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Part I.

Project Execution

1. Objectives

The purpose of the CAVES project was to couple policy concerns for complex human-environmental systems with linked physical, biological and social models based soundly in complexity science. We have produced a constructive demonstration of modelling procedures for the formation of social policy in conditions of uncertainty due to complexity. The demonstration entailed the development of clusters of models for each of three case studies. Two of the case studies related to land use in the face of developing internal stresses and external shocks. We chose to analyse land use issues because they are naturally represented by complex networks of complex networks. The third case study related to the impact of HIV/AIDS on social networks, since it became apparent during the first phase of the project that due to water scarcity agricultural activity in the case study region had ceased to be of primary importance.

The regions chosen for the case studies are differentiated by their observed sensitivity to external pressures. The models associated with these case studies and their use by the relevant stakeholders tested how well agent based models of real, complex social networks enhance our understanding of both social processes and, more generally, processes in complex networks when those models are validated[1] both qualitatively and quantitatively.

To achieve this purpose, the project met three specific objectives:

1. *Evidence*: The substantial qualitative and statistical evidence brought to the project by partners responsible for the case studies was developed further to inform the design and stakeholder validation of models of land use or HIV/AIDS, respectively.

2. *Models*: Agent based social models linked to biogeophysical models were developed to investigate why some external shocks to complex social networks are followed by volatile episodes and some are not. The models were based on and constrained by qualitative and statistical evidence.

3. *Generalisation*: Clusters of consistent models were developed at several levels and axes of aggregation that, at the most descriptive level, captured the relevant detail of complex systems and, at the most abstract level, allowed for ready comparison with models in the literature on complex systems.

[1] We follow the terminology of the social simulation research community here, drawing on that of software engineers. *Validation* is the comparison of simulation model outputs with corresponding data about the social processes and institutions being modeled. *Verification* is formal proof of the properties of the model.

2. Contractors

This chapter summarises the work performed by the different contractors involved in the CAVES project. It gives an overview of the end results, elaborating, where suitable, on the degree to which the objectives were reached.

2.1. Centre for Policy Modelling, Manchester Metropolitan University (MMU)

The CPM has been the coordinator of the CAVES project as well as providing the modelling team for the South Africa case study. Team members were Shah Jamal Alam, Ruth Meyer, Scott Moss and Bogdan Werth.

2.1.1. Work performed

Modelling

A suite of agent-based models was developed for the South African case study. We started with a prototype model implemented procedurally in Java/Repast, which was extended by declarative components dealing with agriculture (CAVES, 2006). After it became clear that instead of land use issues HIV/AIDS is the main stressor in the case study area affecting the social networks, the focus of the modelling effort switched to incorporating an individual-based model of HIV spread. Using agent-based simulation to model the spread of HIV is still a rather novel approach. To our knowledge only a few other models exist today (e.g. Rhee (2006) and Sumodhee et al. (2005)).

We developed two models based on the available evidence, a procedural model (further development of the prototype model without the declarative components) and a declarative model, which captures individual behaviour as rules. A detailed description of the procedurally implemented model can be found in (Alam et al., 2007); its enhanced epidemiological component is discussed in (Alam et al., 2008). Moss (2008) describes some of the key aspects of the declarative model.

Both models represent individuals as agents who are characterised by their sex, age, marital status etc. They live together in households, engage in sexual interaction, marry, work, migrate and maintain kinship and friendship links. Household incomes derive almost entirely from state grants and pensions. The main grants are child grants paid to the household on each child less than eight years of age and pensions paid to older individuals. The grants are pooled within households. There is also borrowing and lending of food in times of need by close family members and friends.

People in rural South African villages form savings clubs called *stokvels* to which all members contribute a specified amount each month and one of the members is given each month's subscriptions e.g. to buy food in bulk. The stokvel has a social function as well and is comprised by adults (not necessarily household heads) who are known to and friendly with one another. There are also funeral clubs, which have many more members and act as an insurance scheme to cover the bulk of the heavy expenditures expected of households when one of their members dies. Other expenditures include *lobola*, which is a substantial bride price.

Mining is a rapidly growing part of the case study area's economy. Due to the lack of empirical data, the representation of mining in the models is largely based on assumptions. A mine will need a certain number of workers, some of which may be recruited from the local population. When a mine opens in the case study area, it will attract workers from outside the region (in-migrants). In-migrant mine workers are only relevant to the modelled village population in their direct interactions with them. These include: establishing friendships with co-workers from the village, having sexual relationships with women from the village and renting accommodation. Therefore these are the only aspects considered in the models. Any in-migrant who cannot get a job after 4-6 months or who develops AIDS (stage 4 in the progression of HIV) is assumed to leave the area (return home).

The behaviour of and social interactions amongst agents determines the social networks that emerge during simulation runs with the models. The models differ in the way behaviour and social interactions are implemented. Whereas the procedural model applies algorithmic descriptions of the social processes, the declarative model uses declarative rules and an endorsement mechanism as introduced by Moss (1995). A comparison of the sexual mixing schemes used in the two models to govern the formation of the sexual networks demonstrates these different approaches.

Procedural model: aspiration and quality In this scheme, based upon a scheme originally proposed by Todd and Billari (2003), agents are assigned an initial aspiration and quality ("attractiveness") log-normally. If the number of current partners is lower than his upper limit, a male agent of age between 16 and 55 looks for a female between 14 and 40 whose attractiveness exceeds his aspiration level. He then sends her a courtship offer. Female agents evaluate all offers received during the current time step. All offers from agents whose attractiveness is below their own aspiration level are rejected immediately. From the remaining suitors a female agent will choose the best and accept his offer. The criteria to determine the best sexual partner change with age. For instance, young female agents prefer males of similar age, while more mature female agents may prefer unmarried employed suitors.

Agents search for sexual partners mostly among their friends and acquaintances, resulting in a high likelihood that the potential partner is of similar age. There is also 5-10% chance for picking a female as potential partner at random. Agents without partners have their aspiration level successively decreased after a particular waiting time. For those satisfied with their current sexual partner(s), the aspiration level is updated incrementally. From the anecdotal accounts of the villagers we know that it takes about one to two years before a couple gets married. Since a male has to pay *lobola* (bride price) to the female's household the marriage of the couple may be delayed even further. Each agent is initialised with a maximal courtship duration sampled from a lognormal distribution with the minimum and maximum cut-off values as 12 and 36 months. The model then updates the courtship duration time (i.e. the time for dating until an agent decides to marry) for agents as they age during the simulation.

Declarative model: endorsements The declarative model makes use of so-called endorsements and individual tags in the agents' decision-making. One can consider endorsements as labels which agents use to describe certain aspects of other agents. The model incorporates both positive labels like is-kin, is-neighbour, is-friend, similar, reliable and negative labels like unreliable, incapable or untrustworthy. Some endorsements are static in that, once applied, they do not change over the course of the simulation (e.g. is-kin), while others are dynamic and may be revoked or replaced according to an agent's experiences (Werth et al., 2007). All agents use the same list of endorsements but differ in their endorsement scheme, which associates each label with a weight to express how much store the agent sets by this particular aspect of a person. Weights are modelled as integer numbers between 1 and n for positive labels and -1 and $-n$ for negative labels, respectively. This allows for computing an overall endorsement value for a person. Agents are assigned random endorsements schemes at creation.

The overall endorsement value allows an endorsing agent to choose the preferred one(s) among a number of endorsees. In case of the sexual network, endorsement values are used to model the attractiveness of potential partners. A male individual finds a female attractive if (i) she is of the same age or younger and (ii) her overall endorsement value is higher than a certain threshold particular to the male individual. We thus assume that partner choice is biased by a preference for particular attributes.

Adults between 15 and 64 are considered sexually active. Males of this age group look for potential partners among the siblings of friends, work colleagues and the social groups they belong to. When they encounter a female adult they find attractive they make a pass at her, modelled as sending her a partner request. Females evaluate all requests received at the same time and pick the best of the "applicants" if (i) their overall endorsement value is higher than the female's threshold and (ii) in case they already have a certain number of current partners, if this applicant's endorsement value is higher than the lowest endorsement value of the current partners. In this case, the current partner with the lowest endorsement value is dropped, thus ending their sexual relationship.

Relationships otherwise may end due to marriage of one of the partners or — in absence of detailed knowledge about real reasons — are broken up randomly. The number of current partners and the person's age influence the probability applied; it is highest for young people with a maximum number of concurrent partners.

Modelling technology

A considerable part of the work undertaken by the CPM was concerned with modelling tools, in particular tools that enable declarative modelling. It is our understanding that declarative modelling is often the most appropriate technique to capture social phenomena (Moss and Edmonds, 2005) whereas many physical or biological processes are best described by numerically based formalisms. Since the models developed in the CAVES project needed to represent both, social and physical processes, it was therefore important that a modelling environment should support declarative modelling as well as imperative modelling.

Our first approach was to develop a package, which supports the implementation of declarative (that is, rule-based) features in otherwise conventional models. The package was written in Java and especially designed to integrate with any agent-based social simulation software. Unfortunately, it turned out that the data structures and algorithms used for the declarative package were very inefficient.[1] We therefore investigated existing alternatives. Combining Repast[2] with JESS, the Java Expert System Shell[3], was deemed the most promising approach. JESS is a rule engine and scripting environment written entirely in Java. Declaring facts and rules is done via a script language with a LISP-like syntax. This language supports not only the manipulation of symbolic facts but also method calls on arbitrary Java objects, thus facilitating the combination of declarative modelling and imperative modelling.

Our first approach was to let each agent have its own rule interpreter (engine). This allows the rules describing the agent's behaviour to be specified in the respective agent class. Global facts like the state of the agents' environment, however, have to be copied for each engine. Because of the high memory requirements of this approach we researched the possibilities of sharing one rule engine amongst all agents. Several options exist, with different advantages and disadvantages. To keep the rulebase as small as possible we settled on defining rules per agent type and collecting them in the model class. This ensures there is only one copy of each rule in the rulebase. Agents are declared as shadow facts so that rules can refer to individual agents easily. In every run of the engine, each rule will fire once per matching agent fact. Thus the engine has to be run only once per time-step to update all agents.

During the model development it was necessary to find a balance between the expressiveness of declarative modelling in Jess and the faster execution of Java code. Our solution has been to strive to reduce both the number of rules and the number of facts by the following measures:

1. Several rules did not deal explicitly with decision processes but were more or less procedural in nature; e.g. updating the households' cash or evolving tags. These were all ported to Java. Since some of them need to have access to the currently existing facts we implemented a Java class (`FactBaseScourer`) that browses through the fact base once per time step and delivers the necessary facts to the respective methods.

2. Whenever suitable, we replaced explicit facts with corresponding fields in Java classes acting as shadow facts in Jess. For example, facts keeping record of household economy were replaced by fields in the Household class and updated from Java. Rules in Jess can access these fields as slots in the shadow fact. This has proven to be much faster.

[1] This was due to the fact that the package borrowed some concepts and their realisation from the SDML language developed and extensively applied at the CPM over the past ten years. Whereas SDML has an underlying list structure, this is not one of Java´s strengths.

[2] `http://repast.sourceforge.net/`

[3] `http://herzberg.ca.sandia.gov/jess/`. Although not open source, JESS is available free of cost for academic purposes.

3. Reducing the number of facts in Jess' memory by removing facts when they are no longer needed. For this we devised a class `DisposalPolicy`, which keeps track of which type of fact can be removed after how many ticks. The disposal policy is executed at the end of every model step after running the Jess engine, ensuring that a time lag of 0 results in immediate removal.

4. Supplying Jess with direct access to model functionality by implementing user functions instead of relying on calls on the model object. This concerns the Jess user functions `(current-tick)` and `(dump)`. The former retrieves the current model tick while the latter "dumps" the text passed as parameter on the console. The dump function invokes the method of the same name on the model class. Together, the two user functions allow for the model shadow fact to be removed from the left hand side of the majority of rules, resulting in a faster Jess execution as the complete Rete network doesn't have to be rebuilt every model tick.

Evidence

Since field work for knowledge elicitation had to be done in parallel, the prototype model was largely based on existing data from previous projects undertaken in the same region; namely the UNRAVEL project (Understanding resilient and vulnerable livelihoods in Malawi, South Africa and Zambia; Ziervogel (2006)) and FIVIMS-ZA (du Toit and Ziervogel, 2004), a project assessing the feasibility of developing a Food Insecurity and Vulnerability Information and Mapping System (FIVIMS[4]) for South Africa. Within the framework of the latter, a pilot study was undertaken in the Sekhukhune district, whose data obtained from a detailed questionnaire was made available to our team. Unfortunately, it turned out that the data pertaining to social networks of individuals and/or households was either missing completely or aggregated in such a way that it was impossible for us to infer the necessary information. For the prototype model we thus had to make a number of assumptions, which we checked with our domain experts from the case study team.

