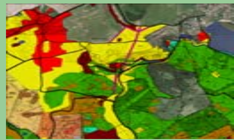

Modelling in GIS

modelling **spatial change**
exemplifying **land use** changes
using **IDRISI** software

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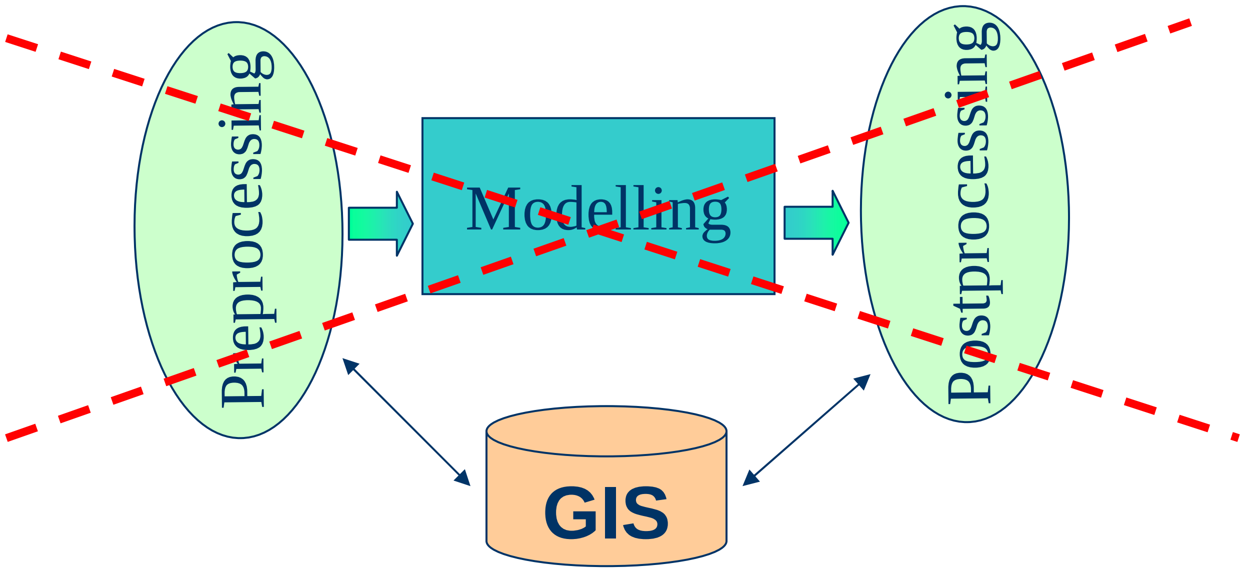
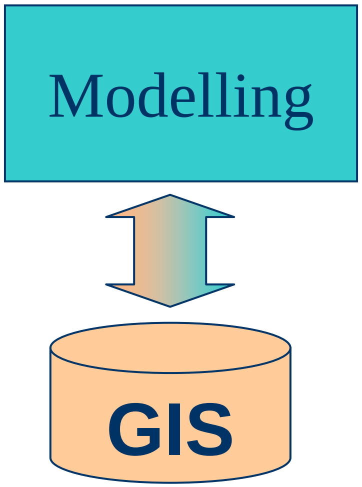
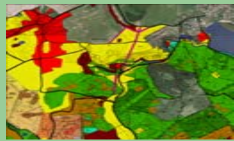
Modelling in GIS

modelling without GIS



modelling using GIS





Modelling in GIS

Comprises several aspects:

- data modelling

  descriptive representation of real-world patterns in a database schema
- **process modelling**

  simulation of processes in the real world
  - static models
  - **dynamic models**
- **space modelling**

  conceptualization of geographic space
  - continuous-field models
  - network models
  - lumped i.e. tessellated space models
    - **polygons**
    - **TINs**
    - **grid cells**
  - individual-level models

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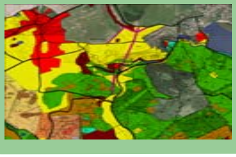
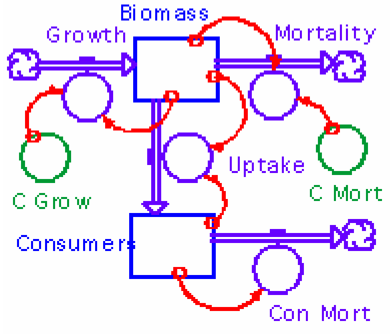


Simulation of

- **dynamic processes using discrete time steps**

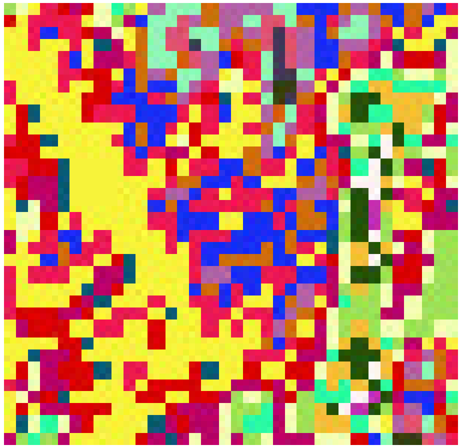
  temporal resolution – the length of the model's time step

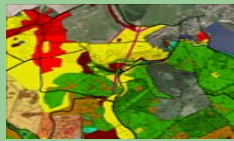


and

- **spatial change using rasterized space**

  spatial resolution – the size of the smallest patch (grid cell)





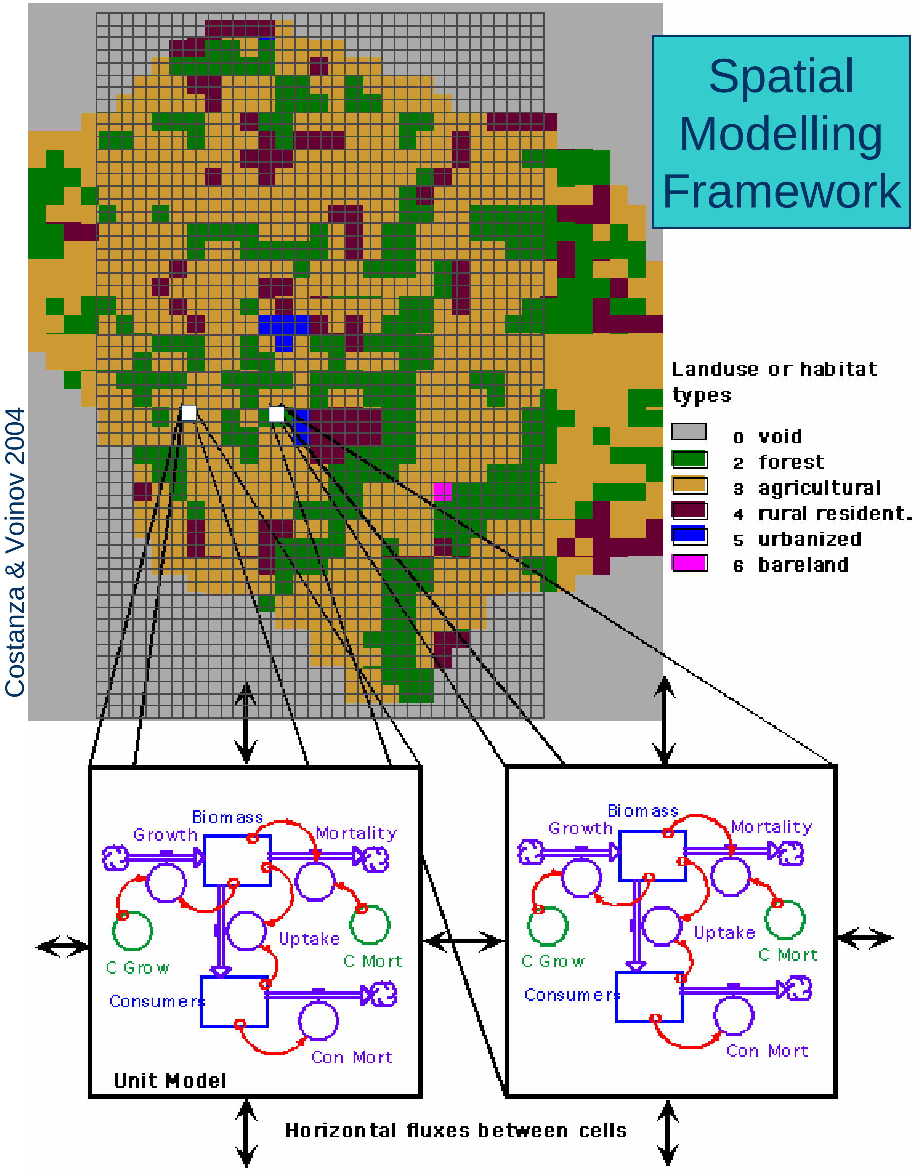
To link dynamic simulation models and GIS

e.g.

STELLA
(software)

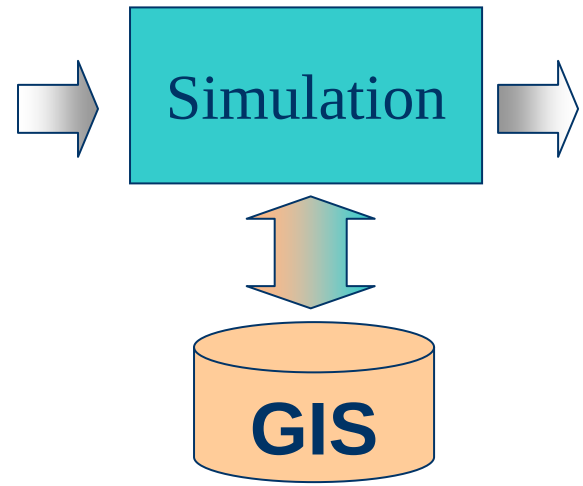
IDRISI
(software)

Spatial Modelling Framework

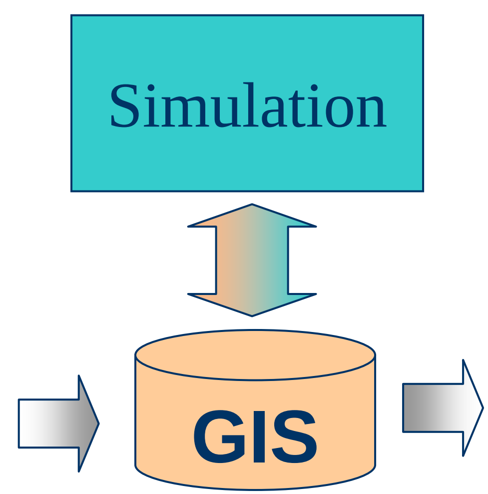


Costanza & Voinov 2004

Simulator-centric approach:



