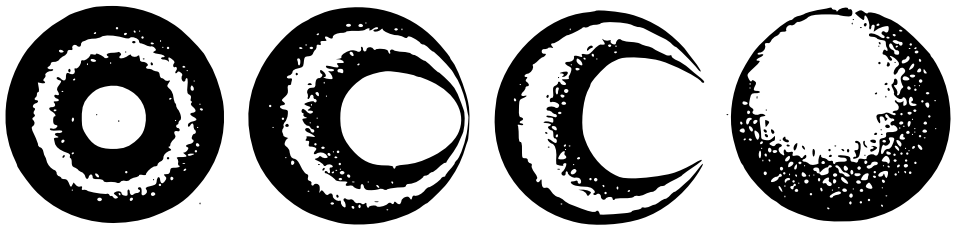
Emergent Properties

Frank Schweitzer

fschweitzer@ethz.ch

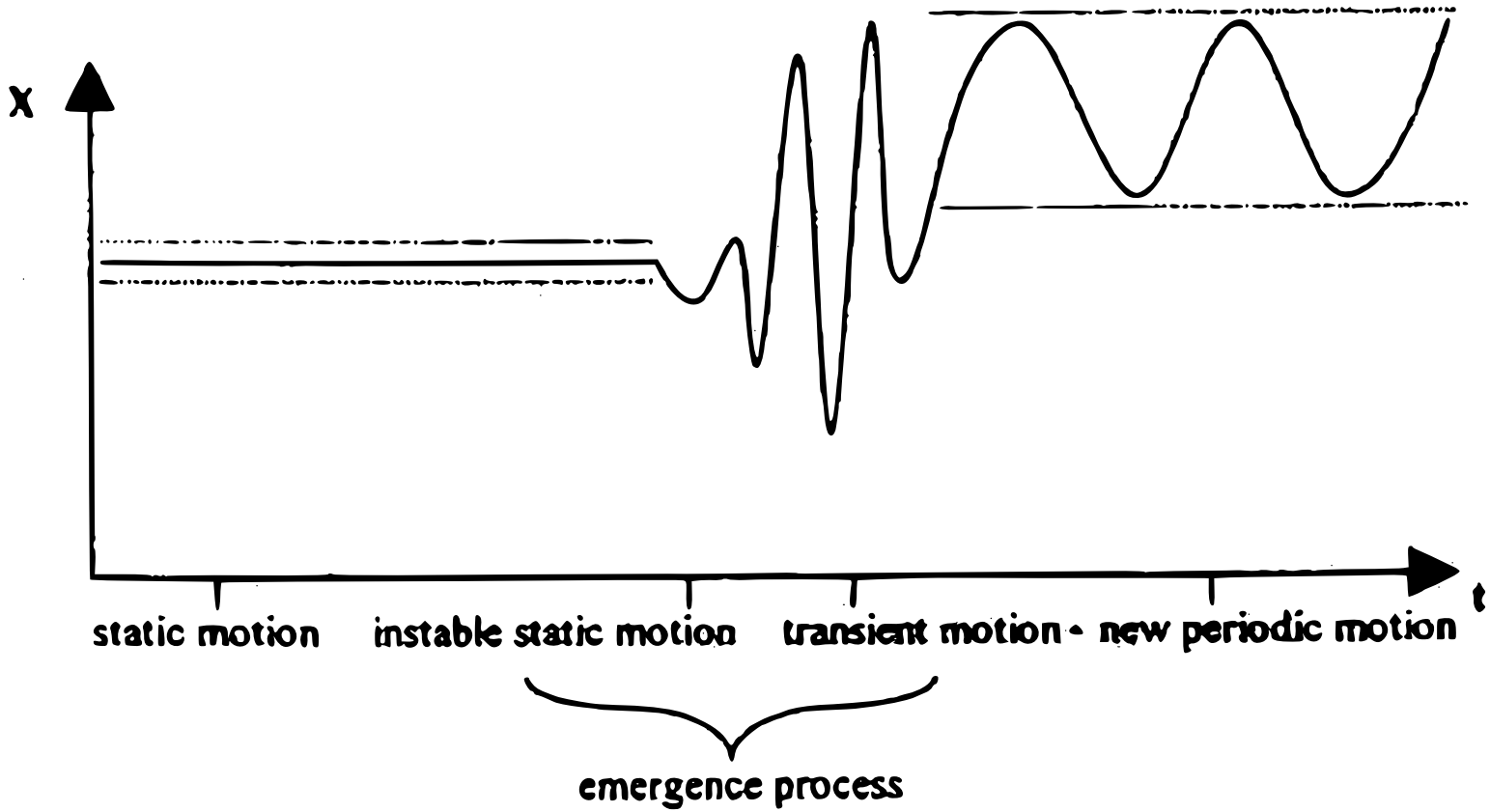
Emergence

- *common understanding:*
  new properties appear on the systems level
- *different interpretations*
  - mathematics: small (*quasi continuous*) changes in x result in large (*discontinuous*) changes in $X \Rightarrow$ non-reductionistic, irreducible