In June 2006 we were able to agree on a collaboration with RADAR (Rural AIDS and Development Action Research Programme[5]), giving us access to longitudinal data from the case study area. Specifically, we obtained data pertaining to several surveys, which were conducted in the context of the IMAGE study (Intervention with Microfinance for AIDS & Gender Equity[6]). This research initiative aims at targeting the prevention of HIV/AIDS and gender-based violence through alleviating poverty via a microfinance-based lending scheme and is based in eight villages in the Sekhukhuneland District. From these surveys we extracted detailed information about household structure, age distribution, income and migrants, which have been used to enhance the models' validity. The extracted data has been especially useful for the model setup.

[4] `http://www.fivims.net/`
[5] `http://www.wits.ac.za/radar/Home.htm`
[6] `http://www.wits.ac.za/radar/IMAGE_study.htm`

Internet Portal

In the project initiation phase a project logo was designed (see figure 2.1) and an internet portal was set up, consisting of a publicly accessible part and a part with restricted access for eligible users. The public area held descriptions of the project and consortium, a list of publications, a knowledge base and a glossary while the private area made related material accessible to the project partners.

Figure 2.1.: The CAVES project logo

In the course of integrating a Wiki[7] component for the knowledge base and glossary it was decided to move the entire internet portal to the Wiki. This had the advantage that all partners could not only contribute to glossary and knowledge base but work collectively on all parts of the portal, making it an even better internal communication tool.

To achieve this, a new Wiki-Layout was designed to match the established layout of the old version. Moreover, the portal was extended to incorporate links to project-related documents and an area to discuss work in progress. The internet portal can be found at `http://caves.cfpm.org`.

2.1.2. Results

Social systems are sources of complexity in that interactions between individuals can give rise to unexpected and unpredictable behaviour at the system level. Agent-based simulation is very well suited to explore the interplay of such interactions, by modelling the individuals' behaviour and interaction at the micro level and analysing the resulting networks at the macro level.

Dynamic social networks

Both the procedural and the declarative model take into account several types of networks such as neighbour and kinship links on the household level and friendship links on the individual level. There are also savings clubs that are, in fact, fragments of networks and less persistent. The resulting social networks are dynamic (number of nodes and links change over time) as well as constrained by the underlying social processes. Traditional social network analysis measures, e.g. degree centrality, do not work for a variety of agent-based models (Edmonds and Chattoe, 2005). Analyzing the topology of dynamic overlapping social networks is therefore a non-trivial task.

[7] See e.g. `http://en.wikipedia.org/wiki/Wiki`.

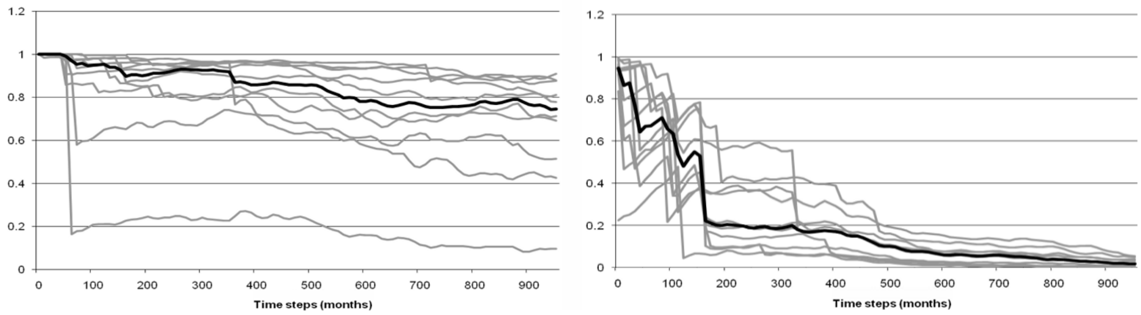

Figure 2.2.: P-scores for the KS test on the neighbour (left) and friendship (right) networks. Snapshots are taken at every 10th time step and compared with the previously taken snapshot; the black line indicates the median of all simulation runs.

For networks of varying size, we have proposed the use of the 2-population Kolmogorov-Smirnov (KS) test (Neave and McConwa, 1987) to compare simulated networks at different time steps (Alam and Meyer, 2008). This test gives a probability (p-score) that two sets of data (e.g. node frequencies) might come from the same distribution; it does not depend upon assumptions as to the type of distribution. A low p-score is thus a good indication that the two sets of data have different distributions. The KS test can indicate if structural changes have occurred in a network during simulation. It takes into account the network as a whole in many different dimensions at once whereas traditional techniques typically provide a one-dimensional aggregate measure. This technique is generic and is not restricted to the degree distribution alone.[8]

In order to investigate changes in the generated social networks, we applied the technique to the neighbour and friendship networks. Figure 2.2 shows the respective p-scores for the node degree distributions of the neighbour and friendship networks for ten simulation runs each. While there is a high variability in the results across single simulation runs for the neighbour network, overall the network structure seems to remain relatively stable. This is due to the fact that the neighbour network only changes when new households are formed (after marriages) or existing households dissolve (death of last remaining adult). The friendship network on the other hand changes much more rapidly, mostly influenced by deaths of individuals due to HIV/AIDS. A high prevalence of HIV/AIDS in the community implies that agents die at a much earlier age and this threatens the viability of the village community in the model.

Model-to-model comparison

Model-to-model (M2M) analysis has grown in recent years into a major research area in the field of multi-agent based simulations as more and more researchers from different backgrounds apply agent-based modelling to the same problems. One of the primary aims is to identify suitable abstraction levels where model comparisons can be made across

[8]It is planned to extend this analysis method to other network characteristics, especially the geodesic distance, which is important in the study of the role of sexual norms in the spread of HIV/AIDS.

different scales, statistical signatures as macro-level output, and micro simulation results with regard to particular case-studies addressing similar social problems. The question we addressed is whether different styles of implementations — in our case declarative vs. procedural programming -– lead to qualitatively different model results.

We have undertaken a model-to-model comparison of the procedural and the declarative model with regard to the sexual mixing scheme these models apply (Alam and Meyer). Typical network signatures were computed to compare the structure of the resulting sexual networks, whereas HIV prevalence and population size were used as relevant macro-level measures. The formation of sexual networks in the models takes into account that people may have several concurrent sexual partners. Since same-gender partnerships are more or less taboo in the case study area the models only consider heterosexual relationships. The resulting sexual networks are therefore two-mode networks with males and females forming the two distinct sets of nodes. Typical signatures for heterosexual networks include spanning-tree like structure, very few cycles, large geodesic distance and diameter for any two connected pairs of nodes, low density and low clustering (Bearman et al., 2004; Robins et al., 2005).

Figure 2.3 shows snapshots of the sexual networks resulting from the two schemes taken in the middle and at the end of the respective simulation runs. As can be seen, the networks from both schemes exhibit the characteristic spanning-tree like structures and few cycles. This reflects the influence of a bias in partner selection, which is not observable in random mixing schemes (Koopman et al., 1997; Kretzschmar and Morris, 1996).

To explore the differences of the two simulated networks we calculated time-series of density, relative size of the largest network component, geodesic distance and diameter of the networks. While the network generated by the declarative model exhibits a higher density and thus a lower geodesic distance, the procedural model's network generally has a bigger largest component, which is reflected in a larger diameter. The difference in component size is due to the random element in the procedural model's sexual mixing scheme, which allows for an easier merging of two smaller components into a large one.

It is interesting to observe clustered volatility in the time series of the network characteristics of both models. This effect, however, is not significant in the prevalence of HIV/AIDS and the population size.

Generalisation

Both, the procedurally and the declaratively implemented agent-based model of the South-African case study were based on and constrained by qualitative and statistical evidence (objective 2). The results from simulations with these empirical models were checked with villagers in Ga-Selala and with officials in the municipality of Tubatse, thus achieving stakeholder validation (objective 1). Work towards achieving the third objective has been the development of a more abstract model, which was implemented as a more abstract and more general implementation of the declarative model (Moss, 2008).

The empirical models are not simple and there is no basis for claiming that they generalises beyond the specific case of Ga-Selala. The abstract model replaced the specific social institutions of rural South Africa with an abstract set of activities in which individual agents could choose to participate. Some activities were specified as children's activities

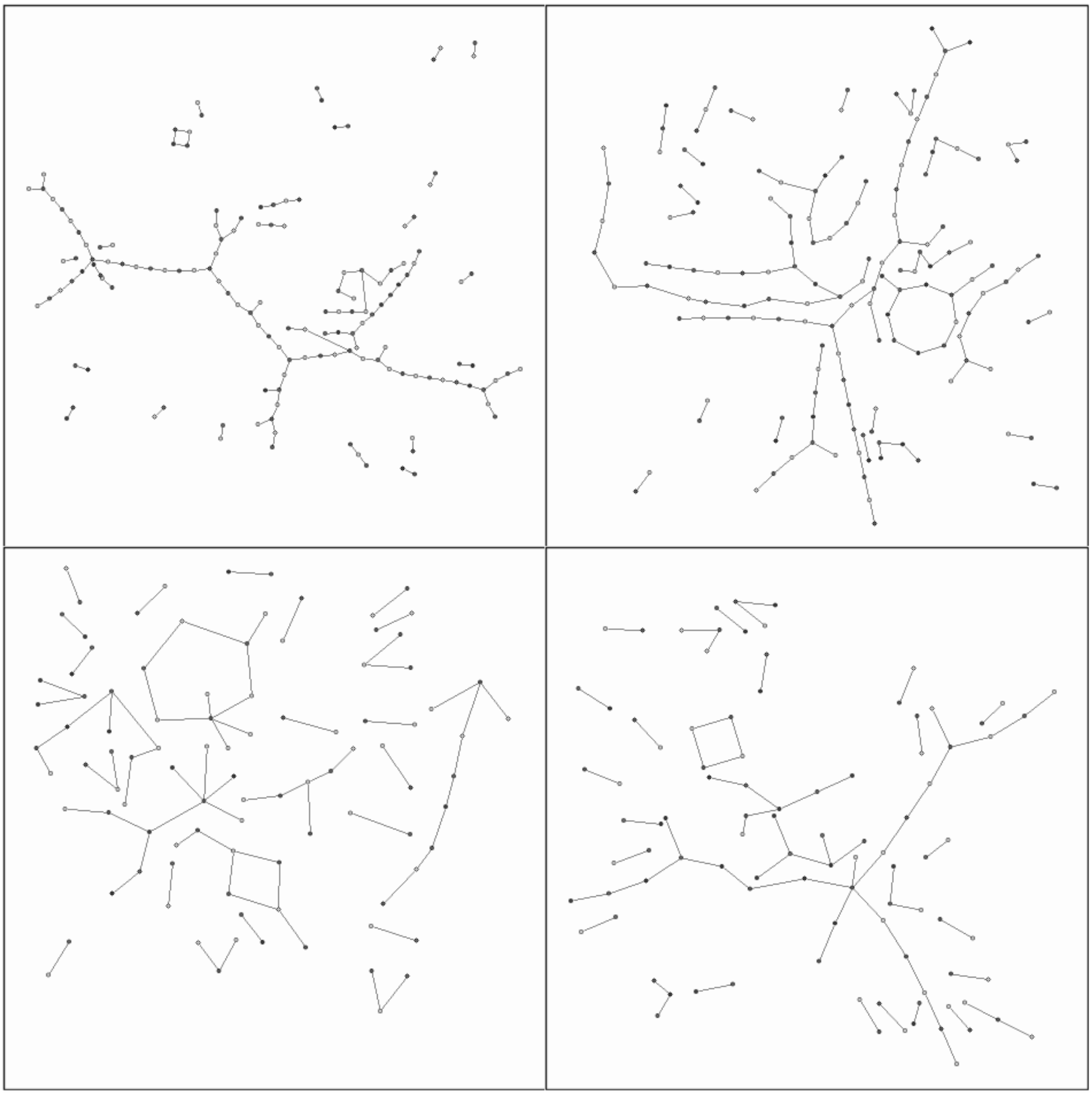

Figure 2.3.: Snapshots of the heterosexual networks generated by the procedural (top) and declarative model (bottom), taken at the middle (left) and end (right) of the respective simulation runs.

and some as adult activities. During model initialisation, individuals were assigned to activities appropriate to their age classification but otherwise at random. Participation in activities by individuals then evolved as agents joined activities in which other agents they valued (or endorsed) most highly participated. Each agent had a randomly assigned maximum number of activities in which it could engage. Religious denominations, which are important features of Ga-Selala, were left out of the abstract model but kinship was retained.

