociology

- Social Networks
- Organizational Theory

Computer Science

- Routing Algorithms

Biology

- DNA Sequencing
- Targeted Cancer Therapy

Characteristics of Networks Today

- ***large-scale nature*** **and complexity of network topology;**
- ***congestion*;**
- **alternative behavior of users of the network, which may lead to *paradoxical phenomena*;**
- **the *interactions among networks* themselves such as in transportation versus telecommunications networks;**
- ***policies* surrounding networks today may have a *major impact* not only economically but also *socially, politically, and security-wise*.**

- **large-scale nature and complexity of network topology**
  - In **Chicago's Regional Network**, there are 12,982 nodes, 39,018 links, and 2,297,945 O/D pairs.
  - **AT&T's domestic network** has 100,000 O/D pairs. In their call detail graph applications (nodes are phone numbers, edges are calls) - 300 million nodes and 4 billion edges

- congestion is playing an increasing role in transportation networks:

  For example in the United States alone, congestion results in $100 billion in lost productivity annually, whereas the figure in Europe is estimated to be $150 billion.

  The number of cars is expected to increase by 50% by 2010 and to double by 2030.

Wasting Away in Traffic

	Annual delay hours/driver
Los Angeles	93
San Francisco - Oakland	73
Washington, DC	67
Dallas	61
Atlanta	60
Houston	58
Chicago	56
Boston	54
Detroit	53
Miami - Hialeah	52

Source: Texas Transportation Institute 2002 Data

- alternative behaviors of the users of the network
  - system-optimized versus
  - user-optimized, which may lead to

paradoxical phenomena.

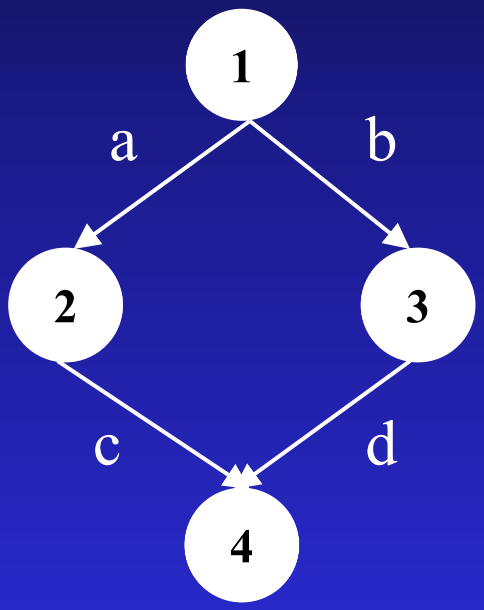
System-Optimization versus User-Optimization

In transportation networks, travelers select their routes of travel from an origin to a destination so as to minimize their own travel cost or travel time, which although *optimal* from an individual's perspective (*user-optimization*) may not be optimal from a societal one (*system-optimization*) where one has control over the flows on the network.

The Braess' Paradox

- Assume a network with a single O/D pair (1,4). There are 2 paths available to travelers: $p_1=(a,c)$ and $p_2=(b,d)$.
- For a travel demand of 6, the equilibrium path flows are $x_{p_1}{}^* = x_{p_2}{}^* = 3$ and
- The equilibrium path travel cost is

  $C_{p_1} = C_{p_2} = 83.$

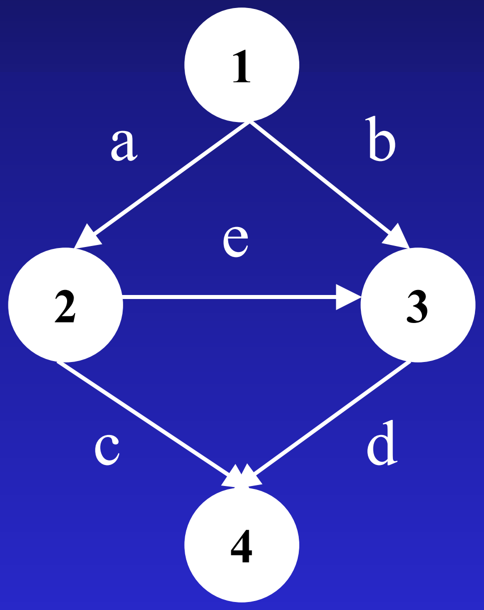


$c_a(f_a)=10\ f_a \quad c_b(f_b) = f_b+50$

$c_c(f_c) = f_c+50 \quad c_d(f_d) = 10\ f_d$

Adding a Link Increased Travel Cost for All!

- Adding a new link creates a new path p_3=(a,e,d).
- The original flow distribution pattern is no longer an equilibrium pattern, since at this level of flow the cost on path p_3, $C_{p_3}=70$.
- The new equilibrium flow pattern network is $x_{p_1}^* = x_{p_2}^* = x_{p_3}^*=2$.
- The equilibrium path travel costs: $C_{p_1} = C_{p_2} = C_{p_3} = 92$.



