Models of Evolutionary Self-organization in Social and Economic Systems

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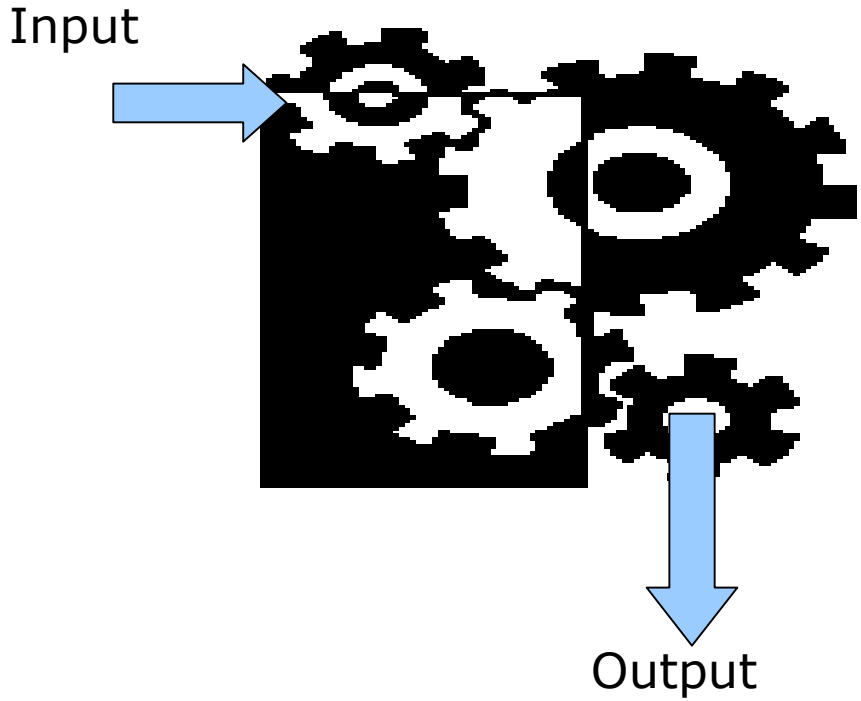
Complex Systems Management Centre,
Cranfield University, April 2004

My (very reasonable) starting point

- Physics must be right (and me too)
- A "system" is a set of interacting components, whose behaviour can be predicted providing we can define their behavioural rules, and their interactions
- All problems can be understood and "solved" if a serious attempt is made to "model" them

And life is therefore:



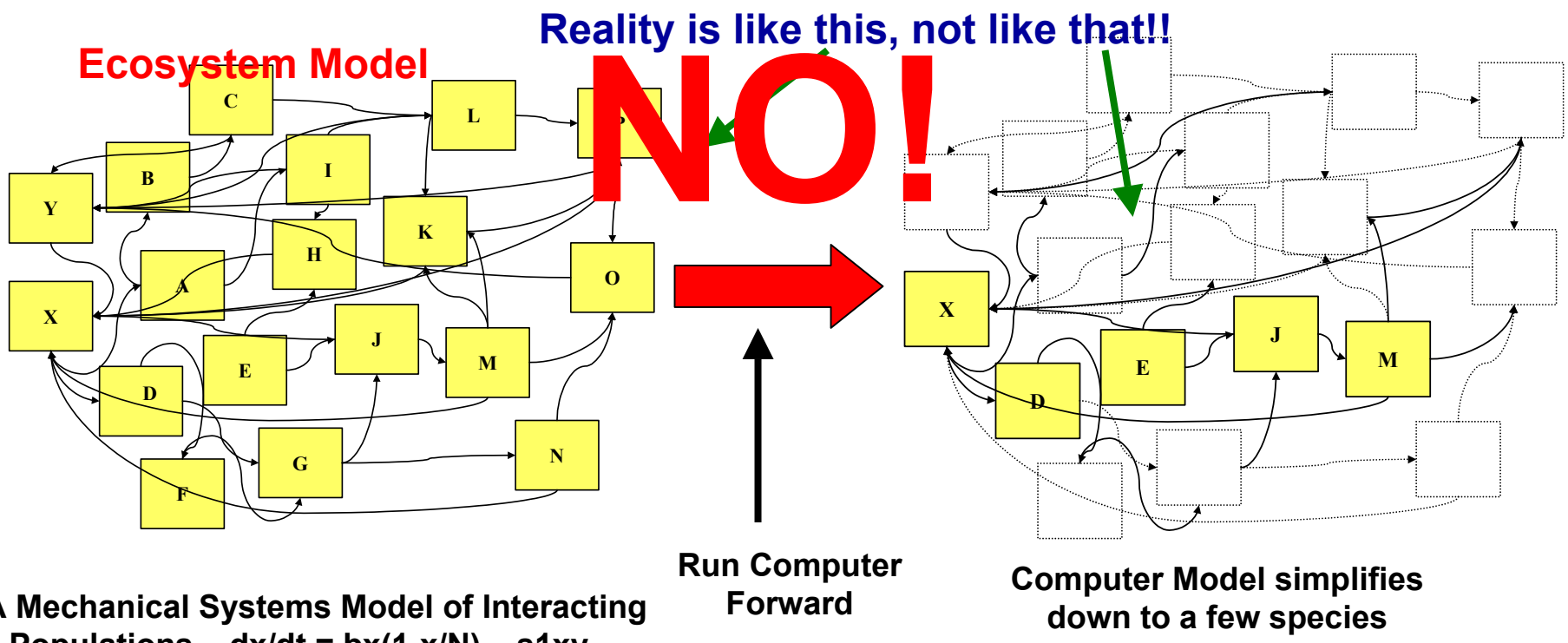
Chesapeake Bay Ecosystem

- We look at a major piece of research aimed at building a "population dynamics" model of the species interacting in Chesapeake Bay. What species where there? And who ate how much of whom??

- Such mathematical models are the most explicit statement of the "rational", left-brain way of understanding the world. And as a physicist I know that they CANNOT be wrong

Can Ecosystems be modelled by mechanical, systems equations?

- If run, the "model" ecosystem collapses. It does not adapt and evolve! **Reality does!**



Why is the model NOT reality?

- Identifying the assumptions used in writing down the equations of population dynamics MUST tell us what REALLY MATTERS!
- Selection between competing food chains is present – but something is missing that counterbalances this - microdiversity
- This appears to be what is NOT in the equations.
  - Individual diversity, local circumstances and luck!!!!! All that is not "average"

Create "KNOWLEDGE" - simplify REALITY to mechanics?

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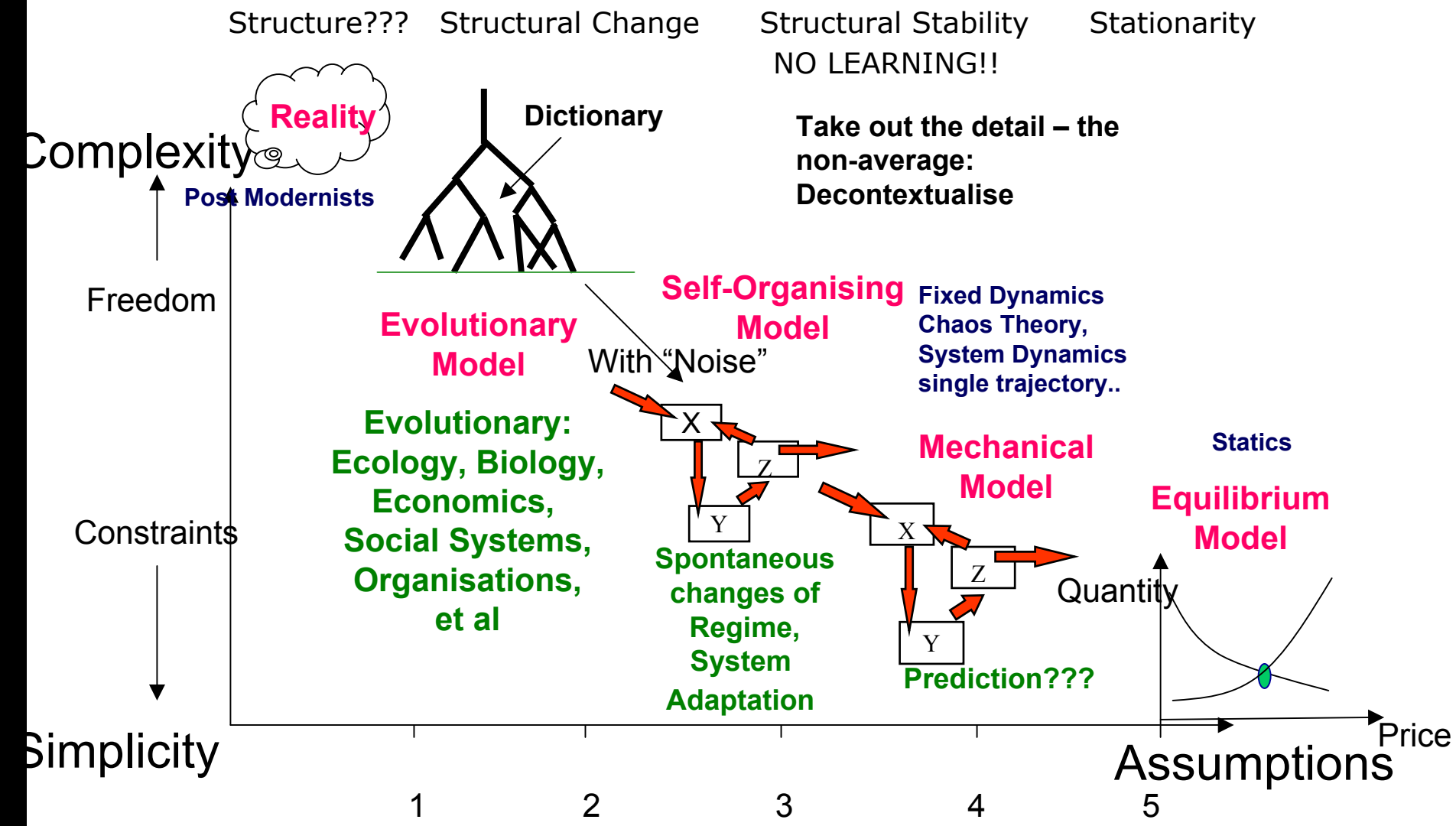
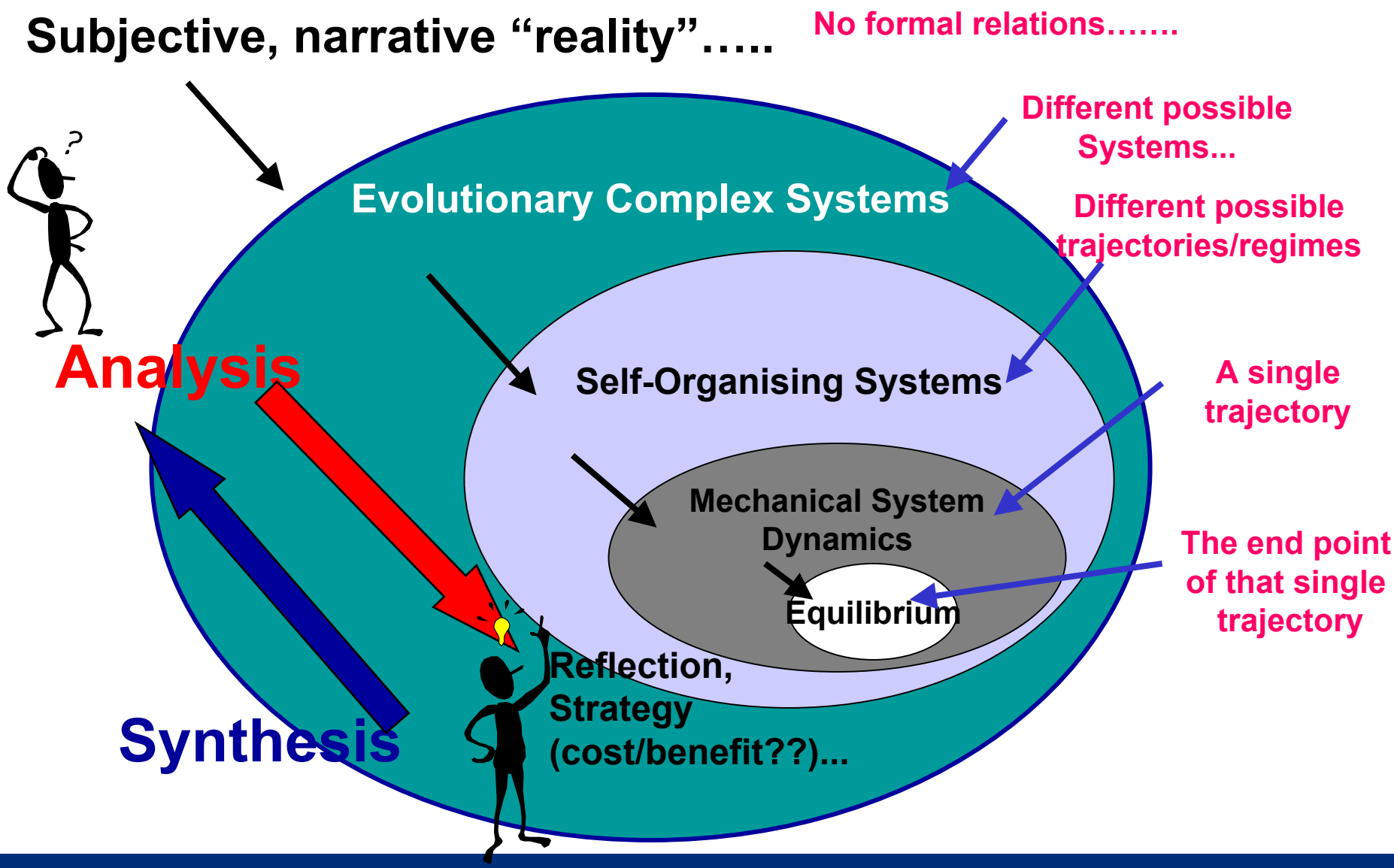



Subjective, narrative "reality"…..
No formal relations…….
Different possible Systems...
Different possible trajectories/regimes
A single trajectory
The end point of that single trajectory
Evolutionary Complex Systems
Self-Organising Systems
Mechanical System Dynamics
Equilibrium
Analysis
Synthesis
Reflection, Strategy (cost/benefit??)...

