Network Dynamics and Scaling

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ppt accompanies this draft

ISCOM overview. This research has largely been conducted independent of other projects in ISCOM. Interlinkage would depend on the development of network datasets in those other projects (some of which has been accomplished in urban economic networks), or by extension of network principles and simulations to their implications for other studies. The testing of network principles cannot be done on the basis of metaphor but requires empirical case studies with measurable network variables. Further investigation of general principles, however, can be done through simulation. Interfacing with the physics research community at SFI has been done in the simulation studies. Study of the Early Renaissance intercity network has depended on collaborations with historians, population ecologists, and mathematical dynamicists. Study of the interorganizational Biotechnology network has been done in collaboration with organizational sociologists and statisticians. Study of emergent phenomena in Marriage networks has involved collaborations with anthropologists, mathematical graph theorists and computer scientists.

It is believed that some of the findings on scaling (scale-free network) properties, in the domain of ring cohesion, provide a potential interface with Geoff West's social scaling projects, while those on structural cohesion and recruitment of diversity in cohesive network formations provide an interface with David Lane and Sander v. d. Leeuw's innovation projects. See Moody and White (2003) and White and Harary (2001) for concepts and measures of structural cohesion.

I. **Empirical Studies**: Early Renaissance intercity network, Biotech interorganizational network, and structurally cohesive emergence (social class, ethnicity, elites) in Marriage networks.

The method I am working with is to observe networks over many time steps, formulate hypotheses about processes, develop models for measurement and testing of hypotheses, and to try to identify and test hypotheses about dynamics and micro-meso-macro links, that is, co-evolution at different levels and between networks and environmental variables.

Looking at the transformations in the Medieval to Modern (European Early Renaissance) intercity network (Spufford 2002, White and Spufford 2005), for example, one dynamical interaction (Turchin 2003 *Nature*) has been tested that governs the rise of money rents for land, expulsion of serfs (and later peasants) from feudal lands (and later estates), migration to cities of displaced agrarian workers and aristocracy, a rising elite consumer economy, monetization, and transformation of organizational forms that carry increased transaction velocities.

I am now in the process of testing a second major network dynamic of economic growth and decline. This is the interaction between long range and large spatial scale of cohesive exchange routes and throughputs and the more localized (with intervening local network variables) benefits, behaviors and becomings (i.e., localize transformations) of agents. This model derives from previous work with Powell and others that has been so successful in modeling the time series data on interorganizational linkages in the biotechnical industry (1999-2004), using the implications of the theoretical measure of structural cohesion as a key dynamical variable (White et al. 2004, Powell et al. 2005, Owen-Smith et al. forthcoming). Structural cohesion, unlike most concepts and measures of cohesion, is a scaleable multiple-unit defining variable. Large scale structural cohesion, e.g., in a trade or information network, facilitates diffusion, exchange, the potentials of intermingled diversity for future innovation. It is not a guarantee, however, that innovation will occur. The factors involved in innovation involve strong localized factors, including local network and positional variables. In the short run, for example, in periods of global (network) expansion in multiconnectivity (a synonym for level of structural cohesion), betweenness centrality benefits local agents and facilitates innovation and organizational transformation. In periods of decline, however, higher betweenness centrality is a predictor of local decline because of overinvestment, e.g., in stocks, personnel or organizational size.

In the biotech network evolution, we observe and have tested the predictiveness of a viable short-term oscillation between times of consolidation of structural cohesion in the organizational field and times of recruitment of newcomers. The latter increases the diversity of potentially innovative agents in the field (especially in its structurally cohesive core) that can be consolidated *as innovation* in the following period. The time scale here is a six year cycle between times of maximal (or minimal) consolidation, with a one year lag between recruitment and consolidation, then a two year lag to minimization of new recruitment and a one year lag to a time of minimal consolidation.