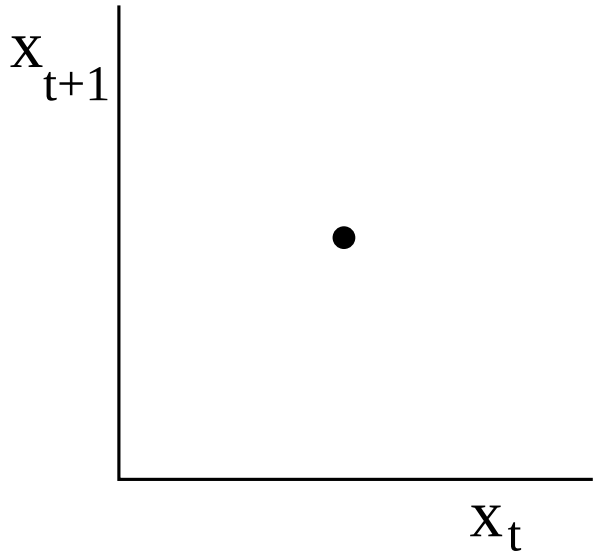
From: P. Eisenhardt, D. Kurth, H. Stiehl: Wie Neues entsteht, Reinbek 1995

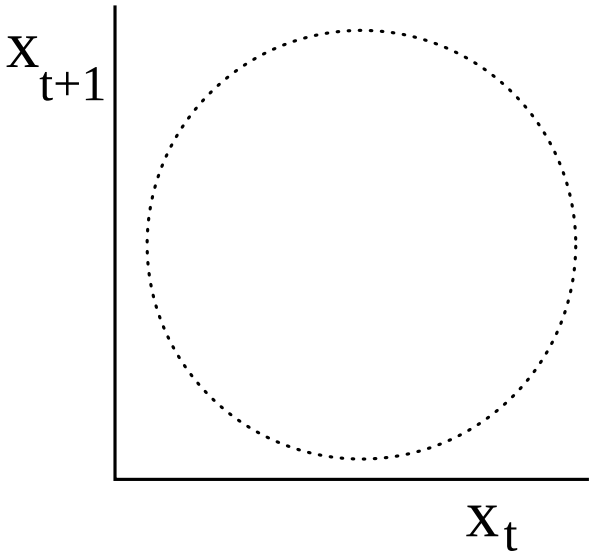
  - role of control parameter $A \Rightarrow$ induced transition
    - ★ same dynamics, but emergence of new attractors
    - ★ adaptation to changing conditions, rather than *novelty*

