

Preface

In Spring 2003, a postgraduate course on *complex systems* was organized at HUT Control Engineering Laboratory.

Complex systems is a hot topic today: Complexity in technical systems and in nature around us is overwhelming. The traditional modeling methods do not seem to be powerful enough to capture this diversity, and it seems that a paradigm shift is needed. It is complexity theory that promises to give us tools for this. But what is it all about — what is it now, and what are the future possibilities? These issues are discussed in this report.

In addition to the printed version, this report is available also in PDF format through the HTML page at the Internet address

http://www.control.hut.fi/hyotyniemi/publications/04_report145/.

I am grateful to everybody who has contributed in this effort. — All authors are responsible for their own texts.



Contents

1	Introduction	7
1.1	Attacking complexity in general ...	7
1.2	... and complexity research in particular	9
1.3	About the contents of the Report	11
1.3.1	Philosophical view	12
1.3.2	Top-down view	12
1.3.3	Bottom-up view	13
1.3.4	Systems view	15
2	Complex Systems	17
2.1	Introduction	17
2.2	Wolfram's "New Kind of Science"	18
2.2.1	About the book and author	18
2.2.2	Basic ideas	18
2.2.3	Cellular Automaton	18
2.2.4	Wolfram's conclusions	19
2.2.5	Criticism	20
2.2.6	Provocation?	20
2.3	Networked systems	21
2.3.1	New findings and inventions	21
2.3.2	From hierarchy to network	21
2.3.3	Networked structures	22

2.3.4	Nodes or only connections?	22
2.4	Conclusions: A way to the New World?	23
3	“What Kind of Science is This?”	25
3.1	Science, what is that?	25
3.2	Is the age of revolutions over?	26
3.3	Is the Truth good, bad or ugly?	27
3.4	Cellular automata ...?	29
3.5	Has the science become just a show?	31
3.6	Where to go?	32
4	Architecture of Complex Systems	35
4.1	Conceptions of Complexity	35
4.1.1	Holism and Reductionism	35
4.1.2	Cybernetics and General System Theory	36
4.1.3	Current interest in complexity	36
4.2	The architecture of complexity	37
4.2.1	Hierarchic systems	37
4.2.2	The evolution of complex systems	37
4.2.3	Nearly decomposable systems	38
4.2.4	The description of complexity	40
4.3	Conclusions	41
5	Towards Decentralization	43
5.1	Introduction	43
5.2	Intelligent agents that interact	45
5.3	Rationales for multiagent systems	46
5.4	Multiagent systems	47
5.4.1	Introduction	47
5.4.2	Motivations	48
5.5	Degree of decentralization	49

<i>CONTENTS</i>	3
5.5.1 A single central server	49
5.5.2 Multiple mirrored servers	49
5.5.3 Multiple, non-mirrored servers	50
5.5.4 Totally distributed peers	51
5.6 Applications	52
5.7 Conclusion	53
6 Networks of Agents	57
6.1 Introduction	57
6.1.1 Reductionism	59
6.2 Advent of Graph Theory	59
6.2.1 Königsberg bridges	59
6.2.2 Random networks	61
6.3 Degrees of separation	62
6.4 Hubs and connectors	64
6.5 The Scale-Free Networks	65
6.5.1 The 80/20 Rule	65
6.5.2 Random and scale-free networks	66
6.5.3 Robustness vs. vulnerability	67
6.6 Viruses and fads	67
6.7 The Map of Life	69
6.8 Conclusions	69
7 Cellular Automata	73
7.1 Introduction	73
7.2 History of Cellular Automata	74
7.2.1 Spectacular historical automata	74
7.2.2 Early history of cellular automata	74
7.2.3 Von Neumann's self-reproducing cellular automata	76
7.2.4 Conway's Game of Life	77

7.2.5	Stephen Wolfram and 1-dimensional cellular automata	79
7.2.6	Norman Packard's Snowflakes	81
7.3	Cellular automata in technical terms	81
7.4	A Mathematical analysis of a simple cellular automaton	84
7.5	Applications	85
8	From Chaos ...	89
9	... Towards New Order	91
9.1	Introduction to complexity	91
9.2	Self-organized criticality	93
9.2.1	Dynamical origin of fractals	93
9.2.2	SOC	94
9.2.3	Sand pile model	96
9.3	Complex behavior and measures	98
9.3.1	Edge of chaos — Langton's approach	98
9.3.2	Edge of chaos — another approach	99
9.3.3	Complexity measures	100
9.3.4	Phase transitions	101
9.4	Highly optimized tolerance	102
9.5	Conclusions	106
10	Self-Similarity and Power Laws	109
10.1	Introduction	109
10.2	Self-Similarity	111
10.2.1	Self-organization	112
10.2.2	Power laws	113
10.2.3	Zipf's law	115
10.2.4	Benford's Law	117
10.2.5	Fractal dimension	119

10.3	References	121
11	Turing's Lure, Gödel's Curse	123
11.1	Computability theory	123
11.2	Gödelian undecidability	124
11.3	Turing Machine	124
11.4	Computation as frame work	126
11.4.1	Computations in cellular automata	126
11.5	The phenomena of universality	128
11.6	Game of Life	129
11.6.1	Making a Life computer	134
11.7	Conclusion	137
12	Hierarchical Systems Theory	139
12.1	Introduction	139
12.2	Process level	141
12.2.1	Sub-system models	141
12.2.2	Lower-level decision units	144
12.3	Upper level	145
12.3.1	Upper-level decision making	145
12.3.2	Sub-system decision making problem	146
12.4	Coordination	148
12.5	The balancing principle	150
12.6	The Langrange technique	152
12.7	A toy example	154
12.8	Conclusions	155
13	Qualitative Approaches	159
13.1	Introduction	159
13.2	History of system dynamics	160
13.3	Beer distribution game	163

13.3.1	Rules of the beer distribution game	163
13.3.2	Management flight simulators	166
13.4	Applications	167
13.5	Basic concepts of system dynamics	169
13.5.1	Stocks and flows	169
13.5.2	Causal loops	169
13.5.3	Equations behind the model	172
13.5.4	Flight simulator	173
13.6	Literature and research institutes	175
13.6.1	System dynamics literature	175
13.6.2	Research institutes	176
13.7	Conclusions	176
14	Systems Theory	179
14.1	General System Theory	179
14.1.1	Introduction	179
14.1.2	History	180
14.1.3	Trends in system theory	181
14.1.4	Ideas in general system theory	183
14.1.5	Open vs. closed systems	185
14.1.6	The system concept	185
14.2	Towards a New Science of industrial automation	186
14.2.1	Towards new paradigm?	189
14.2.2	Theoretical issues concerning New Science	191
14.3	Conclusion	191