Simulation runs with the abstract model yielded results similar to those of the detailed declarative model, leading to a more general theory of the social impact of epidemics such as HIV/AIDS that is not dependent on stokvel, funeral clubs and churches in particular. This successfully demonstrated a procedure for generalising hypotheses from evidence based modelling.

2.2. Stockholm Environment Institute, Oxford (SEI)

The SEI Oxford has been the case study team for the South Africa case study. The team also took the lead in developing a suitable validation protocol for the evidence-based simulation models developed and applied in the CAVES project. Team members were Sukaina Bharwani, Tom Downing, Takeshi Takama, Anna Taylor, Richard Taylor and Gina Ziervogel.

2.2.1. Work performed

Case study

The South African case study aimed to represent rural livelihood security as related to water, health, employment and social networks in the Sekhukhune District Municipality, Limpopo Province in South Africa (see map in figure 2.4). Livelihoods in the region are impacted on by multiple stresses, including those caused by climatic variability, HIV/AIDS and limited employment opportunities. The hypothesis was that social networks within and between the village and municipal level affect the nature of adaptation to these stresses and hence how stresses are experienced.

Fieldwork focused on the district, municipal and village level in Sekhukhune. An innovative and integrated methodological approach was developed that allowed the consideration of vulnerability to multiple stresses within an integrated assessment framework. This approach enabled us to explore how stresses interact at different scales and affect livelihoods as well as district development opportunities. It also led to adaptation strategies being elicited, both from an agency perspective at the individual/local scale and from an institutional perspective at the village and district levels, as well as the broader national context.

The methods used included both qualitative and quantitative approaches. The villages for in-depth research (Ga-Selala, Mohlotsi) were selected from previous household surveys undertaken as part of FIVIMS (Food insecurity and Vulnerability Information Mapping System), a project commissioned by the South African Department of Agriculture. Semi-structured household interviews were undertaken with the identified households and then

Figure 2.4.: The South Africa case study region, the Sekhukune District in Limpopo Province. The village of Ga-Selala is marked with a red triangle.

focus group meetings, Discrete Choice Analysis (DCA), Stated Preference (SP) technique were undertaken at the village scale. Using DCA and SP methods supported by participatory methods were found to be an appropriate basis for the development of a methodological approach to assessing adaptation actions. Semi-structured interviews were used with key stakeholders at the municipal and district level government authorities. Combining qualitative and quantitative research methods and working at both the village and municipal scale addressed some of the methodological weaknesses inherent in each approach and therefore strengthened the results.

We engaged with a range of South African organisations including those involved in FIVIMS and two locally based organisations, RADAR and AWARD. Working in close partnerships with communities, researchers and policy/decision-makers was found to be a good way to facilitate the communication of different perceptions of, and means of adaptation to, multiple stresses between a range of stakeholders and to encourage and enable better co-ordination and integration of adaptation responses.

Validation

Whilst the use of agent-based models has become increasingly popular in the social sciences the validation of such models remains difficult. This is principally due to the fact that the systems that ABMs seek to capture are infinitely complex — they are not "closed systems" for which a set of definitive rules can be generated (Oreskes et al., 1994). The inability, or failure, of agent-based modellers to validate their work results in many of their findings being considered anecdotal (Windrum et al., 2007). The lack of a widely recognised validation approach in ABM tends to undermine the credibility of model findings and may be one of the reasons why research involving agent based modelling has struggled to gain its due recognition in the mainstream literature (Leombruni and Richiardi, 2005; ?).

A literature review and subsequent discussion with the CAVES project partners led to the proposal of a validation protocol that introduces a shift from conventional validation with its focus on making the model as realistic as possible to a new type of validation, which focuses on making the model *useful* to stakeholders and modellers (see Deliverable 8). The model purpose is pre-defined and the guiding principle is to stop when the model is complete enough (*fit for purpose*).

Regarding validation in the South African case study, there have been profound problems with ensuring that data at the local level in South Africa were representative. The initial data were drawn from previous research, in what amounts to a TAPAS (Take a Previous Model and Add Something) approach. Sekhukhune was deliberately chosen due to the activities of previous studies in the region. The FIVIMS (Food Insecurity and Vulnerability Information Mapping Systems) project provided both qualitative and quantitative data and links were made with the RADAR (Rural AIDS and Development Action Research Programme) project, which has data related to HIV/AIDS and social networks, so can be considered as a cross validation process. Macro socioeconomic data were obtained largely through the municipal contacts in Sekhukhune and from nationally available statistics and research results, whereas micro-behavioural data were obtained during the field visits to the village and supplemented by other village-level research from RADAR that had been undertaken in the area. Social networks datasets were also collected during a joint field trip of the case study and modelling teams to Sekhukhune but proved quite difficult to use. While they were not comprehensive enough for comparison with model output on friendship networks in the validation process, they nevertheless helped to identify types of relationships (friends are relatives, neighbours, colleagues, known from school, church or savings clubs). Moreover, we discovered that people in the village do not distinguish between friends and acquaintances — so far one of the assumptions of the models.

The final fieldwork phase of the case study took place in October 2007 and involved validation on both the micro and macro level. The results from simulations with the empirical models were checked with villagers in Ga-Selala and with officials in the municipality of Tubatse. The villagers were given stories drawn from model traces by selecting interesting or curious episodes in the output. Storylines were written up from the traces in order to present more human-understandable forms of the model output that could be read out/translated in the presence of the participants (see figures 2.5 and 2.6).

The macro-level validation exercises were carried out with municipal participants. In this case, simulation runs which focused on investigating the impact of mining on the village communities provided material for the validation activities. Time series macro outputs of the social simulation were used. Here, presenting the real plots might have been misread to suggest that the models produced some usable forecasting outcomes; therefore, schematic diagrams were used instead.

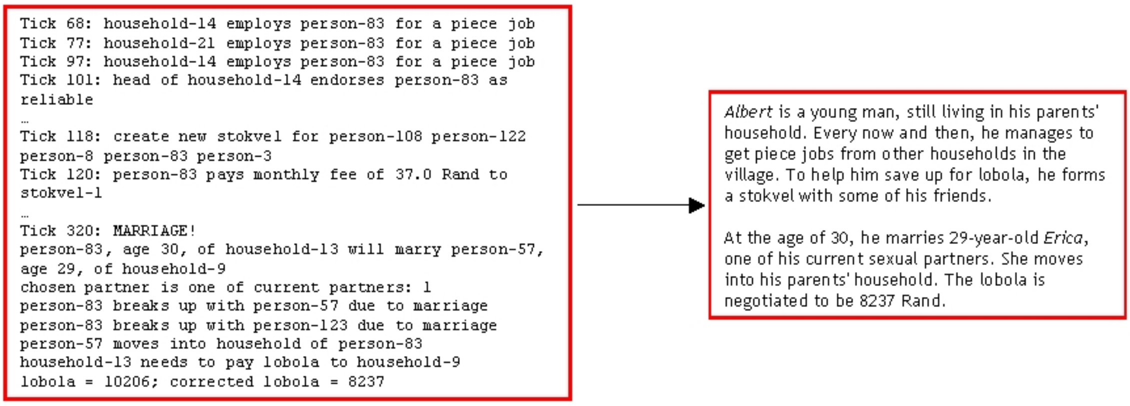

Figure 2.5.: From trace to storyline.

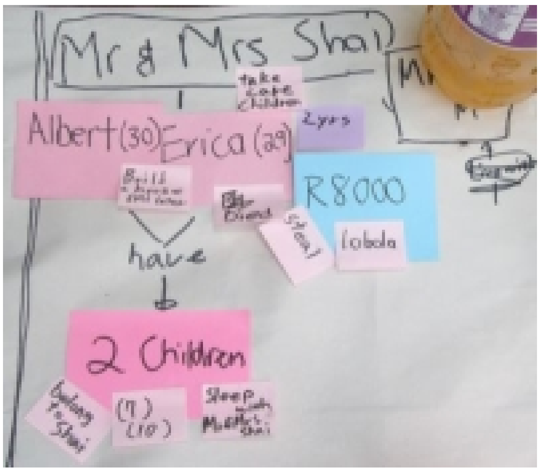

Figure 2.6.: Stakeholder validation of storyline in the village.

2.2.2. Results

Case study

The work has generated a number of insights, both in terms of the perception of stakeholders at different levels as to their vulnerability to multiple stresses, what appropriate coping and adaptation mechanisms might be, and in terms of developing appropriate approaches and methodologies to assess vulnerabilities and adaptation decision-making. The results of this work are expected to be of considerable value to the South African Social Cluster on Food Security that brings together key representatives from different government departments as to the kinds of interventions likely to be appropriate to reduce vulnerability, support positive change and increase resilience.

Even though water stress is one of the key manifestations of climate variability and change in Sekhukhune District, it is generally not perceived as a climate issue alone. Rather, water scarcity is considered to be the result of a combination of insufficient and highly variable rainfall conditions, issues of equitable water resource management, and the absence of drinking water, bulk water and irrigation infrastructure that would enable the distribution of water to all rural villages and hospitals. Food insecurity and a lack of money were identified as key concerns by many households. Most people interviewed highlighted the need to create employment opportunities and to improve water supplies for agricultural activities. However, the decisions relating to water use and distribution are made by stakeholders at the provincial and district levels and prioritise the growth of regional economic activities that do not necessarily reduce the high levels of poverty in rural communities, at least not in the shorter-term.

Because of an increase in the frequency of crop failures, many people are moving away from agriculture/horticulture and are instead seeking to engage in wage earning activities as an adaptation to water and climate stresses. As a consequence, less food is directly available to the household. People in the villages linked changes in food production and availability to decreased health, which is in turn linked to climate, water and economic/financial stresses. The price and availability of food on the informal and formal market fluctuates (often linked to climate variability) and can decrease the accessibility and affordability of (nutritious) foods. Households spending patterns have changed and this can impact on the quantity and quality of food consumed (which is a particular concern for people living with HIV). Although HIV/AIDS was mentioned as a key stress at the municipal level, it was not mentioned as a key stress in the villages where we worked. However, people did talk about the increase in home-based carers in response to increased health-care problems. If this could become a paid, regulated and better supported system this might be a very effective and beneficial sector for job creation.

An important response to lack of employment within the village is to migrate, even though it is seen by many as a last resort. Young people particularly tend to migrate in the hope of finding employment in one of the cities or mining areas. Whilst many people still living in the villages are considering migration, some do not have the opportunity to do so due to financial constraints or the lack of social networks in the target areas.

HIV/AIDS is of considerable national concern as it has many links to poverty, livelihood security and economic development. In Sekhukhune the figures are lower than the national average, yet much remains to be done to curb the spread of the disease. Due to the limited duration of this study, we were not able to gain much information about these issues at the village level. The government recognises the potential scale of the challenge, especially in the areas where the mining is expected to grow rapidly. It is critical that measures are put in place now to curb/minimise the potential negative impacts of the disease, otherwise it will undermine development in the long term.

Validation

In the South African case study there have been challenges in ensuring that modelling activities address the methodological challenges they set out to explore, while at the same time representing the case study material in a way that integrates multiple stresses and social networks and that can be validated by stakeholders. These challenges have been addressed via an iterative interaction between the field researchers and modellers and the field researchers and stakeholders. This model of interaction between modellers and stakeholders enabled a more representative capturing of stakeholder attributes in the constructed models.

The experience of all CAVES research teams lent credence to the notion that a standardised approach to validating social systems, and agent based models in particular, remains elusive if not impossible. However, we suggested procedures that may be followed in order to ensure a greater level of confidence and credibility in the models (see Deliverable 8). The challenge is to show the validity of agent based models and their findings without forfeiting their ability to capture complex social realities. Successful validation will enhance the credibility of agent based models and allow for comparisons across the three case studies.

2.3. Center for Environmental Systems Research, University of Kassel (UNIK)

The CESR has been the modelling team for the Odra case study. Team members were Michael Elbers, Andreas Ernst, Friedrich Krebs and Claudia Zehnpfund.