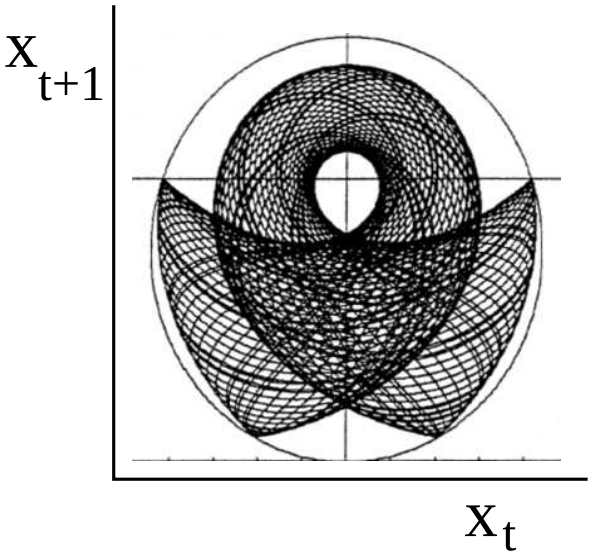


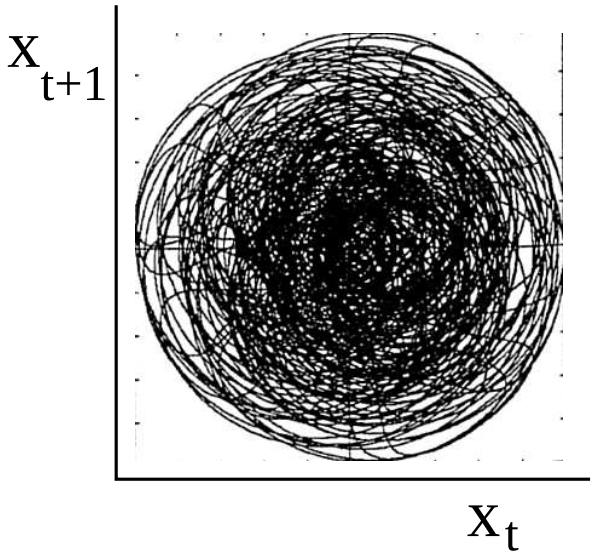
From: W. Völcker, Mimeo 1999

Same Dynamics – Different Attractors









Emergence from collective interaction

- Physics/Biology: emergence as collective phenomenon, resulting from interaction
- *Self-organization in distributed systems:*
  - based on the non-linear coupling of "individual" actions
  - feedback mechanism: self-consistent "field"
    indirect communication, exchange of information
  - non-equilibrium system: activity requires energy
  - self-organization: emergence of new solutions