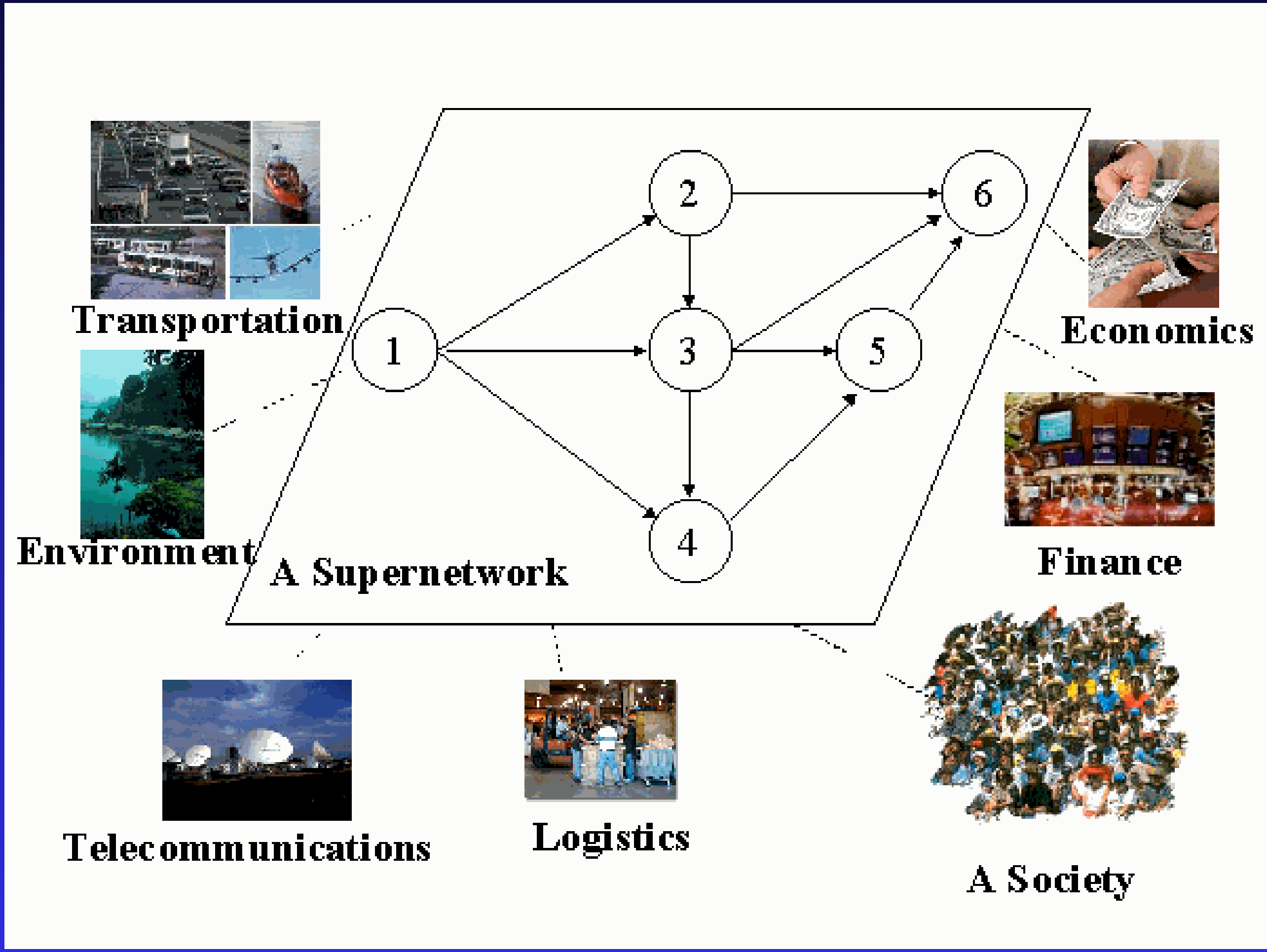
$c_e(f_e) = f_e + 10$

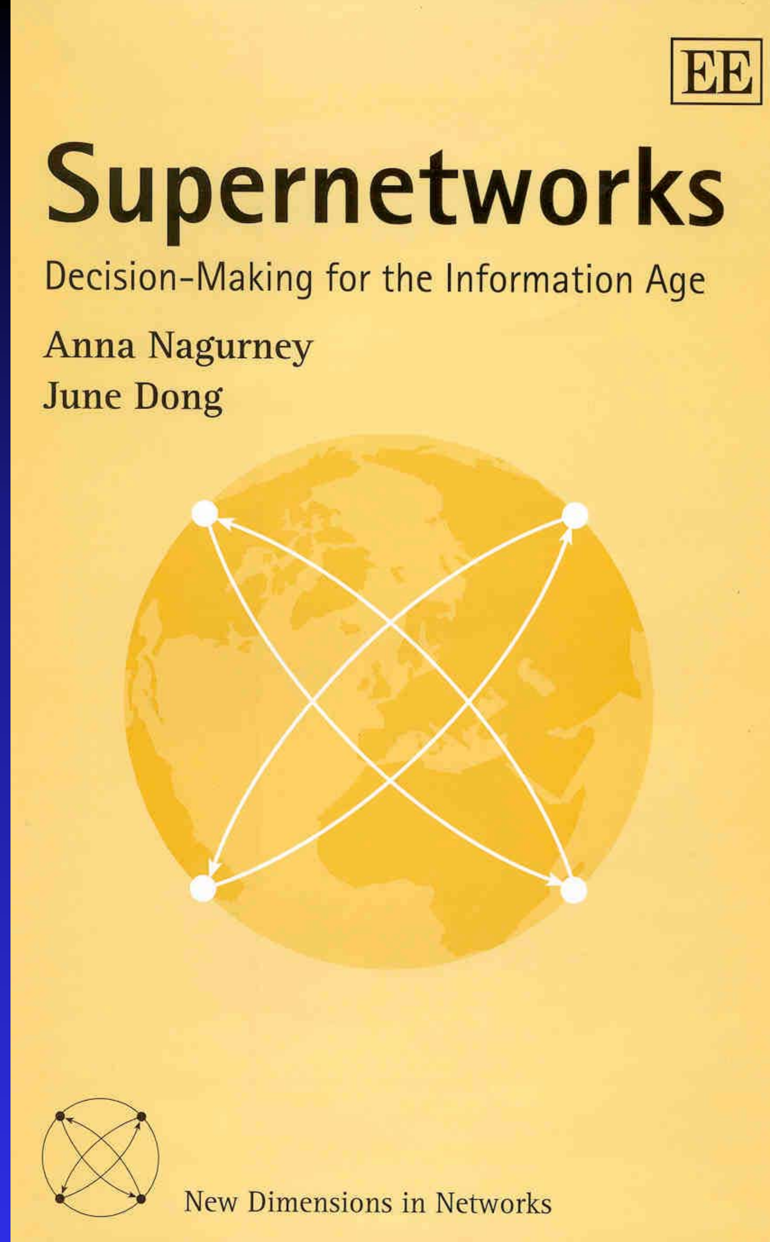
This phenomenon is also relevant to telecommunications networks and, in particular, to the Internet which is another example of a noncooperative network.

The Price of Anarchy!!!

A New Paradigm

Supernetworks: A New Paradigm

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Supernetworks
Decision-Making for the Information Age
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June Dong
New Dimensions in Networks

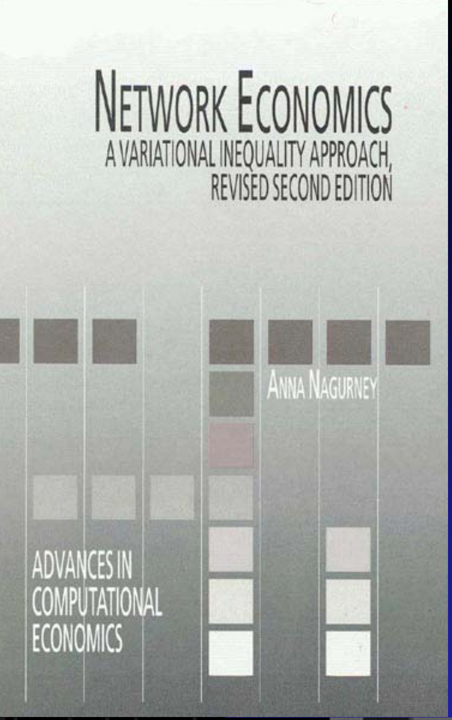
Supernetworks

- 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*.