2.3.1. Work performed

Modelling in the Odra case study has proceeded from abstract to more detailed. The Kassel team started with a model that captured the basic characteristics of the domain but abstracted from details like land reclamation or land use changes (SONATA). This prototype model was followed by a more detailed model that represented the features of the domain and was coupled with a biophysical model (SoNARe).

SONATA

The SONATA model (SOcial Networks of Abstract Task-Oriented Agents) has been realised in the RePast agent programming framework[9]. Core features of the case study were

[9] http://repast.sourceforge.net

abstracted. Instead of looking at farmers having to decide on maintaining or not maintaining the land reclamation system, relying on social networks of friends and/or collaborators the SONATA model incorporates agents with goal- or task-directed behaviour, which use the networks at their disposition to fulfil their abstract tasks.

The model follows a rather strict distinction between physical environment and social environment of the agents. This distinction focuses on a separation between physical and social spaces both in terms of semantics and techniques used for their representation. For various reasons, the simulation of the agents' physical environment uses a traditional grid based approach. The social "location" of an agent is given by his position within a social network context, where an agent is viewed as a node and social relations are represented by edges. Since agents are considered in more than one social context an agent's social environment generally consists of more than one network layer: one is a friendship or acquaintances network and one is an advisor or collaborator network.

The friendship network is initialised with an assumed small-world topology and kept fixed during a simulation run. The collaborator network does not exist initially. Once a task is assigned to an agent, it polls its social friendship network for expertise needed to accomplish the specific task additionally to its own. The search is started in the direct social neighbourhood of the agent. If the collected expertise provided by the network neighbour has been successfully applied, the agent builds up an edge to the respective node in the collaborator network. Next time the agent first polls the collaborator context when looking for a new strategy. If the agent cannot find all the necessary expertise in the directly neighbouring links of the collaborator network it pursues the search in the neighbourhood of collaborators, i.e. collaborators of collaborators to find additional expertise.

SoNARe

As a successor to the SONATA model, we developed the SoNARe (Social Networks of Agents' Reclamation of land) model. It is much more concrete in terms of phenomena observed in the Odra case study and allows for the interfacing with the Odra biophysical model developed by the Wrocław University of Technology group. The agents of the model are situated along an abstracted canal in an upstream-downstream asymmetric dependency.

The overall computational model consists of two sub-models (see figure 2.7). SoNARe, the main sub-model, aims to capture farmer decision making and some of the main social characteristics of the Odra case in an agent-based model. The second sub-model is a simple and abstracted hydro-agricultural model (SHAM, cf. section 2.4.1) that reflects the main environmental characteristics of the target region. It provides the SoNARe agents with feedback about hydrological dependencies and crop yields under fluctuating climate conditions in the simulated area.

Technically, the SoNARe model is a hybrid model. It uses productions rules implemented in JESS and its reasoning engine to represent the cognitive control structure and decision making of the agents. Rules operate on mixed symbolic and numeric structures. Apart from that, large parts of the code are written in Java and the Repast library functions respectively to provide efficient execution of network functionality etc.

Two versions of SoNARe have been developed. The rationale for this separation of the modelling effort into two strands has been to be able to investigate more or less indepen-

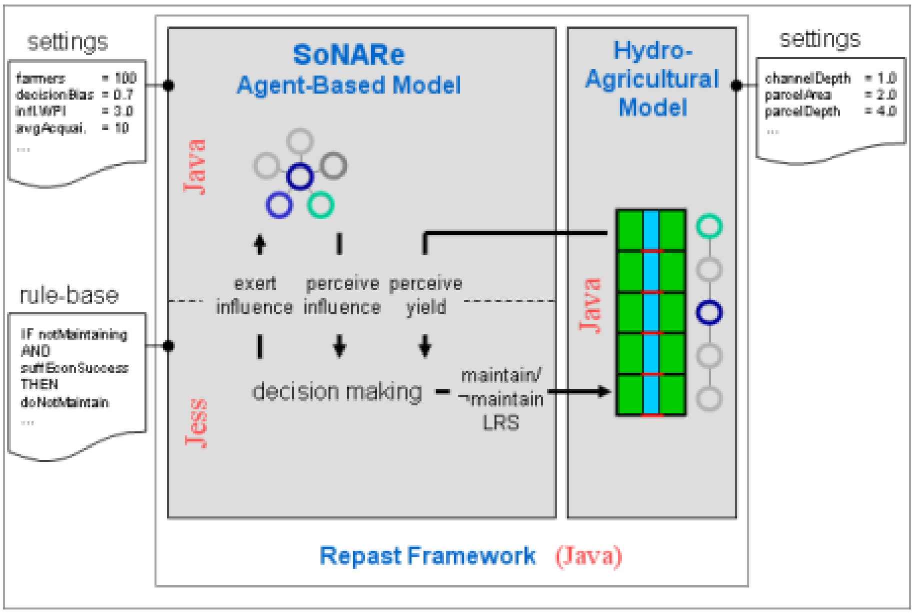

Figure 2.7.: Architecture of the SoNARe model, coupled with the biophysical model SHAM.

dently the abstract features and phenomena of the case study, i.e. those which are presumed to be found also in other problem settings, and the more case-study specific features and phenomena. The centre of interest of both strands has been to explore those consequences for the collective action necessary on the part of farmers to reactivate a neglected land reclamation system (LRS) that arise from the relation between the social dimension and the economic dimension of farmer decision making against the background of the structure of their social network and the inherent hydrological inter-dependencies caused by the spatial location of the land parcels the farmers manage.

SoNARe-A, the abstract version, takes a quantitative approach to modelling farmers' perceptions and their consideration of social and economic factors that bear on their decisions. Amongst other things, this allows the investigation of sets of scenarios that show shifts from more economically driven farmer populations to more socially driven farmer populations and vice versa.

SoNARe-D on the other hand includes more data from the actual case study (e.g. an elicited network structure and an additional farmer type) and is thus more evidence-driven than the more abstract version. In addition, it attempts to more closely capture the symbolic/qualitative nature of agents' decision-making and differentiates a set of social influencing factors.

While the abstract model has undergone some detailed sensitivity analyses, the evidence-driven model — largely owing to its novelty and added complexity — has still to be thoroughly investigated.

2.3.2. Results

SoNARe-A

The goal of SoNARe-A has been to investigate how a collective effort of the farmers involved can be triggered to transform the neglected LRS found in the Odra region at present to a collectively managed working LRS.

Farmers have individual perceptions of their economic success over a past sequence of years. The economic success is determined by the farmers' profit from their farming activities. Farmers evaluate their profit with respect to a certain (fixed) threshold below which the profit of a year is considered "too low". Profit is composed of production costs, costs for LRS maintenance (if maintaining), attained yield from a farmer's field, and compensation payments in case of crop losses.

Farmers are embedded in a social network; their opinion about LRS maintenance (pro/con) is propagated over the network links and perceived by others. The sum of all influences received over the social network links constitutes a farmer's perception of social support of his opinion concerning LRS maintenance.

We consider two decision scenarios: In the Selfish Scenario farmers decide about whether to contribute to the LRS maintenance solely based on their economic success, i.e. they disregard all social aspects. In the Social Scenario farmers balance their decision equally between individual economic success and perceived social support.

All simulations start out from the status-quo observed in the Odra region: The LRS is not functioning and none of the farmers is willing to start maintaining it. There are no economic incentives for maintaining the LRS because farmers who experience crop losses in wet years are fully compensated.

Starting from year 11, one of five compensation policies takes effect:

1. Pay no compensation
2. Pay compensation always to all farmers
3. Pay compensation always to farmers who maintain LRS
4. Pay compensation to all farmers, but only when LRS initiator promotes maintenance
5. Pay compensation only to farmers who maintain LRS, but only when LRS initiator promotes maintenance

An LRS initiator observes the individual profits of the farmers and starts to promote LRS maintenance (by exerting social influence pro LRS) if a certain proportion of farmers (here 10%) have very low profits. The activity of the LRS initiator is only relevant in the Social Scenario because in the Selfish Scenario farmers disregard all social influences.

The simulated dynamics for different combinations of decision scenarios and compensation policies lead to the following interpretation:

Compensation Policy 0 Cutting back compensation payments to 0 introduces a phase of economic stress (decrease in profits). This breaks up the initially passive behaviour of the farmers and triggers a phase of volatility in the opinion dynamics. In the Selfish

Scenario a majority of around 80% gets mobilised to maintain the LRS, whereas in the Social Scenario the economic stress induces a mobilisation of 100% of the farmers.

Compensation Policy 1 In the Selfish Scenario a minority of the farmers (around 40%, located upstream) starts to maintain the LRS because the reduced maximum amount of compensation does not equalise their crop losses. The remaining farmers may well live with the compensation paid and the benefits from the partly installed LRS.

In the Social Scenario the permanent flow of compensation prevents the LRS initiator from breaking up the social coherence between the farmers. A small proportion of (upstream) farmers have high crop losses in wet years which makes them start to maintain but in subsequent normal years social pressure makes them shift back to passive behaviour (see relative changes). In total almost none of the farmers maintain

Compensation Policy 2 In both decision scenarios the selective input of compensation payments to farmers maintaining the LRS reduces the total payments required and provides sufficient economic incentives to mobilise a majority of around 80% of the farmers.

Compensation Policy 3 and 4 When pulsed compensation is paid to all farmers (policy 3) in both decision scenarios nearly 100% of the farmers are mobilised. In addition, compensation payments decrease over time and fall to zero at the end of the simulation. For both decision scenarios the "pulsed" input of compensations further reduces the total payments.

When pulsed compensation is paid selectively to LRS maintainers (policy 4) in both decision scenarios compensation inputs are further reduced while in the Selfish Scenario profits increase and in the Social Scenario remain constant.

SoNARe-D

Agents in the SoNARe-D model are equipped with a quasi-qualitative decision mechanism based on endorsements. Each agent possesses two separate memories for storing endorsements, one for its maintenance decision related endorsements and another for its agent related endorsements. First of all, each year each farmer agent endorses each of its neighbours in the social network on two dimensions: LRS maintenance strategy (*sameStrategy*, *differentStrategy*) and profit (*lessProfit*, *similarProfit*, *moreProfit*). These endorsements serve as the basis for the endorser to rank its neighbours with respect to how similar to itself it considers them to be and which neighbours it deems worthy of being imitated because of their economic success.

Having endorsed its network neighbours, the farmer agent then endorses its options with respect to LRS maintenance. Currently, maintenance is endorsed on four dimensions by each agent: economic success (*bigLossesWhenMaintaining*, *bigLossesWhenNotMaintaining*), strategy of the most similar neighbour (*mostSimilarNeighbourMaintains*, *mostSimilarNeighbourDoesNotMaintain*), strategy of the richest neighbour (*bestOffNeighbourMaintains*, *bestOffNeighbourDoesNotMaintain*) and strategy of the majority of neighbours (*mostNeighboursMaintain*, *mostNeighboursDoNotMaintain*). Whether all or just some of

