

**Dynamic Networks. An interdisciplinary study of network  
organization in biological and human social systems.**

**Karen Jane Tesson**

**A thesis submitted for the degree of Doctor of Philosophy**

**University of Bath**

**Department of Psychology**

**June 2006**

**COPYRIGHT**

Attention is drawn to the fact that copyright of this thesis rests with its author.

This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the prior written consent of the author.

This thesis may be made available for consultation within the University Library and may be photocopied or lent to other libraries for the purposes of consultation.

Signature:

## Abstract

This thesis is about a metaphor; it explores the idea that human organizations could be treated “as if” they behaved like biological systems. The thesis focuses on one biological metaphor in particular – the idea of a living *network*.

The thesis begins with an exploration of the philosophical background to my research. The development of rationalistic and reductionist approaches to systems enquiry is described, and the limitations of these approaches are discussed. This is followed by a discussion of non-linear, holistic and other approaches, including a newly emerging perspective known as Inclusionality. Communication is an important aspect of both human and biological systems, so I continue by examining established theories of communication, showing how they have influenced the way we understand communicative systems. A chapter is devoted to the subject of metaphor, which explains how in contemporary research, metaphor is treated not merely as a linguistic device, but as a *cognitive* tool that reflects how we make connections between ideas. Various metaphors for human organizations are discussed, including the network metaphor.

I deal with network theory itself in some detail, firstly exploring conventional network theory, which is concerned with networks that are *node* based, and secondly with the organization of natural biological networks which are quite different in form and are the products of autocatalytic *flow*. The concept of the “flow-form network” as a metaphor for human organizations is explored, and some of the methodological issues concerning the study of such networks are discussed.

The latter part of the thesis describes a practical study of a human organization, where communicative patterns were investigated. The study highlights how flow-form networks might be identified in human organizations, as well as the limitations that conventional methods of enquiry pose in such an investigation.

## Acknowledgements

It would not have been possible for me to produce this thesis without the help and support of a great many people.

My thanks go firstly to my research colleagues and supervisors, particularly to my supervisors Alan Rayner and Helen Haste. Alan's inspired ideas on natural systems were what brought me to this study. He has continued to inspire and encourage me, helping me to find the words to express difficult ideas, and introducing me to new ways of looking at old problems. Thanks also to Helen, who helped me find my feet within the Department of Psychology when I feared I would not, and opened up a whole new world to me of metaphor, culture and social ideas that I had never looked at in such depth before.

I am grateful also to all the members of the Teamwork Maan team, particularly to Siegrid Stessels the Maan team leader. Thanks are also due to the Knowledge Capture team at Liveweek, especially Richard McWilliams and Paul Fletcher, who permitted me to conduct the research at Liveweek, and also to Isao Matsumoto for kindly giving me copies of the Knowledge Capture CD's. I am grateful also to David Sands and Alan Pillinger of Bourne Steel Limited for permitting me to take part in Liveweek on behalf of Bourne Steel, and for the use of their printing facilities.

To my long-suffering friends and family, who have supported and stood by me while I was unsociable and studious, thank you all! My particular thanks go to Tom, for his books, his enthusiasm and really difficult questions, and to Debbie – for reminding me to breathe, and generally being a wonderfully supportive friend as well as an inspiring teacher.

To my sister Johanna, and my brother Diccon, thank you both for all your encouragement and support. Finally to my parents, who have steadied me when I feared I might fall, picked me up when I did, and who have loved, supported and trusted me throughout all - you have allowed me to open a door to a world full of possibilities, without you I could not have reached this place; thank you both.