We assume that "simpler" = "more general"……

Replace actual people by "simplified" functional types, with "average" behaviour and interactions. This is the basis of rational Strategy and Planning.

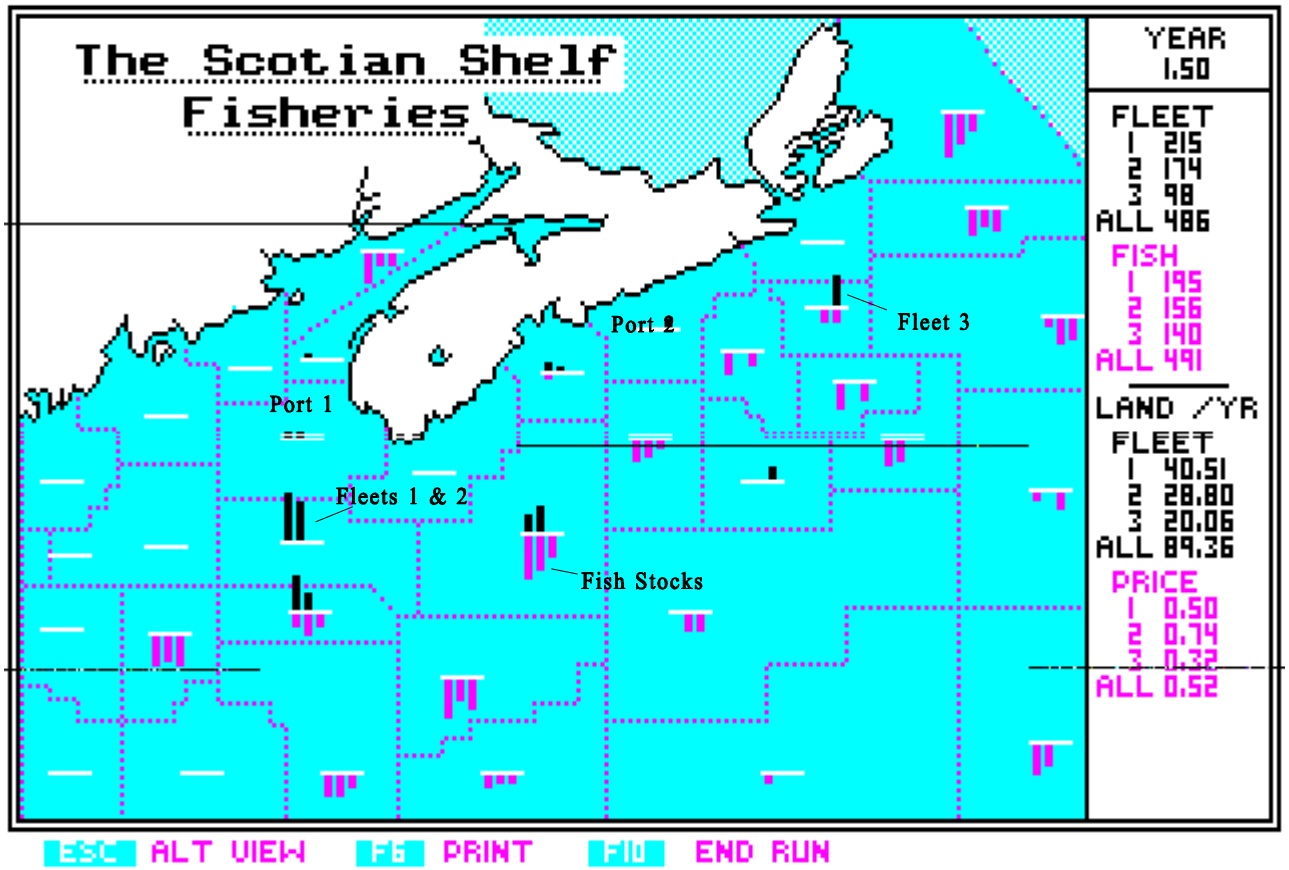
But it may just be "less true"!!!

A Fisheries Example

(My second shocking moment)

Let us look at management, strategy and knowledge dynamics in a simple example

40 Spatial Zones with Cod, Haddock and Pollack stocks
3 Fleets (2 Trawlers, 1 Long-liner)



Time

Number of Boats

ktons of Fish

Value of Landings

$/kg of each fish

You are a Fleet Manager

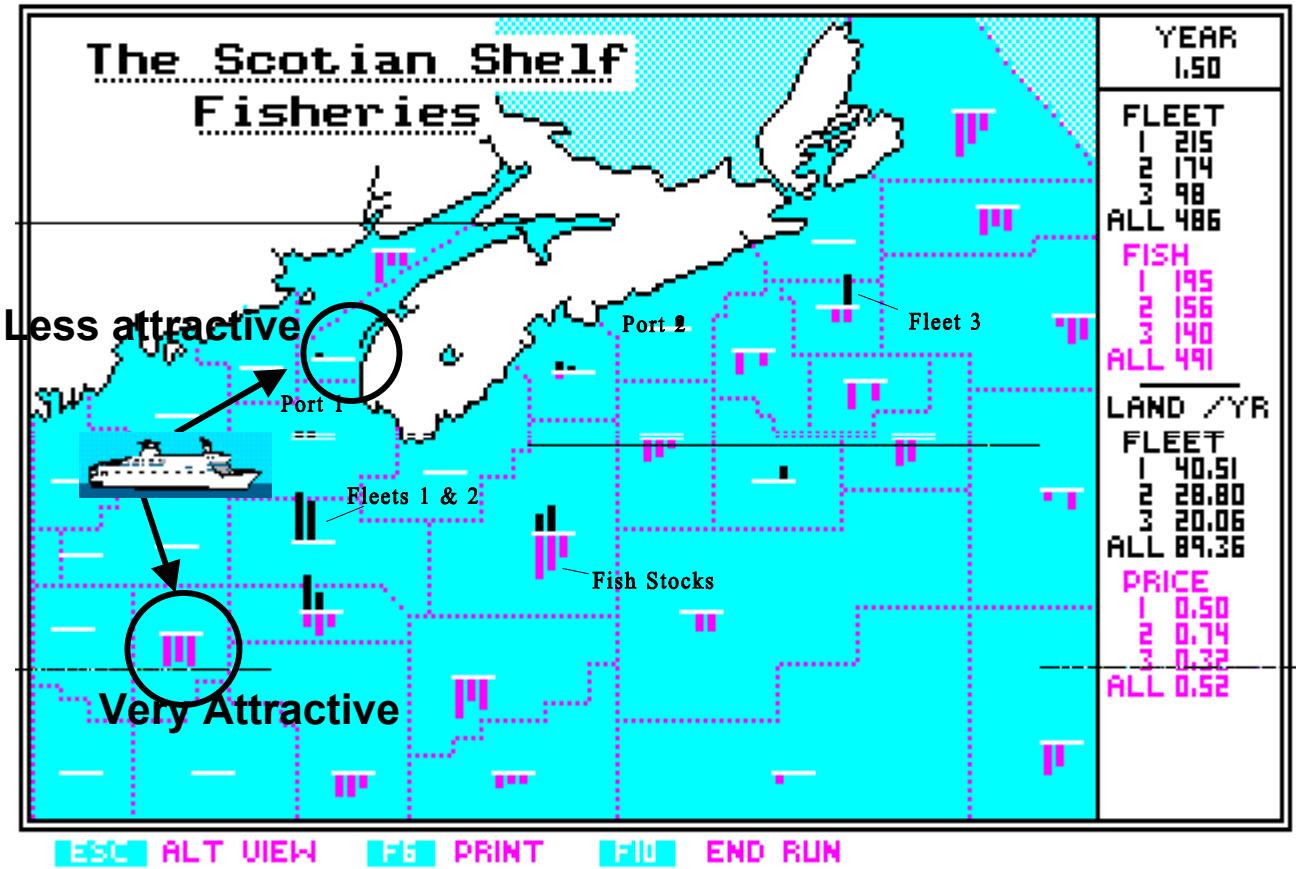
- In this example you will decide the strategy of your fishing fleet.
- You, and the fishermen are profit seeking - but how is this achieved?
- By catching fish! What behaviour should I impose on my fleet?

- Each Zone i exerts an attraction on a fishing boat in zone j - (A_{ij}).
- What makes a zone attractive? - High Catch rates of valuable fish! (Utility U_{ij})
- Boat movements are driven by the response of skippers to this. (R, Rationality)

$$A_{ij} = \text{Exp}\{R.(U_{ij})\}$$ R = "Rationality" U = Utility

$$U_{ij} = \alpha_f \Sigma_{f'} \varepsilon(f,f') \omega(f,f') \Sigma_k \, y(f',i)[\text{Revenue}(f')/\{1+by(f',i)\}] - a2d_{ij} - a3d_{ip}$$

"R" determines the degree of concentration of the fleet in high or low value zones!



The Effect of "R" – the rationality

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R	Zone 1	Zone 2			10% More Fish
	100	110	Att(1)	Att(2)	% Response of Fleet
0,1	1,221403	1,246077	0,495	0,505	1,00%
0,5	2,718282	3,004166	0,475021	0,524979	5,00%
1	7,389056	9,025013	0,450166	0,549834	9,97%
2	54,59815	81,45087	0,401312	0,598688	19,74%
3	403,4288	735,0952	0,354344	0,645656	29,13%
4	2980,958	6634,244	0,310026	0,689974	37,99%
6	162754,8	540364,9	0,231475	0,768525	53,70%
8	8886111	44013194	0,167982	0,832018	66,40%

Therefore R acts like the "Internal Rate of return"….

How can we be successful ?

Go Fishing

8 Fleets
R=.1
R=.5 Stochasts
R=1
R=2
R=3
R=4
R=6 Cartesians
R=8

Place your bets!

Knowledge, Ignorance and learning…..

- Their behaviour is focused by present information. (They only go where they know there will be high returns)
- They are therefore **EFFICIENT**, and the high R will out-compete others in the short term.
- High internal rate of return on fleet actions….

- **SPATIAL DECISION NOT FIRMLY BASED ON THE EXISTING INFORMATION!!!!!**
- **Not pursuing PROFIT maximally!!!!**
- **Clearly Stupid, Mad or both!!!**

Yet they WIN!!!!!!!!

What does this mean?

Our simple model of fishermen who mindlessly seek ONLY profit shows us that over time this is NOT achieved by seeking profit but..

by sailing around NOT particularly seeking profit!!

Optimists who will travel "hopefully" win over Pessimists who won't. Learning requires exploration…

Implications for Management -

- It is not the efficient exploitation of KNOWLEDGE at any moment that wins.
- It is the LEARNING PROCESS that allows knowledge to be created and up-dated. This requires SUB-OPTIMAL behaviour. It requires MICRO-DIVERSITY.
- It requires social relationships within and between people – conversations, trust, loyalty, competition..) as "research clusters"
- There is no single "OPTIMAL" strategy, but instead an evolving "spectrum" of compatible strategies – evolved ECOLOGY of behaviours.