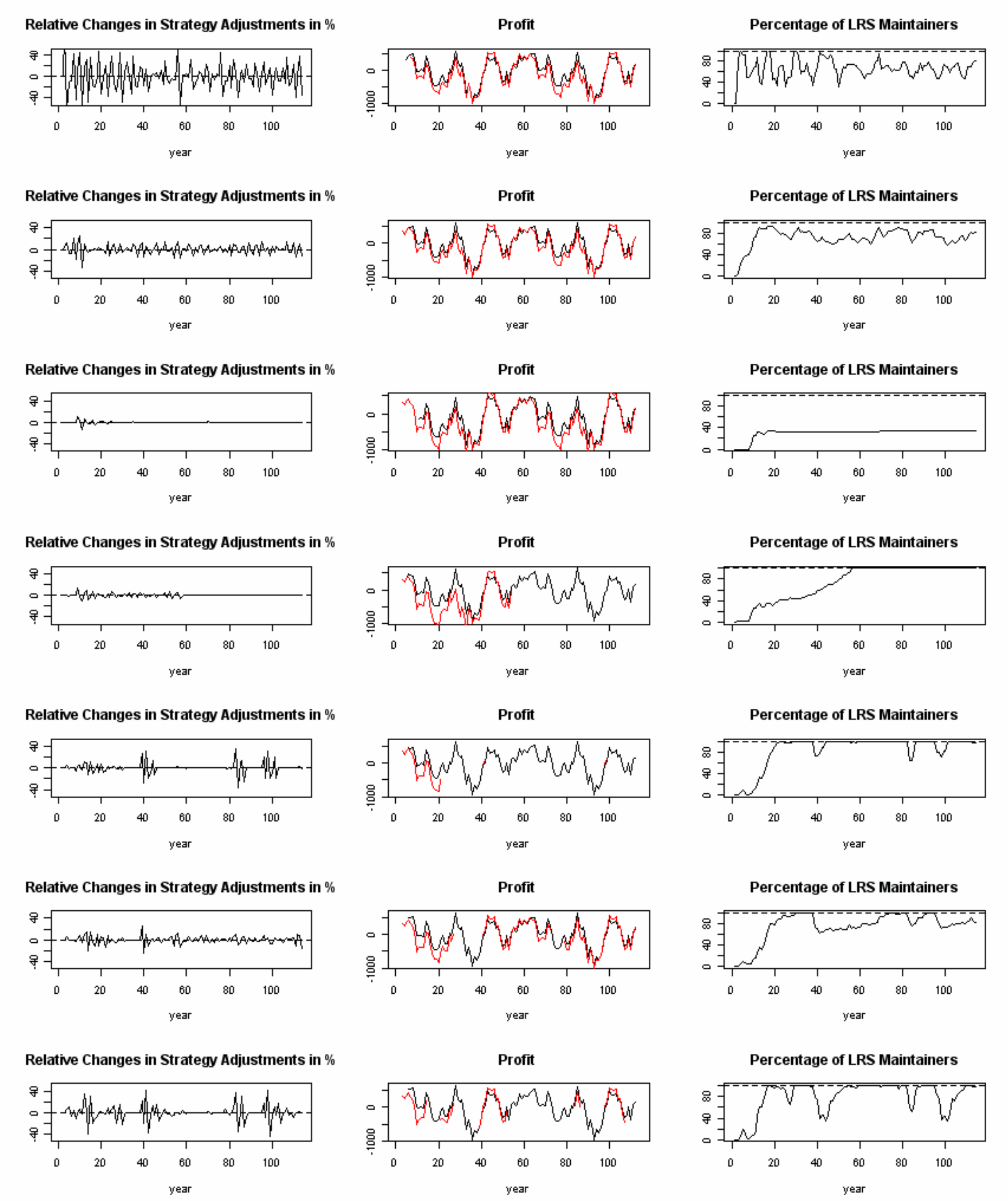

Figure 2.8.: Simulation results of SoNARe-D for seven maintenance endorsement scenarios over 114 simulated years.

them are actually taken into account when evaluating the two options and making a decision depends on the maintenance endorsement scheme assigned to the individual agent. If the result is positive, then the agent will maintain its LRS section(s) in the next year; otherwise it does not maintain. The following schemes are considered:

1. economic: *bigLossesWhenMaintaining/NotMaintaining* = 1/-1; all others set to 0.
2. most + eco: same as economic, but *mostNeighboursMaintain/DoNotMaintain* = 1/-1
3. most similar + eco: same as economic, but *mostSimilarNeighbourMaintains/DoesNotMaintain* = 1/-1
4. best-off + eco: same as economic, but *bestOffNeighbourMaintains/DoesNotMaintain* = 1/-1
5. most + best-off + eco: combines most and best-off, but *bigLossesWhenMaintaining/NotMaintaining* = 2/-2
6. most + most similar + eco: combines most and most similar, but *bigLossesWhenMaintaining/NotMaintaining* = 2/-2
7. most + most similar + best-off + eco: combines most, most similar and best-off, but *bigLossesWhenMaintaining/NotMaintaining* = 3/-3

For each of the seven maintenance endorsement schemes a model run was performed, i.e. seven scenarios are compared and within a scenario all farmers use the same scheme. The results (see figure 2.8) show that volatility is far higher in the purely economic/egocentric scenario than when social considerations/aspirations play a role. This can be seen as an indication for a social lock-in or coherence effect in the more social scenarios (2-7), as had already been identified in early versions of the abstract model. This finding is mirrored in the percentage of LRS maintainers which stabilises much more in those scenarios than in the economic case. However, if agents only compare themselves with the neighbour they consider to be most similar to themselves —- with regard to profits and maintenance strategy application —- it stabilises on a much lower level than in all other cases (around 40

2.4. Politechnika Wrocławska (WUT)

The team from WUT has taken the lead in work on generalisation, starting from the opposite end of the modelling spectrum. In this work they have been liaising with the partner from IIASA. They also provided the biophysical model for the Odra case study and a computer-based role-playing game used for knowledge elicitation and validation. The main team members were Paulina Hetmann, Grzegorz Holdys, Piotr Magnuszewski and Joanna Stefanska.

2.4.1. Work performed

The team from WUT was responsible mainly for the development of abstract models and theories based on results of the CAVES project. We also had a supporting role in building models for the Odra case study and in the data gathering process for this case study.

Generalisation

A core feature of the CAVES project is that it starts from evidence and problems as specified by stakeholders independently of any prior theoretical constraint. This is arguably a different approach from that pursued in the complexity and social simulation literature by physicists who adopt and possibly adapt formal techniques from physical science. This approach was followed by WUT and formed a key element in the evaluation of the relative strengths and weaknesses of an evidence and problem driven approach.

Work started with the investigation of the properties of two classes of discrete choice (opinion dynamics) models. One of them, more often used by economists, is formulated using a generalized utility function, where utility may include subjective components. The evolution of the second class is formulated using ”supporting” and ”persuading” influences on individuals states. We found that these two approaches can be formulated in a uniform way and each of them can be expressed in terms of the other. We proposed a general framework for individual-based binary choice, social interaction models. We show that under the assumption that an agent’s choice depends on her/his previous choice, the economic models using the utility function and social psychology models using the impact function are mathematically equivalent. This equivalence allows us to use insights from both economics and social psychology to develop models applicable to a wider range of situations.

In the generalized model for the binary choice problem the utility function is assumed to be an additive form of individual preferences, inter-personal influences, randomness and ’self-supportiveness’ (individuals’ inertia). Individual preferences can result from personal characteristics or can be a result of external influence. In physics of phase transitions this component is called the ’external field’. With these assumptions we obtained a more specific condition for systems equilibria. Using specific assumptions, many binary choice models known from literature can be obtained from our generalized model (Ostasiewicz et al., 2006).

Generating social networks

The difficulties of gathering evidence on the exact structure of social networks in the case studies directed as into an attempt to recreate a social network structure based on the rules of network evolution. We developed a theoretical model of evolution of an affiliation network. The model aimed to generate a social network based on affiliation data, with an underlying assumption that shared group membership (affiliation) increases the probability of link formation but it does not assure it. To diagnose whether the obtained network structure is typical for a social network, the clustering coefficient (indicating existence of well interconnected subgroups) and degree correlation (correlation between degrees of neighbouring nodes) were computed. Both indices were shown to have significantly higher values for social networks than for other types of networks.

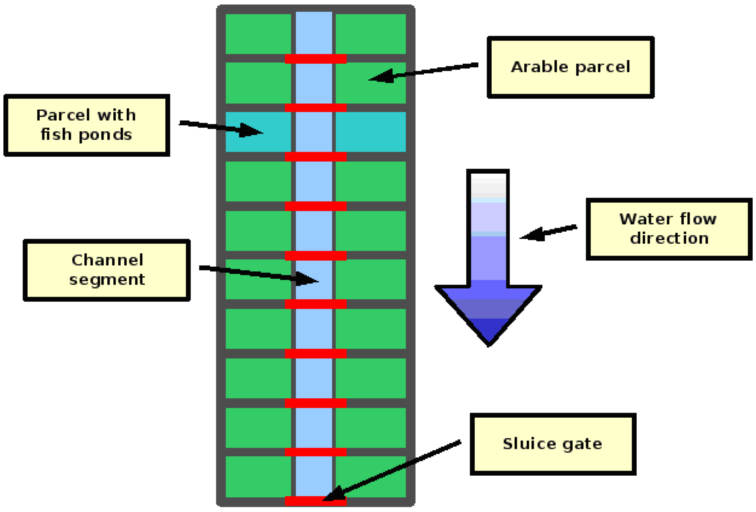

Figure 2.9.: The Simple Hydro-Agricultural Model (SHAM)

Based on the assumption of (Newman and Park, 2003) regarding positive assortativity as typical for social networks, we created an algorithm that constructs networks of the desired high assortativity. The algorithm is based on mechanisms that are as plausible from the point of view of social science, as possible at this stage of research. The mechanisms include: group membership that allows forming social ties within the group with relatively high probability; inborn human tendency to maintain fairly stable (yet different for different people) number of friends; and human ability to adapt to social environment and modify these inborn preferences depending on the situation. Different attractiveness of social groups has been taken into account as well, operationalised as probability of becoming a member of each group. What is more, parameters of the algorithm, such as affiliation distribution or degree distribution were based on results of big social surveys, such as The International Social Survey, The General Social Survey and DDB Life Style Survey.

Biophysical model

The model for the Odra Case Study, developed by the Kassel team, requires a biophysical model responsible for hydrology simulation, weather generation and crop prediction. The first version of such a model was developed during the first half of the CAVES project. The biophysical model is spatially explicit. It models such processes as water movement in the saturated and aeration zones of the soil, surface runoff, crop growth, interception of rainfall by canopies, evapotranspiration, channel water routing, maintenance and natural deterioration of land reclamation system etc. In order to fulfil all those tasks, the model requires a wide array of input data, most of which are spatial. These include the following: DEM of the modelled region, a vector map of the land reclamation system, a vector map of land parcels divided according to property and soil class, a crop database, a weather data file.

Due to the heavy data requirements and level of detail of the model, the Kassel team requested a simplified version, which would be easier to integrate with the more abstract agent-based model of farmers' behaviours. The Simple Hydro-Agricultural Model (SHAM) is a quasi two-dimensional abstraction of the environmental situation typical for the Odra region (see Figure 2.9). It reflects the hydrological dependencies between neighbouring landowners and simulates the effects of different weather conditions, LRS maintenance and LRS neglect as well as sluice gate operations on the water levels, different land uses and the crop yields of individual land parcels along a channel. The outputs of the Simple Hydro-Agricultural model were – on the given level of abstraction – validated with stakeholders and experts.

The hydro-agricultural model offers a number of parameters to be varied across simulation runs. These parameters allow setting e.g. the current weather conditions, channel length, number of land parcels or LRS condition on a specific parcel. Furthermore various output data are provided by the model e.g. annual crop yields, water levels or the present LRS condition.

AgroGame

During the last eight months the WUT team in cooperation with the team from Wroclaw University worked on a role playing game, designed as a validation tool for the model built by the Kassel team. The game is built on top of the SHAM biophysical model and a simple economic model. To make the game more attractive, we created a set of graphics that represent various game concepts like economic condition, profit, or yield. The game is designed for a network play. Each player has a computer and connects to the game server via a local connection.

Each player of the game plays the role of a farmer, who owns a parcel. There are six such parcels in the game, each owned by a different farmer. The parcels lay on a piece of land of small and homogeneous slope, along a homogeneous channel, that runs through the centre of every parcel. The parcels' area and land use is homogeneous. The game works with a yearly time step and in each time step it calculates yields and a simple economic balance for every parcel. At the start of the game, each farmer has the same amount of money. During the game farmers spend their money on agricultural production and optionally on maintaining the ditch. They earn money by selling agricultural products. A player can perform certain operations, like cleaning their part of the ditch, or filing a complaint against a neighbour, who does not clean their part of the ditch. A player against whom such a complaint is filed will have to pay a penalty in the next time step.

2.4.2. Results

Generalisation

Associated with the work on generalised abstract models was an investigation into measures to be used across case study models to compare their results. Regarding social networks, which play a major part in all of these models, different measures of clustering were researched (Hetman et al., 2006). They can be divided in two main groups: cluster size distribution and common neighbors distribution measures. Additionally, we introduced the

Figure 2.10.: Main screen of the AgroGame

clustering coefficient analogous to the measure of network transitivity. A 'good' measure of clustering should indicate whether and how far an observed spatial pattern differs from the pattern under random configuration. This condition is satisfied by the measures that use the statistics methods of hypotheses testing (join-count, spatial autocorrelation) and by the group-level index of clustering. However, the latter is not (so far) easily determinated in non-regular network case.

Following discussions at the project meeting in Kassel, a generalisation framework for CAVES was proposed (Hetman and Magnuszewski, 2008). Diversity of issues and modeling paradigms do not allow for a direct generalisation of the models built for CAVES case studies. Instead, abstract representations (concepts) of certain aspects of CAVES case studies models were identified. This allows us to introduce measures related to these representations and compare the same set measures over all case studies models. The generalisation framework and its related measures are described in more detail in section 4.3.