# Contents

	Page
<b>Abstract</b>	2
<b>Acknowledgements</b>	3
<b>Contents</b>	4
<b>List of Figures</b>	14
<b>List of Tables</b>	16
<b>Chapter 1 – Introduction</b>	17
1.1 An intellectual journey	17
1.2 My origins in biology	17
1.3 Starting postgraduate research – beginning an association with psychology	24
1.4 Metaphor theory	27
1.5 My involvement with and contribution to Inclusionality theory	28
1.6 The Teamwork study	30
1.7 The Teamwork study as a catalyst for further research on communicative networks	31
1.8 Flow-form: and Inclusional interpretation of communicative networks	32
1.9 Flow-form - model, metaphor or advocacy?	33
1.10 Navigating this thesis	34
<b>Chapter 2 – From Mechanism to Inclusion: a discussion of selected literature on the philosophy of science and systems</b>	36
2.1 Introduction	36
2.2 Classical modes of enquiry	36
2.3 Systems theory, chaos and complexity	42

2.3.1	Systems theory and cybernetics	43
2.3.2	Chaos theory, complexity theory and emergence	47
2.4	Holism	51
2.4.1	Problems with the holistic view	54
2.5	A new approach: Inclusionality	55
<b>Chapter 3 – Communication theory</b>		<b>58</b>
3.1	Introduction	58
3.2	Model 1 – Meaning in the words: language and semiotics	59
3.2.1	The signs specialists: Saussure and Peirce	59
3.3	Model 2 – Meaning in the transfer of information: systems and cybernetic views of communication	62
3.3.1	Systems theories of communication	62
3.3.2	Information theory	63
3.4	Model 3 – Meaning emerges through the dialogue between speakers and hearers	65
3.4.1	Conversation studies	65
3.4.1.1	Turn-taking	67
3.4.1.2	Common ground	68
3.4.2	Conversation analysis	70
3.4.3	A critique of dialogic models	71
3.5	Model 4 – Meaning emerges through co-relation between communicators and their social contexts	72
3.5.1	The holistic approach	72
3.5.2	Discourse analysis	73
3.5.3	A critique of discourse analysis	74
3.6	Conclusions – An Inclusional view of communication?	76

<b>Chapter 4 – Metaphor</b>	77
4.1 Introduction	77
4.2 Theories of metaphor	77
4.2.1 Linguistic theories of metaphor	77
4.2.2 Cognitive theories of metaphor	81
4.2.3 The conceptual blending model	83
4.3 Metaphorical framing	85
4.3.1 Metaphors and models	88
4.3.2 Metaphor as a tool for transdisciplinary study	89
4.4 Metaphor in the everyday world	90
4.4.1 Metaphorical schemas and human organizations	90
4.4.2 Machine metaphors	91
4.4.3 Organic metaphors	92
4.4.4 Metaphors based on non-linear sciences and network theory	94
4.4.4.1 Network theory metaphors	95
4.5 Conclusions	97
 <b>Chapter 5 – Conventional network theory</b>	 98
5.1 Introduction	98
5.2 The history and development of conventional network theory	98
5.2.1 Social network theory	99
5.2.2 Graph theory	100
5.2.3 Six degrees of separation	101
5.2.4 The strength of weak ties	101
5.2.5 Watts and Strogatz' "Small worlds" model	103
5.2.6 The significance of hubs	104

5.3	Conventional network theory as a metaphor for systems and organizations	105
5.4	A critique of conventional network theory	108
5.4.1	The risks of applying a nodal network model to a non-nodal system	111
5.5	Conclusions	113
<b>Chapter 6 – Natural networks: towards a new metaphor of networks formed through <i>flow</i></b>		114
6.1	The structure of natural networks	114
6.2	Networks in the natural world	116
6.2.1	Previous research on natural network structures	118
6.2.1.1	Leaf venation patterns	118
6.2.1.2	Angiogenesis	119
6.2.3	A natural network in detail: the mycelial network	121
6.2.3.1	Anastomosis	125
6.2.3.2	Responses of communicating pathways to environmental heterogeneity	126
6.3	How natural systems manage <i>flow</i>	127
6.3.1	The properties of natural boundaries	128
6.3.2	Boundaries create <i>potential difference</i>	129
6.3.3	Branching and boundary sealing	130
6.3.4	Anastomosis and the creation of parallel pathways	131
6.3.5	The role of nodes in natural systems	132
6.4	Conclusions: labyrinths and webs, strings and pipes: towards a new model of networks as <i>flow-forms</i>	133
6.4.1	Flow-form network as a mental model	135