From learning about the resource to learning how to transform the organisation:

- Evolution of Manufacturing Organisations
- History in terms of the exploratory bundling of practices that occur in auto-manufacturing organisations (McKelvey, McCarthy et al.)
- Cladistics of Organisations – history of successive "invasions" of organizations by new ideas.
- Look at organisational forms as bundles of practices, and the performance of a bundle depending on the synergy or conflict of its practices

NEXSUS: work involving Cranfield and Jim Baldwin at Sheffield, Inst of Mechanical Engineering

Evolving Dictionary of "practices" - 53 Characteristics

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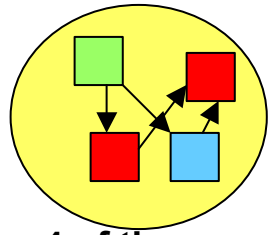
Standardisation of Parts	1
Assembly Time Standards	2
Assembly line layout	3
Reduction of Craft Skills	4
Automation (Machine paced shops)	5
Pull Production System	6
Reduction of Lot size	7
Pull procurement planning	8
Operator based machine maintenance	9
Quality circles	10
Emloyee innovation prizes	11
job rotation	12
large volume production	13
mass sub-contracting by sub-bidding	14
exchange of workers with suppliers	15
Training through socialisation	16
Proactive training programmes	17
Product range reduction	18
Automation (Machine paced shops)	19
Multiple sub-contracting	20
Quality Systems	21
Quality Philosophy	22
Open Book Policy with Suppliers	23
Flexible Multifunctional workforce	24
set-up time reduction	25
Kaizen change management	26

TQM sourcing	27
100% inspection sampling	28
U-Shape layout	29
Preventive Maintenance	30
Individual error correction	31
Sequential dependency of workers	32
Line balancing	33
Team Policy	34
Toyota verification of assembly line	35
Groups vs. teams	36
Job enrichment	37
Manufacturing cells	38
Concurrent engineering	39
ABC Costing	40
Excess capacity	41
Flexible automation of product versions	42
Agile automation for different products	43
In-Sourceing	44
Immigrant workforce	45
Dedicated automation	46
Division of Labour	47
Employees are system tools	48
employees are system developers	49
product focus	50
Parallel processing	51
Dependence on written rules	52
Further intensification of labour	53



4 of the possible 53 practices

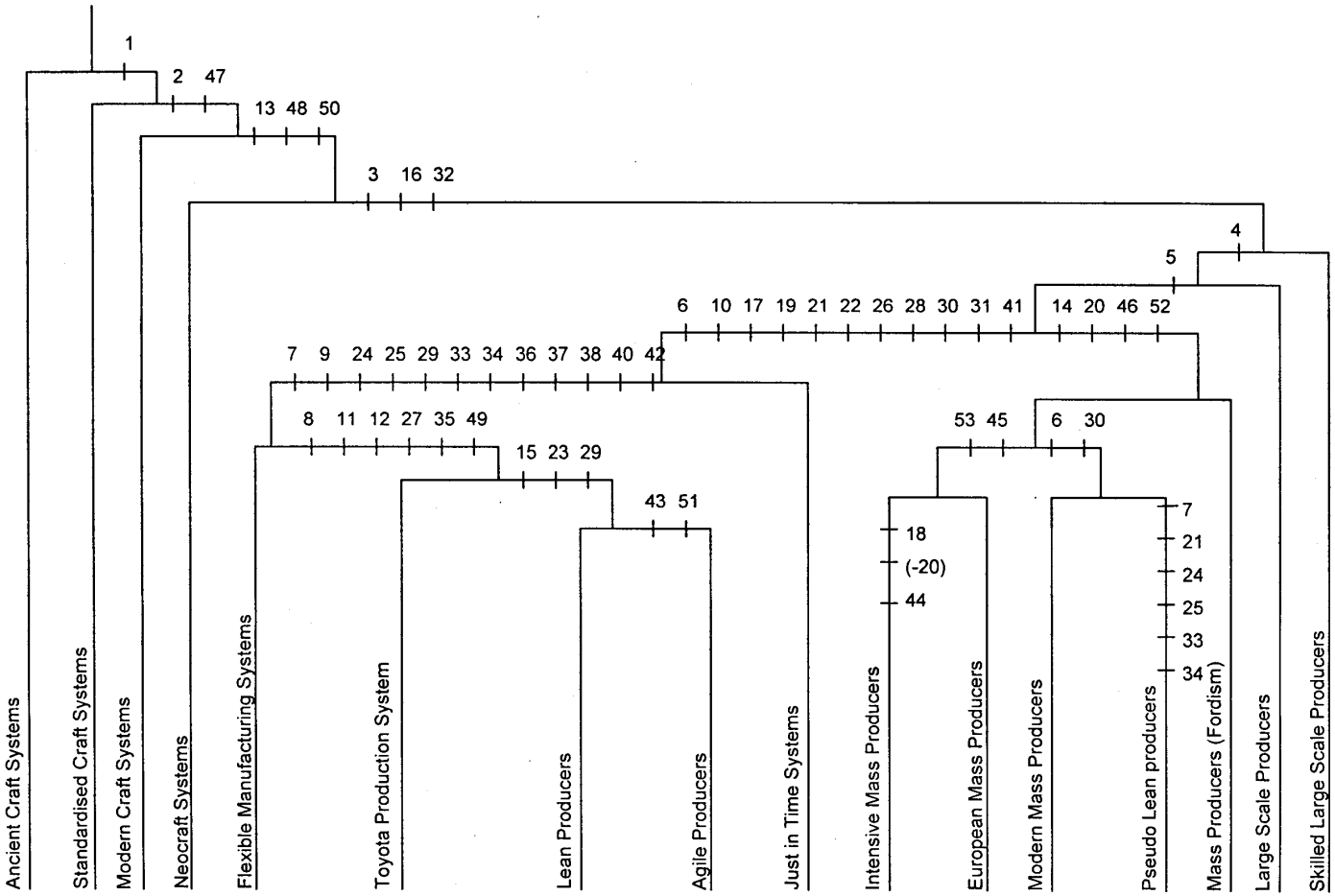
Auto Manufacture: 16 Organisational Forms:

1. Ancient Craft System
2. Standardised craft System
3. Modern craft System
4. Neocraft systems
5. Flexible Manufacturing
6. Toyota production
7. Lean producers
8. Agile producers
9. Just in time
10. Intensive Mass producers
11. European mass producers
12. Modern Mass Producers
13. Pseudo lean producers
14. Fordist Mass producers
15. Large Scale producers
16. Skilled large Scale producers

Are these Structural Attractors?

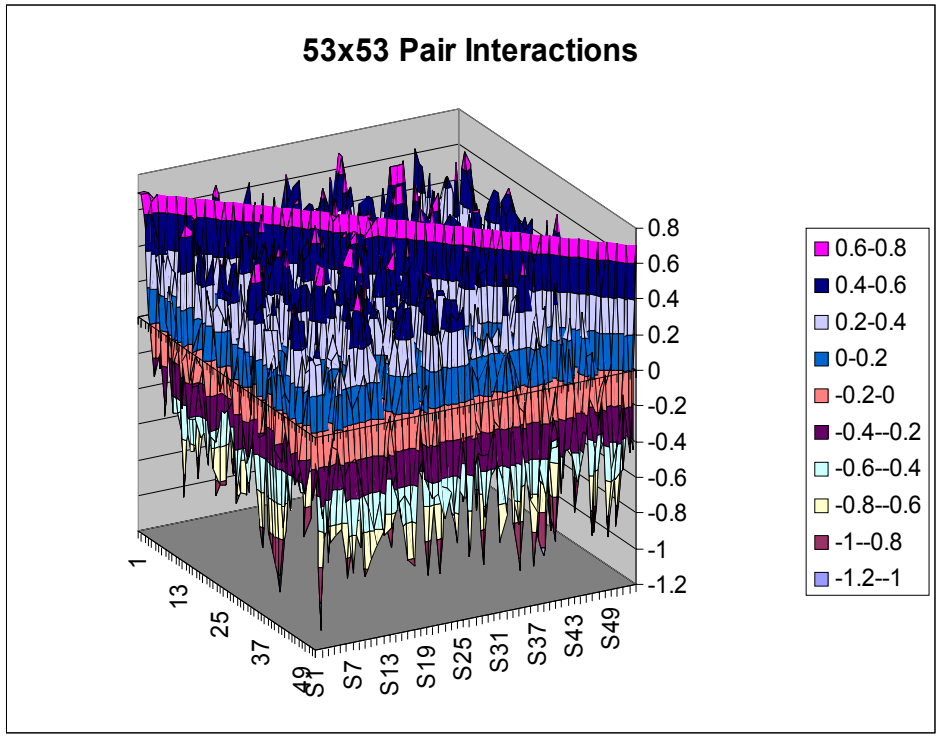
Evolution of Organisational Forms

From McCarthy, 1997



But different new practices interact…

- The 53 characteristics interact
- Some are "synergetic" and some "conflict"
- Questionnaire (Jim Baldwin) returned by 70 companies
- So we can explore possible structures…