New Tools

The tools that we have been using in our supernetworks research include:

- network theory
- optimization theory
- game theory
- variational inequality theory and
- projected dynamical systems theory (which we have been instrumental in developing)
- network visualization tools.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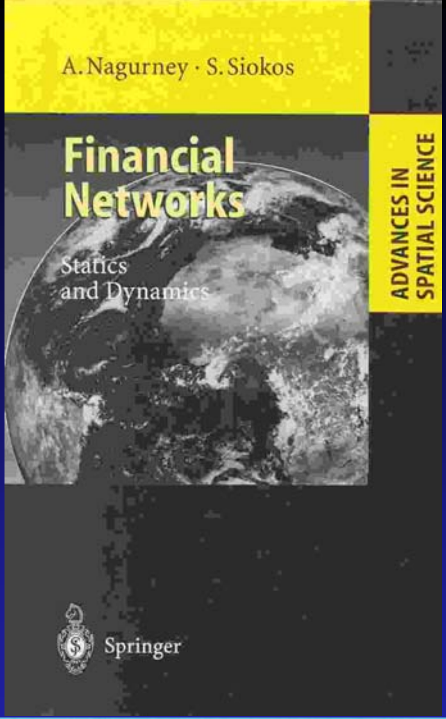
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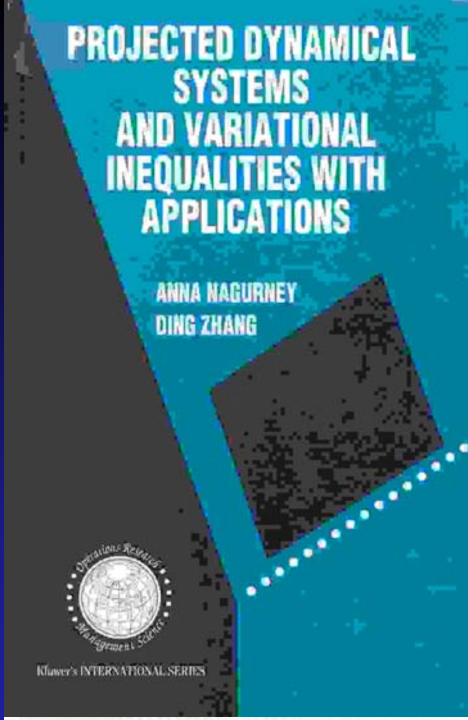
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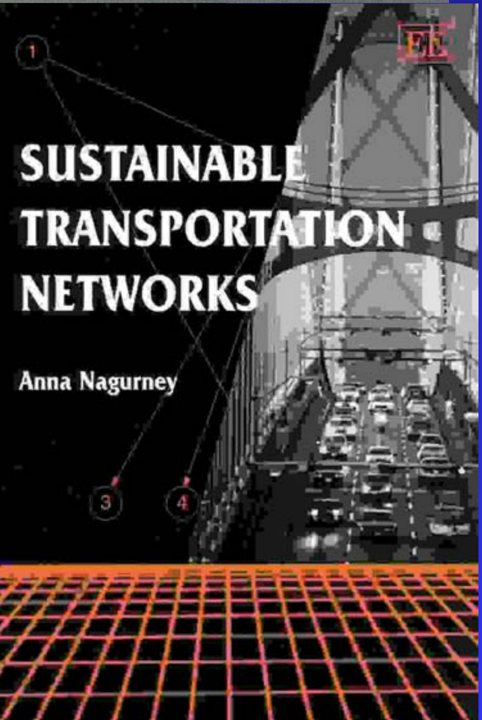
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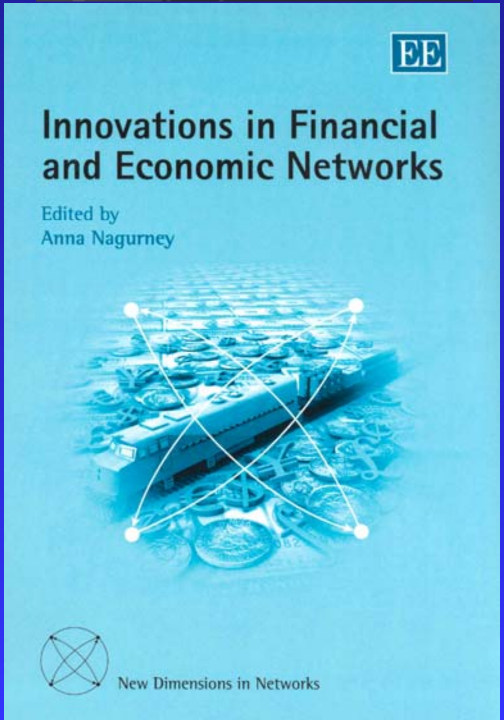
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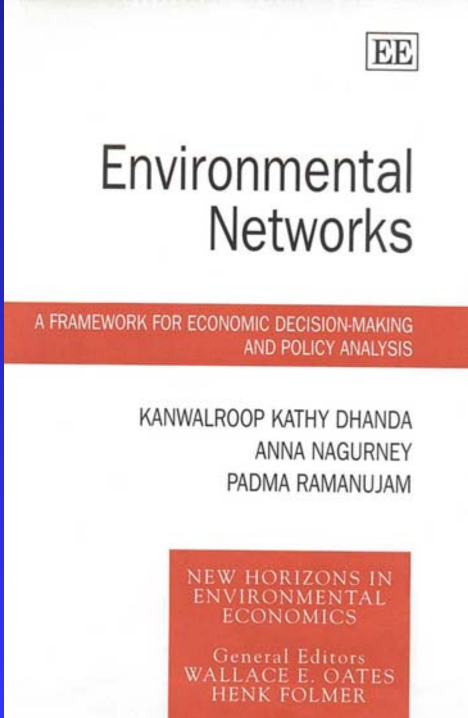
New Dimensions in Networks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A FRAMEWORK FOR ECONOMIC DECISION-MAKING
AND POLICY ANALYSIS
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- We are interested not only in addressing topological issues in terms of connectivity but in predicting the various flows on the networks whether physical or abstract subject to human decision-making under the associated constraints, be they budget, time, security, risk, and/or cost-related.