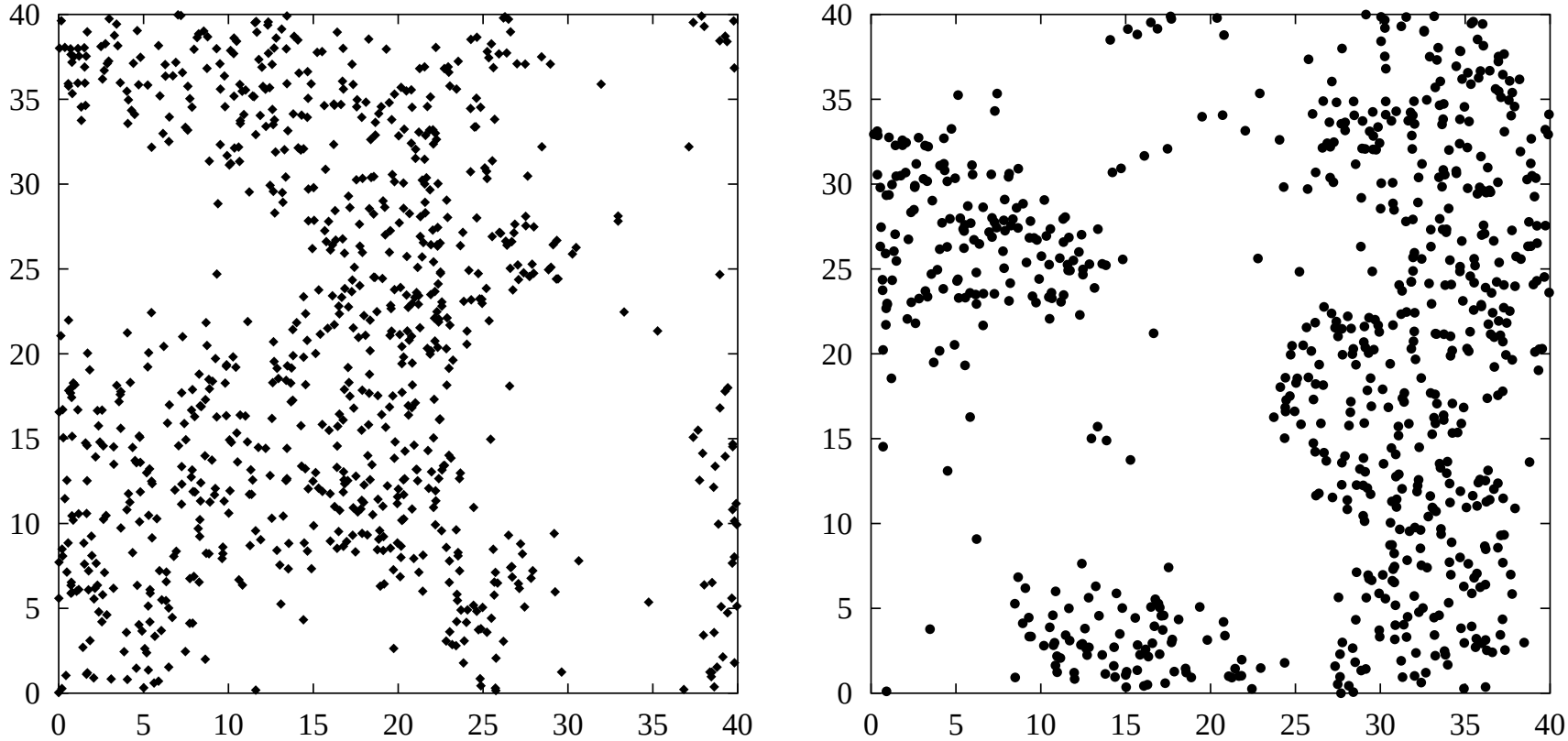
Simulation

Emergence of coordinated decisions

- N agents: position $\mathbf{r}_i \in \mathbb{R}^2$, "opinion" $\theta_i \in \{-1, +1\}$
- *binary choice*: to change or to keep "opinion" θ_i

$$w(-\theta_i|\theta_i) = \eta \exp\left\{-\frac{h_\theta(\mathbf{r}_i, t) - h_{-\theta}(\mathbf{r}_i, t)}{T}\right\}$$

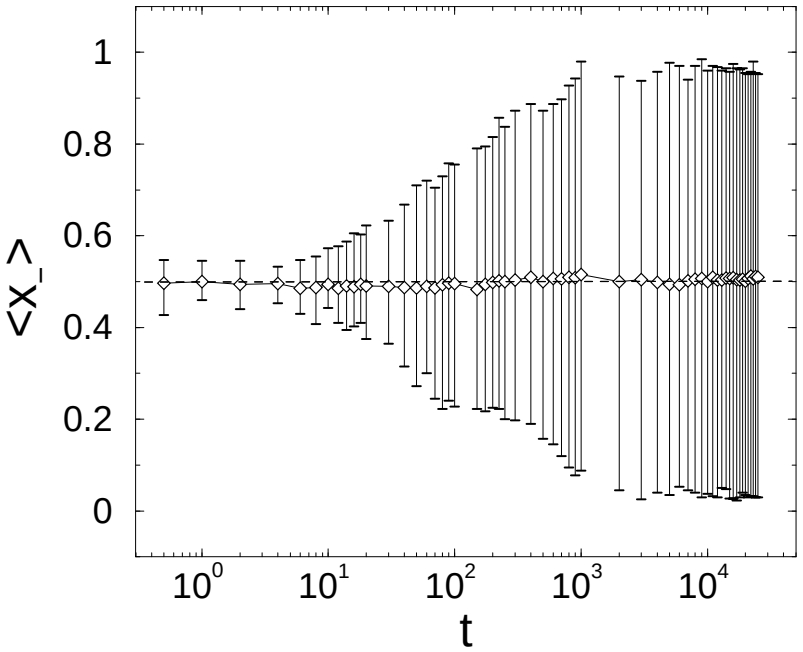
  - "herding behavior" $\Rightarrow$ depends on information $h_\theta(\mathbf{r}_i, t)$ about decisions of other agents
  - η: defines time scale
  - T: "social temperature"
    measures *randomness* of social interaction
    $T \to 0$: deterministic behavior



System size: $A = 1600$, total number of agents: $N = 1600$, time: $t = 5 \cdot 10^4$, frequency: $x_+ = 0.543$

Results: (closer inspection)