Generating social networks

The role of groups was examined in the context of social network formation. An analytical approach was applied to examine notions of clustering and assortativity that were hypothesized to take specific values for social networks only (as opposed to non-social networks). Results of the analysis and simulations revealed that the existence of groups (with high probability on in-group link formation) does not guarantee high degree correlation. Correlation between node degree and the number of nodes in all groups to which the node belongs contributes to a positive degree correlation as well as the correlation between node degree and number of affiliations contributes to a positive degree correlation.

Generally speaking, the developed affiliation network model allowed to examine various mechanisms that were hypothesized to stand behind high degree correlation coefficient observed in many social networks. Results of the study suggest that high degree correlation is an effect of a certain specific combination of initial conditions and cannot be reasonably expected to occur in all social networks and this conclusion seems to be supported by recent developments of the field.

Our model can also be used as a useful and simple tool to generate networks with desired degree distribution, division into groups and a few other important parameters.

2.5. International Institute for Applied Systems Analysis (IIASA)

Jan Sendzimir from IIASA provided the CAVES project with his expertise on resilience, liaising mainly with the partners from WUT.

2.5.1. Work performed

From the early stages of the project it has been important to consider the issues that the developed models would be used to address and the procedures to be used in addressing them. To this end, IIASA produced a review of the literature on social resilience and related it to complex adaptive systems (Deliverable 6).

Further work has contributed to the work on generalisation of the partners at WUT (see section 2.4.1).

2.5.2. Results

A key point in Deliverable 6 is how to approach an understanding of the ability of a society to absorb disturbance, i.e. reorganise in a process of ongoing change whilst continuing to function. In more traditional approaches, the key concepts were based on social equilibrium and the possibility of multiple equilibria. An essential aspect of social (as well as natural) complexity is the occurrence of change that is unpredictable in its timing, magnitude, duration and even the outcome once volatility has passed. The resilience literature entails the wholesale use of metaphor which might serve as a stimulus to thinking about the problems of complexity and attendant volatility but is either formalised in ways that depend on inappropriate concepts such as equilibrium or lack precision. The IIASA paper was drafted from the standpoint of scholars who accept and have participated in the development of resilience theory. It thus provided a benchmark and perhaps a target for the assessment of how the case study with modelling techniques developed in the CAVES project can lend precision and constraint to the analysis of social phenomena associated with a loose and frequently contentious concept of resilience and its complement, vulnerability.

For further results, please refer to section 2.4.2.

2.6. Macaulay Institute (MLURI)

The partners from Macaulay Institute have been solely responsible for the Grampian case study, thus combining fieldwork and modelling in one team. Team members were Nick Gotts, Gary Polhill and Lee-Ann Sutherland (nee Small).

2.6.1. Work performed

Case study

The Grampian study site (see map in figure 2.11) was chosen because of the relatively limited amount of land use change that has occurred there in recent decades, in comparison to the Polish and South African study sites. This resilience in the type of agricultural production characteristic of the region has taken place in the midst of changes to the EU Common Agricultural Policy in 1992 and 1999, the BSE epidemic (which restricted beef exports from 1996 - 2006), and the exit of sterling from the ERM in 1992.

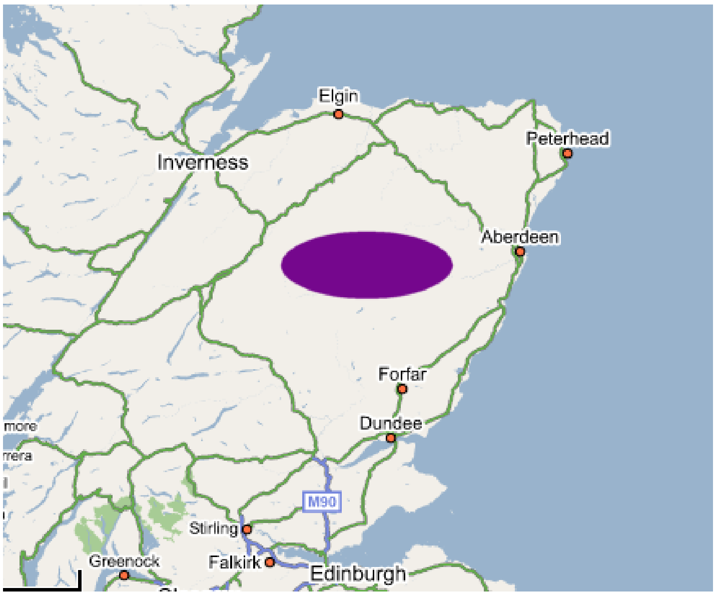

Figure 2.11.: The Grampian case study region, the Upper Deeside area.

The purpose of the Grampian case study was to provide policymakers with scenario analyses for land use change in the region over the medium term, based on computer-generated models of land use change processes. These models were based on findings from qualitative interviews with agricultural land users. This qualitative research was conducted in three parts: pilot study, primary field research and validation, undertaken between February 2006 and September 2007. The combination of pilot study and primary field research resulted in total interviews of 44 (24 farmers, six successors, five estate factors and nine key informants). The total number of interviewees was 51, reflecting seven farmer interviews in which a partner (typically a spouse) also participated. For the validation, eight of the original respondents participated for a second time, providing feedback on the decision-rules derived from the original field research.

Modelling

The Grampian models have been based on existing software called FEARLUS (Framework for Evaluation and Assessment of Regional Land Use Scenarios), which is implemented using the Swarm[10] system developed at the Santa Fe Institute. The modelling team has also undertaken extensive work on ontologies.

Ontologies Different modellers and domain experts have their own views of the relationships among concepts and how these can be modelled. The issues here are considered by philosophers under the heading of *ontology*. In the context of CAVES, ontology means the structure of relations among relevant concepts. An ontology is typically a hierarchical data structure containing all the relevant entities and their relationships and rules within the particular domain. The main objective for using ontologies was to find a common ground and vocabulary for the different teams and approaches. To this end, a workshop on ontologies was organised at the Macaulay Institute in June 2005. One of the issues raised at this workshop was the lack of a formalism for describing processes (dynamics) in a case study. Nonetheless, in terms of describing concept hierarchies and relationships between concepts, ontologies offer a more transparent formal description of a scenario than the source code of a more traditional object-oriented computer model, with at least the potential for the evidence base to be rigorously established.

A survey of the most relevant parts of the extensive literature on ontologies informed decisions about how to use ontologies within FEARLUS, and also proposals for their use within CAVES as a whole. Two application domains of particular interest to CAVES are that of geospatial entities and relationships (Agarwal, 2005), and that of processes (Grüninger, 2004). The main geospatial applications are in relation to GIS. The representation of processes within ontologies has been explored in relation to domains including workflow management, Web services and manufacturing systems. More general process ontologies have also been attempted. Issues include sequence and repetition, causality, agency and the distinction between continuous processes and discrete events.

Further work focussed on ways in which ontologies, and related formalisms and procedures, can be used in support of agent-based simulation, and specifically in linking models and evidence more transparently (Gotts and Polhill, 2006b,a).

Extension of FEARLUS The prototype model for the Grampian case study (FEARLUS-0-8) enhanced the previous version of the FEARLUS agent-based model of land use change by updating the land market model and generalising the biophysical component of FEARLUS to incorporate the use of look-up tables. The land market model, in contrast to currently existing such components of agent-based land use change models, does not assume that farmers are profit-maximisers. The lookup tables were designed to be flexible enough to allow incorporation of any biophysical factors that are believed to influence farm decision making and/or yield in a symbolic form, and specified, for all combinations of land use/management decisions and influencing factors, the outcomes that affect farmers and policy-makers. This enabled FEARLUS to integrate with existing biophysical models

[10] `http://www.swarm.org`

where the latter are able to provide yield information for all combinations of situations in which crops might be grown.

The successor, FEARLUS-0-8-2, enabled more realistic representation of the environment, facilitating import of data from a GIS. The environment is divided into two layers: the cell layer, which stores data from the GIS; and the land parcel layer, which represents the division of the land into decision-making units. Agents are land managers who base their decisions on a balance of desire for profit and for their neighbours' approval. Figure 2.12 shows the basic cycle of events in the FEARLUS model, from selection of land uses via calculation of returns and possible subsequent land sales to the social interactions between the land managers, which result in approval/disapproval of their neighbours' actions.

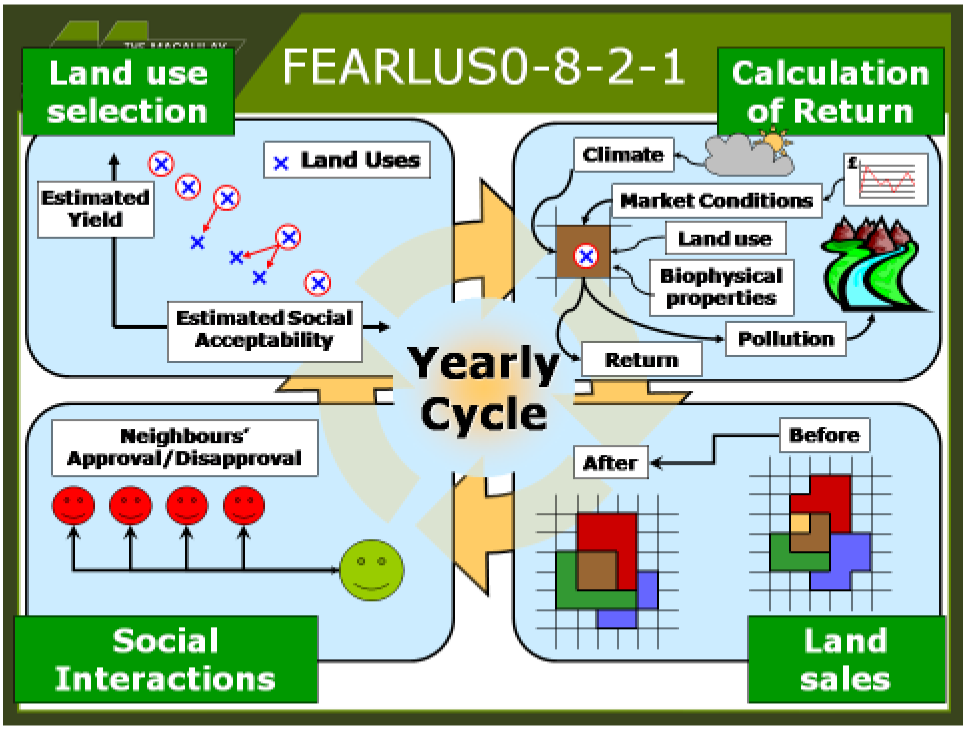

Figure 2.12.: Cycle of events in the FEARLUS model, which uses a yearly time step.

FEARLUS-1-0, a major re-design of the model, was founded on the use of ontologies:

- the domain ontology consists of a description of the realworld concepts;
- the framework ontology is intended to represent the concepts that are implemented by FEARLUS-1-0;
- a scenario ontology describes the concepts applying to a particular scenario or case study;
- the model ontology brings FEARLUS-1-0 and the scenario together, linking the evidence to the model through importing both the framework ontology and the scenario

ontology.

A small number of narrative scenarios was devised to act as starting points for the Grampian case study model, each telling a 'story' which would guide us in the selection of parameter sets and the assessment of model outputs. These scenarios comprised the recent past (1987-2003) and two extrapolations of the present, one concerned with future climate change and the other with a possible epidemic.

The final model for the Grampian case study (FEARLUS-1-14) featured the following additions to increase its realism:

- Use of lookup tables to calculate per-parcel yields from land uses, and the resulting gross economic return, in place of bitstring matching. These tables make it possible to specify climatic and local biophysical effects on yields, and the effects of economic factors on gross economic returns, in a far more realistic, flexible and comprehensible way.

- Use of an endogenous land market model (ELMM) involving sealed bid auctions in place of a mechanism by which all parcels had a fixed (and equal) price.

- Methods to implement economies of scale via a farm-scale fixed costs parameter, which can be made to vary over time, and parameters that reduce overheads in proportion to area of land assigned to a particular land use. Note that the approach taken can also be employed to represent the fact that different land uses have different costs even when both are applied to the same amount of land; and indeed this has been its primary use thus far.

- Provision for land managers to have off-farm income sources.

- Augmentation of Case Based Reasoning decision making agents with the possibility to use imitative and other experimentation strategies when aspiration thresholds are not met. The Case-Based Reasoning algorithm was further modified to bound the size of the Episodic Memory and to allow the exchange of Cases between Land Managers in an 'advice network'.