The Supernetwork Team
2005 - 2006













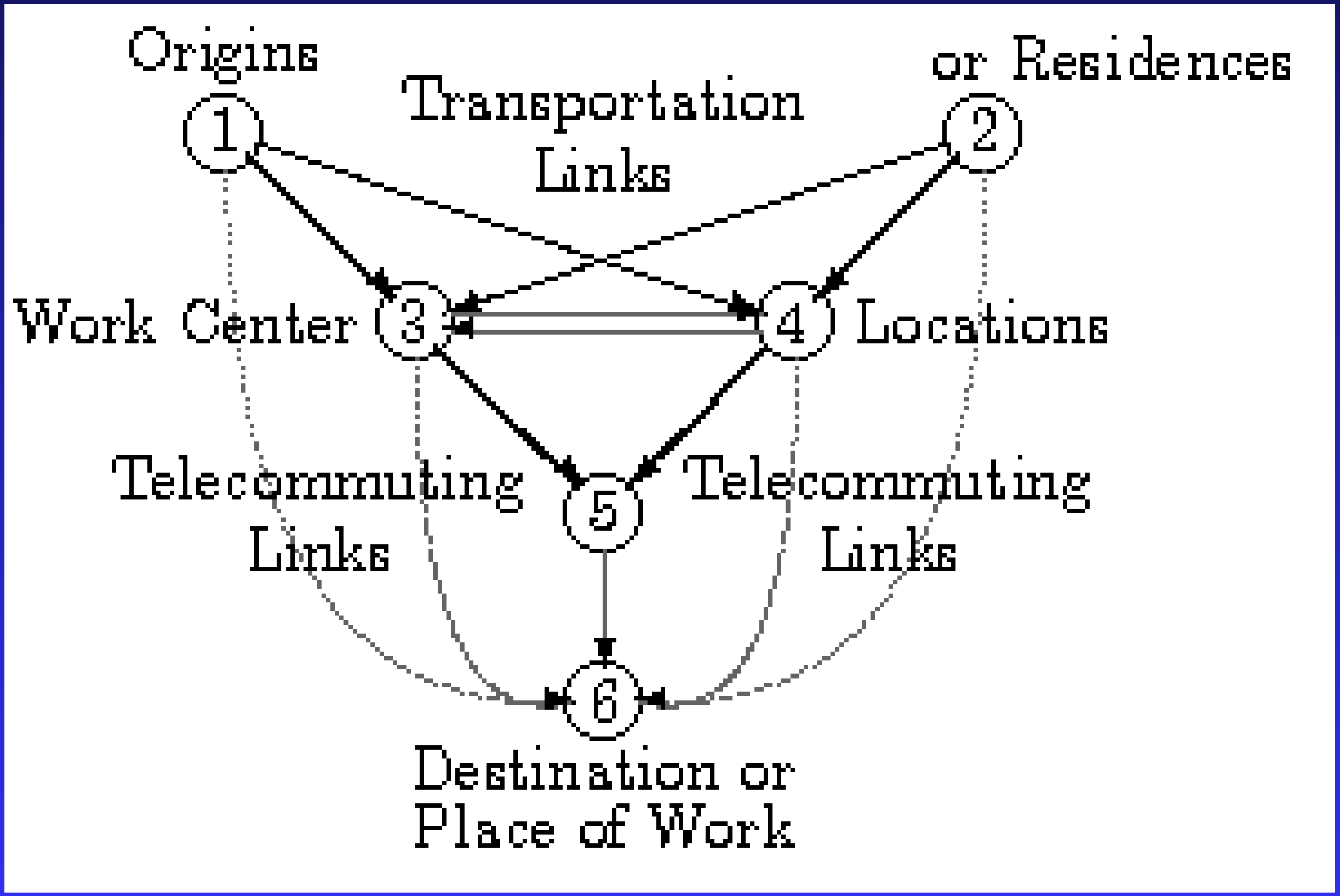


Novel Applications

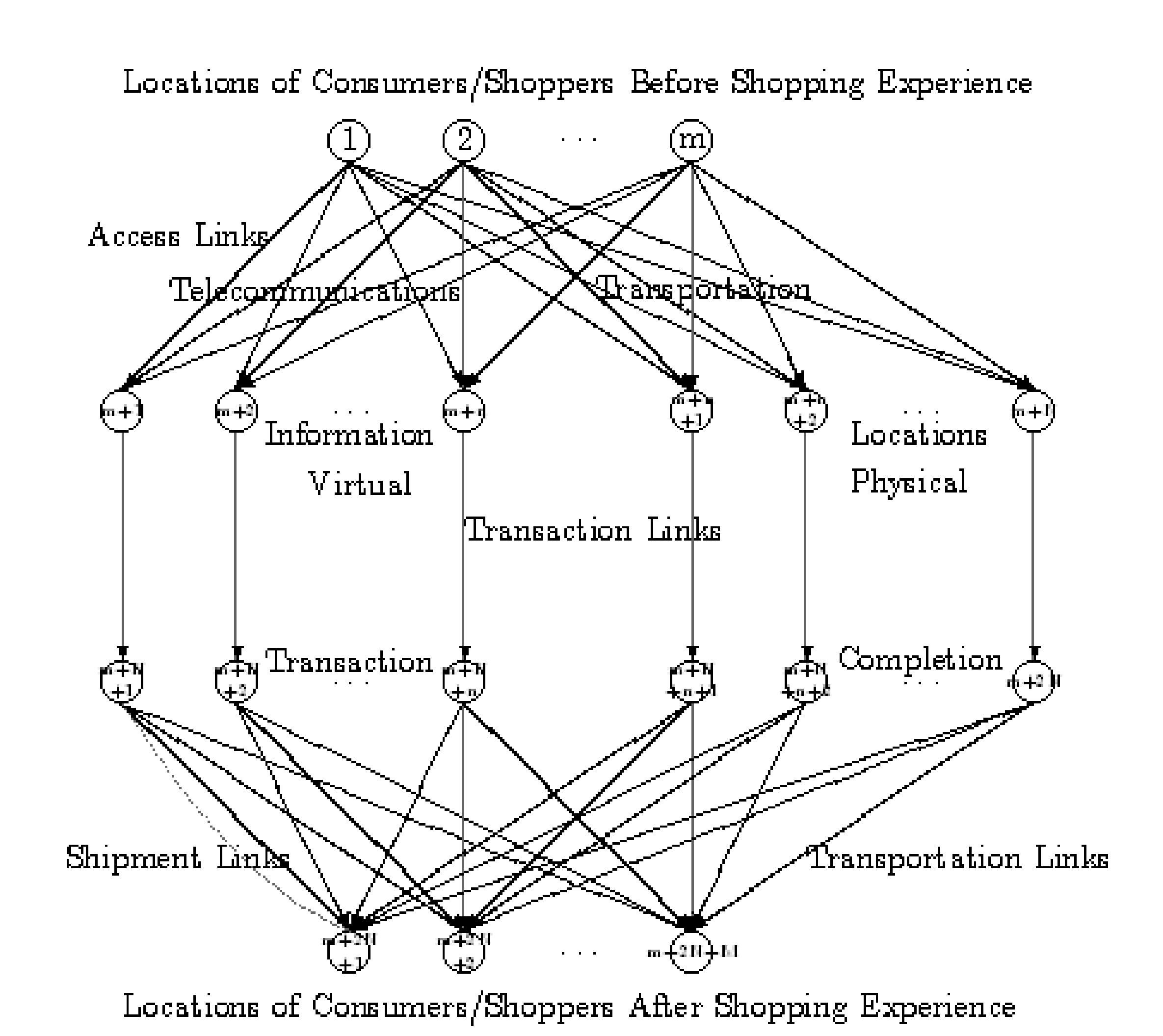
Applications of Supernetworks

- 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
- Knowledge Networks
- Energy Networks/Power Grids