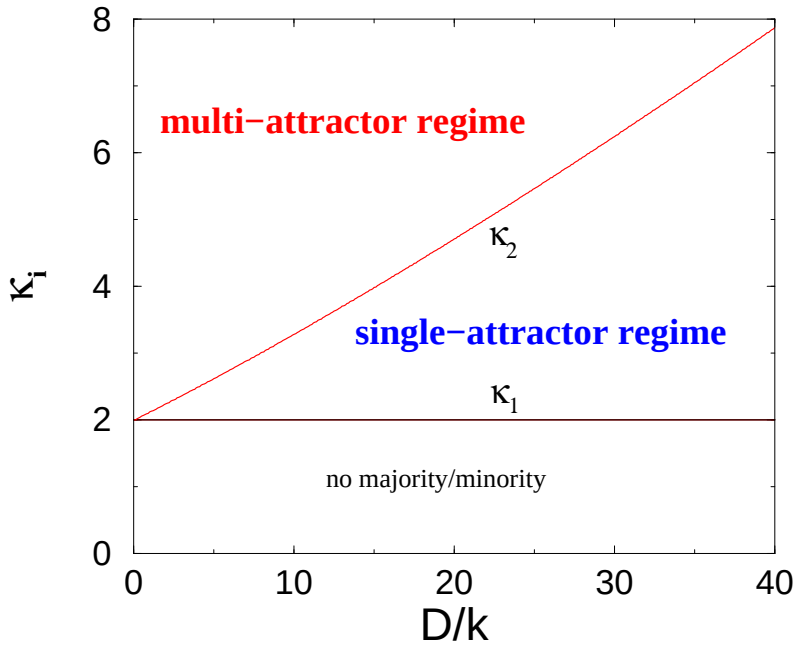
- *single-attractor regime:* fixed minority/majority relation
  multi-attractor regime: variety of spatial patterns
  almost every minority/majority relation may be established



- dependence on information dissemination (D), memory (k), agent density (N/A) ??

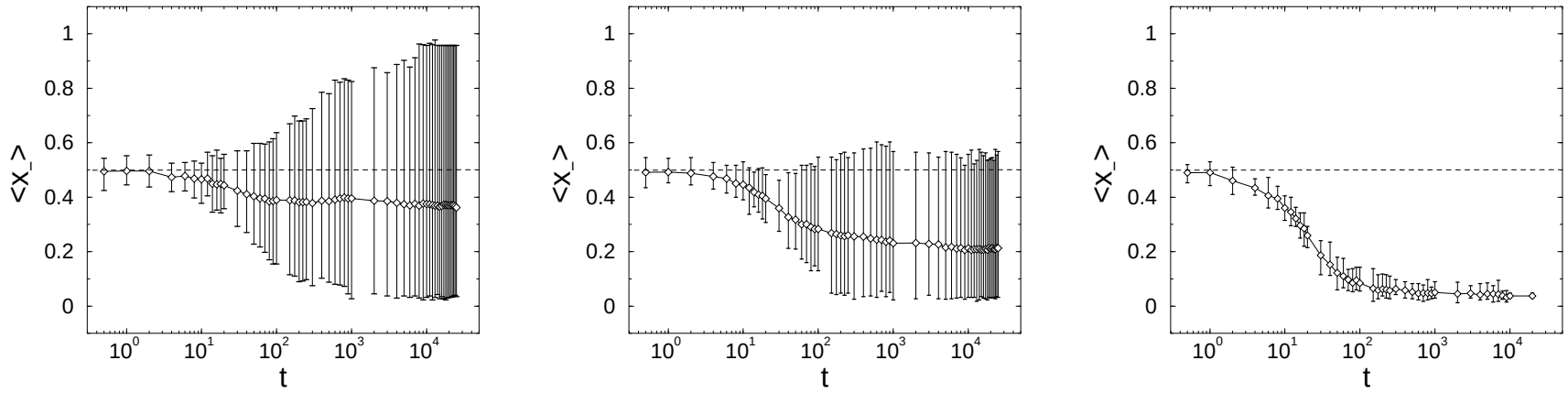
Analytical Investigations

- impact of information $\kappa = 2\nu/T$: relation between net information density $\nu = \bar{n}\, s/k$ and efficiency $\sim 1/T$
- existence of two bifurcations:
  $\kappa > \kappa_1 = 2$: minority/majority
  $\kappa > \kappa_2(D/k)$: multi-attractor regime