<b>Chapter 7 – The study of flow-form networks: an introduction to the methodological issues and challenges</b>	137
7.1 Introduction: the challenges of studying flow-form networks	137
7.2 Investigative tools that do not disrupt flow in networks	138
7.3 The risks in unknowingly applying conventional tools to flow-form networks	139
7.3.1 An example – Lumeta’s Internet map	140
7.3.2 The Internet map’s inherent problems	143
7.4 How conventional tools may be used to study flow-form networks	145
7.4.1 Multiple methods in one study	145
7.5 Methods for study of human social networks	146
7.5.1 Social network analysis	147
7.5.1.1 Analysis of data in social networks	149
7.5.2 Using other methods in conjunction with SNA	150
7.5.2.1 Content analysis	150
7.5.2.2 Analysing use of <i>artefacts</i>	152
7.6 A combined methodological approach to studying human flow-form networks	155

<b>Chapter 8 – Teamwork study: aims, context and rationale</b>	157
8.1 Introduction – aims of the study	157
8.2 The context of the study: Teamwork	158
8.2.1 Background to the study context – the British construction industry	159
8.2.2 The Teamwork tasks in detail: how Teamwork differed from the conventional approach	161
8.3 Rationale of the study	162
8.4 Methodological approach	164
8.4.1 Some practical considerations	165
8.4.2 Study 1 - the structure of interaction networks between team members	166
8.4.3 Study 2 - dialogic communication in the collaborative design process	167
8.4.4 Study 3 - use of artefacts as communicative tools	169
8.4.5 Integrating the data, comparing datasets, looking for repeated patterns	170
8.5 Conclusions	171
<b>Chapter 9 – Teamwork study: procedures</b>	172
9.1 Situation of the study	172
9.1.1 Timing and Location	172
9.1.2 Access and consent	175
9.1.3 The study population	175
9.2 Overall comments on how the data were gathered	177
9.3 Study 1 – The structure of interaction networks between team members	177
9.3.1 Data collection for Study 1	177

9.3.2	Analysis of data from Study 1	178
9.4	Study 2 – Dialogic communication in the collaborative design process	179
9.4.1	Data collection for Study 2	179
9.4.2	Analysis of data from Study 2	180
9.5	Study 3 – Use of artefacts as communicative tools	184
9.5.1	Data for Study 3	184
9.5.2	Analysis of data from Study 3	185
9.6	Methods used to conduct combined analysis of data from all three studies	186
9.6.1	Relations between the social network and dialogue data (Studies 1 and 2)	186
9.6.2	Relations between the dialogue and artefact data (Studies 2 and 3)	186
<b>Chapter 10 – Teamwork study: results and analysis</b>		<b>187</b>
10.1	Results of Study 1 - the structure of interaction networks between team members	187
10.1.1	Initial analysis	187
10.1.2	Relations between network sizes and densities	190
10.1.3	Analysis of individual actor characteristics	191
10.1.4	Clustering of actors	193
10.1.5	Relationship between density of network and links to non-team members	193
10.1.6	Social network map of all interactions observed at Liveweek	194
10.2	Results of Study 2 - dialogic communication in the collaborative design process	196