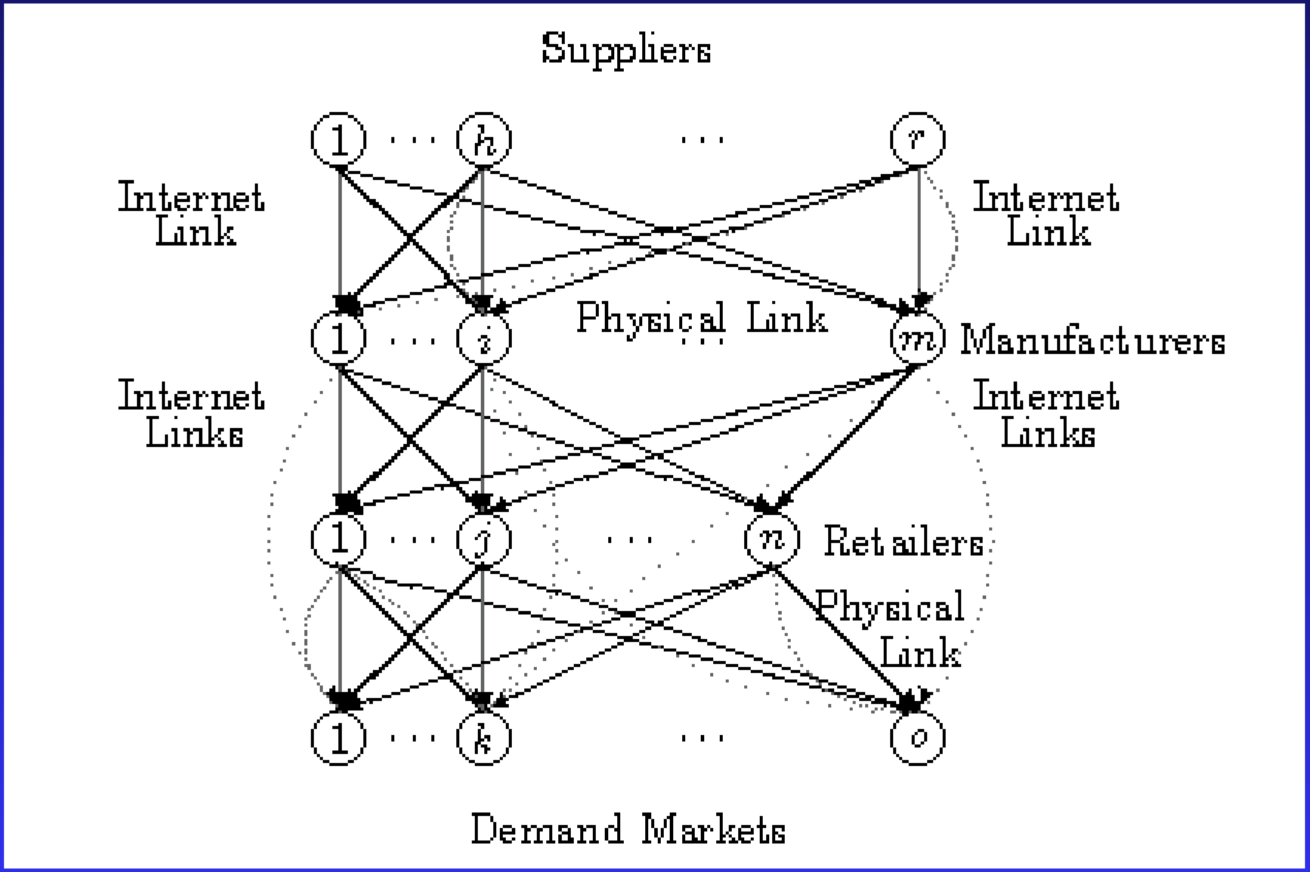
A Supernetwork Conceptualization of Commuting versus Telecommuting



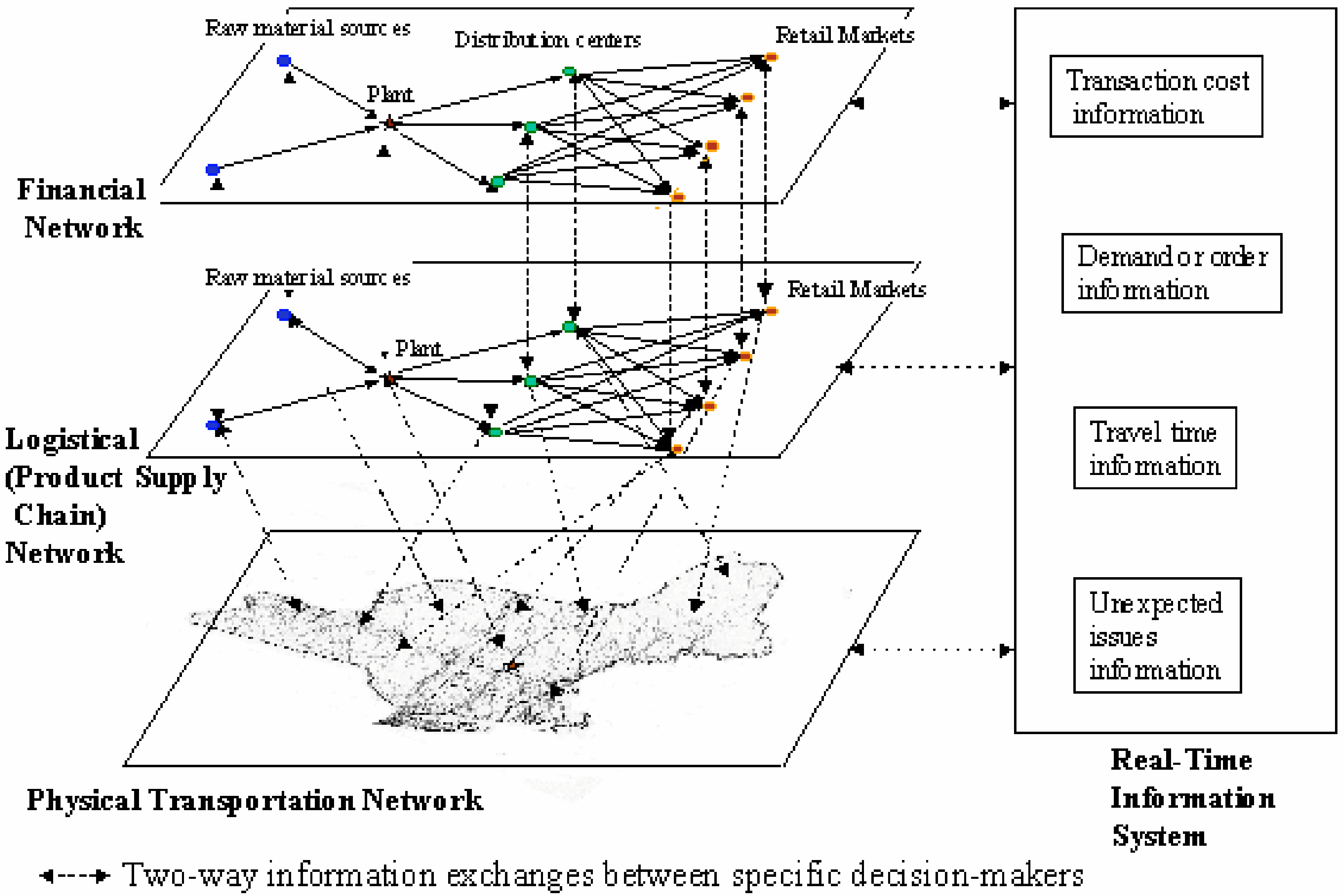
A Supernetwork Framework for Teleshopping versus Shopping