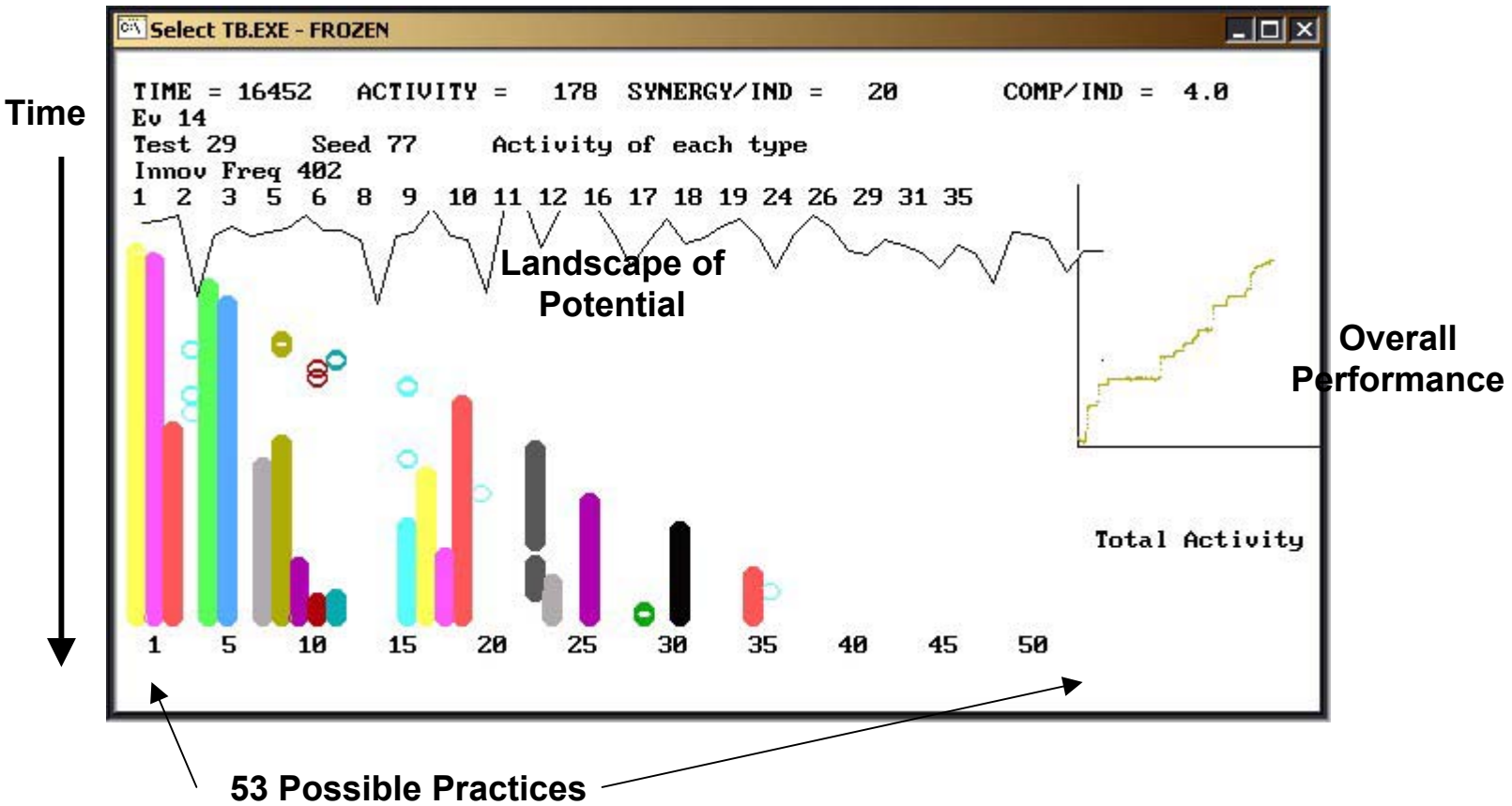


Total Positive = 207

Total Negative = 351

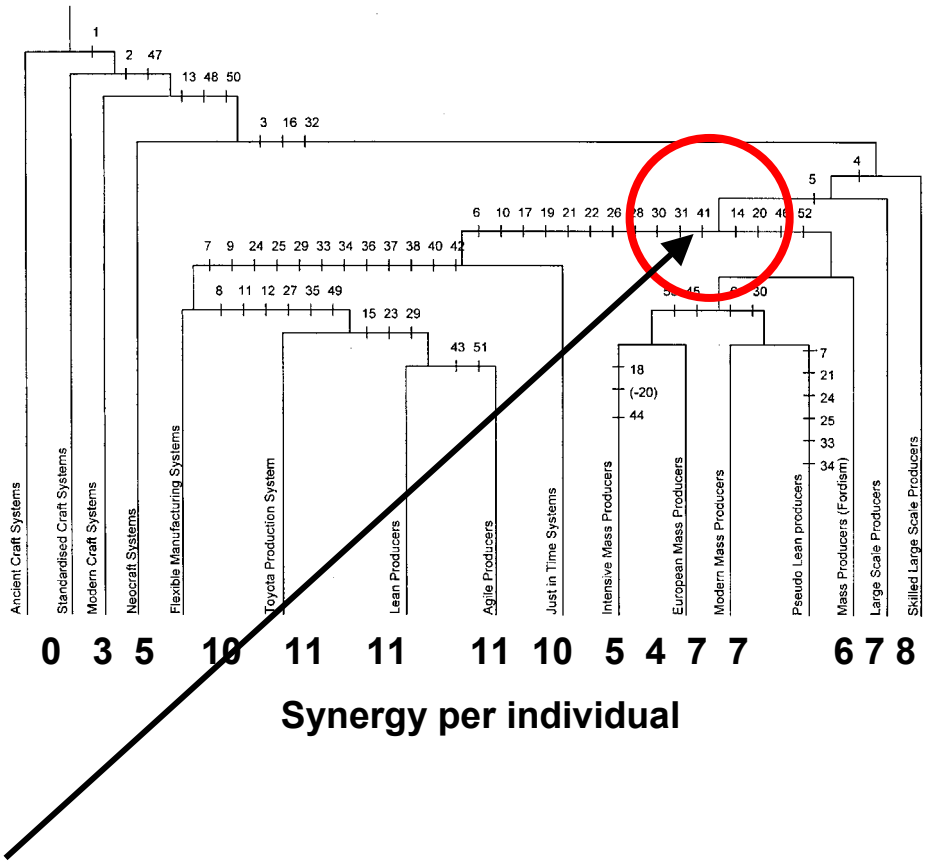
Out of 2809

Manufacturing Evolution



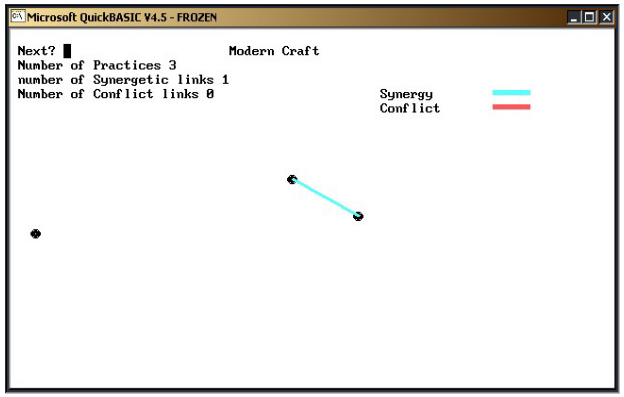
Evolution is to increasing SYNERGY

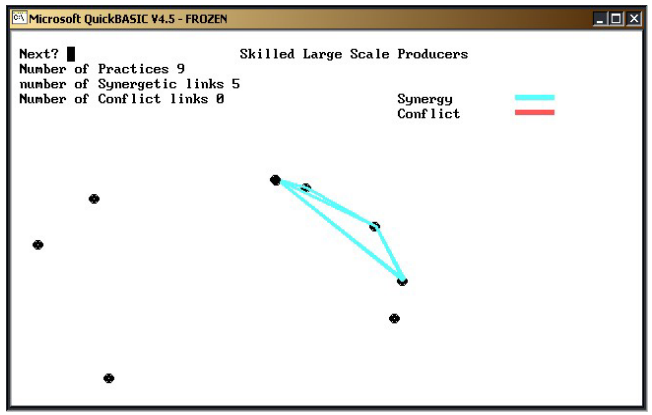
- Successive structures have greater synergy
- Organisational forms are STRUCTURAL ATTRACTORS
- Key branching leads to forms that conflict

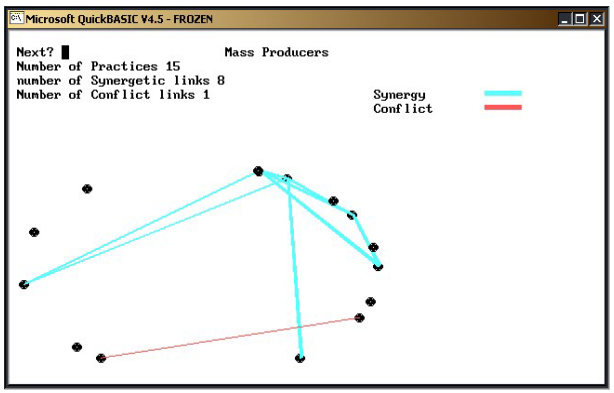


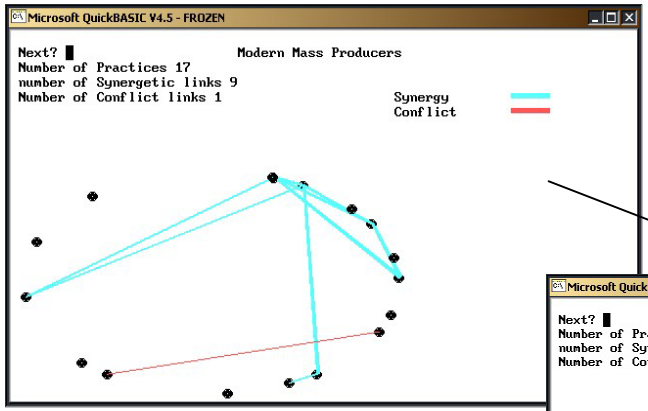
17 conflicting factors

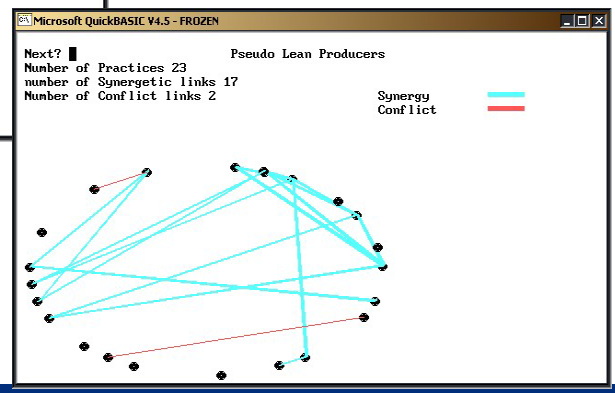
Modern Craft - Practices











Successive structures

Towards highly co-operative practices:

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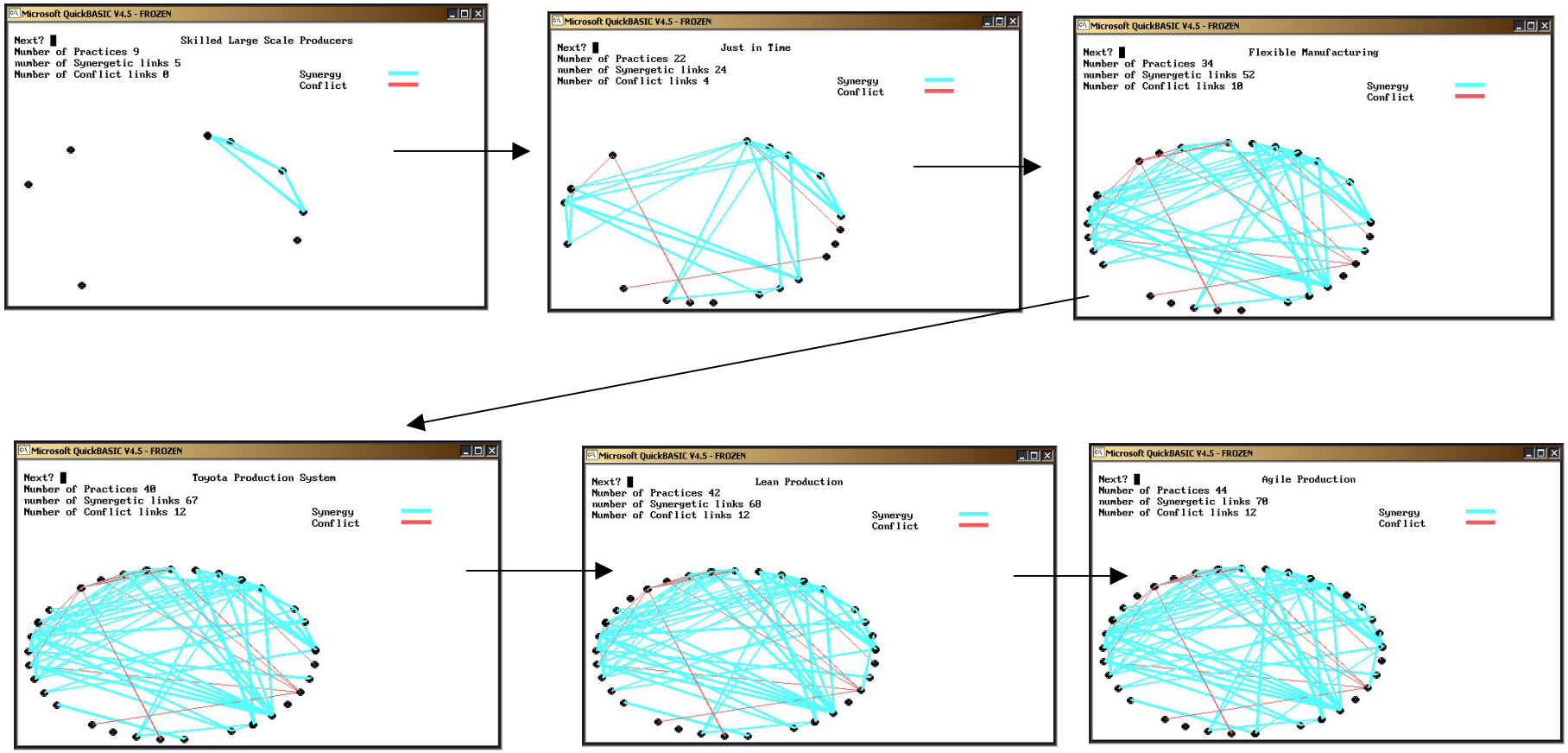
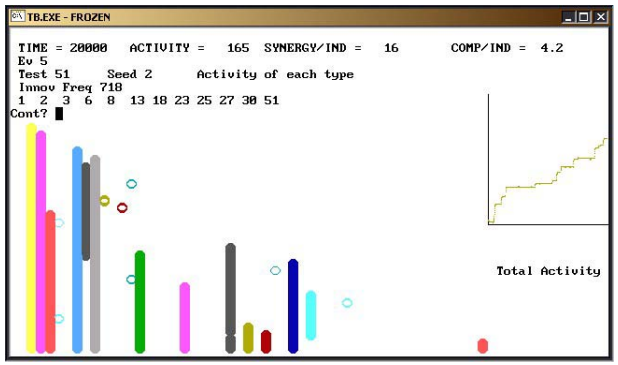
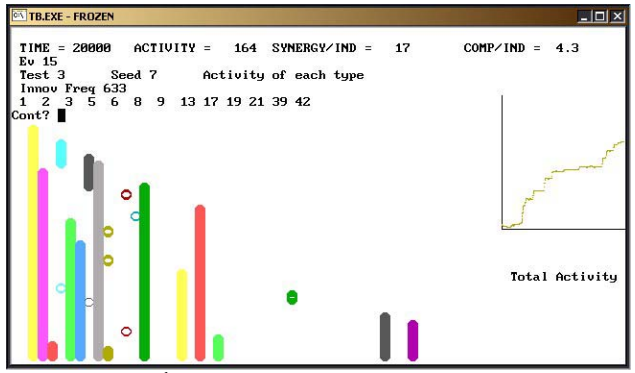
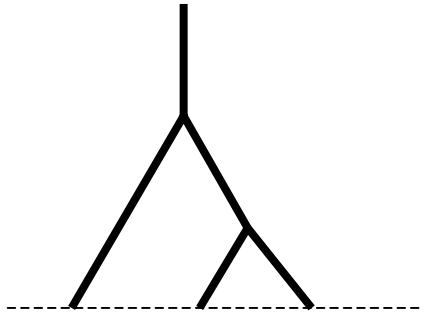