- Government policy classes to implement various ways in which a government might try to influence land use choice.

- Functionality to enable Managers to sell up and quit farming with a small probability (rather than just quitting through being bankrupt).

- Reports to generate output conforming to the CAVES generalisation framework document sent by the Polish team.

With the addition of the capabilities for requesting and giving advice, the FEARLUS model can include four kinds of interaction between neighbouring Land Managers: the ELMM land market, imitation of land uses employed by neighbours (this can be used as an alternative to CBR, and an individual Land Manager may use both in the same year), social approval and disapproval, and requesting and giving advice.

2.6.2. Results

Case study

Major findings of the field research Respondents were unanimous that farm size in the region is increasing, supporting this contention with evidence that their own farms had increased in size - often double the previous land base of 20 years before. Production of the primary commodities of the region - beef and sheep - have remained fairly constant in terms of total outputs, but as of 2004 were being produced by approximately 2/3 the number of farms, in comparison to 1987. While consistent with reports of increasing farm scale, this does not necessarily indicate increased intensity of production. Although this was certainly the case on some farms, other farms simply grew larger in land-base, apparently producing at similar or lower intensity, as overall production has not increased, nor has significant agricultural land gone out of production. Production of other commodities: field crops (barley, wheat, turnips, potatoes), dairy, pigs and poultry have all declined, supporting respondent statements that their farms were producing fewer commodities in general, and fewer arable crops in particular. Engagement in environmental programs is a new phenomenon in the study site, and most of the farmers had some degree of involvement. The extent of land involved in these programs is not yet recorded in census statistics. Labour on the farms has also reduced, with a 29% reduction in full-time occupiers and 26% reduction in staff. The number of part-time farmers has increased, however, as has the number of part-time spouses, suggesting that some farms have made the transition from primary to secondary employment for household members.

Analysis of census statistics demonstrated that the most notable change in land use in the region over the past 20 years was an increase in the area of woodlands: from 700 to 6000 ha. This is most likely due to a government program (the Native Pinewood Scheme) in the late 1980s. The increase in woodlands was mentioned by only one of the interviewees, himself a factor heavily involved in woodland development on his estate. This suggests that the forestry program did not impact strongly on farmers in the study site.

Decision making Analysis of farmer decision-making focussed in two areas: acquisition of new land (through purchase or tenancy) and change in commodity. In the case of land acquisition, the process primarily involves *opportunity*, rather than a formally reasoned business plan. Land is a limited resource, only available when another landholder decides to reduce his or her holdings. This occurs primarily upon the retirement or death of the existing holder, or if the holder goes out of business, and thus access to a specific plot may occur once in 10 - 90 years, depending on farm succession. However, farm land in a neighbourhood would come available on a much more frequent basis (owing to the number of land holders), as demonstrated by the expansion of most farms in the study over the past 20 years. Due to the physical limitations to transport of labour and equipment, land in close proximity to the existing holding is of high value for expansion, which is in turned believed by most farmers to be necessary for ongoing business success.

In terms of decision-making regarding commodity change, this typically occurs on a *'needs-must'* basis. Economic pressures, such as the high cost of inputs, labour scarcity and declining commodity prices, have driven most commodity changes. Farmers typically act incrementally at first, gradually increasing or decreasing stocking density or acreage of a field crop. In discontinuing a commodity, typically a breaking point is reached, following the gradual decrease, in which production is stopped completely. Examples of this breaking point range from the drop in beef prices following the BSE outbreak in 1996, to the steady decline of potato prices through out the 1960s and 1970s. In both cases, discontinuing the commodity was considered for several years before it was undertaken. Although farms have increased intensity of production, the only new 'commodity' in the area is engagement in environmental programs. Farmer respondents indicated that they entered these programs primarily to benefit from resultant subsidies.

Social networks In the study, four primary facets of network relationships were addressed: access to information, social norms, resource sharing and community engagement. Analysis of access to information revealed network structures that were complex and diverse, reflecting the specific commodities and business structures of the farmers involved. As most producers in the study site produced both commodities, there was considerable overlap in these information networks at a basic level. However, should a third 'commodity' - such as a diversification activity - be added, engagement in other networks reduced of necessity, given the time constraints of the farmer. Choice of information resources also reflects the personal preferences of the farmer.

Unlike information access, resource sharing was found to be highly localised in geographic terms, as most labour and equipment sharing occurred between immediate neighbours. These relationships are highly based on, and restricted by, trust.

Social norms proved difficult to adequately evaluate, as farmers were reluctant to admit that their decision-making was influenced by others' expectations, while key informants clearly believed this to be the case. From the study of farmers' networks, it is clear that a farmer's reference group is not always his immediate neighbours. Instead, farmers may draw social approval from members of a dispersed network, as in the case of breeding society or diversification network members, and therefore be less influenced by more locally held norms. Farmers also refer to positive examples for reference - the 'best' farms in the neighbourhood - rather than all farms equally.

Reputation was found to be important for labour and equipment sharing: farmers are in a position to physically observe the practices of their neighbours, and those believed to be rough with machinery were not trusted with others' equipment. Reputation was also a factor in access to rental land (although land sales went to the highest bidder). Land owners prefer to rent land to a 'safe pair of hands' (in terms of both land maintenance and apparent economic success), and used reputation as part of their land allocation decision.

Community engagement was also investigated, but not found to be particularly relevant to land-use decision-making.

Modelling

A FEARLUS 0-8-2-1 model was used with a variety of parameter settings to investigate the feasibility of combining collective rewards with social interactions in the control of diffuse agricultural pollution. The approach modelled involved mutual monitoring of the production of pollutants by neighbours, among a group of farmers offered a collective reward by a "Government Agent" if measured levels of the pollution they produce between them are satisfactory.

FEARLUS agents representing farmers ("Land Managers") had preferences which cannot be reduced to a single measure of "utility". The Land Manager agents in the simulations in which the Government Agent pays a reward if total pollution is below a threshold face a form of social dilemma, if they are considered as profit maximisers: each individually will generally be better off if they adopt the land uses with high pollution intensity, as these also have high mean profitability; but if all (or enough) do this, the reward will not be paid. There is abundant empirical evidence that people often act more cooperatively than if they were rational profit maximisers in such situations; and that this is more likely to occur if there is or has been social contact between those involved.

The parameter settings used in different runs allowed us to examine the consequences (in terms of pollution levels and other effects) of providing a collective reward of various sizes and subject to different allowable pollution thresholds (or no such reward), in combination with a range of assumptions about how farmers might react to their neighbours' production of pollution (including a condition where they did not react to it at all). Figure 2.13 shows the change in land uses over time for four different scenarios. *NoSAF* stands for "No Social Approval Function", i.e. neighbours neither approved nor disapproved of each other; *Dis-D* is one of the Social Approval Functions used (the others had similar effects). The top two subfigures show output from runs with no collective reward, the bottom two from runs with a pollution threshold of 2000 (pollution) units and a reward of 50 (monetary) units per parcel managed. The left two subfigures show output from runs without social (dis)approval interactions, the right two subfigures from runs with such interaction.

Work with FEARLUS models from version 1-0-1 onwards has focused on developing a "semi-realistic" model of land use and greenhouse gas production in the Upper Deeside area of the Grampian region from 1980-2005. By "semi-realistic" we mean that the land uses (or more precisely land management strategies) employed are similar to those employed in Upper Deeside, the yields and net economic returns from those strategies under a range of conditions are at least qualitatively plausible, and the physical environment used is (for some model runs) based on maps taken from the UK Agricultural Census. It was considered that ensuring that such a semi-realistic model gives plausible outputs is a necessary stage in adapting an originally abstract land use model for use in a specific geographical and socio-economic context.

Available quantitative information on the changes in land use in Grampian region has been used for input calibration and macro-validation of the model as applied to the past. Since the actual course of events must be considered nondeterministic, no single run of the model could be expected to reproduce the actual course of events precisely; besides which, the quantitative data available on both inputs (climatic, land suitability and price data, and data on the effects of climate and land suitability on yields) and outputs (land use and farm size data) is limited, and in some case affected by confidentiality restrictions. Therefore we assessed whether the model is able to reproduce the direction and magnitudes of the trends found in the data concerning land use and farm size, given the best available data relevant to model inputs. Future work on modelling Upper Deeside within FEARLUS will be funded by the Scottish Government.

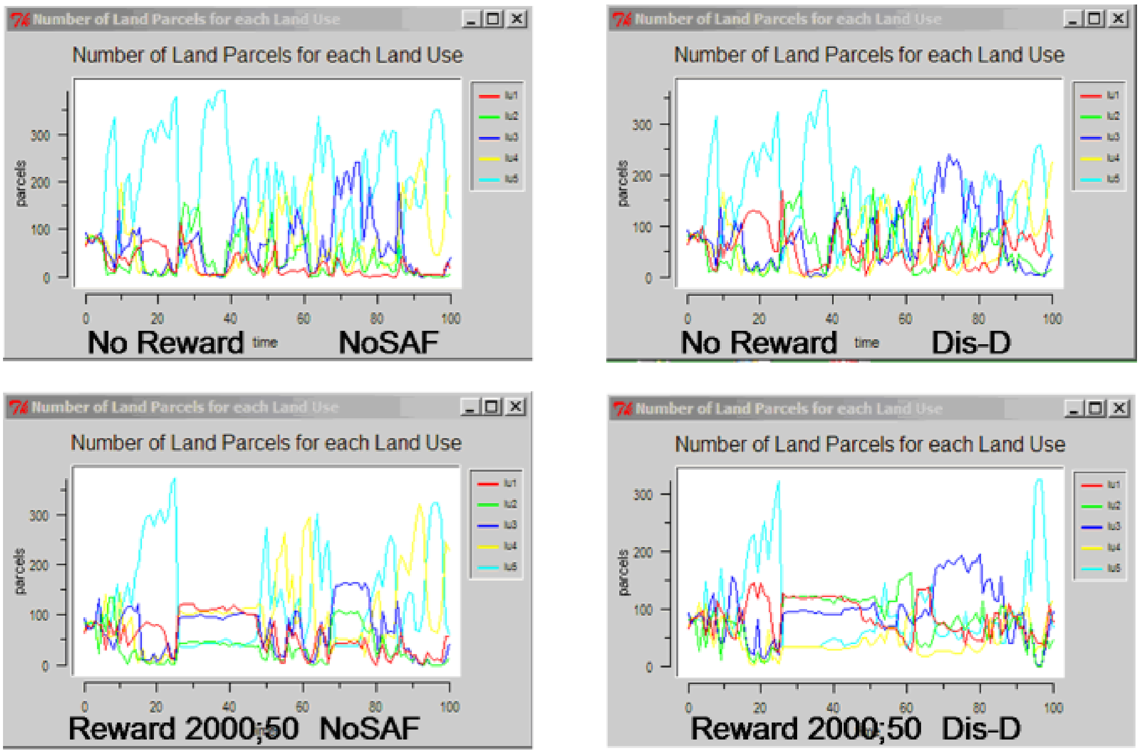

Figure 2.13.: Change in land uses over time in four example runs of FEARLUS 0-8-2-1 model.

Validation

The Grampian model is based on the TAPAS (Take a Previous Model and Add Something) approach to model design. The FEARLUS modelling framework was in development for several years prior to the CAVES project, with the structure informed largely by literature review. What the Grampian field research has brought to the FEARLUS model is data specifically derived for use in the model. Due to the focus of CAVES on complexity and social networks, these are the areas in which the model has most advanced. For the purposes of the validation component of the CAVES project, a questionnaire was derived from model components and assumptions. These include the comprehensiveness and relative importance of factors in land use change, principles of land use change, and the decision-making process.

Validated model components:

- the decision rule that farmers do not change their current crop or type of stock when their aspiration threshold has been reached, even if there are higher prices in a different commodity.
- the general principle of innovation by a small number of innovative farmers, copied by other farms

- in ordering the factors which farmers take into consideration when changing commodity, the profitability of the new commodity is of primary importance
- land is differentially desirable, on the basis of previous (and therefore anticipated) profitability.
- In historical runs, farmers will always bid on neighbouring land, if they have sufficient resources. This is less likely to be true in future-based runs.
- Farmer types: entrepreneurial, traditional, pluriactive, lifestyle/hobby/environmental
- Fixed costs associated with commodities.

The validation process has generated broad support for the accuracy of the field research, while raising issues for further exploration following the completion of the CAVES project. Respondents did not identify any major problems with the model inputs and process, and confirmed several aspects which were intended for addition to the model.