Communication on different time scales

vary: $d = D_{+1}/D_{-1}$

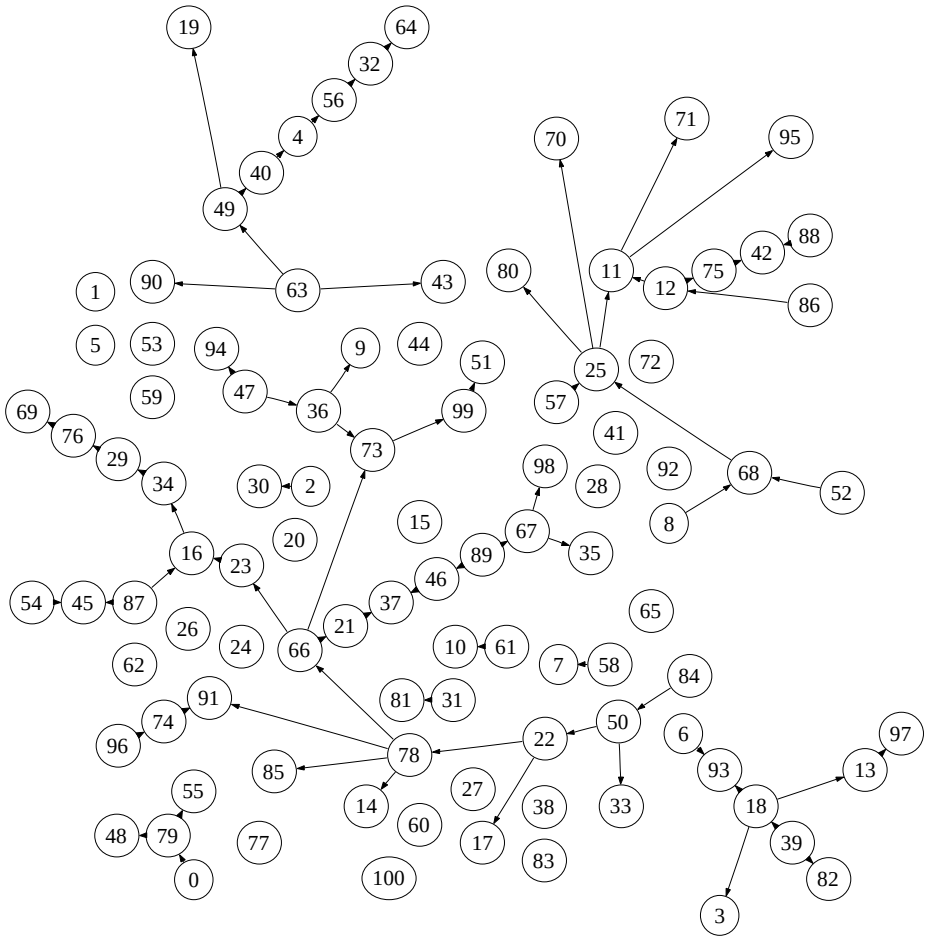


d=1.1 d=1.2 d=1.5

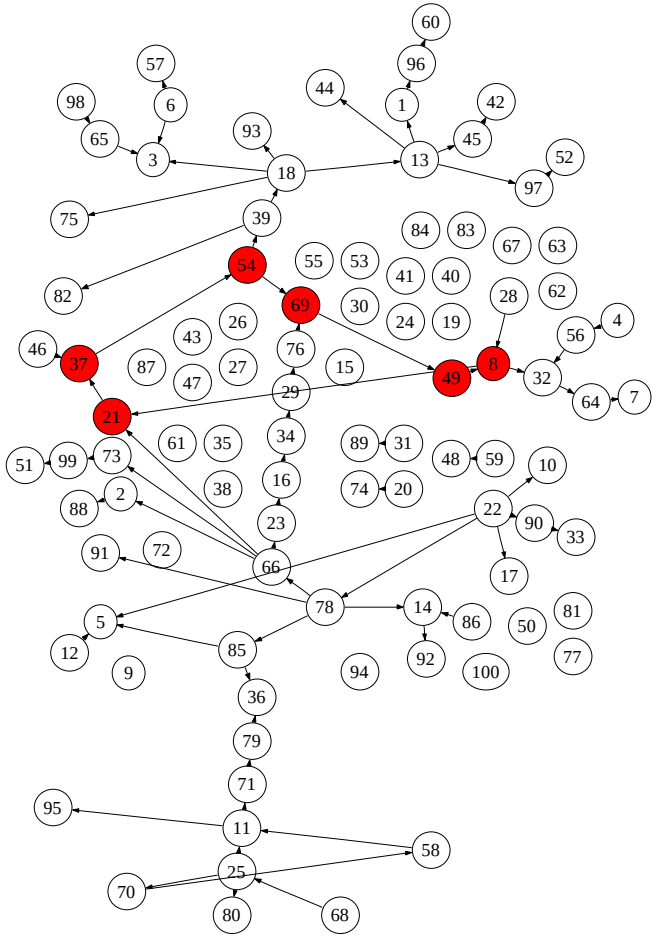
- subpopulation with the more efficient communication becomes "always" the majority