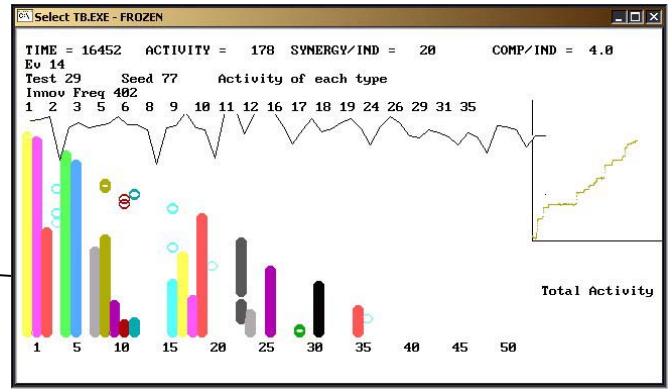
Evolution in Character/practice space



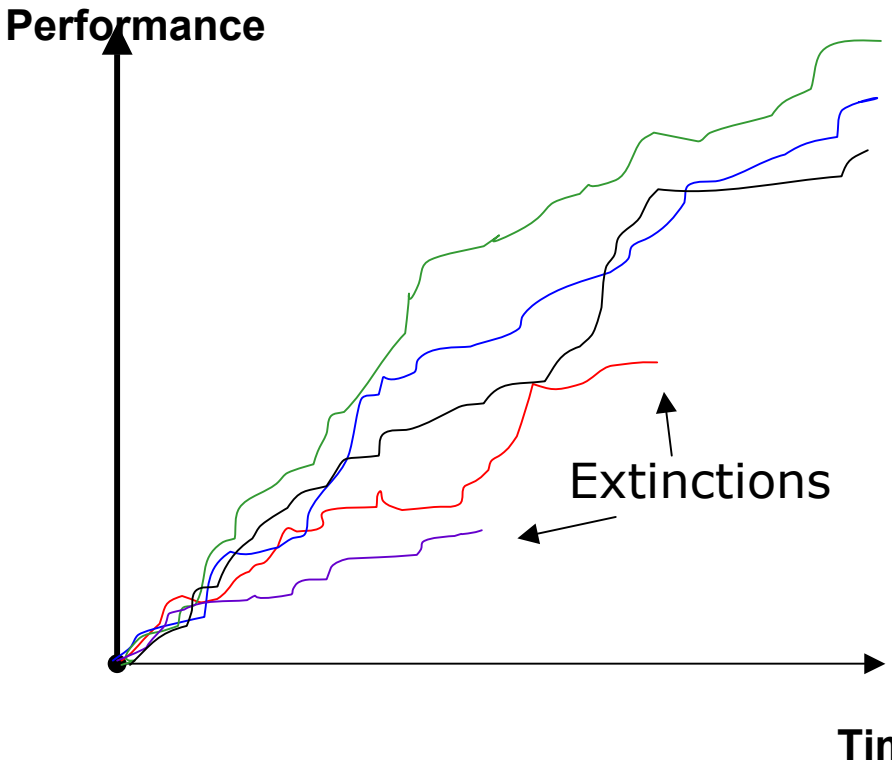




Competition….



But different branches compete….



As performances evolve at different rates some evolutionary branches are eliminated

On the whole faster innovation tends to win, but enough time is Needed for "co-evolution"

We see that an "industry" is an "ecology" of possible species of organisation which are alternative co-operative "bundles" that can themselves co-operate….

Another shock – because we are always told competition is what matters most!!!

But this all applies to the organisation of cities, regions and nations:

- Evolutionary models can be built of urban and regional development (Since 1976…) that co-generate possible structures and flows
- They allow the permanent monitoring of the flows of goods, services and information that **are necessary** for their functioning
- Such models allow us to study the resilience of different possible structures/future trajectories to various possible events

The Interaction mechanisms of "Brussaville" 1980s – Multi-agent modelling….

Transport Networks Road, Rail, Buses, trams, walking…

Flows on all links of all networks a dynamic output of the model….

Impacts of changed infrastructure, with feedbacks…..

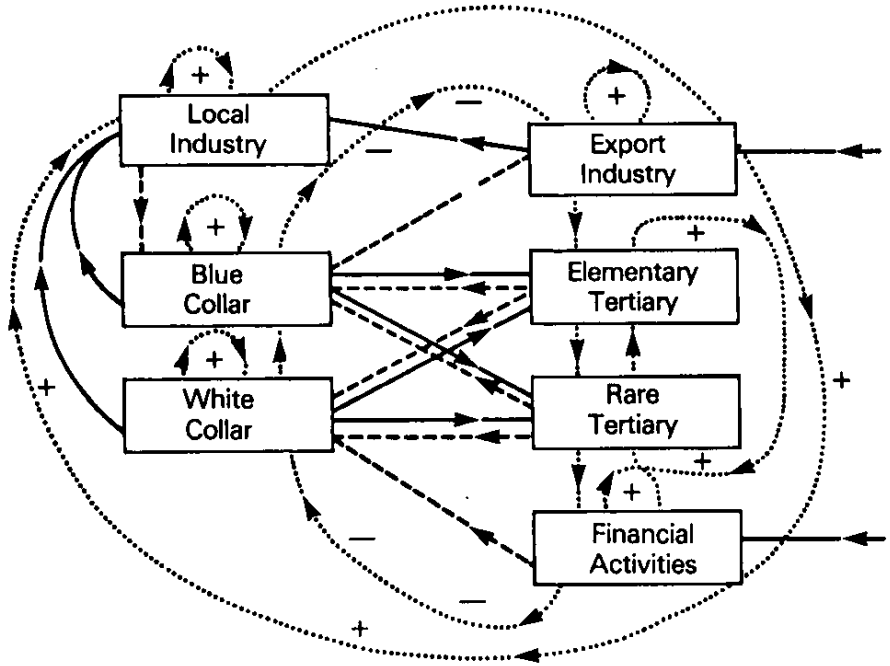
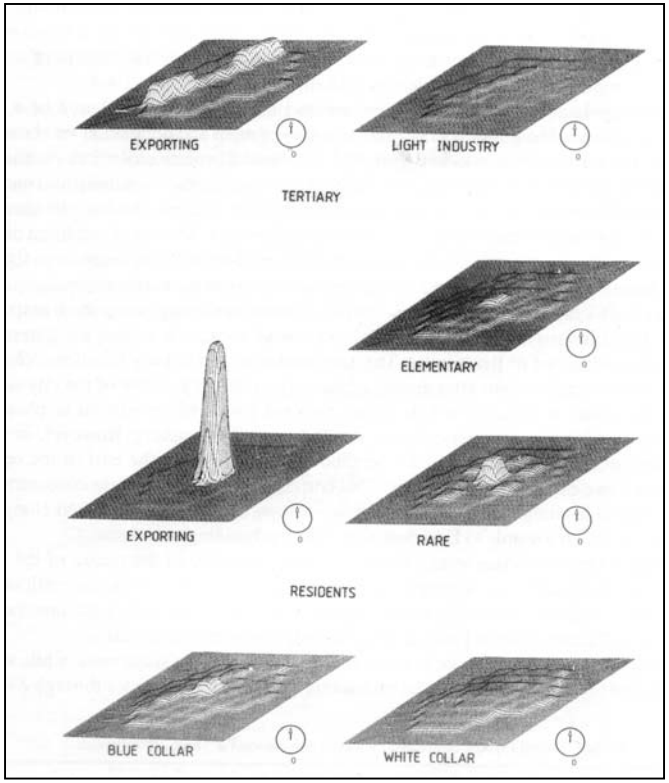


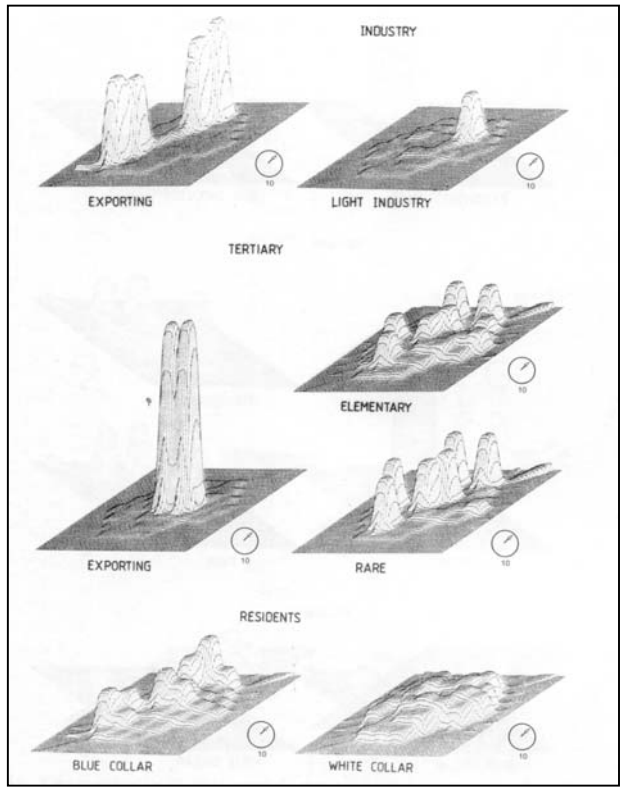
Figure 9.1 The scheme of interaction for an intraurban evolution.

Allen, 1997, Self-Organising Cities and Regions: Models of Complexity, Taylor & Francis, London

Emergent, self-organising Brussaville….

The model can explore possible emergent structure/flows, with
All the necessary flows of goods, services and information…





One of many possible trajectories….

Cannot understand the spatial evolution of one variables without the others

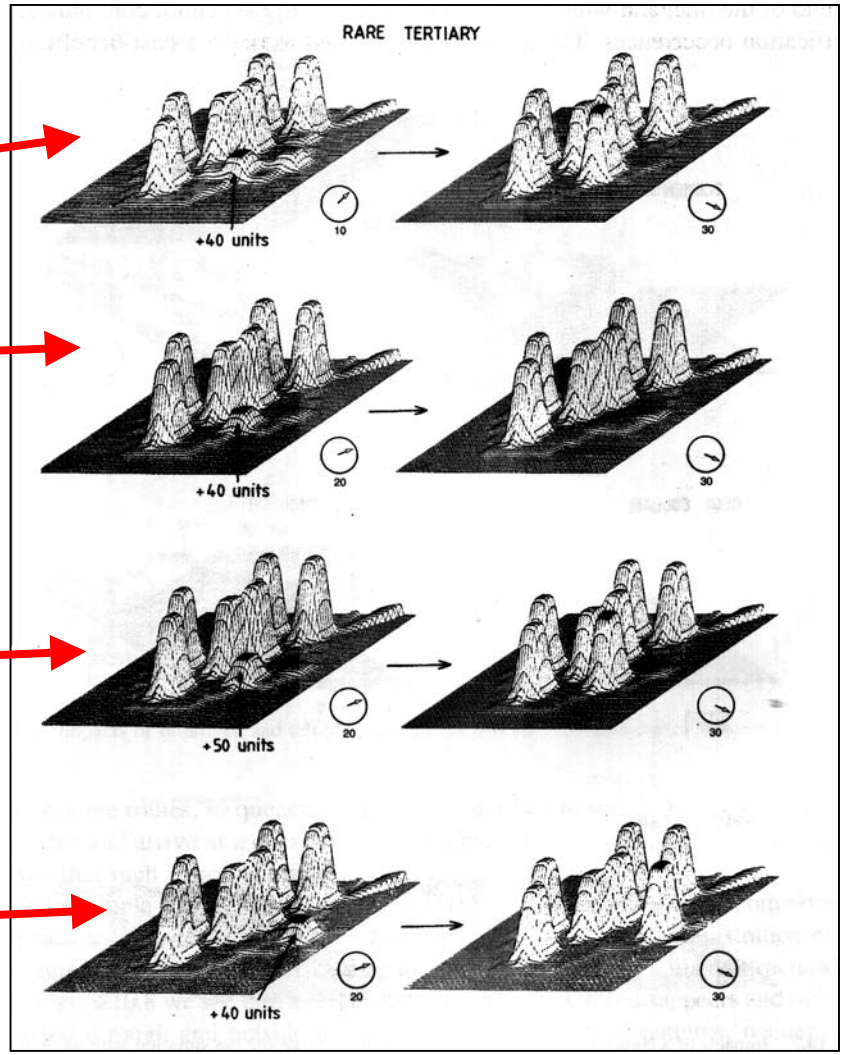
Retail Strategies....