10.2.1	Actors' skills and roles	196
10.2.2	Overall results of the dialogue coding	197
10.2.3	Utterance types used by each actor	199
10.2.4	Correlations between utterance types	200
10.2.5	Uncategorized statements	201
10.3	Results of Study 3 - use of artefacts as communicative tools	202
10.4	Results of combined analysis of data from all three studies	204
10.4.1	Relations between the social network and dialogue data (Studies 1 and 2)	204
10.4.2	Relations between the dialogue and artefact data (Studies 2 and 3)	205
10.4.3	Percentage use of the different programs	207
10.4.4	File sharing between users on different workstations	207
<b>Chapter 11 – Teamwork study: discussion</b>		<b>209</b>
11.1	Discussion of the results of Study 1 (network analysis)	209
11.1.1	Initial analysis	209
11.1.2	Relations between network sizes and densities	209
11.1.3	Analysis of individual actor characteristics	210
11.1.4	Clustering of actors	212
11.1.5	Relationship between density of network and links to non-team members	212
11.1.6	Social network map of all interactions observed at Liveweek	212
11.2	Discussion of the results of Study 2 (dialogue study)	213
11.2.1	Actors' skills and roles	213
11.2.2	Overall results of the dialogue coding	214
11.2.3	Utterance types used by each actor	214

11.2.4	Correlations between utterance types	216
11.3	Discussion of the results of Study 3 (artefact analysis)	217
11.4	Discussion of combined analysis results	218
11.4.1	Relations between the social network and dialogue content data	218
11.4.2	Relations between artefact data and content data	220
11.4.3	Percentage use of different programs	220
11.4.4	File sharing between users on different workstations	221
11.5	Overview and critique of the study	223
11.5.1	Possible reasons for lack of strong relationships between the datasets	224
11.5.2	What the methodology left out; the space around the numbers	226
11.5.3	Liveweek as a flow-form network?	228
<b>Chapter 12 – Concluding discussion</b>		230
12.1	Some concluding reflections on my study	230
12.1.1	How does this thesis differ from my original research concept?	230
12.1.2	The strengths and shortcomings of my study	232
12.2	The nature of what I have proposed in this thesis	234
12.2.1	Flow-form network – ontology or epistemology?	234
12.2.2	Advocating flow-form networks	237
12.3	The status of my research in the academic domain	239
12.3.1	What the flow-form concept might contribute to psychology	239
12.3.2	How this thesis contributes to the debate on tools and methodologies in the social and natural sciences	243

12.3.3	Potential methodologies to use in further research on flow-form	245
12.3.4	Possible research programmes which might follow from the adoption of the flow-form network model	247
12.3.4.1	Projects that expand on the Liveweek study	247
12.3.4.2	Investigating the role of IT in generating and supporting flow-form communication patterns	248
12.3.4.3	Other research possibilities, in psychology and elsewhere	249
12.4	What has been proposed in this thesis about the relationship between Inclusionality theory and psychology	249
12.5	A concluding statement on my own intellectual journey through this research	251
	<b>References</b>	253
<b>Appendix 1</b>	Scheme used to transcribe video-recorded dialogue in Study 2	268
<b>Appendix 2</b>	Raw data and initial analysis for Study 1 - The structure of interaction networks between team members during Liveweek	269
<b>Appendix 3</b>	Excerpt of transcribed and coded content data from Study 2 (dialogue study)	288

## List of Figures

Figure 2.1	Feedback relationships	45
Figure 3.1	Peirce's notion of the triangular relationship between an object, what it is signified by, and how this is interpreted	60
Figure 3.2	Simple communicative feedback scheme	63
Figure 3.3	Shannon and Weaver's Information Theory model of communication	64
Figure 3.4	Grice's conversational maxims	66
Figure 5.1.	A typical sociogram	100
Figure 5.2	Different patterns of linking in regular, small-world and random networks	103
Figure 6.1	Vein network in an ivy leaf	116
Figure 6.2	Venation on dragonfly wing	116
Figure 6.3	A foraging swarm of <i>Dorylus</i> driver ants produces a networked pattern	117
Figure 6.4	The "great trek" – pattern created by a herd of wildebeest on the Serengeti plain in E. Africa	117
Figure 6.5	Leaf with open venation pattern	119
Figure 6.6	Leaf with closed venation pattern	119
Figure 6.7 a and b	A capillary network, and a capillary network that has begun angiogenesis (sprouting)	120
Figure 6.8	Fungal fruit bodies are the outer manifestation of a hidden network	121
Figure 6.9	A mycelial network 'in the wild'	122
Figure 6.10 a)	Diagram of part of a mycelial network, where the hyphal branches are growing in an <i>assimilative</i> mode	123
Figure 6.10 b)	Diagram of part of a mycelial network, where the hyphal branches are growing in an <i>exploratory</i> mode	123
Figure 6.11	Spore germination and early development of a mycelial network	124
Figure 6.12	Anastomosis of branches to create a network that is <i>self integrated</i>	125
Figure 6.13	The development of a mycelial system between two nutrient sources	126
Figure 6.14	Diagram of a begonia leaf, showing leaf axil and growth around it	133