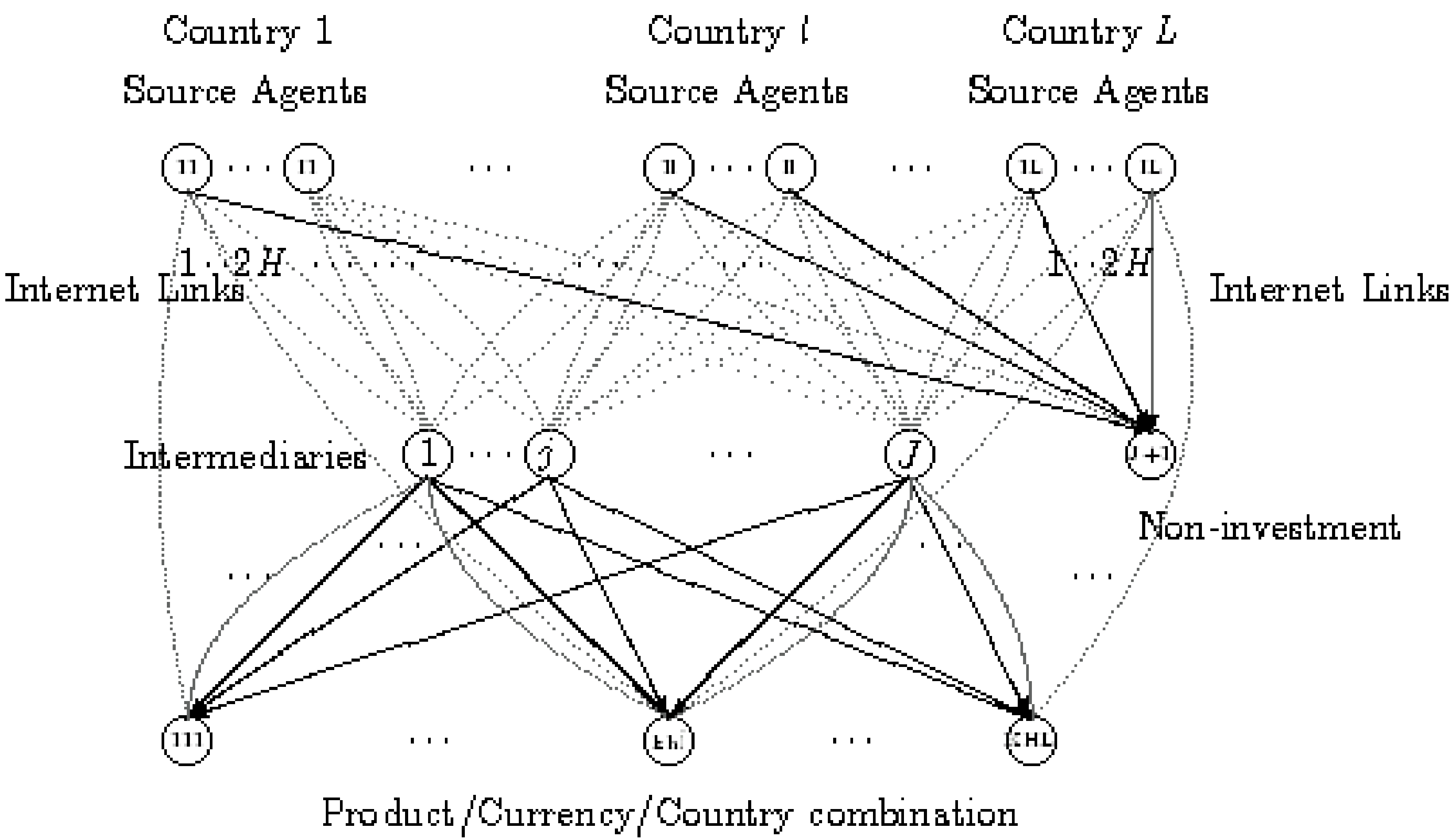
The Supernetwork Structure of a Supply Chain Network



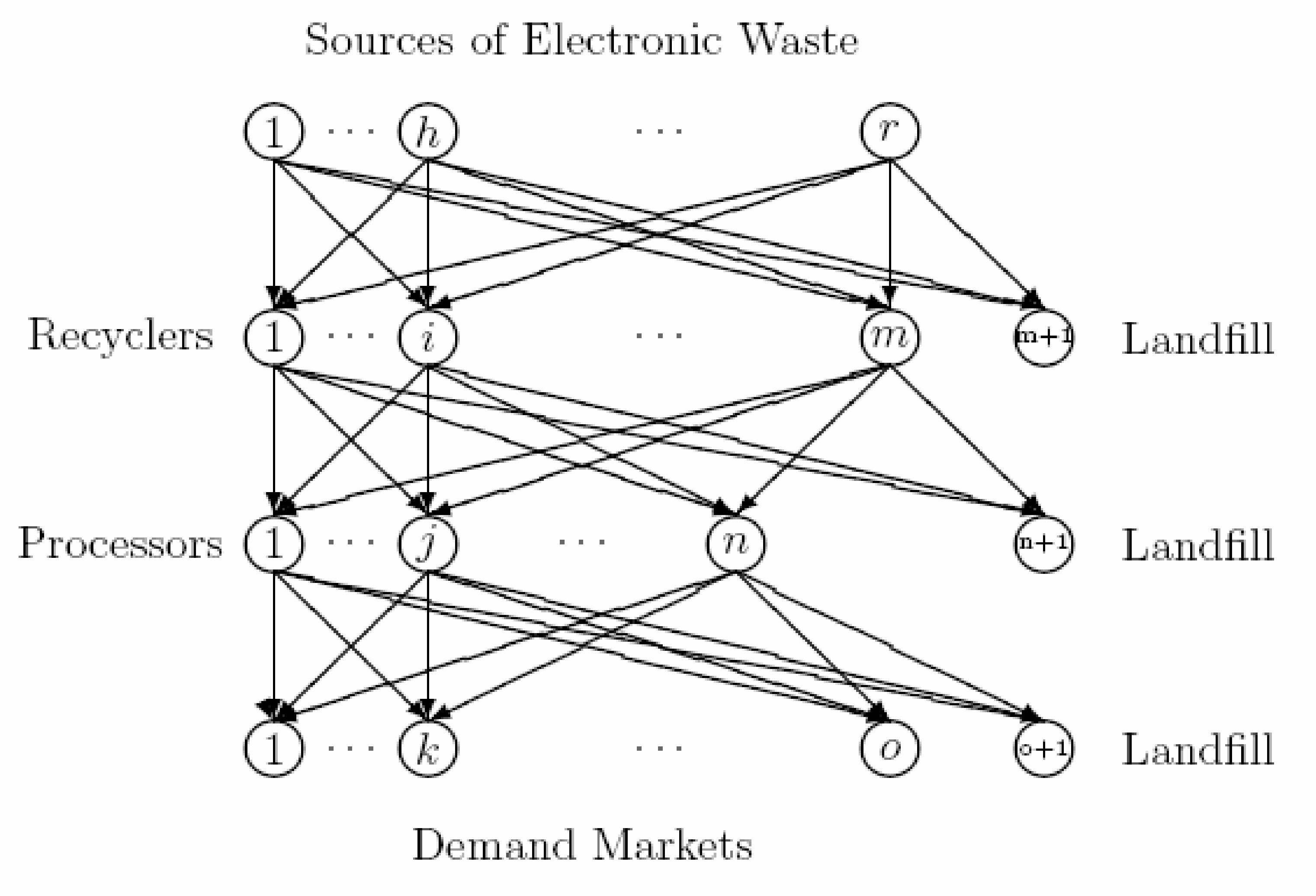
Supply Chain -Transportation Supernetwork Representation