Taking these dynamics one step further, analysis of the European Early Renaissance (EER) indicates that there may be a very different effect of *flow centrality* on local agents than that of betweenness centrality. *Flow centrality* (White and Smith 1988, Smith and White 1992, Freeman, Borgatti and White 1991) is a global measures, its effects are longer term, and its potential for beneficial effects seem to operate independently of economic expansion/decline cycles. For the EER it predicts the long-term emergence of profit centers such as banking in a monetized economy, which have low stocks and are less vulnerable to losses in a cyclical business cycle.

II. Simulations (roughly sketched)

The empirical results of these studies of network dynamics lead to some general research questions that we explore through network simulations: What kinds of very general or specialized types of dynamical network evolution can occur through various kinds of balance between feedforward ("perceptron") processes and feedback ("agency") processes? Of these, which commonly (or uncommonly occur) and in what contexts? And of these, what are their evolutionary paths?

A framework for studying network dynamics.

I am going to give a three parameter model of network growth (α, β, γ) and a five parameter model for generalized network growth and decay (α, β, γ, δ, ε) given: a local structural measure in the network, nodal degree *d*; a dynamic traversal measure, *dist*, distance traveled by an information token sent by an agent to evoke feedback from a prospective target; and one pair, $A_{i,j}$ and $A_{j,}$, of dynamic adjacency) measures for each pair of nodes i,j_i, for respective accumulative traversal frequency from i to j and j to i.

α, agent action (probability bias that an agent will act, e.g., search for a target). $f(d^{\alpha})$, $\alpha \geq 0$.

β, target search (probability bias on the distance to which an agent can search for a target). $f(dist^{\beta})$, $\beta > 1$.

γ, intermediary traversal (probability bias on the intermediary selected for the next-step taken in a network neighborhood as the agent's token travels in search of a target). $f(d^{\gamma})$, $\gamma \geq 0$.

δ, node deletion (probability bias on the deletion of a node). $f(d^{\delta})$, δ + or -.

ε, edge deletion (probability bias on the deletion of an edge). $f((A_{i,j} * A_{j,i})^{-\varepsilon})$ $\varepsilon \geq 0$.

In the simplest case, we model an iterative dynamic in which at each iteration a node k is selected to search for a target at a distance D whose probability P(D) ~

dist$^{\beta}$ by sending a token that traverses successive neighborhoods, with a traversal bias γ at each intermediate step, starting with i and ending with either finding a prospective target j at distance D (who signals back to i to form an arc <j,i>) or expiring because backtracking is not allowed and distance D is not reached. In the case of token expiration, a new node k' is recruited into the network and connected to k by an arc <k,k'>.

Unlike catalytic networks where i can catalyze j but if so, j cannot catalyze i, these networks are social: if <i,j>

The parameters (α, β, γ, δ, ε) are used to specify families of networks that change dynamically by (1) additions or deletions of nodes or arcs, (2) traversal of arcs, forward or back, (3) summative weightings on arcs based on traversal, (4) linear or non-linear transformations of properties of edges (e.g., sigmoidal rectification) based on the weightings of the reciprocal arcs that comprise them.

A **layer** in a network is an emergent node or cohesive unit that receives inputs and throughputs (to other layers) from other nodes, starting with the initial set of **layer 0** nodes. A stack of mutually distinct and connected layers will be said to have **feedforward** with no feedback loops.
An example of emergent nodes would be summative properties on cohesive neighborhoods as super-nodes with distinctive k-component properties. Stacks and overlaps of k-component layers have vertical **feedforward** where information flows up to higher k-components, and horizontal **feedback** can occur where information (including effects of a behavior) flows through k-component overlaps and cycles from an information sender (**agent**) back to influence (stimulate, inhibit) the sender (or agent behavior). A maximal set of overlapping (connected) k-components constitutes a **field** (minimally 1-connected). A dense set of overlapping (connected) k-components with hierarchies (embedded k-components) constitutes an **organization**.