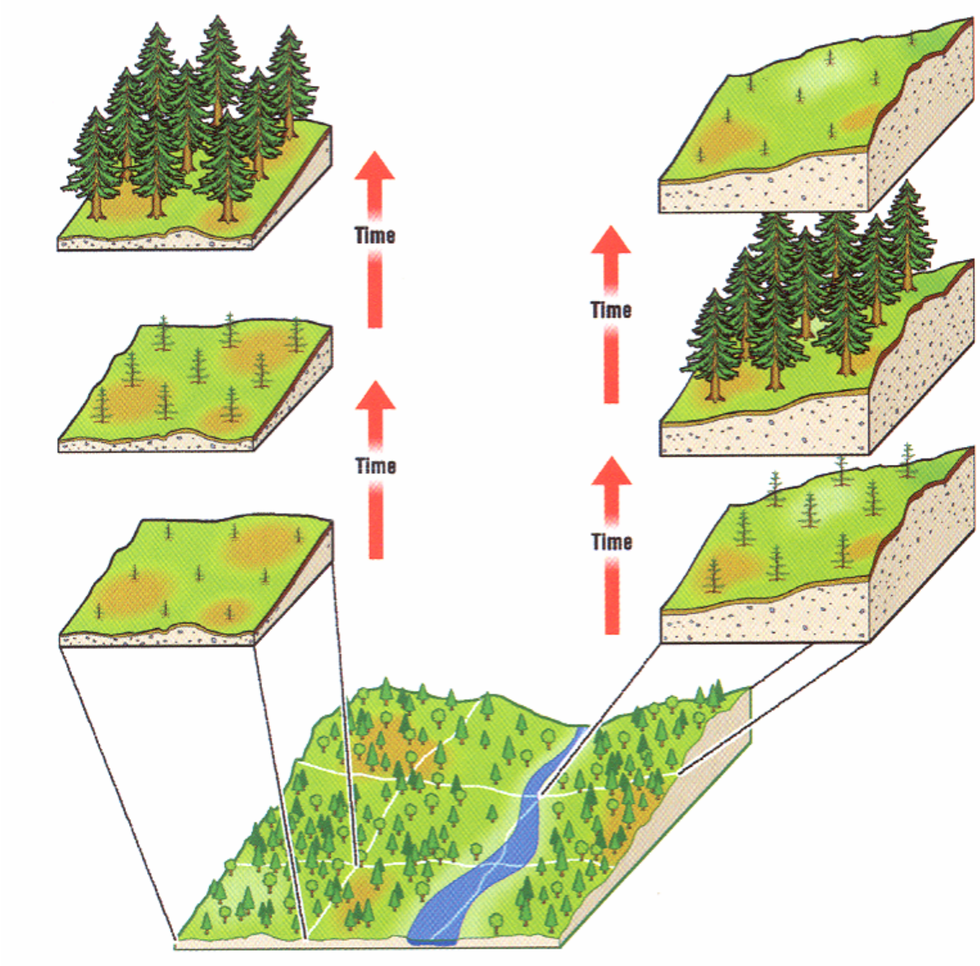
GIS-centric approach:

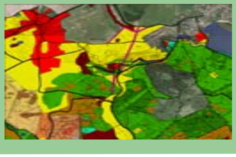


Models complexity

according to Miller e.a. 2005

- **Simple evolution models**
  - simple prediction model for an attribute
  - the same rule for all grid cells
  - no interactions between neighbouring grid cells

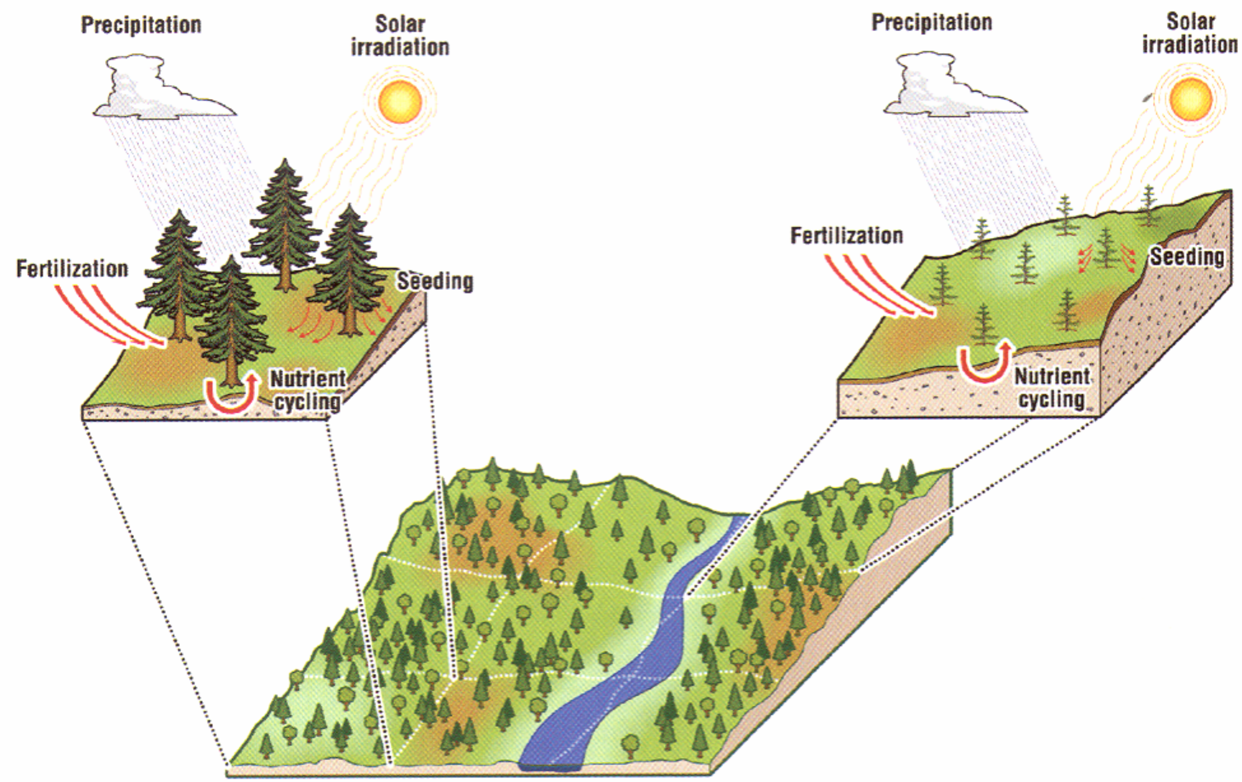




Models complexity

according to Miller e.a. 2005

- **Local dynamics models**
  - dynamic interactions of a **number** of local parameters
  - the same **model** for all grid cells
  - no interactions between neighbouring grid cells



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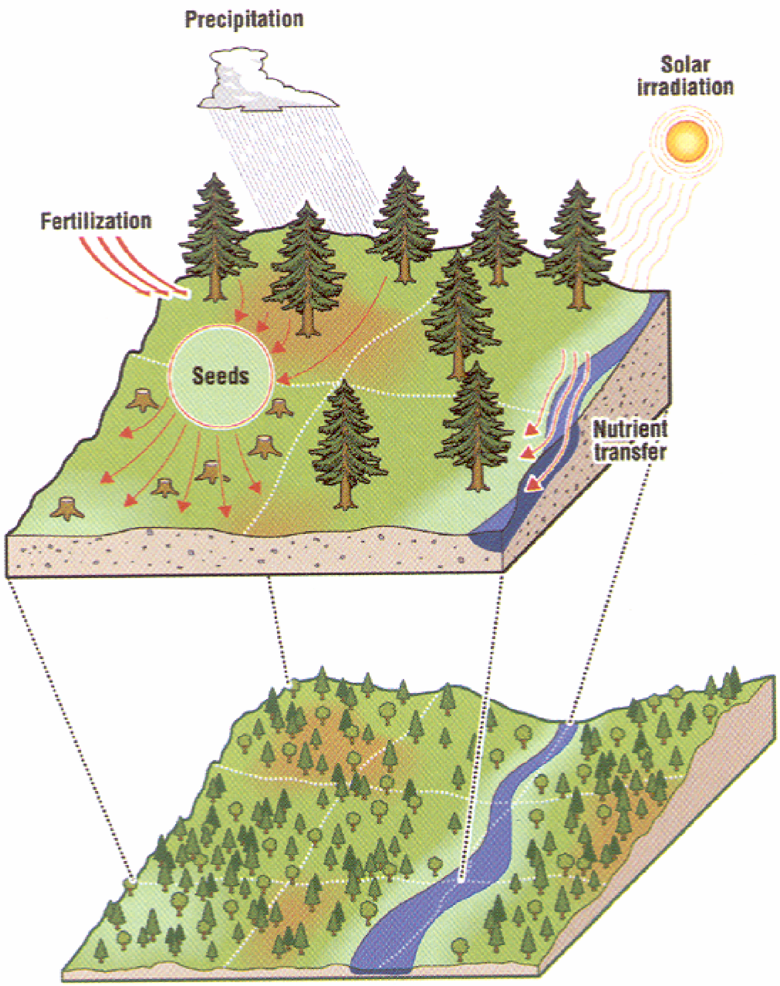
Models complexity

according to Miller e.a. 2005

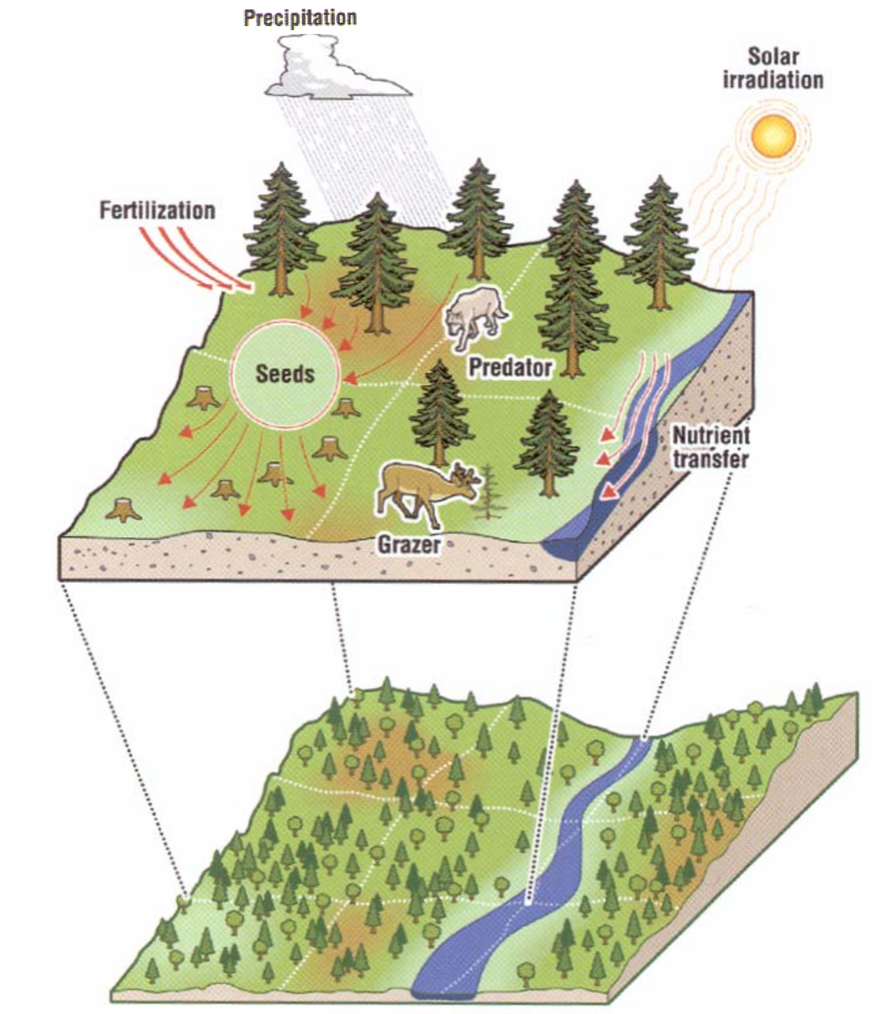
- **Coupled dynamics, single-system models**
  - dynamic interactions of a number of local parameters
  - the same model for all grid cells
  - **takes into account interactions between neighbouring grid cells**