Launching 40 units at t=10 SUCCEEDS..

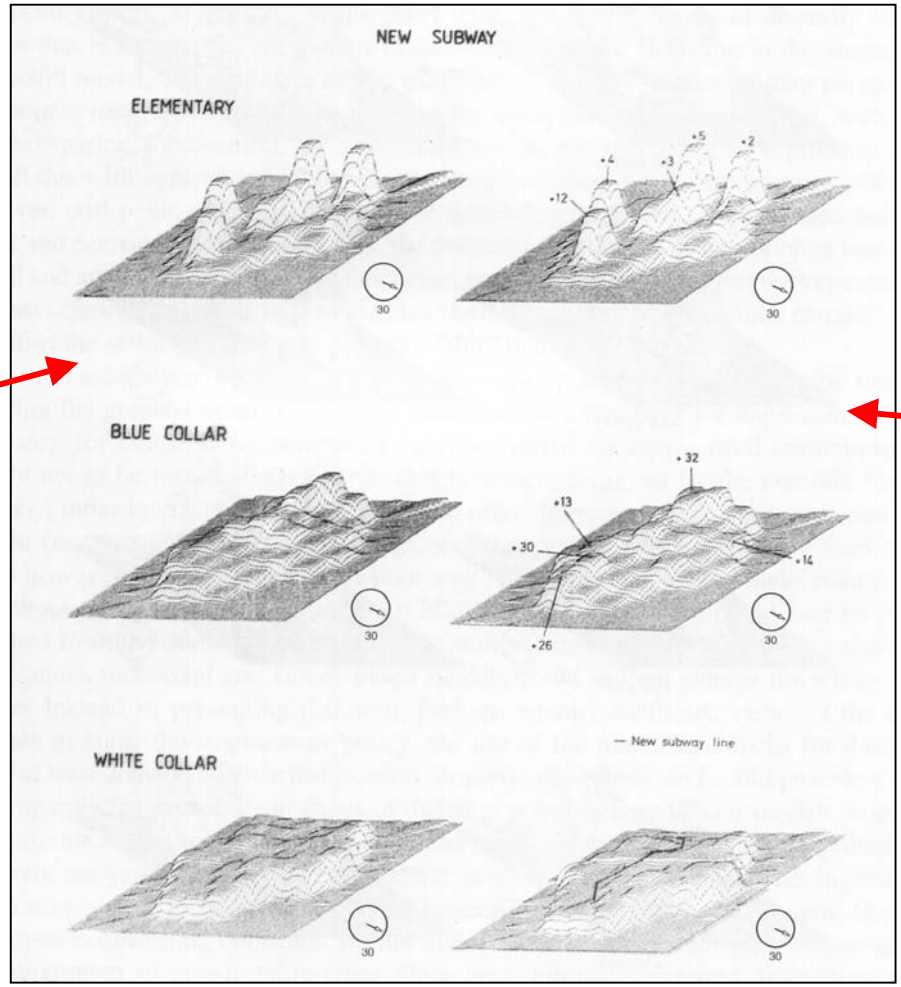
Launching 40 units at t= 20 FAILS

Launching 50 units at t=20 SUCCEEDS

Launching 40 units at a Different location at t= 20 SUCCEEDS



A New Metro System……



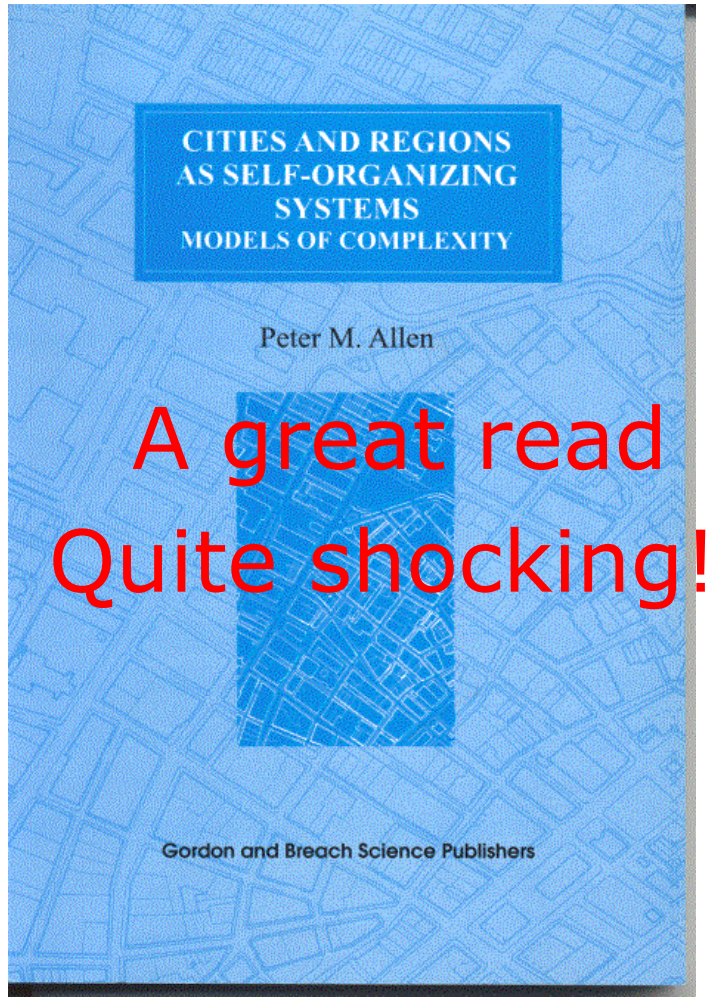
Without the New Metro

With the New Metro

Changed distribution of tertiary services, and of residents.
Changed house and land prices, commuting patterns, traffic flows,
Congestion and pollution….

Self-Organising, dynamic spatial models:

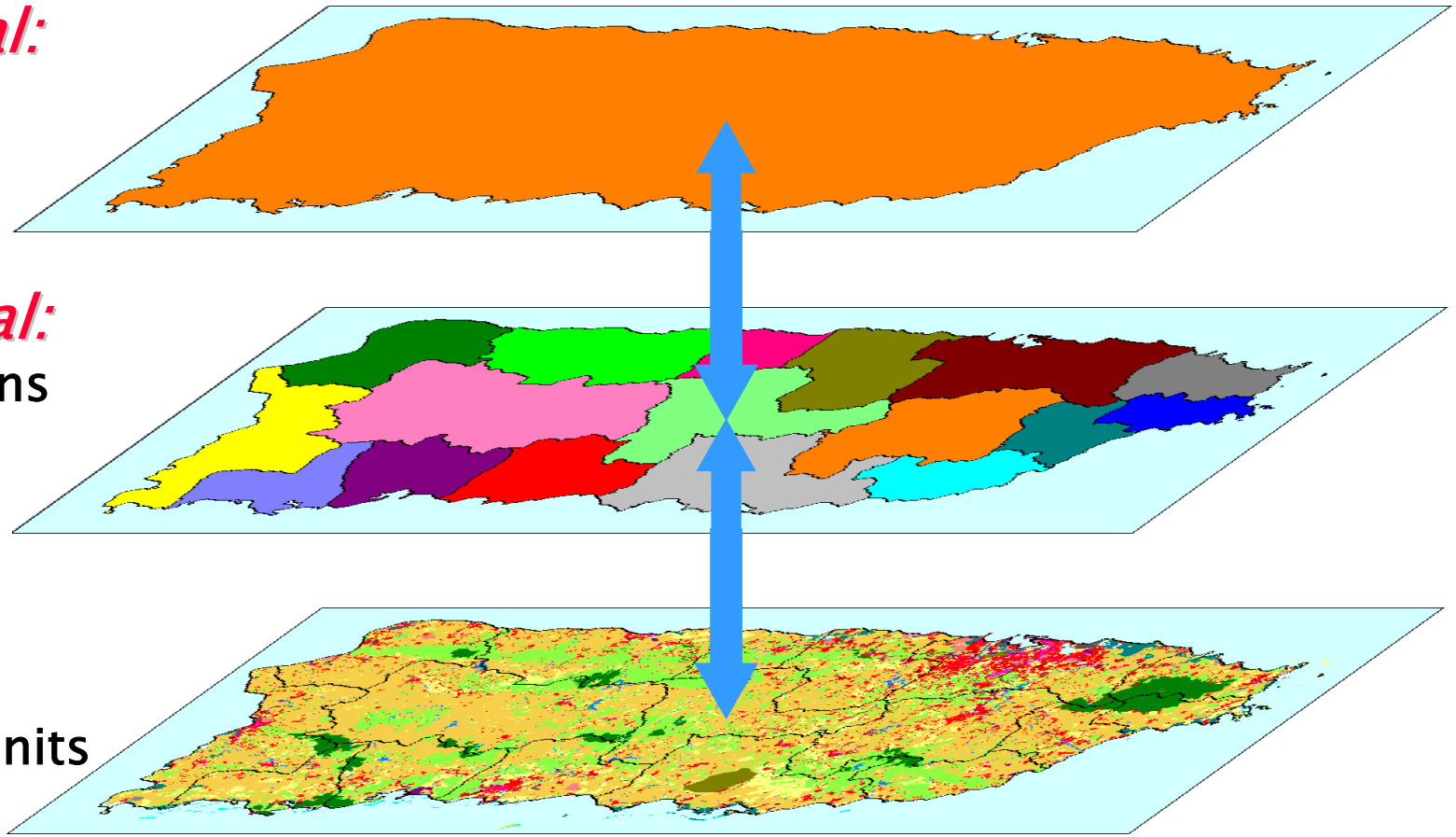
- Taylor and Francis, ISBN - 9056990705 and 9056990713 – Great Read
- 1975- 1995: Urban, Regional models
- Integrates Urban Change, land-use and transport
- Also, links to environmental factors (air, water, land, etc.)
- Still not used



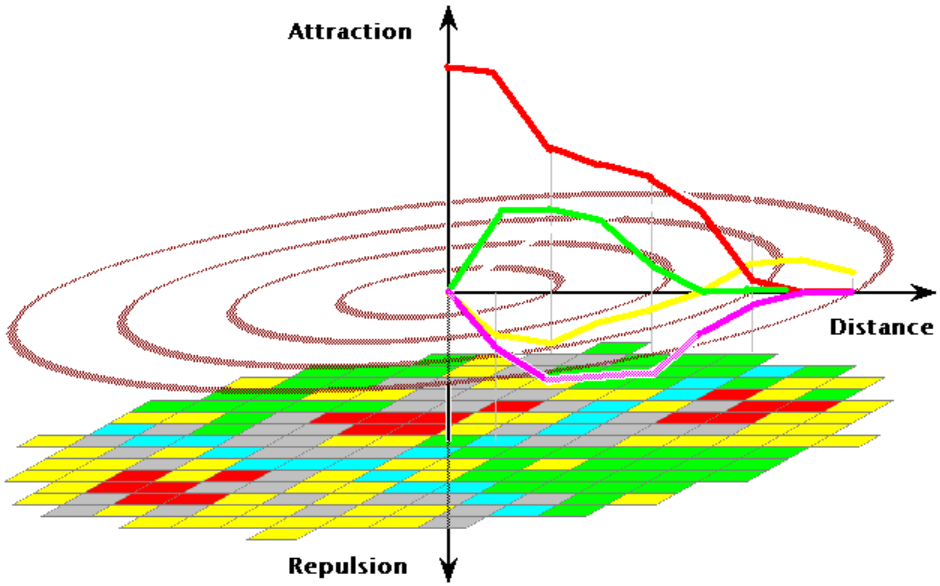
National:
1 Nation

Regional:
17 Regions

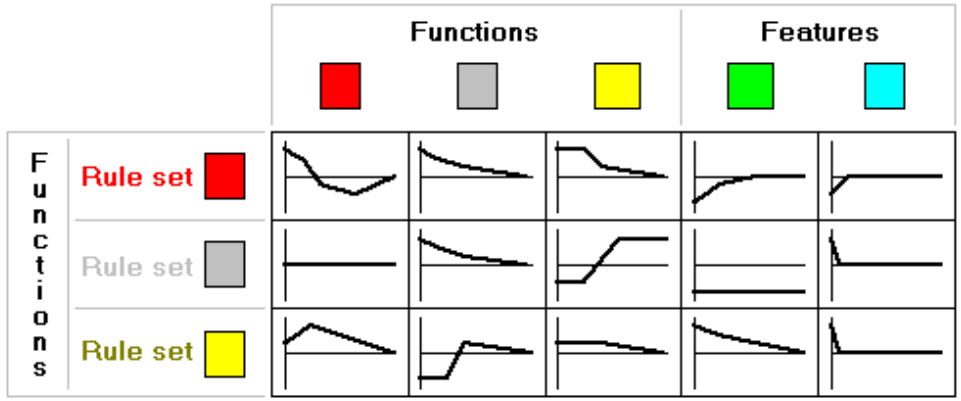
Local:
225000
cellular units



From Guy Engelen, www.Riks.NL



- 250 m resolution;
- 17 identical and coupled CA models: 1 per Region;
- Neighbourhood 8 cell-radius, 196 cells;
- Overall growth of each function is determined at the