Emergence of cooperation

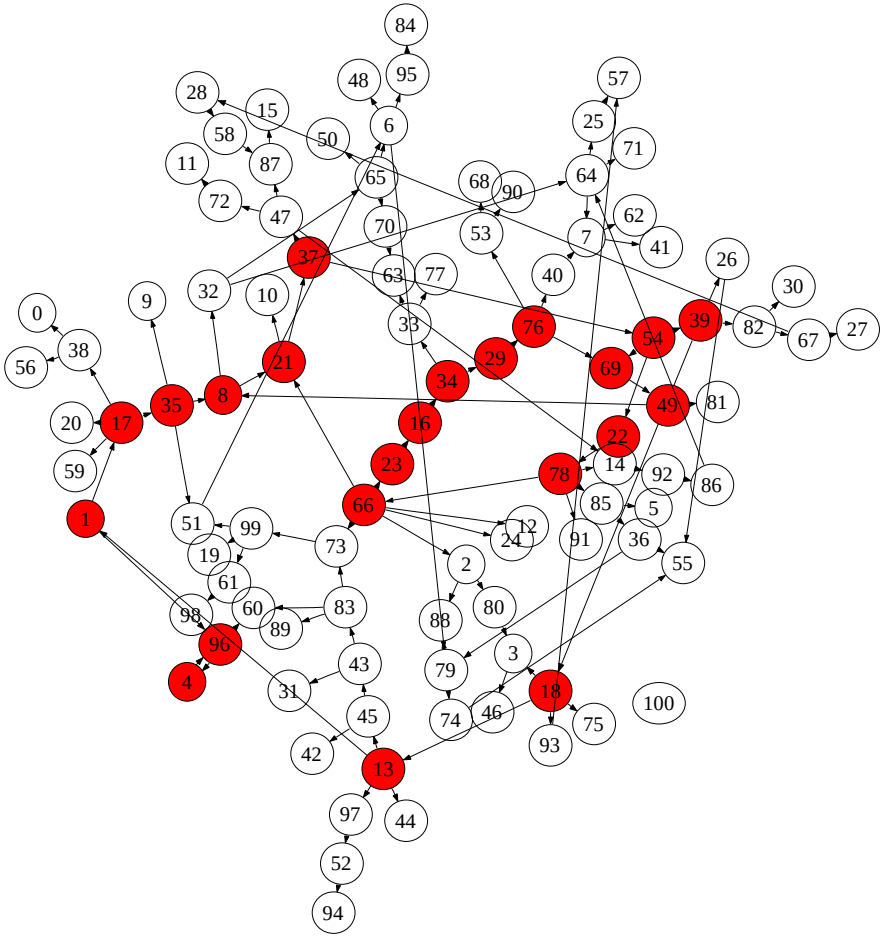
- network model of connected agents (directed links)
- *two time scales:*
  agent dynamics (fast), network dynamics (slow)
- **Questions**:
  - Under which conditions do agents survive?
  - Which structures of networks emerge?
  - What happens if selection pressure is increased?
- **Results of computer simulations**:
  Emergence of a core of *cooperative* agents, and a *parasitic* pheriphery, considerable crashes and recovery


19
64
32
56
4
40
49
70
71
95
88
42
75
80
11
12
86
1
90
63
43
5
53
94
9
44
51
59
47
36
99
25
72
57
41
69
76
29
34
73
98
28
92
68
52
30
2
15
20
67
8
16
23
89
35
54
45
87
46
37
65
26
24
66
21
10
61
7
58
84
62
91
81
31
74
50
6
97
96
22
93
13
78
85
27
38
33
18
55
14
60
17
39
48
79
77
83
82
0
100
3