A model is wanted where a dynamic network can have **feed-forward**, as when additions of nodes or arcs are made or summations are made to the network by traversal of arcs, and **feedback**, when information (behavior) can have cycles of influence. Further, we want to enable **agency**, where a node can signal in search of a target (node) that can signal back to the source.

Agent behavior and agent organization can be adaptive. Reciprocity, for example, can influence individual agent **behavior**; or small world organization of reciprocal links ("strong ties") can influence the **field** of behavior.

> e.g., arcs accumulate directed traversals (linear accumulation). When reciprocal arcs have high values, i.e., **multiplicative**, a non-linear rectification, their edge acquires **reciprocity**, and can form part of a **strong-tie small world**.

The thesis: When we endow nodes in a network with **agency** (thus a potential for **feedback**), we automatically endow it with **feedforward** as well, because of the endogenous accumulative capacity of networks. The feedforward occurs in the **field** of interaction, and alters the **context** for agency, while **agency** shapes the field and its **organization**. The links between field, agency and organization in interaction networks constitute a means of studying micro-meso-macro co-evolution and some of their intrinsic linkages (i.e., theorems as to how micro-macro influence one another through meso).

In our simulation, the red edges are those formed by feedback between a located target and the agent seeking a target. We can …

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References

Spufford, P. 2002. Power and Profit: The Merchant in Medieval Europe 2002. London: Thames & Hudson

Turchin, P. 2003. Evolution in population dynamics. *Nature* 424:257-258 (17 July). ***http:***//www.nature.com/nature http://eclectic.ss.uci.edu/drwhite/Global/424257a_r.pdf/

Selected References, drw

2005 **Network Analysis and Ethnographic Problems: Process Models of a Turkish Nomad Clan**. drw & Ulla Johansen. Boston, MA: Lexington Press. Distribution by AltaMira Press.

2002 **Networks and Complexity** Special Issue, ed., drw. ***Complexity*** 8(1) ***http:***//eclectic.ss.uci.edu/~drwhite/Complexity/SpecialIssue.htm

1998 **Kinship, Networks and Exchange**, eds. Thomas Schweizer, drw. Cambridge University Press.

1996 **Social Network And Discrete Structure Analysis**, Special Issue, ***Social Networks*** 18(3), eds. drw and V. Duquenne. Elsevier Press. ***http:***//www.elsevier.com/wps/find/journalspecialissues.cws_home/505596/specialissues

1989 **Research Methods in Social Network Analysis**, eds. L. C. Freeman, drw, A. K. Romney. George Mason Press. Reprinted 1991, Transaction Press.

2005 Civilizations as Dynamic Networks. (drw and P. Spufford) Working paper. ***http:***//eclectic.ss.uci.edu/~drwhite/pub/FeedBack_paper_24_3.pdf

2005 Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences. (W. W. Powell, drw, K. W. Koput & J. Owen-Smith) ***American Journal of Sociology*** 110(4):901-975. ***http:***//www.journals.uchicago.edu/AJS/journal/available.html

2005 Network Growth and Consolidation: The Effects of Cohesion and Diversity on the Biotechnology Industry Network (J. Owen-Smith, W. W. Powell, and D. R. White) Forthcoming, ***Management Science***, Special issue on Complex Systems Across Disciplines. ***http:***//eclectic.ss.uci.edu/~drwhite/pub/submission_draft_complete.pdf

2004 Network Analysis, Social Dynamics and Feedback in Social Systems. ***Cybernetics and Systems*** 35(2-3):173-192. ***http:***//taylorandfrancis.metapress.com/openurl.asp?genre=issue&eissn=1087-6553&volume=35&issue=2