18 land-use classes:

- 8 Function states
- 8 Feature states
- 2 Vacant states

This model calculates on a yearly basis the changing land use for 225,000 cells (250 m resolution, 18 land use categories)

From Guy Engelen, www.Riks.NL

ics in non-homogeneous
raphical space

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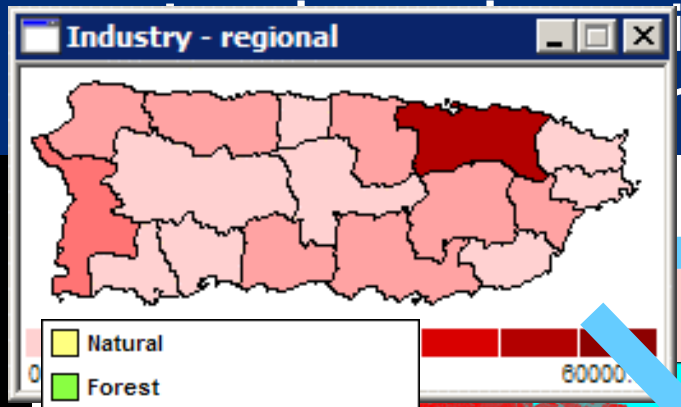
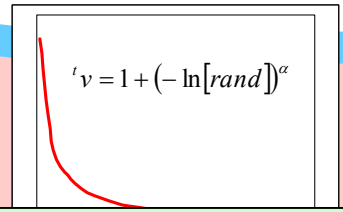
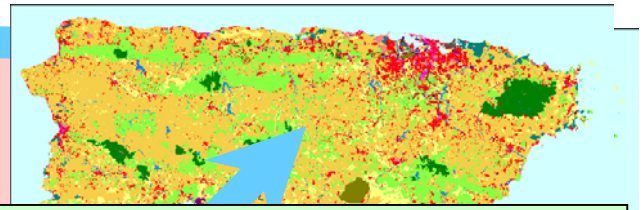
nagement



Stochastic perturbation



Land use at time T+1



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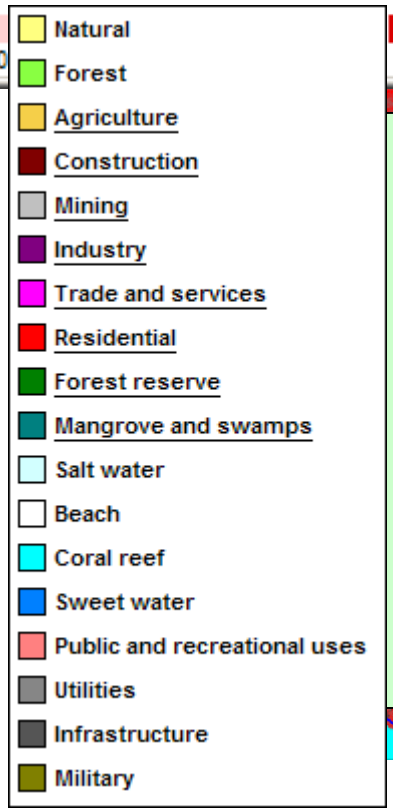

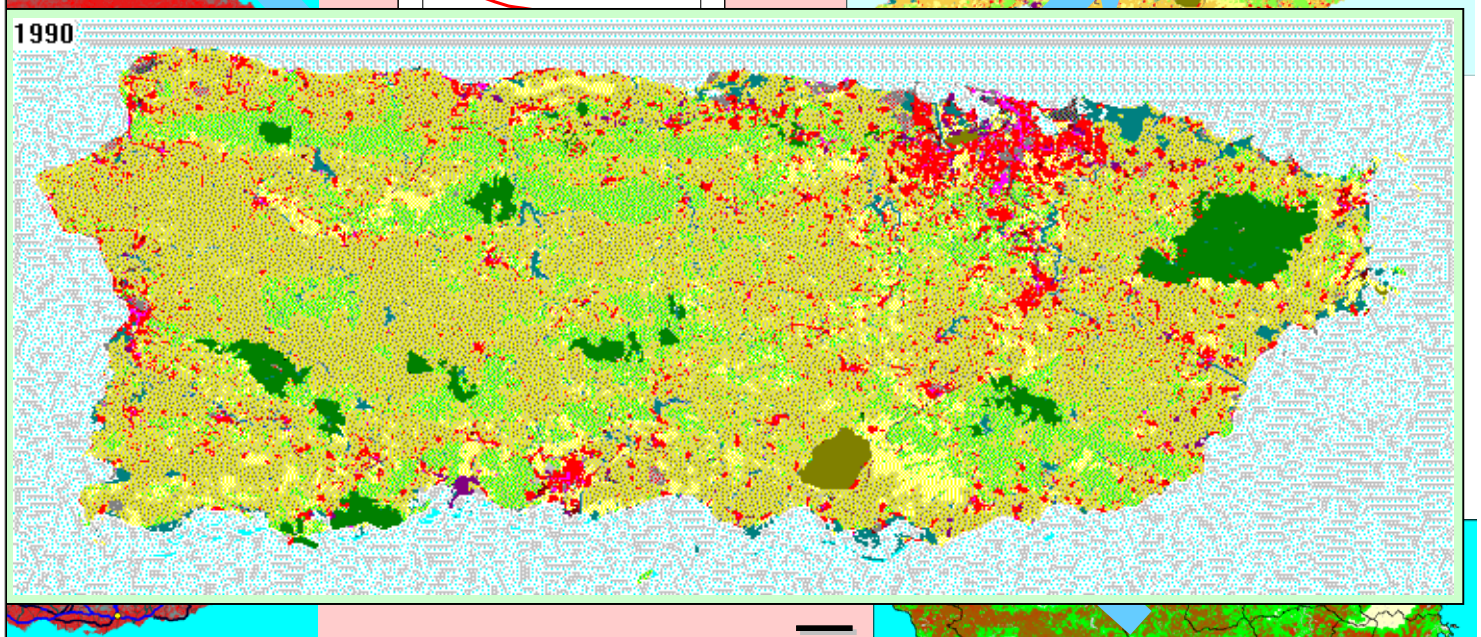

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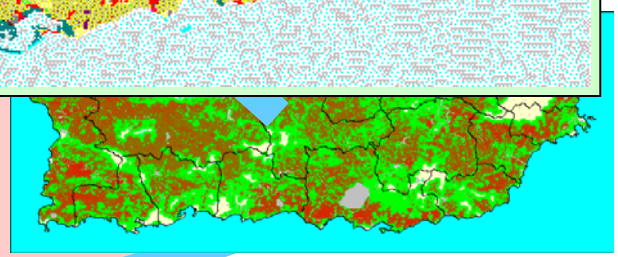
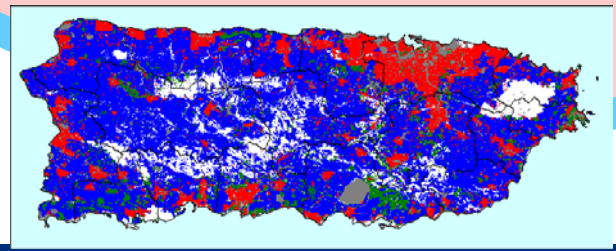


Zoning

&



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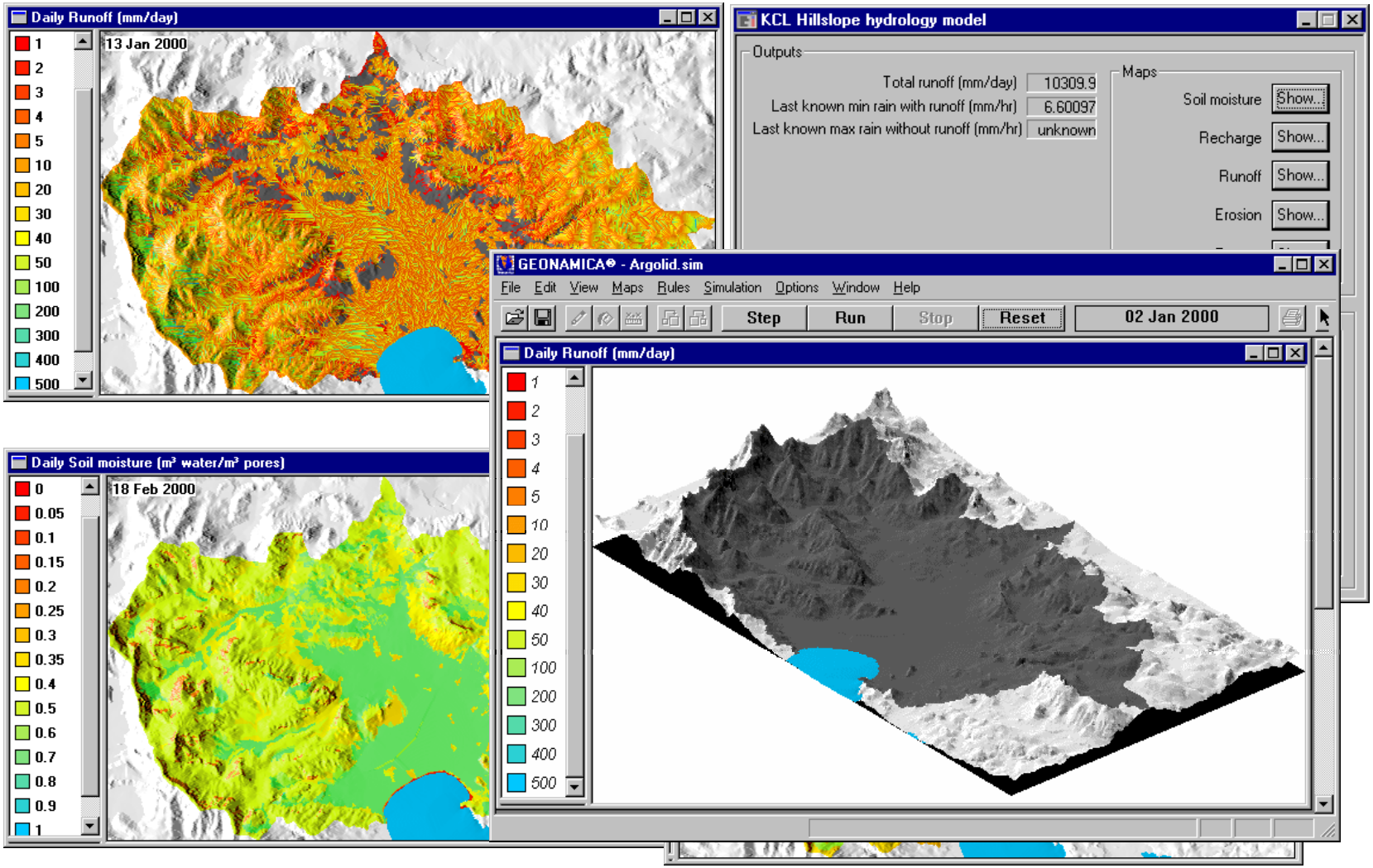
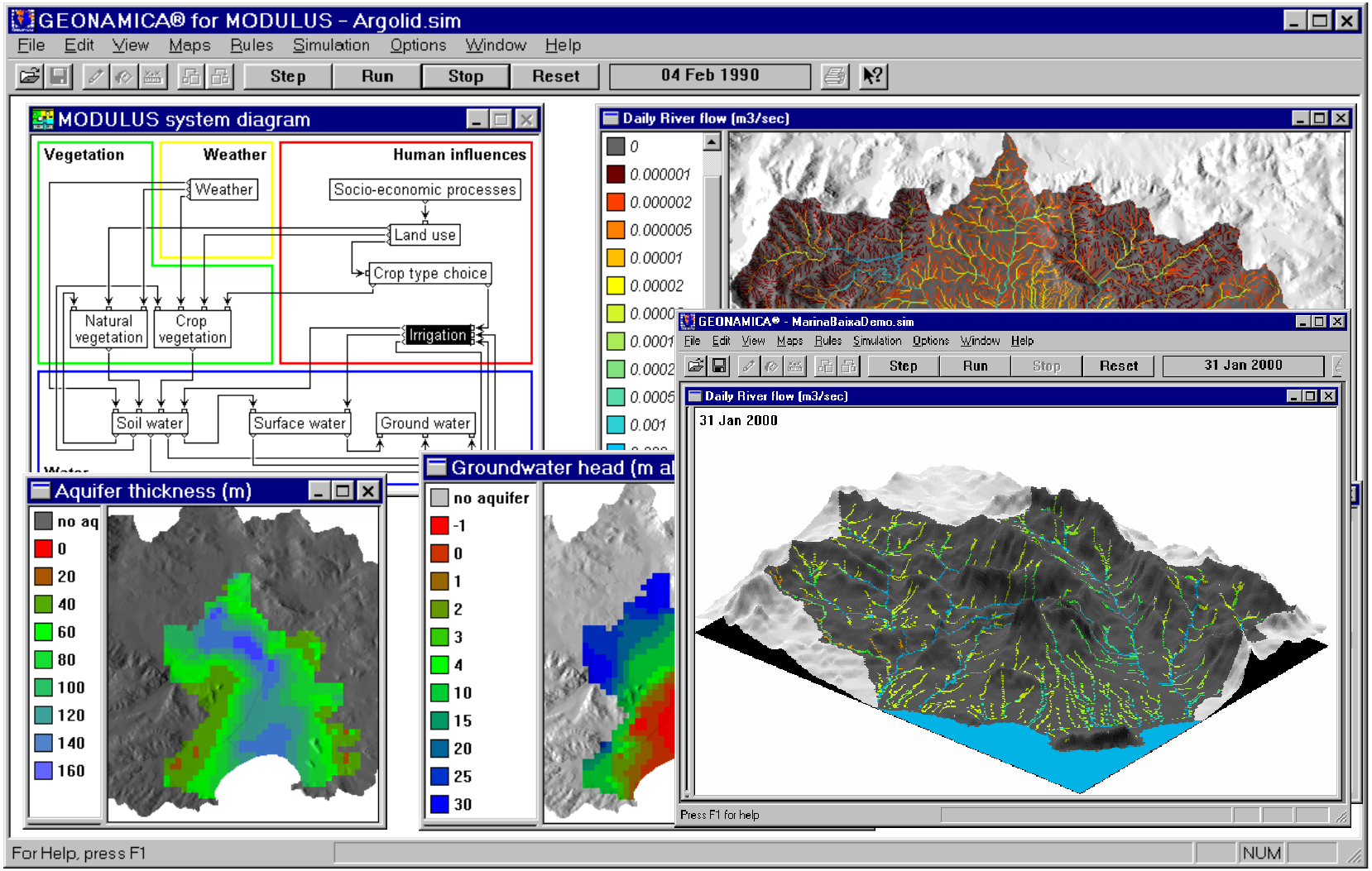
Surface & Soil processes