Models complexity

according to Miller e.a. 2005

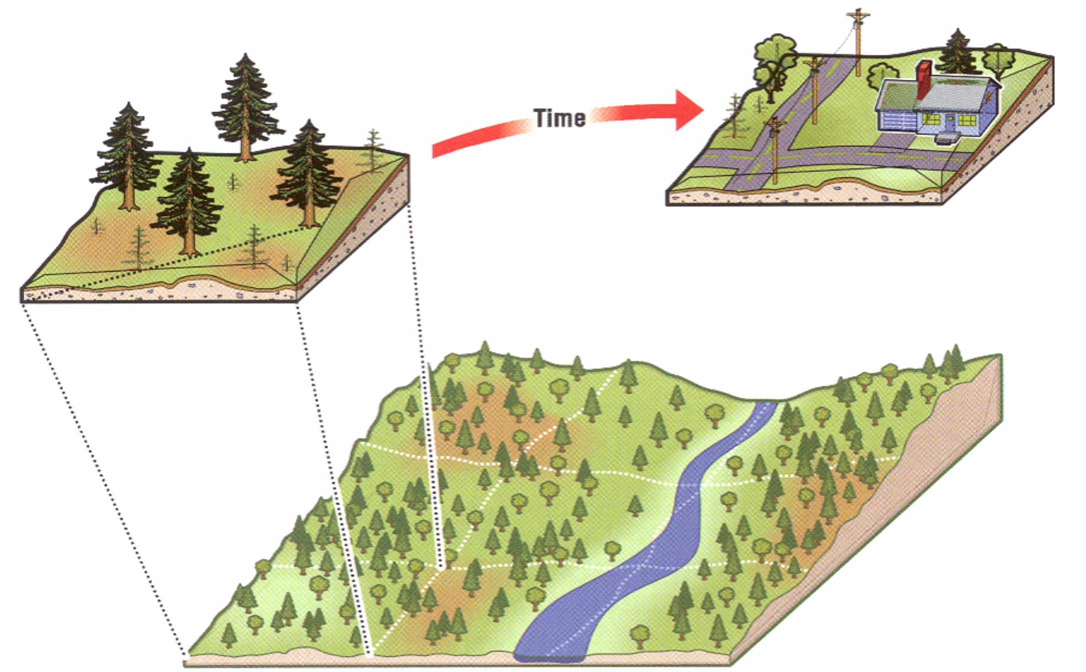
- **Coupled dynamics, multiple-system models**
  - dynamic interactions of a number of local parameters
  - **multiple models for different grid cells**
  - takes into account interactions between neighbouring grid cells



Models complexity

according to Miller e.a. 2005

- **Models with dynamically changing structure**
  - dynamic interactions of a number of local parameters
  - multiple models for different grid cells
  - **character of interactions** between neighbouring grid cells **may change**
  - **one local model may be replaced with a new one; some properties inherited**



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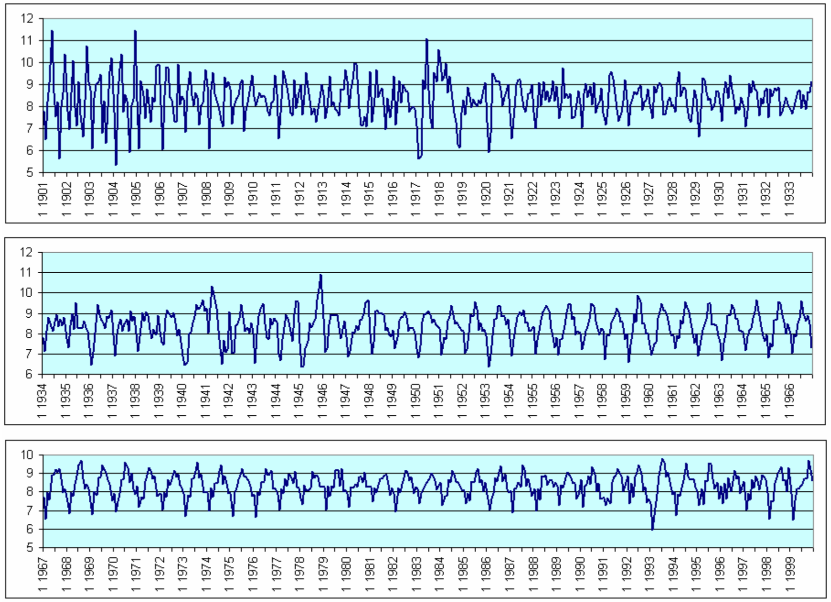
Modelling of change



- **Time series**
  - climatology
  - hydrology
  - more and more in human studies
- **Spatial time series**
  - Classics: Bennett, R.J. 1979. Spatial time series. Pion Limited, 674 pp.
  - Image comparisons and analyses in IDRISI
    - CROSSTABULATION
    - CVA
    - TSA
  - Predictive change modelling
    - a suite of modules in IDRISI with the focus on **land cover change modelling**

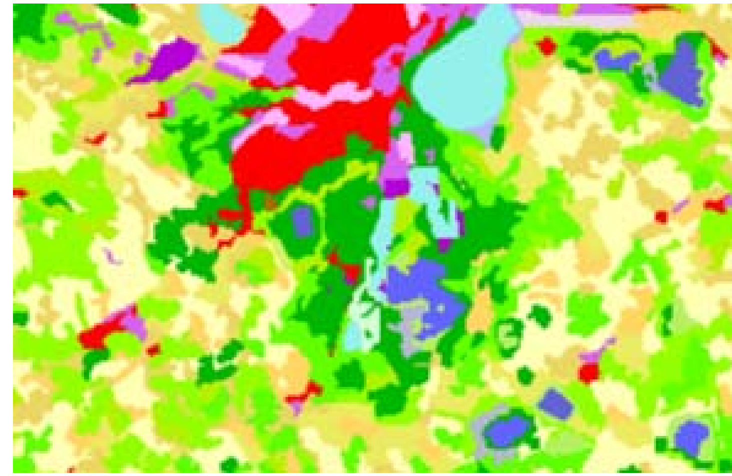
LUCC modelling

- **Land Use and Cover Change (LUCC) modelling**
  - actual “*because land-use change is one of the most important ways that humans influence the environment” (Pontius & Chen 2006)*
  - GIS based
- **Classic overview paper:**
  - Agarwal,C., Green,G.L., Grove,J.M., Evans,T. & Schweik,C. 2002. A review and assessment of land use change models: dynamics of space, time, and human choice. – Gen. Tech. Rep. NE-297. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 61 p. [http://www.treesearch.fs.fed.us/pubs/5027]
  - review and comparison of 19 models of land use change:

1. General Ecosystem Model (GEM) (Fitz et al. 1996)
2. Patuxent Landscape Model (PLM) (Voinov et al. 1999)
3. CLUE Model (Conversion of Land Use and Its Effects) (Veldkamp and Fresco 1996a)
4. CLUE-CR (Conversion of Land Use and Its Effects –Costa Rica) (Veldkamp and Fresco 1996b)
5. Area base model (Hardie and Parks 1997)
6. Univariate spatial models (Mertens and Lambin 1997)
7. Econometric (multinomial logit) model (Chomitz and Gray 1996)
8. Spatial dynamic model (Gilruth et al. 1995)
9. Spatial Markov model (Wood et al. 1997)
10. CUF (California Urban Futures) (Landis 1995, Landis et al. 1998)
11. LUCAS (Land Use Change Analysis System) (Berry et al. 1996)
12. Simple log weights (Wear et al. 1998)
13. Logit model (Wear et al. 1999)
14. Dynamic model (Swallow et al. 1997)
15. NELUP (Natural Environment Research Council [NERC]–Economic and Social Research Council [ESRC]: NERC/ESRC Land Use Programme [NELUP]) (O’Callaghan 1995)
16. NELUP - Extension, (Oglethorpe and O’Callaghan 1995)
17. FASOM (Forest and Agriculture Sector Optimization Model) (Adams et al. 1996)
18. CURBA (California Urban and Biodiversity Analysis Model) (Landis et al. 1998)
19. Cellular automata model (Clarke et al. 1998, Kirtland et al. 1994)

Land cover *vrs*. land use

- **Land cover**
  - concept
    developed in the remote sensing



Corine Land Cover

- **Land use**
  - implies human activity

Land use in Basic Map

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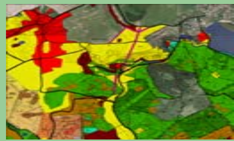

LUCC modelling tools in IDRISI

Details on MARKOV...

Details on CA_MARKOV...

Details on GEOMOD

- **since I32R2**
  - MARKOV (+STCHOICE)
  - CA_MARKOV (MARKOV+CELLATOM+MOLA)
- **since Kilimanjaro**
  - GEOMOD
- **Andes Edition**
  - **LCM** – so-called vertical application

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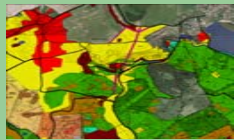
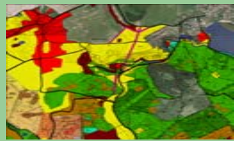


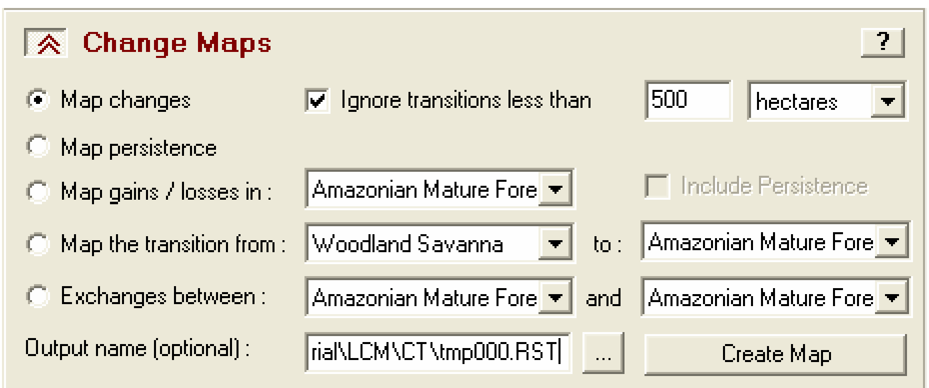
LUCC modelling ideology in IDRISI

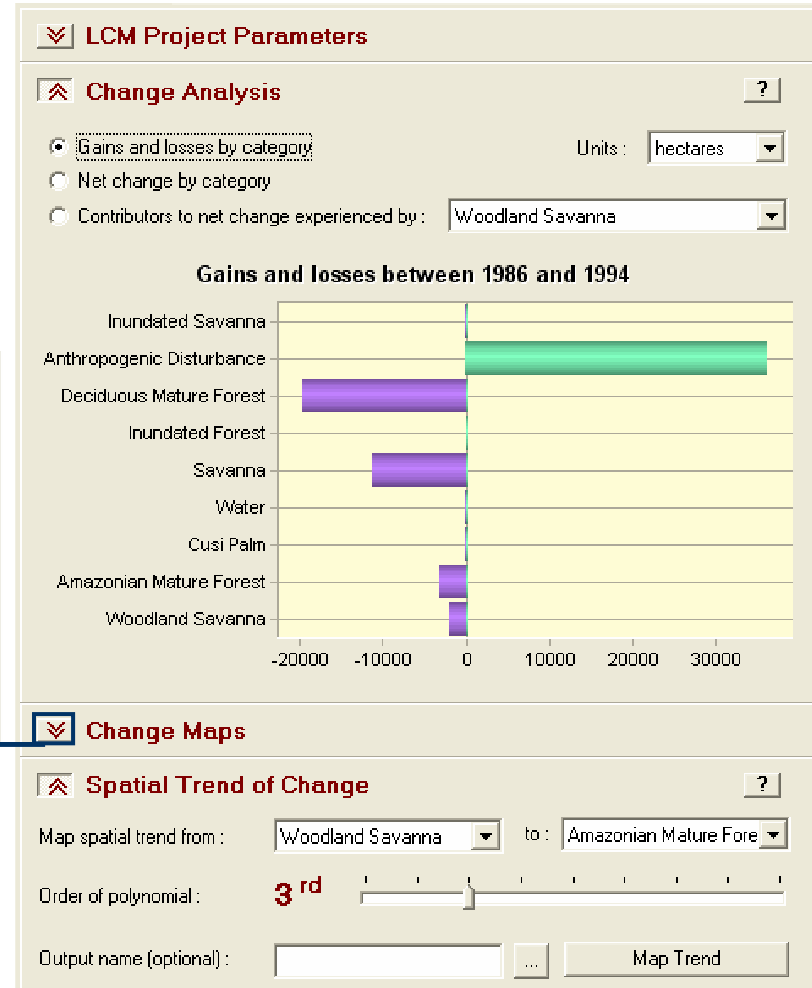
- **finding changes in past** (as a basis for prediction)
  - what kind of transitions have been taken place?
  - what might be the driving forces of changes?
- **generating model for these changes**
  - to identify explanatory variables
  - to select suitable modelling method
- **predicting land use changes**
  - to find change demand
  - to make change allocation
- **assessing the impact of changes**
  - for ecological sustainability
- **attaching human interventions**
  - to introduce infrastructure changes
  - to add constraints / incentives