Figure 7.1	A map of the Internet	141
Figure 7.2	An unhealthy mycelial network	143
Figure 7.3	Network graph showing newspaper-purchasing relationships	149
Figure 9.1	Schematic map of the RIBA hall where Liveweek was held	174
Figure 10.1	One of the eighteen maps of observed interactions, created from data collected during Liveweek	187
Figure 10.2	Graph of the number of actors at present in the Liveweek hall at timed intervals	190
Figure 10.3	Graph of the densities of interaction networks observed during Liveweek	191
Figure 10.4	Scatter plot of the density of an actor's egonet, against the frequency of interaction links they made with members of the same team as theirs	194
Figure 10.5	Map of all observed interactions during Liveweek	195
Figure 10.6	Scatter plot of the relationship between the total utterances (of all team members whose dialogue was transcribed) in Coding Groups 1 (offering information) and 5 (information-seeking)	201
Figure 10.7	Part of a typical screen capture	202
Figure 10.8	General layout and positions of workstations and their users in the Yellow team area	206
Figure 11.1	Excerpt from a transcription of video-recorded dialogue, recorded during the second day of Liveweek (10.19am on Tuesday 11 <sup>th</sup> June 2002)	221
Figure 11.2	Excerpt from a transcription of video-recorded dialogue, recorded during the second day of Liveweek (11.02am on Tuesday 11 <sup>th</sup> June 2002)	223
Figure 12.1	Figure 12.1 Venation pattern on an ivy leaf ( <i>Hedera helix</i> ) in autumn	242
Figures A2.1 to A2.18	Data: maps of locations of actors during Liveweek, and social network maps representing these data.	270-287

## List of Tables

		Page
Table 7.1	Typical response to a traceroute query	142
Table 7.2	Network matrix showing newspaper-purchasing relationships	148
Table 9.1	Coding scheme used to code and analyse the video dialogue	182
Table 9.2	Coding scheme for Study 3 (artefact analysis)	185
Table 10.1	One of eighteen matrices of interaction data, created from the maps of observed interactions	188
Table 10.2	Summary data for all eighteen sets of observation data, showing the number of actors and the network densities	189
Table 10.3	Degree centrality and betweenness of each actor	192
Table 10.4	Mean betweenness scores of the actors in each Liveweek team	193
Table 10.5	Identities, genders, nationalities and roles of the actors whose dialogue was transcribed from the video data recorded at Liveweek	196
Table 10.6	Summary of coding of the Yellow team members' dialogue	197
Table 10.7	Distribution of utterance types for each actor	199
Table 10.8	Names, descriptions and frequencies of appearance of various computer programs in the screen capture images taken during Liveweek	203
Table 10.9	Results of correlation tests between various network measures of Yellow-team actors at Liveweek and the number of statements they uttered in each code category in their dialogue	204
Table 10.10	Summary of workstation use by the Yellow team members during Liveweek	206
Table 10.11	Frequencies of use of Autocad and Microsoft Word by the members of the Yellow team during Liveweek	207
Table 10.12	Computer files shared between actors	208
Table A1.1	Outline of coding scheme used to categorize the data from Study 2 (dialogue content)	268
Table A3.1	Outline of coding scheme used to categorize the data from Study 2 (dialogue content)	288