River & Ground water



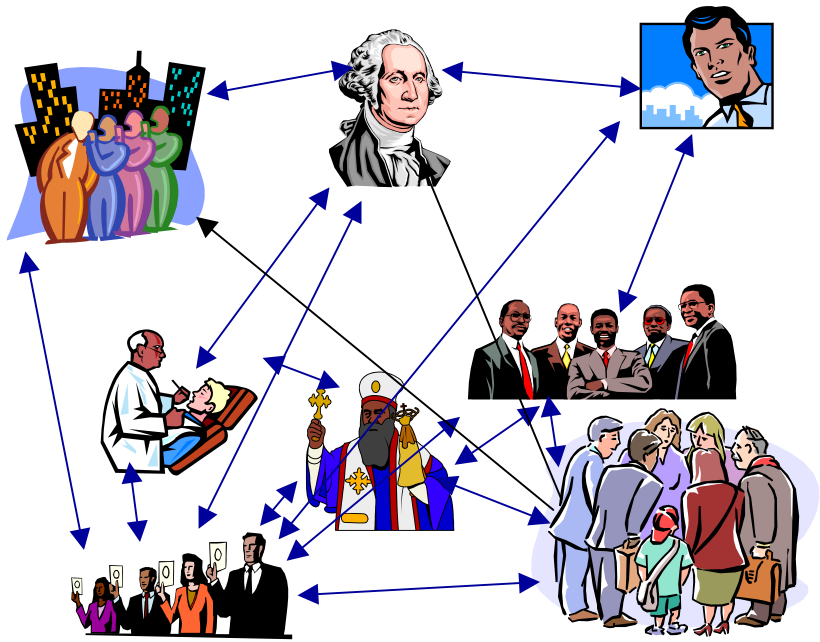
But we really have EVOLUTION:

- The internal "nature" of the players evolves with their experiences
- This could be that as the "dictionary" of possible activities changes, people adopt them
- It could be that there are situations of success or of poverty that lead to internal changes in health and abilities (Glasgow Centre for Population Health)
- Also, as the system "runs" how do people's internal models evolve? Do they learn new skills and fill new opportunities? Or is their sense of injustice deepened and hatred between different groups grows?

Can "conflict" invade?

- Can classify our interacting agents into different types
- Can develop a "Conflict Matrix" - What does each "type" think about the others?
- Is the operation of the current system REINFORCING or REDUCING these sentiments?
- Can we link policy to changing vulnerability and to changing animosity?

	Government 1	Opposition 1	Radical 1	Government 2	Opposition 2	Radical 2
Government 1	2	-2	-3	-1	-2	-4
Opposition 1	-2	2	0	0	2	0
Radical 1	-4	-2	2	-4	-2	0
Government 2	-1	-3	-5	2	-3	-3
pposition 2	-3	0	0	-2	2	-2
dical 2	-5	-3	0	-4	-2	2



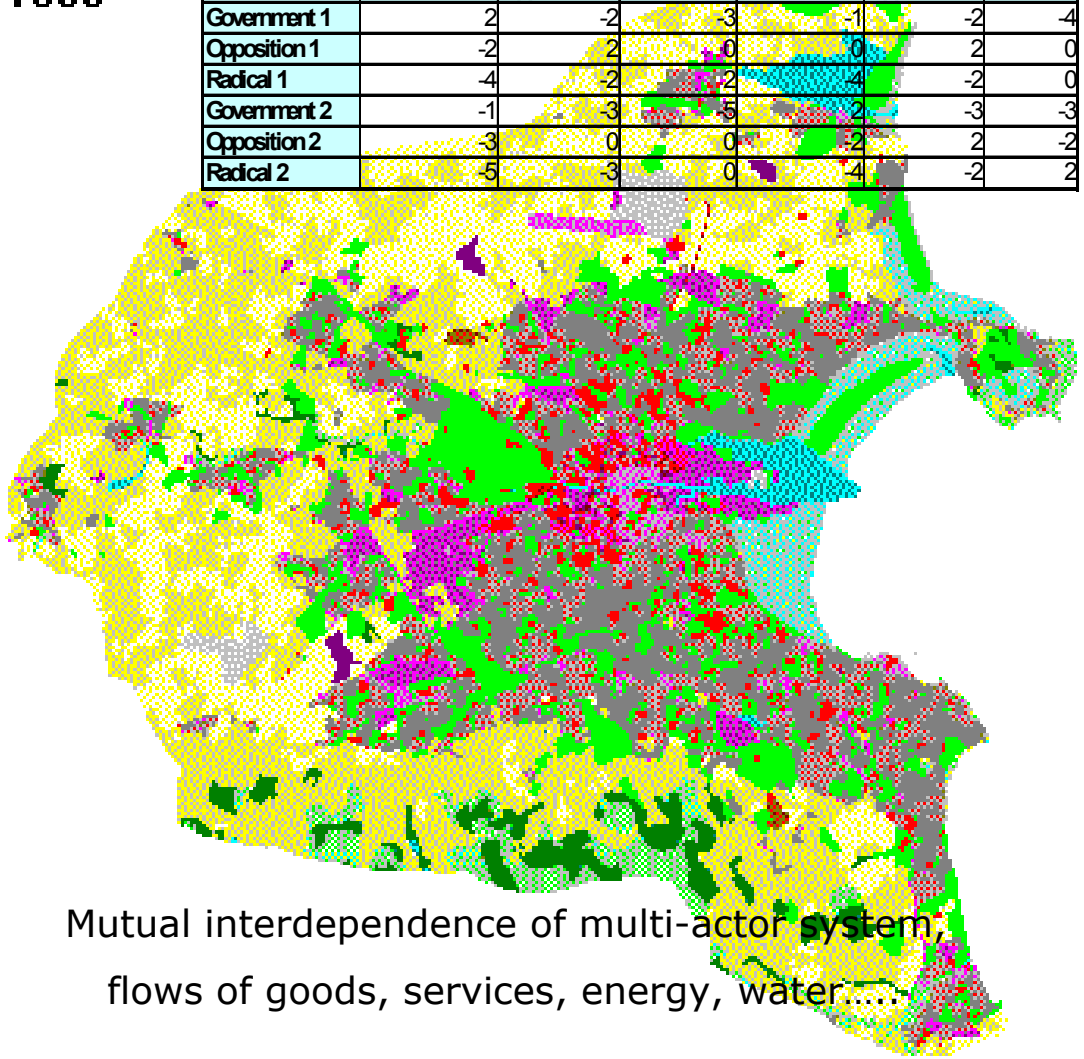
Dynamic spatial models:

Connected evolution of the different Variables

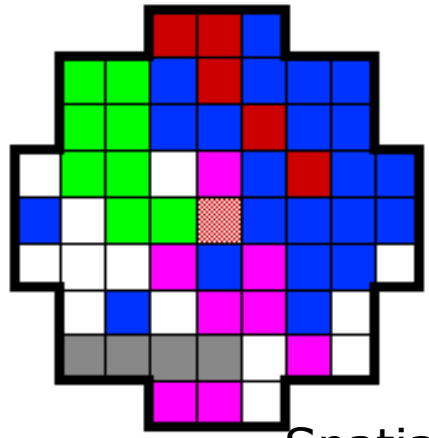
Recent models use cellular automata

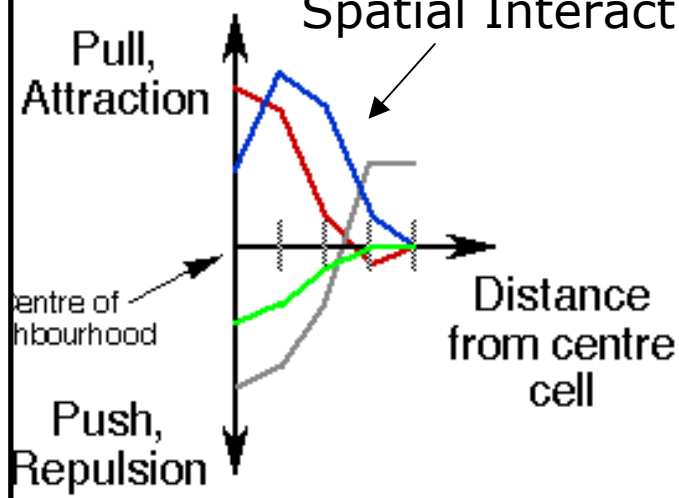
1988

	Government 1	Opposition 1	Radical 1	Government 2	Opposition 2	Radical 2
Government 1	2	-2	-3	-1	-2	-4
Opposition 1	-2	2	-0	0	2	0
Radical 1	-4	-2	-2	-4	-2	0
Government 2	-1	-3	-5	2	-3	-3
Opposition 2	-3	0	0	-2	2	-2
Radical 2	-5	-3	0	-4	-2	2



Mutual interdependence of multi-actor system, flows of goods, services, energy, water.....





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Many different complex systems models:

- Urban, regional and national (Current work for Asian Development Bank on West Bengal, Nepal…)
- Entire river basins as management "unit" – people, activities, agriculture, water, waste, erosion, tourism, transport….(Rhone, Escaut, Argolida, Marina Baixa, Elbe, …)
- Market dynamics, networks, supply chains, structural evolution of business, clusters, etc.
- Integrated models for policy support. For exploring regional development: housing, employment, transport, healthcare, energy/emission reduction, climate change, flood and contingency planning, education, demography and aging, quality of life …

Conclusions - 1

- Complex Systems Models can be used in social and economic situations to support policy and decision making.
- Their primary importance is to LINK different people, perspectives and disciplines of a situation, and allow an integrated view of possible futures
- For the first time they allow us to think sensibly about people, families, economics, jobs, transport, environment, climate and weather, floods and other contingency planning, supply chain and economic vulnerabilities among other things.

Conclusions - 2

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- we must always perform in two contradictory ways:
  - Targeting goals efficiently using "knowledge"
  - Exploring beyond these and reflecting on the discoveries
- Everything above shows us that we need to understand and value relationships and multiple perspectives and a priority must research into "links" rather than "nodes"
- Complexity allows to understand our place in a creative universe – where learning and transformation are key rather than knowledge and efficiency
- Build models to explore the errors in your own beliefs – but don't believe them. Be prepared to be shocked!!!

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