LUCC modelling ideology in IDRISI

- **Change description and analysis**
  - tools for rapid assessment of change





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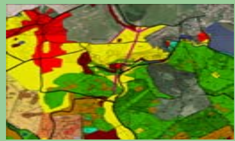
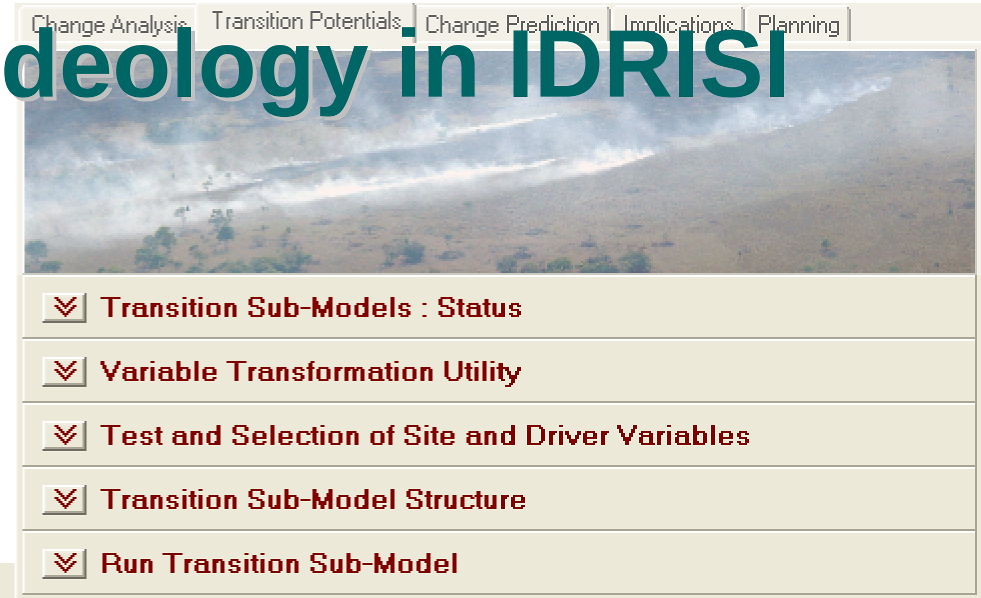
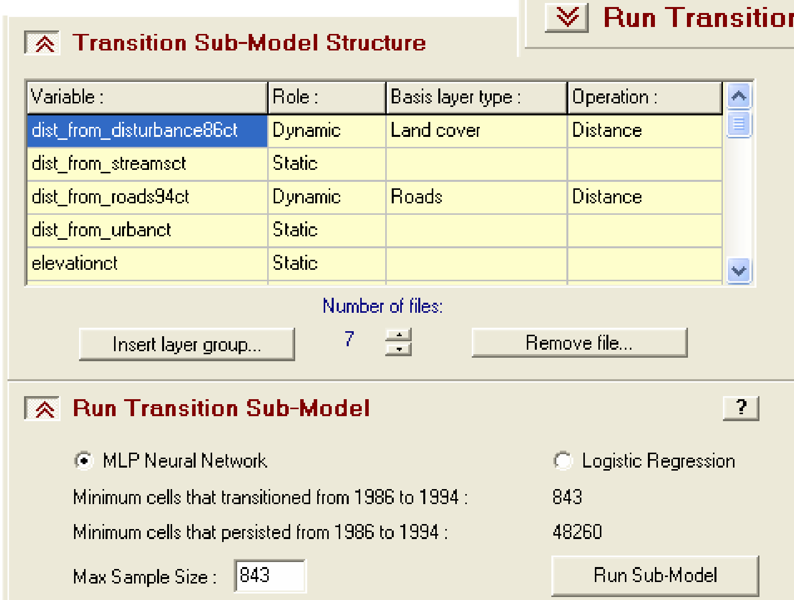


LUCC modelling ideology in IDRISI

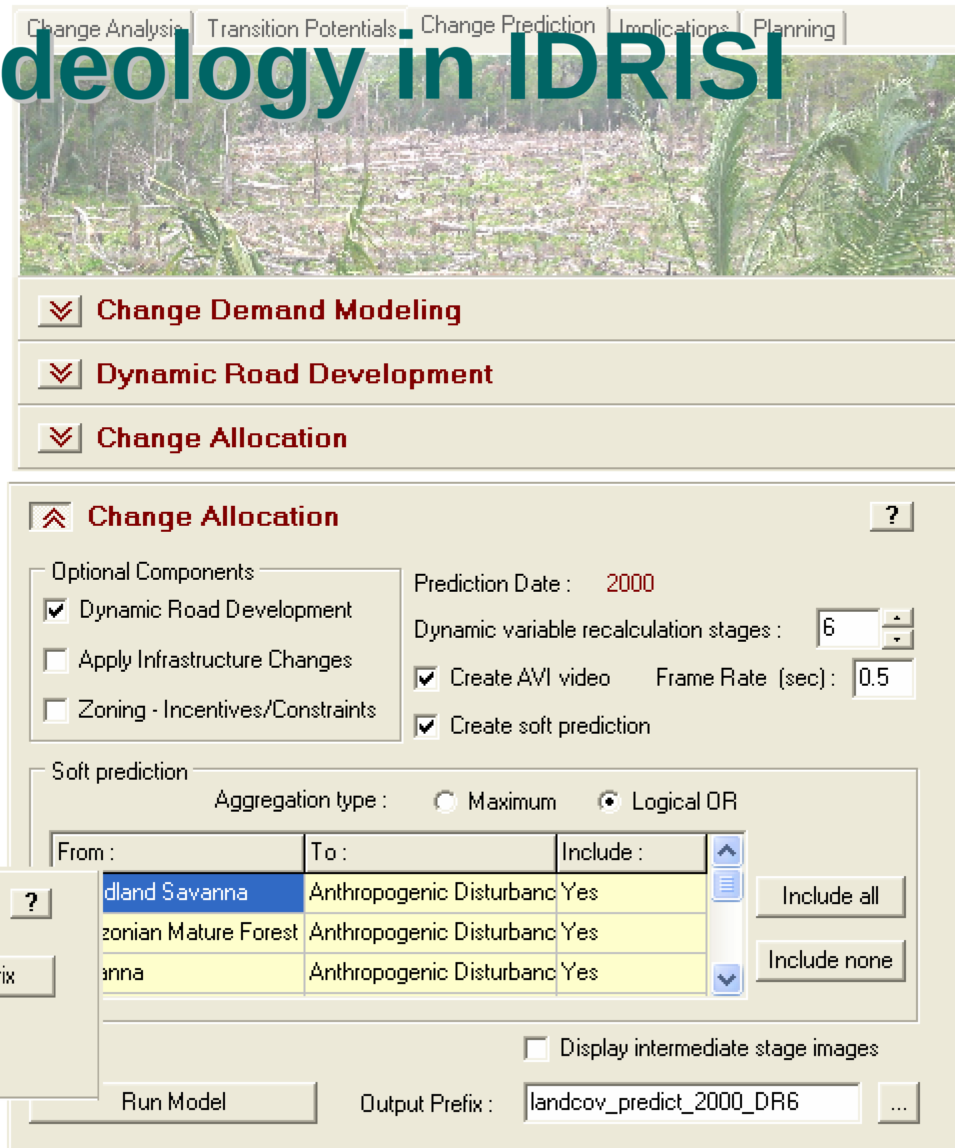
- **The transition potentials**
  - choose and identify sub-models to estimate the rates of change between land types
  - two modelling methods:
    - logistic regression
    - MLP neural network

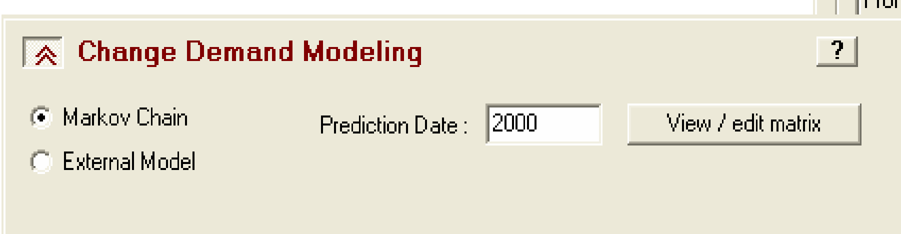


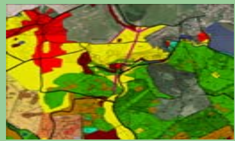


LUCC modelling ideology in IDRISI

- **Change prediction**
  - rates of change between land types – transition matrix;
  - a model to predict road development may be included;
  - change allocation as a **spatial decision** process
    - hard decision – predicted (according to the scenario) land use map
    - soft decision – vulnerability to certain/all changes

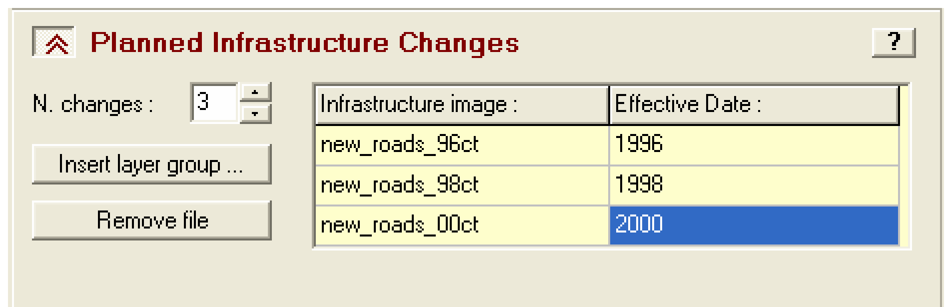






LUCC modelling ideology in IDRISI

- **Planning**
  - extrapolation of past land use history may be inadequate due to new interventions
  - new land use policies
  - new protected areas
    - incl. biological corridors
  - building new roads