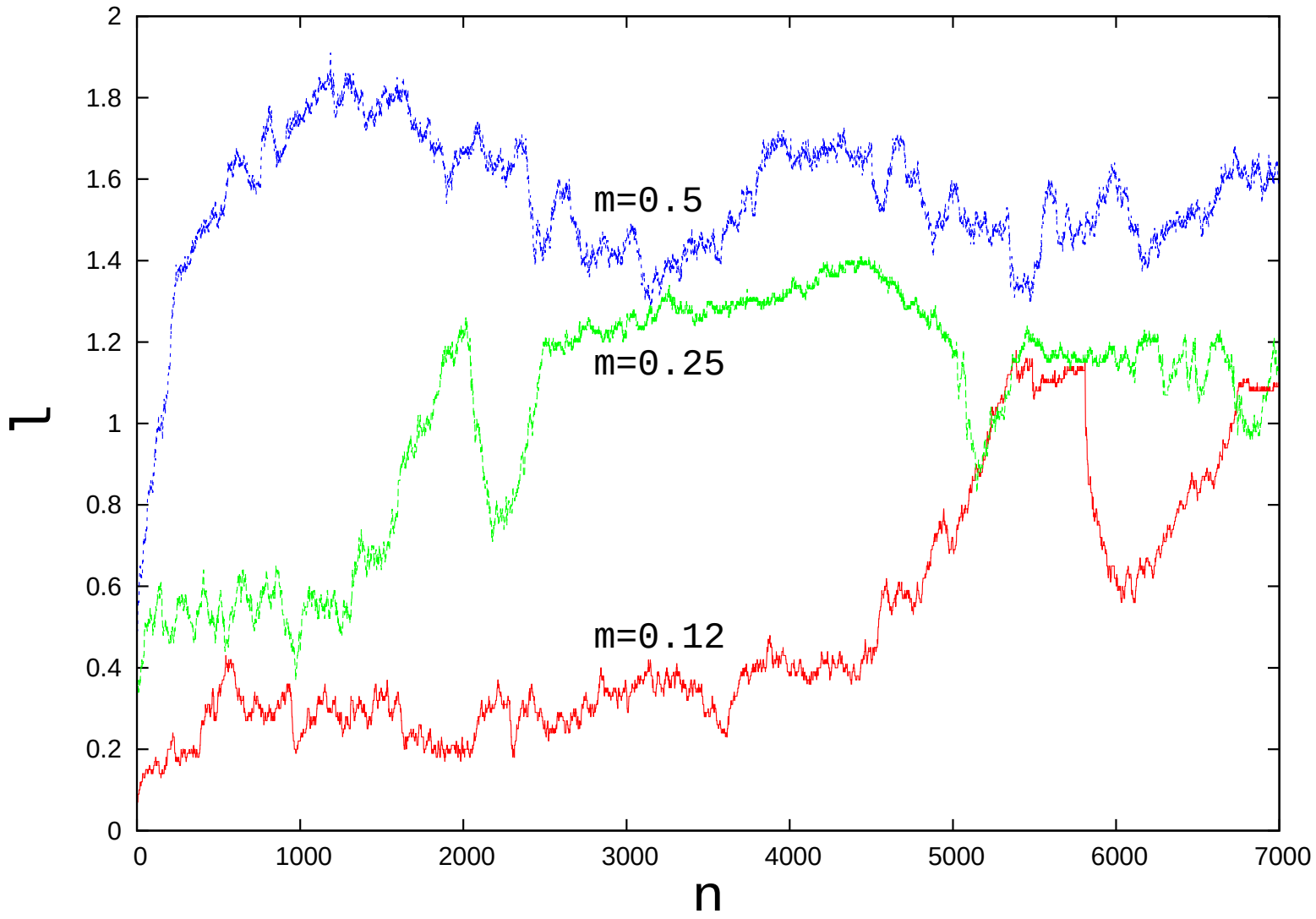
t=800


60
96
57
44
1
42
98
6
93
45
65
3
18
13
52
97
75
39
84
83
67
63
54
55
53
41
40
82
69
30
28
62
24
19
4
56
46
43
26
76
37
87
27
15
49
8
32
47
29
64
7
21
61
35
34
89
31
51
99
73
48
59
10
16
74
20
38
2
22
88
23
90
33
91
72
66
17
78
14
5
86
50
81
12
85
92
77
9
94
100
36
79
71
95
11
58
25
70
80
68

t=973


84
48
95
57
28
15
6
25
58
50
71
11
87
65
68
90
64
72
47
70
53
62
7
41
37
63
77
40
26
32
10
33
30
0
9
76
39
82
67
27
38
21
29
54
69
56
34
8
35
49
81
20
17
16
22
59
23
78
14
92
86
1
66
85
5
51
99
12
24
91
36
55
19
73
2
61
98
60
83
88
80
89
96
43
79
3
4
31
18
100
45
74
46
75
42
93
13
97
44
52
94

t=1290


m=0.5
m=0.25
m=0.12
L
n
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
1000
2000
3000
4000
5000
6000
7000