2004 Networks, Fields and Organizations: Micro-dynamics, scale and cohesive embeddings (drw, W. W. Powell, J. Owen-Smith. J. Moody) ***Computational and Mathematical Organization Theory*** 10(1):95-117. ***http:****//www.springerlink.com/openurl.asp?genre=issue&eissn=1572-9346&volume=10&issue=1*
2003 Structural Cohesion and Embeddedness: A Hierarchical Conception of Social Groups. (J. Moody, drw) ***American Sociological Review*** 68(1):1-25. Outstanding Article award in Mathematical Sociology, 2004. American Sociological Association. ***http:****//www.asanet.org/journals/ASRFeb03MoodyWhite.pdf*
2001 The Cohesiveness of Blocks in Social Networks: Node Connectivity and Conditional Density. Drw & F. Harary, ***Sociological Methodology 2001*** (31):305-359. ***http:****//www.ingentaconnect.com/content/bpl/some/2001/00000031/00000001;jsessionid=caew7r81aa3c.henrietta*
1999 Controlled Simulation of Marriage Systems. ***Journal of Artificial Societies and Social Simulation*** 2(3). ***http:****//jasss.soc.surrey.ac.uk/2/3/5.html*
1997 Class, Property and Structural Endogamy: Visualizing Networked Histories. (L. A. Brudner & drw). ***Theory and Society*** 25(2):161-208. ***http:****//repositories.cdlib.org/postprints/3/*
1996 Kinship Networks and Discrete Structure Theory: Applications and Implications. (drw & P. Jorion). ***Social Networks*** 18:267-314. ***http:****//eclectic.ss.uci.edu/~drwhite/pw/White-Jorion1992.pdf*
1994 Centrality Measures for Oriented Graphs. (drw & S. Borgatti) ***Social Networks*** 16:335- 346.
1993 Using Galois lattices to represent network data. (L. C. Freeman & drw) ***Sociological Methodology 1993*** (23):127-146. ***http:****//links.jstor.org/sici?sici=0081-1750(1993)23<127%3AUGLTRN>2.0.CO%3B2-9*
1992 Structure and Dynamics of the Global Economy: Network Analysis of International Trade 1965-1980. (D. Smith & drw) ***Social Forces*** 70:857-894. ***http:****//eclectic.ss.uci.edu/~drwhite/WorldTrade/Cray.pdf*
1991 World-System and Regional Linkages as Causally Implicated in Local Level Conflicts at the Ethnographic Horizon. ***Zeitschrift fur Ethnologie*** 115:111-37.
1988 Evidence for a Long Term Process Scale for Social Change in Modern Man Settled in Place via Agriculture and Engaged in Trade and War. (A. Iberall & drw) ***GeoJournal*** 17:311- 338.
1983 Graph and Semigroup Homomorphisms. (drw & K. P. Reitz) ***Social Networks*** 5:193-234.
1982 Multivariate Modeling with Interdependent Network Data. (M. M. Dow, drw, M .L. Burton) ***Behavior Science Research*** 17:216-245.
1977 Entailment Theory and Method: A Cross-Cultural Analysis of the Sexual Division of Labor. (drw, M. Burton, L. Brudner) ***Behavior Science Research*** 12:1-24. ***http:****//eclectic.ss.uci.edu/~drwhite/pub/Entail77.pdf*
1974 Mathematical Anthropology, pp 369-446, *In* J. J. Honigmann, ed., **Handbook of Social and Cultural Anthropology**.

END ----- SOME NOTES

feedforward - A multi-layer perceptron network in which the outputs from all neurons (see McCulloch-Pitts) go to following but not preceding **layers**, so there are no feedback loops.

➔ e.g., a summative process, global or local, or arbitrarily local
e.g., linear summations, non-linear rectification

feed-forward - the anticipatory effect that one intermediate in a metabolic or endocrine control system exerts on another intermediate further along in the pathway; such effect may be stimulatory (positive f.) or inhibitory (negative f.).

➔ our parameter **gamma**: an effect is exerted on choice of a path in a neighborhood

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what did Lou say about cycles – if sinusoidal, have integer properties; if log (tau) sinusoidad, have rational numbers, that is ratios of integers?