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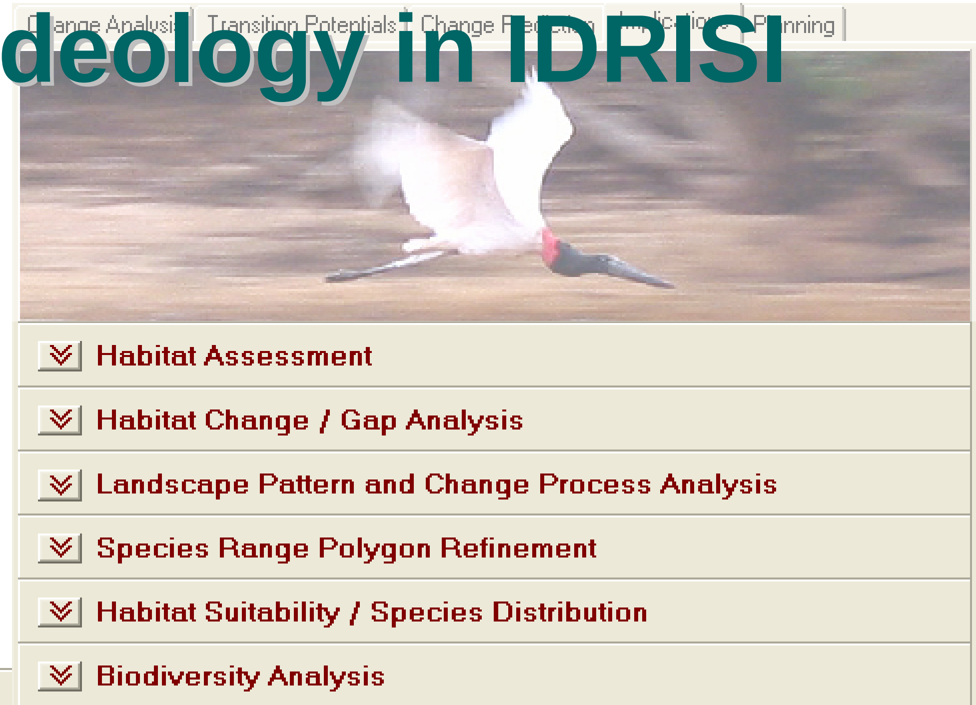
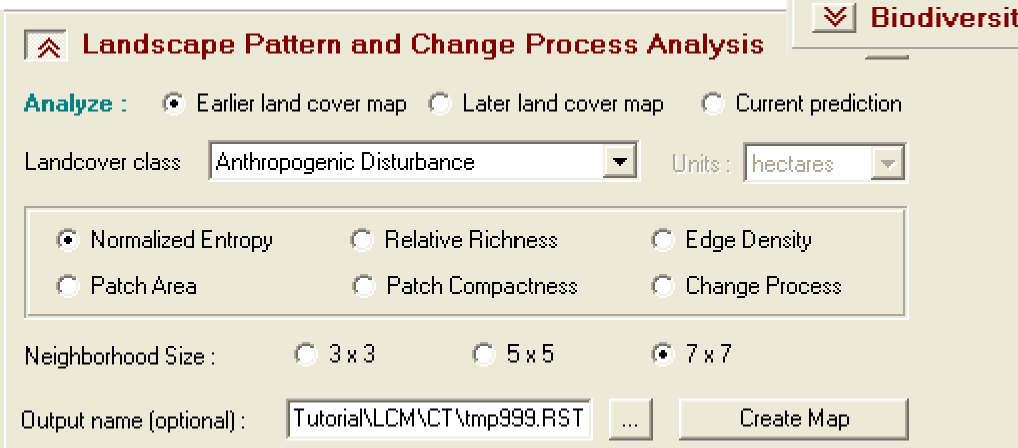
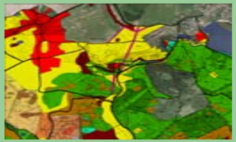
LUCC modelling ideology in IDRISI

- **Implications**
  - different landscape ecological tools
    - e.g. PATTERN





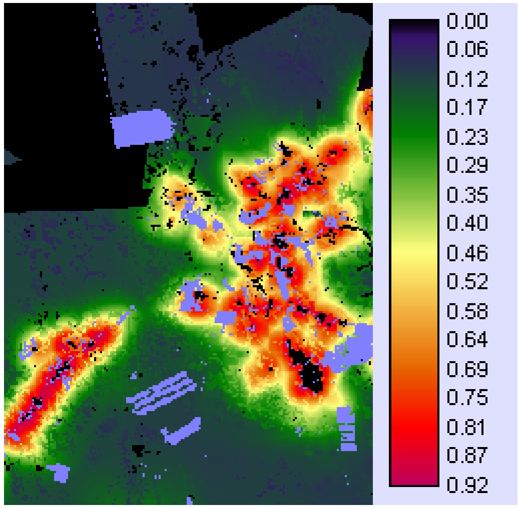
What about validation?



LUCC modelling ideology in IDRISI

- **Validation**
  - image comparison tools
    - VALIDATE
    - CROSSTAB
    - ROC
  - we need to compare not “predicted land use” with “actual land use”
    but
    “predicted change” with “actual change”

soft prediction
versus
“truly changed” (blue)



LUCC modelling as a problem of data integration

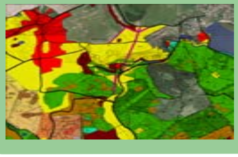
- **many data layers**
- **no sufficient data**
  - historical maps are incomparable
  - problems of scale and generalisation
  - feature definitions are incomparable
  - much data are not explicitly spatial
- **a need to harmonise results with expert knowledge**

An example...

LUCC example

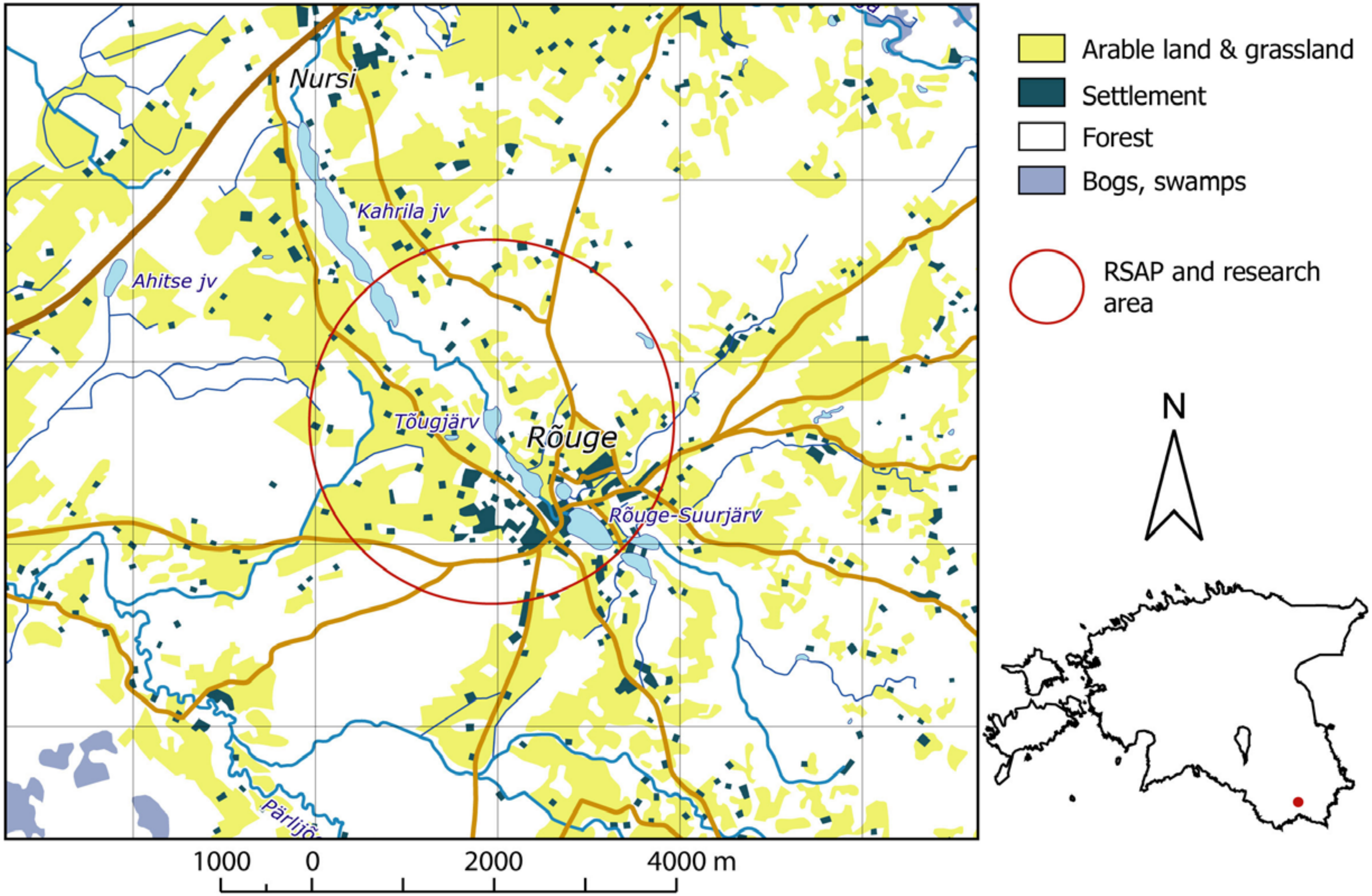
Edgar Sepp, BSc Theses: **Historical** land use reconstruction in the research area around Lake Rõuge Tõugjärv. Tartu 2004.

- **Problem**: how to reconstruct <u>spatially explicit</u> land use having time-series of nonspatial data, very limited spatial data (maps) and expert knowledge on spatial dependencies?
- **Research domain**: application of pollen diagrams for historic reconstructions.
- **Method**: GIS modelling using Idrisi32R2 CA_MARKOV (plus necessary supplementary tools) with customised filters.
- **Results**: various land use reconstructions for different periods between 3000 BC and today.
- **Validation**: expert opinions only; no indisputable verification method found up to now.
- **Discussion**: how relevant are pollen data for such kind of reconstructions?



Historical land use reconstruction

Sepp, 2004



Research area

Historical land use reconstruction

Sepp, 2004

- Input data
  - Pollen data, historical data and expert knowledge

    Pollen → land use classes (empirical choice):

    Forest: *Picea, Pinus, Betula, Alnus*

    Arable land: *Cereale, Cannabis, Linum, Brassicaceae, Centaurea cyanus*

    Grassland: *Poaceae*

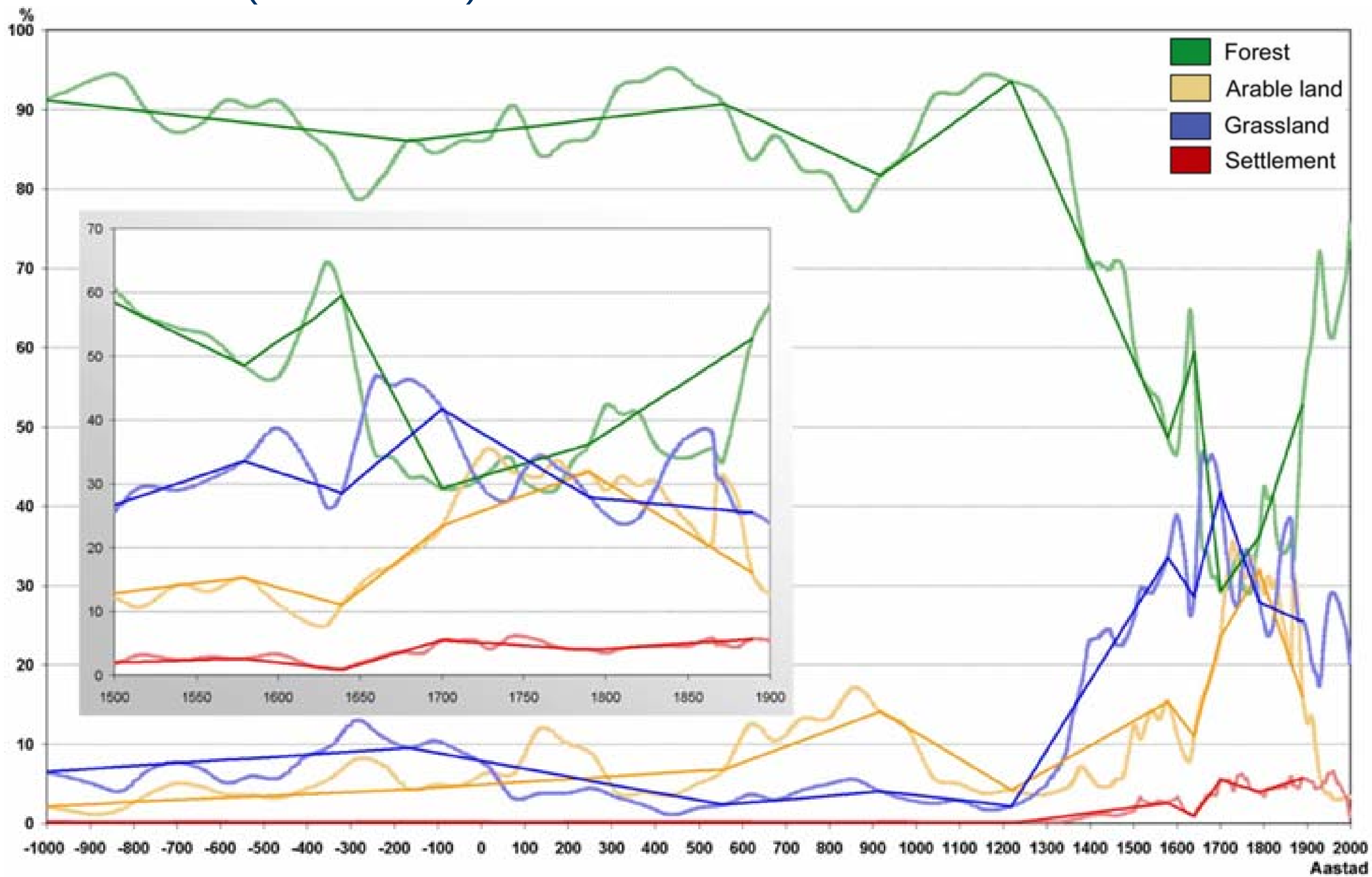
    Settlement: *Plantago lanceolata, Plantago major, Plantago media, Centaurea scabiosa, Polygonum arenastrum, Polygonum persicaria, Polygonum oxyspermum, Epilobium angustifolium, Urtica*