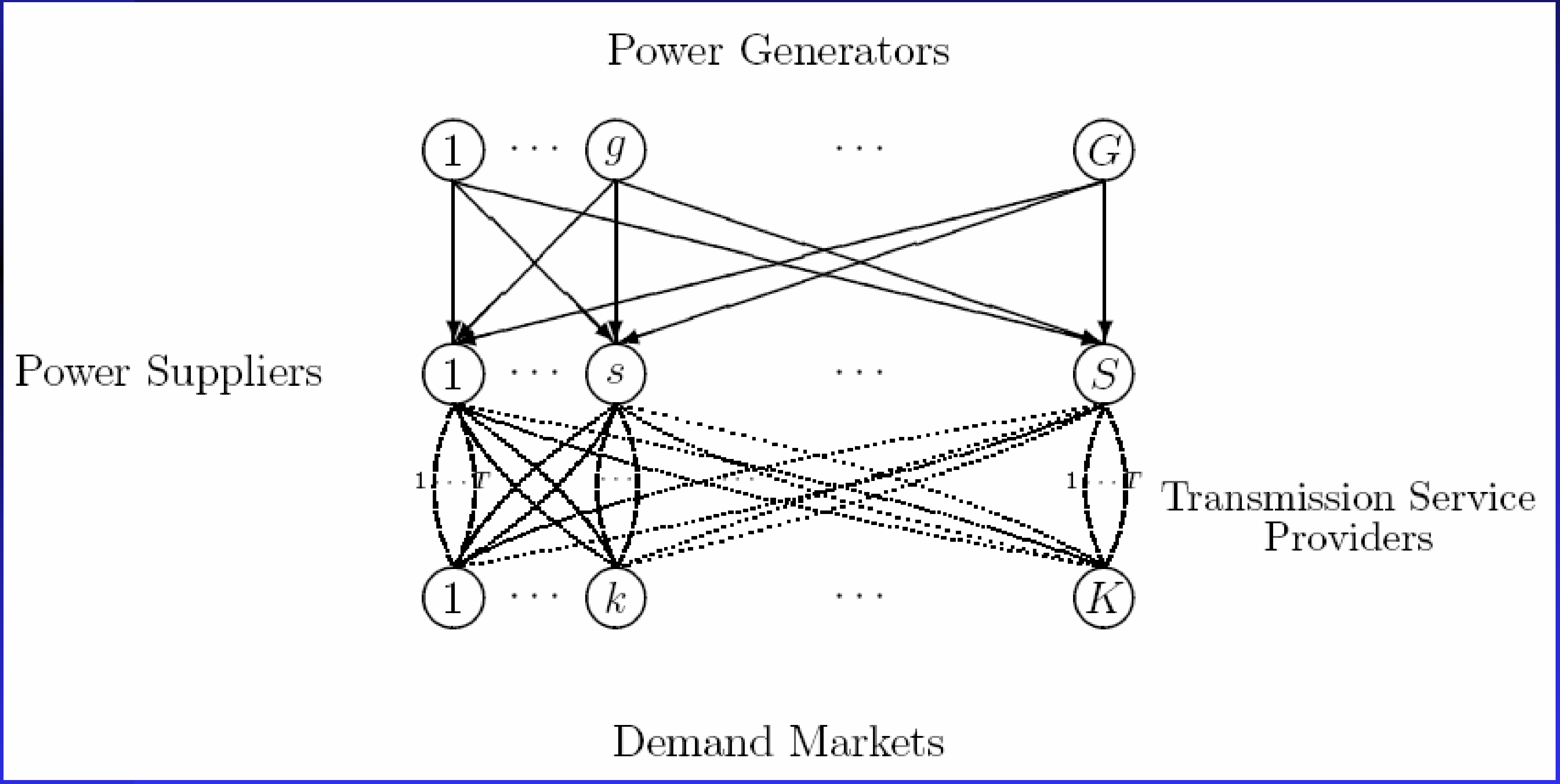
International Financial Networks with Electronic Transactions



The 4-Tiered E-Cycling Network



The Electric Power Supply Chain Network



Supernetworks Integrating Social Networks

The models explicitly consider the role that relationship levels play in other network systems and include multicriteria decision-making with individual weights for the criteria such as:

- maximization of profit
- minimization of risk
- maximization of relationship value.