    Pollen % → land use % (empirical):

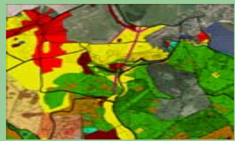
Forest		Settlement		Arable land		Grassland	
Pollen %	Land use %	Pollen %	Land use %	Pollen %	Land use %	Pollen %	Land use %
>85	>90,0	>3,5	>3,0	>3,0	>40,0	>2,5	>40,0
75,0-85,0	60,0-85,0	2,5-3,5	1,0-3,0	2,0-3,0	20,0-40,0	1,5-2,5	20,0-40,0
65,0-75,0	35,0-60,0	1,5-2,5	0,5-1,0	1,0-2,0	5,0-20,0	0,5-1,5	5,0-20,0
55,0-65,0	30,0-35,0	0,5-1,5	0,1-0,5	<1,0	<5,0	<0,5	<5,0
<55,0	<30,0	<0.5	<0,1				

Historical land use reconstruction Sepp, 2004

- Input data
  - Pollen data (linear trend):



Pollen data



Historical land use reconstruction — Sepp, 2004

- Input data
  - Transition matrixes (empirical):

1000 BC ... 166 BC

	Forest	Arable	Settlem.	Grassl.
Forest	46419	2323	67	5156
Arable	0	0	0	0
Settlem.	0	0	0	0
Grassl.	0	0	0	0

166 BC ... 557 AD

	Forest	Arable	Settlem.	Grassl.
Forest	45066	1250	0	103
Arable	349	1626	0	348
Settlem.	0	6	55	6
Grassl.	3549	800	7	800

557...918 AD

	Forest	Arable	Settlem.	Grassl.
Forest	43702	4203	10	1049
Arable	232	3000	5	445
Settlem.	6	0	45	11
Grassl.	142	410	10	695

918...1219 AD

	Forest	Arable	Settlem.	Grassl.
Forest	42487	992	3	600
Arable	6130	1290	0	193
Settlem.	52	0	18	0
Grassl.	1820	0	4	376

1219...1579 AD

	Forest	Arable	Settlem.	Grassl.
Forest	25837	6455	1174	17023
Arable	200	1780	0	302
Settlem.	0	0	25	0
Grassl.	150	30	200	789

1579...1639 AD

	Forest	Arable	Settlem.	Grassl.
Forest	25000	500	0	687
Arable	3000	5024	0	241
Settlem.	640	0	400	359
Grassl.	3480	400	102	14132

1639...1700 AD

	Forest	Arable	Settlem.	Grassl.
Forest	15014	7549	2544	7013
Arable	500	5000	0	424
Settlem.	60	0	400	42
Grassl.	240	100	25	15054

1700...1790 AD

	Forest	Arable	Settlem.	Grassl.
Forest	14500	1100	40	174
Arable	341	11050	0	1258
Settlem.	200	304	2105	360
Grassl.	4507	4769	13	13244

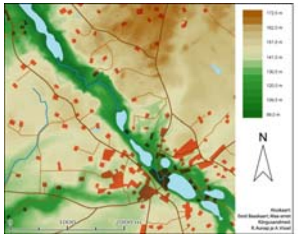
1790...1889 AD

	Forest	Arable	Settlem.	Grassl.
Forest	19000	290	100	158
Arable	8144	8215	397	467
Settlem.	58	25	2000	75
Grassl.	1288	130	557	13061

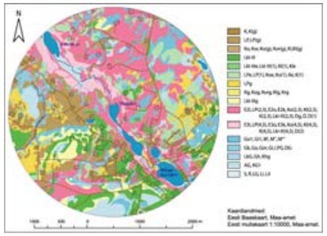
Pollen data

Historical land use reconstruction

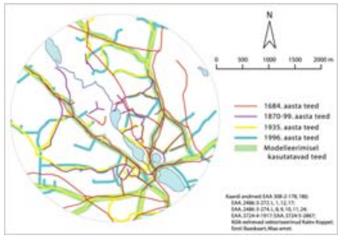
Sepp, 2004



topography



soils



roads

- Suitability maps
  - Choice:

    Research from K. Remm (1999) on the ground of Estonian basemap (1:20 000) and different statistics

    M. Konsa (1999) – archaeological data
  - Weighing:

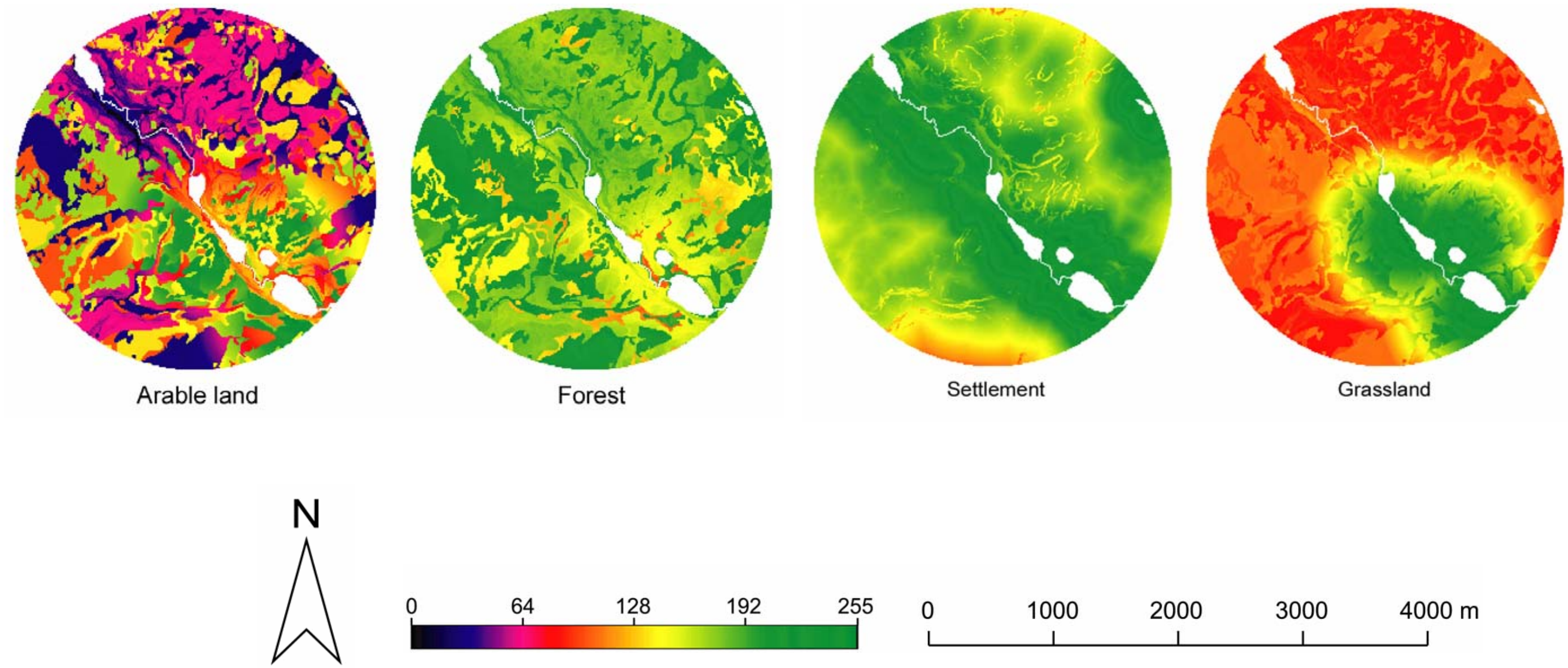
    Expert knowledge (Saaty method)

Settlement		Forest		Grassland		Arable land	
Distance from water bodies	0.437	Soil	0.700	Distance from settlement	0.537	Soil	0.637
Distance from good soils for agriculture	0.309	Distance from roads	0.100	Soil	0.364	Distance from settlement	0.258
Slope angle	0.161	Slope angle	0.100	Slope angle	0.099	Slope angle	0.105
Distance from roads	0.093	Distance from settlement	0.100				

Historical land use reconstruction

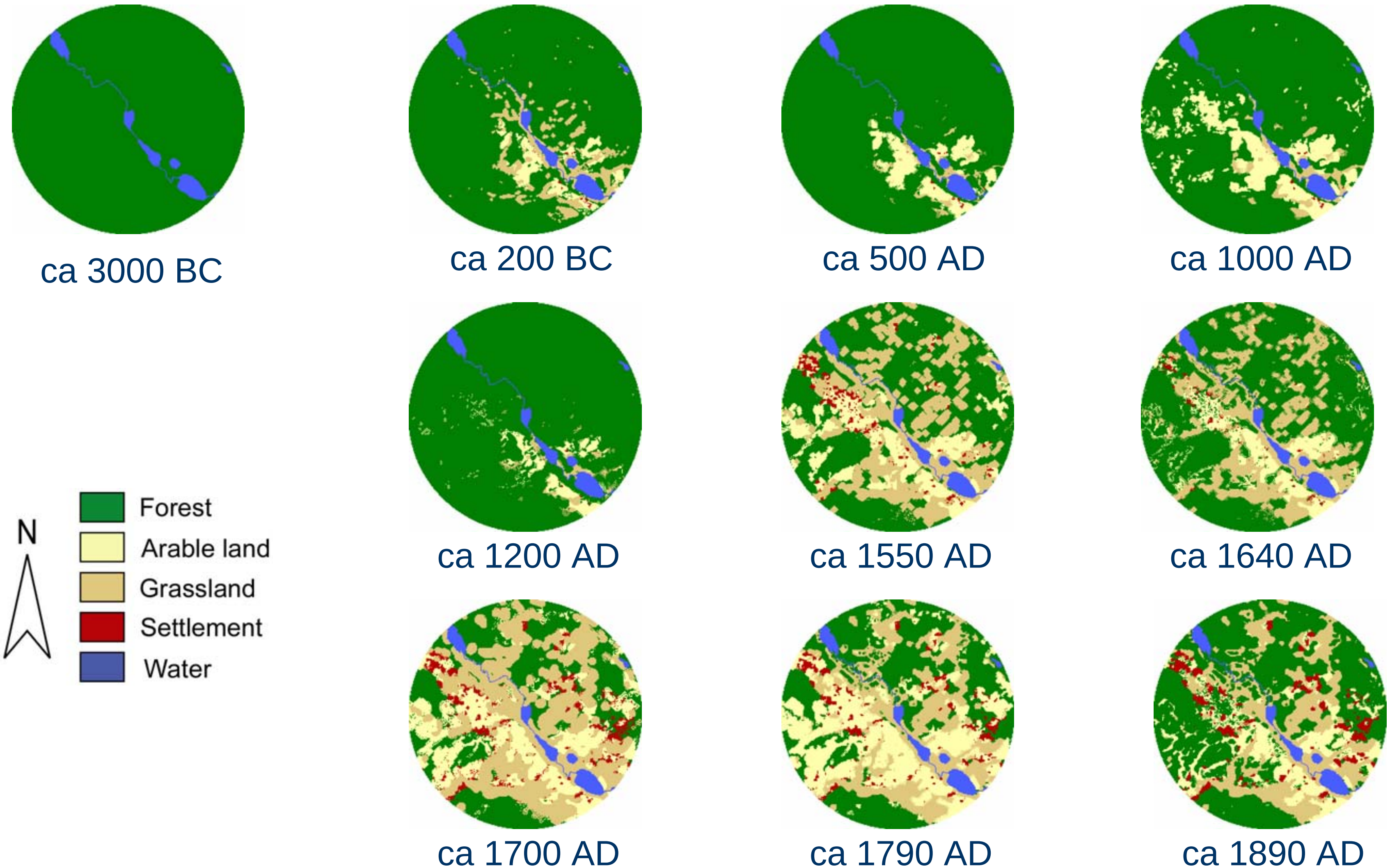
Sepp, 2004

- Suitability maps
  - are regenerated before every iteration
  - suitability <u>for</u>:



Historical land use reconstruction

Sepp, 2004



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Thank you!

MARKOV + STCHOICE

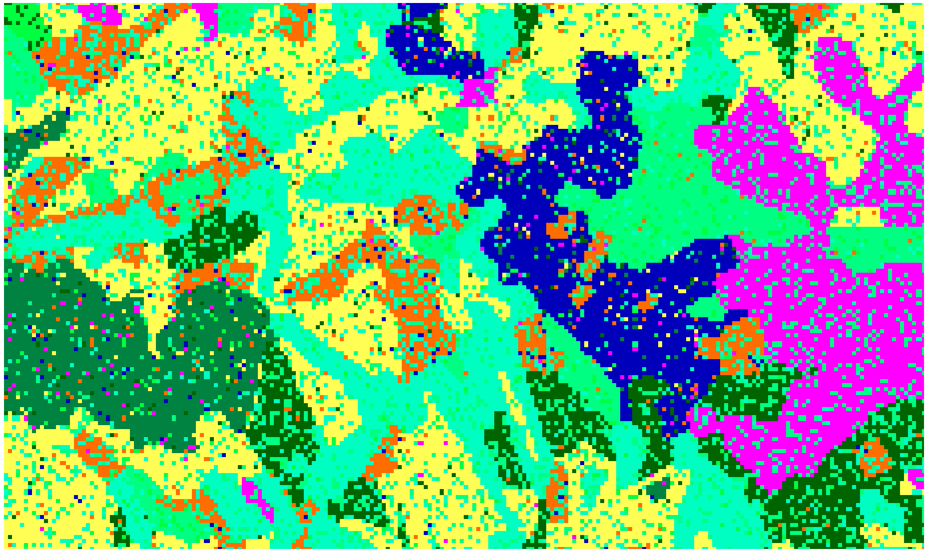
- Modelling system's states using **Markov chain**
  - A Markov chain describes at successive times the states of a system. At these times the system may have changed from the state it was in the moment before to another or stayed in the same state. The changes of state are called <u>transitions</u>. The Markov property means the system ... does not "remember" the states it was in before, just "knows" its present state, and hence bases its "decision" to which future state it will transit purely on the present, not considering the past. [Wikipedia]
  - Transition rules are defined with probabilities considering only present state.
- The **MARKOV** module analyzes a pair of land cover images and outputs a transition probability matrix
  - The result <u>is not</u> spatial – one can calculate how much land use of type A changed to type B but additional information is needed to specify <u>**where**</u>
- **STCHOICE** makes this decision as a <u>random choice</u> creating a stochastic land cover map.

MARKOV + STCHOICE

2 / 2

Return!

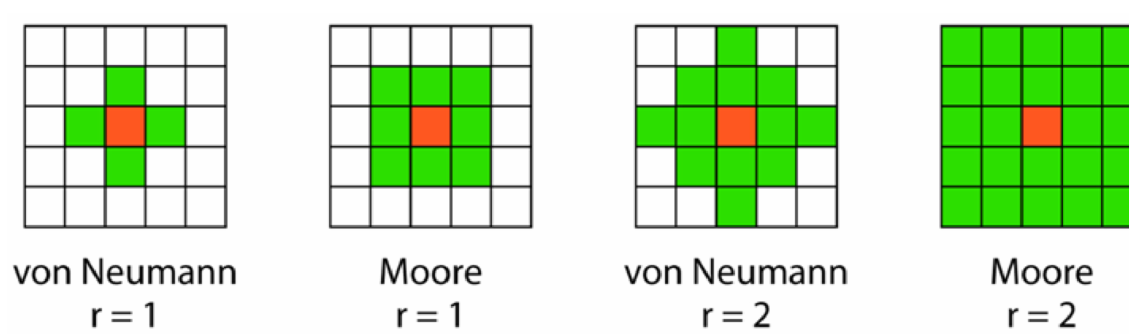
- As a result, **spatial pattern of land use changes <u>is not realistic</u>** even though the quantities of changes are correct
  - changes are alike spatial noise:



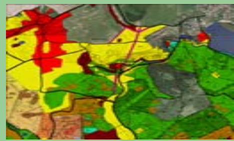
CA_MARKOV

- **CA_MARKOV** combines Markov chain analysis (as input) with **Cellular automata** (CELLATOM) and **Multi-Criteria / Multi-Objective Land Allocation** (MOLA) in order to add an element of spatial contiguity as well as knowledge of the likely spatial distribution of transitions.
- Cellular automata adds to the transition rules **dependency on neighbouring cells**
  - different neighbourhood definitions are possible:

In GISc:
Rook's case
King's case

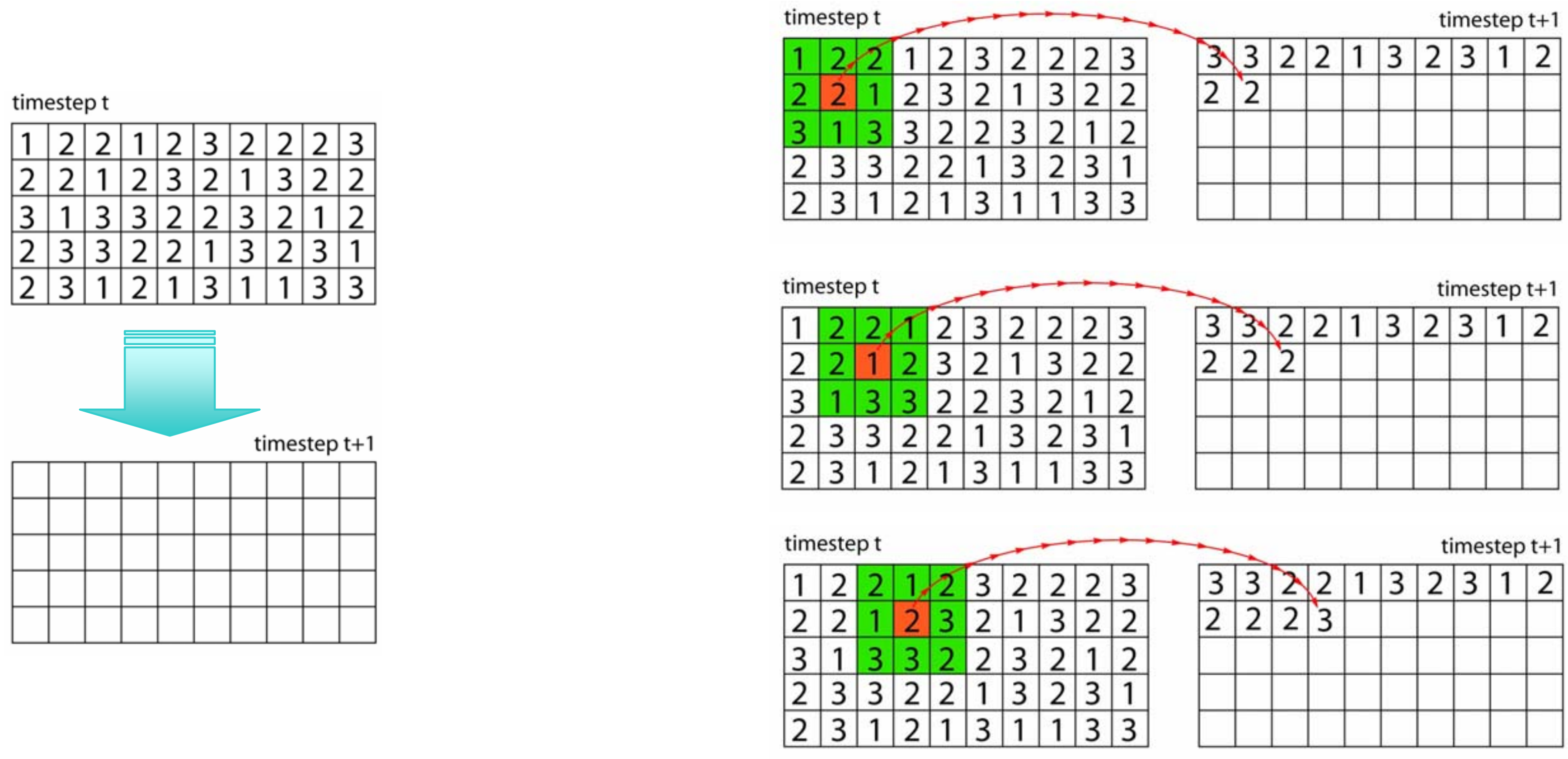


Sepp, 2004



CA_MARKOV

- CELLATOM: neighbourhood FILTER plus RECLASSification:



Sepp, 2004

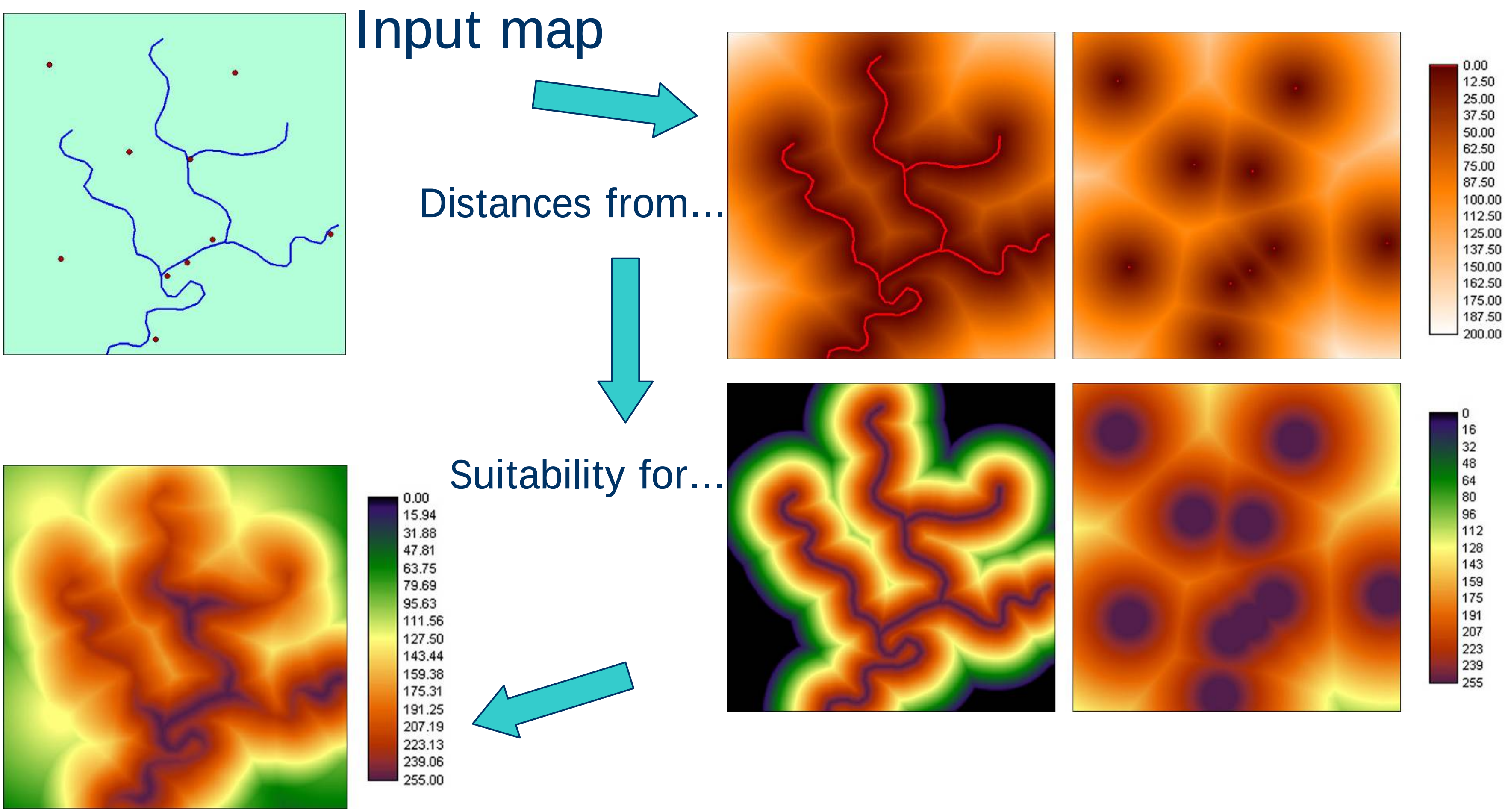
CA_MARKOV

- MOLA allocates land use changes spatially on the base of **suitability maps**
  - Suitability maps are created individually for each land use class and estimate how suitable is every cell in the map for specific land use class
  - All kind of different data can be included to make a suitability map
    - Topography, historical, physical, pollen, socio-economical…
    - Quantitative, qualitative (factors, criteria)…
    - Expert knowledge
    - One possible method also good to determine **weights** / importance of different factors is Analytical Hierarchy Process (Saaty method)

a special topic, not itemized here

  - quite often suitability maps are based on proximity maps

CA_MARKOV



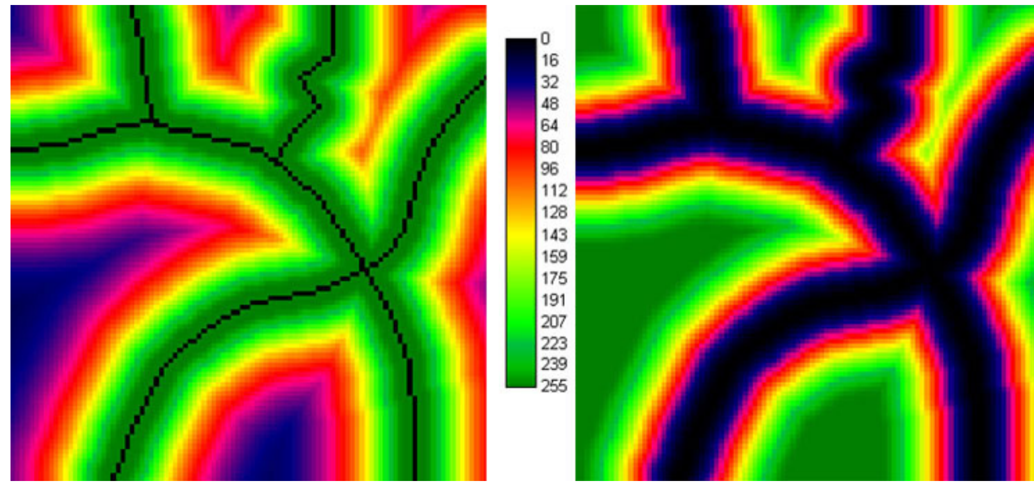
Suitability map (equal weights)

Sepp, 2004

CA_MARKOV

- Simple modelling example how CA_MARKOV works (Sepp 2004):

Input map



Suitability maps

	Class 1	Class 2
Class 1	2000	3000
Class 2	3000	2000

Transition matrix

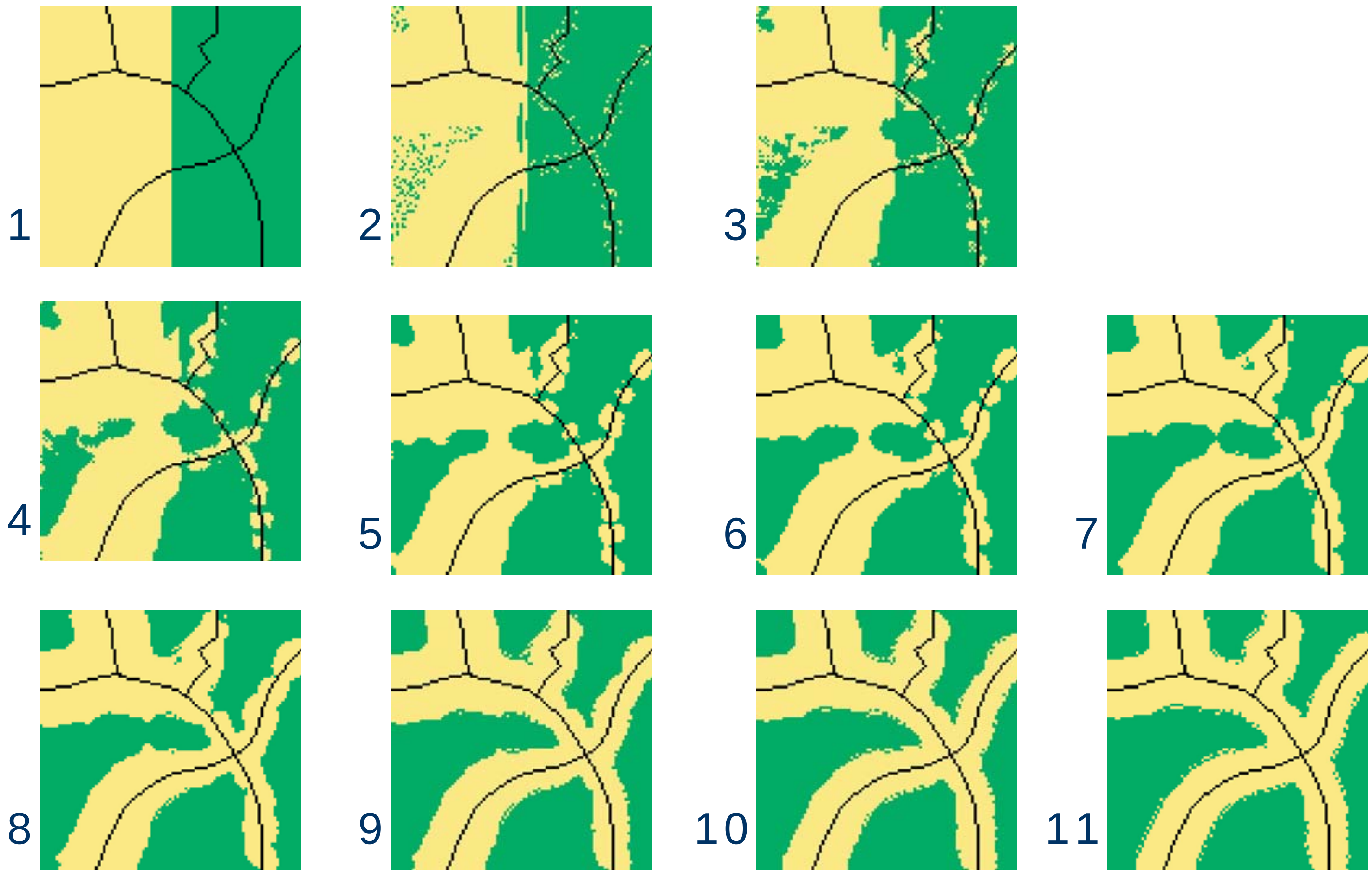
Time factor: 10

0	0	1	0	0
0	1	1	1	0
1	1	1	1	1
0	1	1	1	0
0	0	1	0	0

Neighborhood filter

CA_MARKOV

Return!



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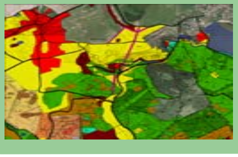
GEOMOD

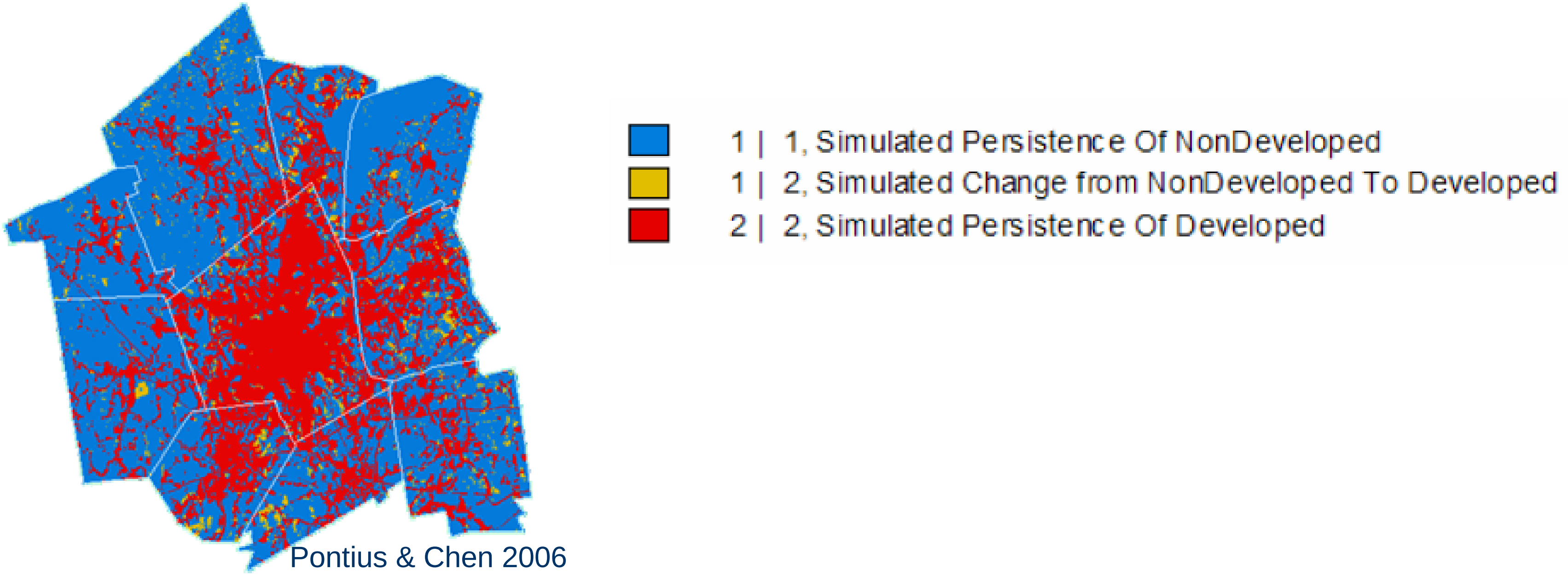
- Separate model, in detail described in IDRISI by its author (Pontius & Chen 2006)
- Simplified in comparison with CA_MARKOV but more quick
  - simulates change between “non-developed” (1) and “developed” (2);
  - minimum inputs are
    - image of the initial state
    - the beginning and ending times
    - quantities of (1) and (2) at ending time (i.e. nonspatial data)
    - optional suitability maps
- GEOMOD can make regionalised simulations i.e. different parts of an image may have different changing tendencies
- GEOMOD includes neighbourhood constraint (Rook’s case) with different (and in some cases changing in iterations) width
- Suitability for a chosen driver component is calculated as proportional to the cross tabulation of this component and the initial state.



GEOMOD

Return!

- Suitability maps are constant during a simulation run
- GEOMOD is designed for environmental impact analysis and can calculate it as a product of impact factors
  - similar analysis also can be easily made by other tools of IDRISI



Pontius & Chen 2006

Jüri Roosaare (assoc.prof., University of Tartu)