Supernetworks Integrating Social Networks

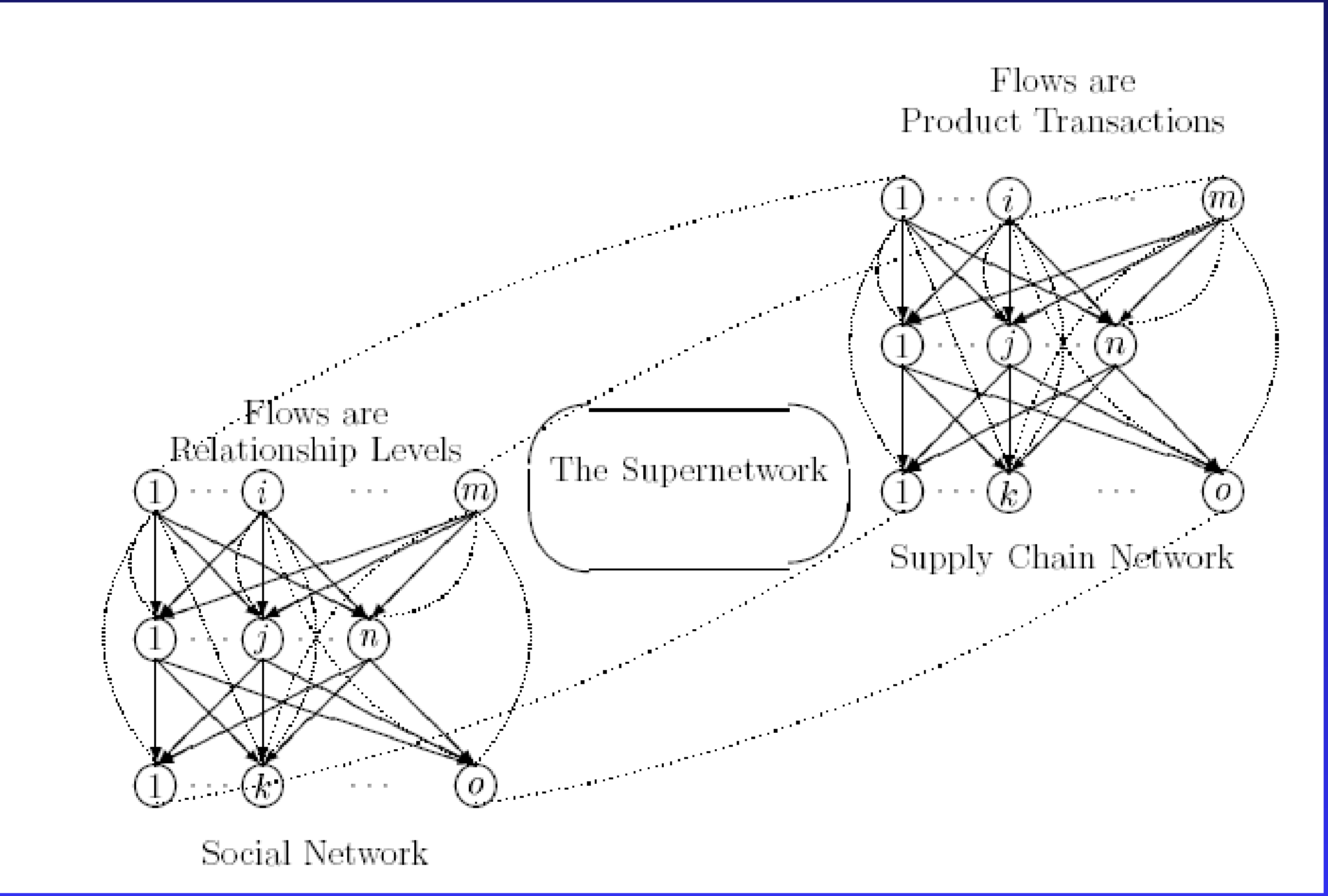
Decision-makers in the network can decide about the relationship levels [0,1] that they want to establish.

Establishing relationship levels incurs some costs.

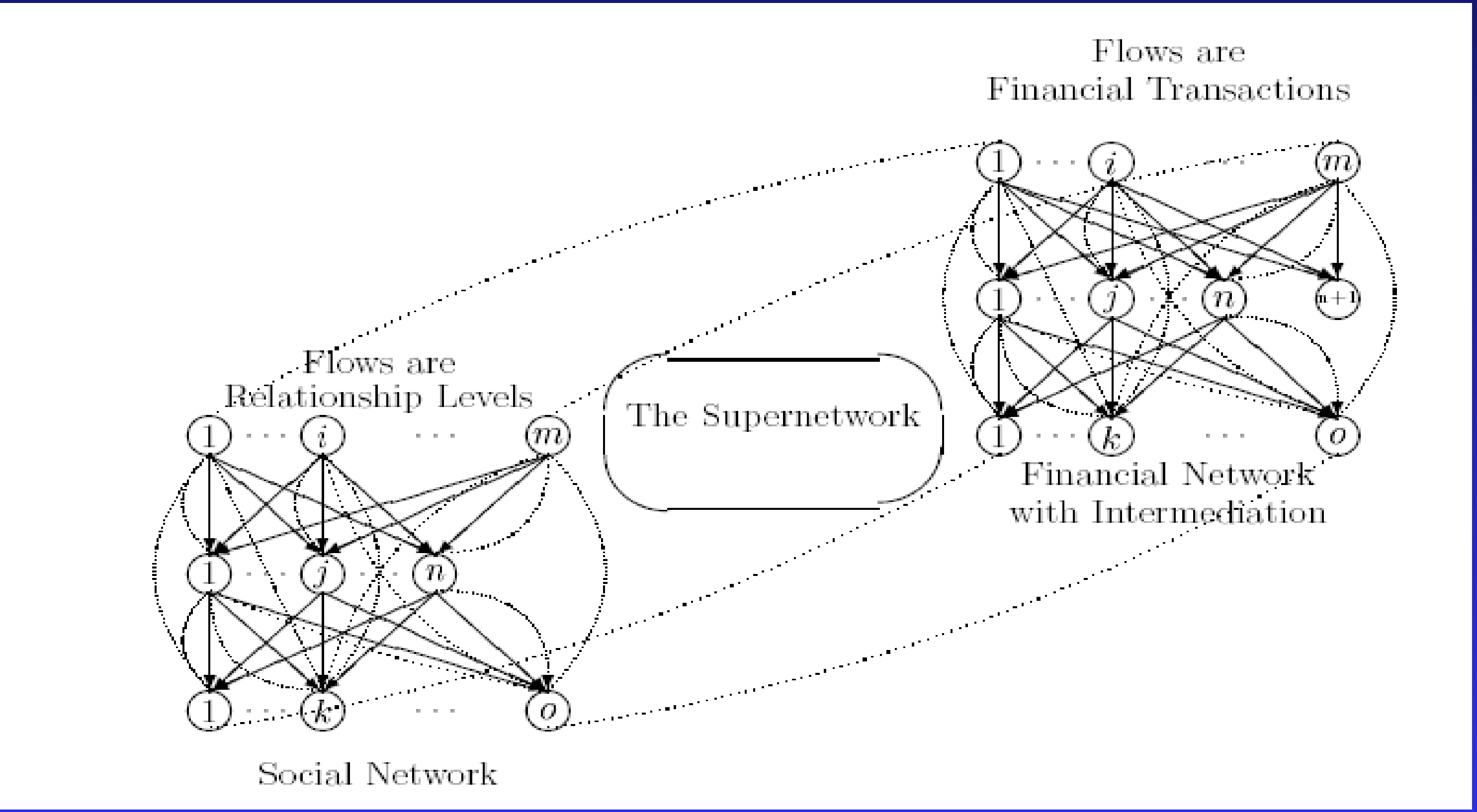
Higher relationship levels

- Reduce transaction costs
- Reduce risk
- Have some additional value (relationship value).

Supernetwork Structure: Integrated Supply Chain/Social Network System



Supernetwork Structure: Integrated Financial/Social Network System



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

Summary and Conclusions

- We have seen the pervasiveness of networks and have pointed out some of the tools used for the study of networks today.
- We have also emphasized the reality of today's networks from congestion to interactions among networks and different behaviors of those using networks.

- Finally, we have illustrated through a wide spectrum of applications how networks span disciplines.

- The topic and importance of networks to our economies and societies is **bringing different communities together** from scientists to practitioners in order to further advance the **science of networks** and its fascinating applications.

Additional Material and Information can be found at the Virtual Center for Supernetworks site: http://supernet.som.umass.edu