2.7. Wrocław University (UWR)

The partners from UWR have been the case study team for the Odra case study. Main team members were Andrzej Dunajski, Karolina Krolikowska and Maciej Sieczka.

2.7.1. Work performed

Case study

The Odra case study addressed the issues of land and water use and collective action with reference to land reclamation system (LRS) maintenance in the middle Odra Valley in Poland (see map in figure 2.14). The Odra land reclamation system consists of a network of drainage pipes, ditches and canals, sluice gates and fish ponds that drain land, particularly during the early spring thaw, in order to facilitate crop production. The better-maintained canals and sluice gates also serve as an irrigation resource. The primary purpose of the fish ponds is fish farming, however, under the national water law they are viewed as a component of the LRS and serve a key role in the drainage system.

Responsibility for LRS maintenance has been transferred from government to individual land users. Prior to 1989, obligatory, top-down Water Partnerships (WPs) were responsible for LRS maintenance. Subsequent efforts to transform WPs into "bottom up" institutions have failed. Farmers neither want to pay for WPs not take private responsibility for LRS maintenance. At the same time farmers complain that the LRS is declining and perceive this fact as a real problem.

Land reclamation in the Odra valley thus contains important environmental and socio-economic dimensions and provides insight into the role of social networks (collective action of neighbours along canals) in land-use (functioning of land reclamation affects the yields).

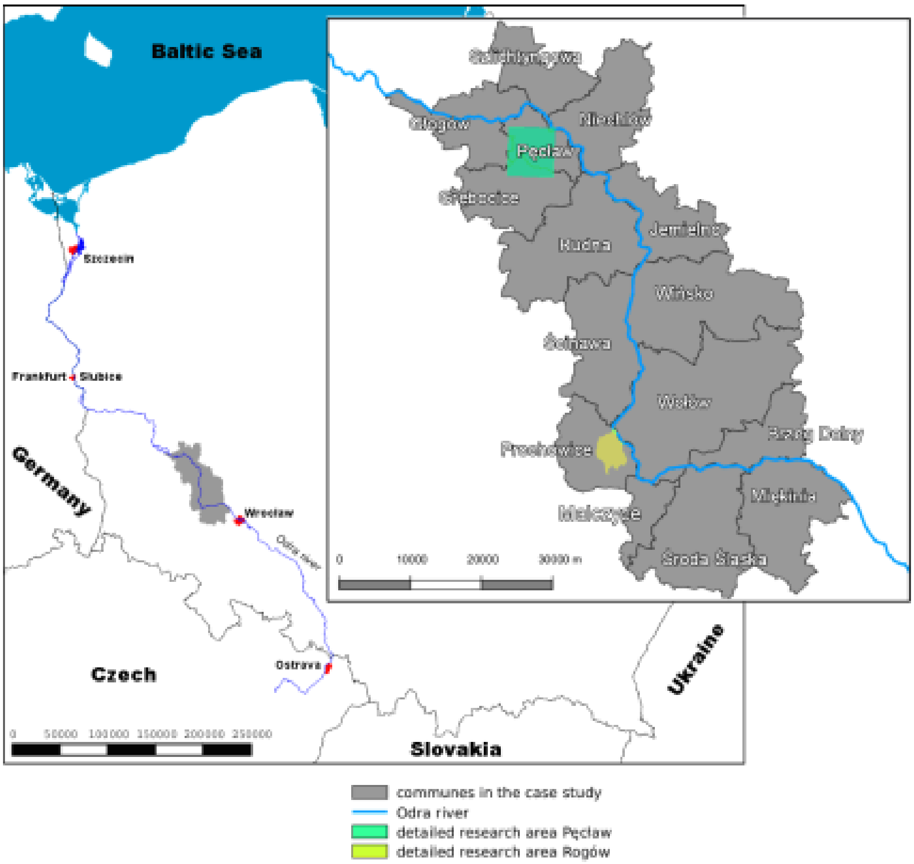

Figure 2.14.: The Odra case study region, indicating the location of the areas chosen for detailed research.

Knowledge elicitation Stakeholder participation allowed the Odra case study to achieve the level of policy relevance required by CAVES. Workshops with local communities and stakeholders were used to inform the research and modelling tasks. In other words, the choice of the modelling subject resulted exactly from the workshops' findings with regard to the most important problems in the study area.

At the beginning of the project, workshops were held in Zaborow and Kwiatkowice villages in order to elicit knowledge on local problems. Attendants were asked to write down three main problems of the region. The results showed flood risk and LRS maintenance to be the chief concerns. In addition, key experts in the fields of land use, water management and social welfare were consulted in a workshop held in Wroclaw in order to elicit knowledge on main regional development determinants and to discuss problems pointed out by local communities.

These workshops were augmented by fieldtrips, expert meetings and key informant interviews which were used to verify workshop data and deepen the research teams' understanding of the domain. This understanding has been applied in:

- the selection of Rogow Legnicki village as a representative area for detailed research, GIS inventory and biophysical model development;

- drawing-up of a semi-structured interview questionnaire aimed at eliciting decision rules regarding both land use and land reclamation maintenance and understanding the role of social networks in the formation of these decision rules;

- and finally, the design of the agent-based models.

The farming household was used as the sampling unit of this research and was attributed as interview "respondent". Every household was given a number (*owner_code*) in the GIS data base and every interview was marked with the corresponding number. This enabled the researchers to relate interview results (and storylines) to landownership/land use maps.

After the first phase of research in Rogow Legnicki the interview questionnaire was modified. Modified interviews were performed in two additional villages, Kawice and Kwiatkowice, both in the nearest surrounding of Rogow Legnicki. The third and final wave of interviews was performed in the Peclaw area, where LRS is maintained properly, thus providing a reference for comparisons with the Rogow L. area.

Spatial data for the biophysical model Following GIS data were created for the detailed biophysical model:

1. Digital elevation model (DEM). A raster DEM of cell size 10m was created in the open-source geographical information system GRASS (Neteler and Mitasova, 2007) by means of natural neighbour interpolation from TIN (triangulated irregular network) data provided by Lower Silesia WODGiK (Voivodship Department of Geodesy and Cartography). In order to extend GRASS to include natural neighbour interpolation a script was developed, which is published under GPL v2 license on the GRASS GIS AddOns website[11].

2. Land parcels of Rogow Legnicki. Parcels were digitized from a 1:5000 map into a GRASS vector map, and connected with a database of land ownership, land use and soil quality. The data were obtained from Prochowice Commune and Legnica District authorities.

3. Watercourses. Watercourses were digitised from a 1:5000 map and supplemented with watercourses digitised from a 1:10 000 map, to provide a complete coverage for the whole biophysical model area. Each watercourse was divided into segments, one segment per DEM cell, and a minimum elevation for each segment was calculated, so that a water flow down the watercourse is enforced. To automate the drainage enforcement, another GRASS script was developed and published under GPL v2 license on the GRASS GIS AddOns website[12].

[11] http://grass.osgeo.org/wiki/GRASS_AddOns#r.surf.nnbathy

[12] http://grass.gdf-hannover.de/wiki/GRASS_AddOns#v.breach

2.7.2. Results

Case study

From the qualitative interviews and additional surveys the case study team was able to derive data about social networks in the area, establish different types of farmers (agents) and determine decision rules governing their behaviour.

Farmer types Agent types were designed based on elicited knowledge gained in the form of storylines derived from interview transcripts. They differentiate between big farmers, for whom farming is the main source of income, and part-time farmers, who usually inherited some land and use it to produce crops for their own use, if they produce any crops at all. These basic types can be further divided with regard to their attitude towards and influence of the LRS maintenance, resulting in the following agent types:

- Unwilling part-time farmer (UPTF)
- Willing part-time farmer (WPTF)
- Big farmer without fish pond (BFNP)
- Fish pond owner (FPO)

A fifth agent type, the Water Partnership Initiator (WPI) was included to allow for the forming of water partnerships, i.e. co-ordination of LRS maintenance. These are usually people from local authorities. But any person, who is socially skilled and rather well known as well as respected in the local community could start a WP if he/she finds at least three persons interested.

Table 2.1 gives an overview of all agent types and their properties. A + denotes a property required of an agent type, a − denotes a property that has to be absent in a particular agent type.

Decision rules Decision rules for farmers were abstracted based on storylines derived from the semi-structured interviews. LRS maintenance is regarded with respect to social influence and economic factors. The basic reason for maintaining LRS is of economic nature and relates to losses in crops in case of flooding or drought. The majority of farmers are aware of the relation between the state of LRS and yields, although it is not easy to calculate it very precisely. Apart from economic factors, farmers can also be convinced by experts to adhere to good practice, including LRS maintenance. When asked about sources of advice and information in interviews farmers usually mention professional advisors from Advisory Centres. Thus we can assume that socially active experts, including WP Initiators, can be a serious source of social influence. If a farmer's strategy is to maintain ditches, there are two options: the farmer can either do it on his/her own or participate in a Water Partnership. Most of the interviewed farmers admit they would enter a WP if it existed and worked properly. In case a WP does not exist, some farmers maintain the LRS on their own, some do not. From interviews we know that most big farmers maintain LRS no matter what.

Table 2.2 gives examples of decision rules derived from storylines.

Agent property	Property values	UPTF	WPTF	BFNP	FPO	WPI
Land ownership	big farm			+		
	small farm	+	+			
	no farmland	−	−	−		
Fish farming	yes				+	
	no	+	+	+		
Activity related to LRS maintenance	Take leadership					+
	Member of or willing to join WP		+	+	+	+
	Not member of WP but cleaning ditches	−	−	+	+	
	Do nothing but willing		+	−	−	
	Do nothing and unwilling	+		−	−	
Agricultural knowledge	high			+		+
	middle		+			
	low	+				
Social network integration	high					+
	low					

Table 2.1.: Agent types and their properties in the Odra case study.

Storyline	*Rule*
In case of flooding the losses are up to 40% usually and 80% if ditches are plugged. He cleans ditches himself and has them clear to protect his crops. He doesn't care about LR since he has no problems with floodings.	IF bigLosses THEN consider myLRSStrategy == MAINTAIN
He never had something in common with a WP no one has called him up to a WP.	IF askedByWPInitiator THEN consider myLRSStrategy == MAINTAIN
He manually cleans ditches from branches and he deepens the canal every few years with a mechanical digger. He does it all on his own despite the strong conviction that it should be done by the State.	IF myLRSStrategy == MAINTAIN AND noWPExists THEN cleanDitches
WP was liquidated 5 years ago. He always participated in WP and its meetings. WP wanted everybody to pay dues so he paid them. But only few farmers in the village think in this way. He tries to maintain it, as far as he can, but he misses specialist equipment and time. Formerly he belonged to WP because it was a duty, but he would participate even if it wasn't obligatory.	IF (exists(WP) AND (myLRSStrategy == MAINTAIN)) THEN beMemberOfWP
He would share in a WP if he was sure that local officials and other farmers support him.	IF (otherLRSStrategy == myLRSStrategy) THEN supportOther

Table 2.2.: From interview storylines to decision rules

Social networks From the empirical data of the village of Rogow Legnicki two types of networks were constructed: a family network and a neighbourhood network.

In order to construct a complete neighbourhood network, a field trip to Rogow Legnicki was undertaken to draw a map of the village indicating the location and number of all houses. From this, direct neighbours of every agent (household) were identified. With the help of a database linking name and address to unique agent ID it was easy to convert house numbers to agents' identifiers. A different type of neighbourhood network could also be defined through neighbouring land parcels. Data on this kind may be easily derived from the landownership map.

The family network could only be partially constructed. Part of the necessary information came from a land ownership registry provided by the local authorities. This document lists the names of every landowner's parents. In some cases this made it possible to deduce the exact nature of the relationship (parents, sister etc.). In other cases this was not possible and only common family names and/or addresses indicated that some kind of family relationship exists. In a few cases information about family relationships came from field research, however not directly from interviews. Instead, the information was revealed during informal conversations of our interviewers with the local people, which seems to be a more efficient method of eliciting this kind of information than direct questions about these issues in the questionnaire.

Validation

Three levels of stakeholder/data validation were identified for the Odra case study:

1. Validation of survey results. This was conducted following approved scientific standards aimed at establishing the reproducibility of the results. Another task involved ascertaining the credibility of the interviewed farmers by comparing their statements with the point of view of experts. This was necessary so as not to be biased by the attitudes of one group of stakeholders, even if their decisions were basis for the agent design.

2. Validation of behaviour rules, to check whether the translation of knowledge from natural language to formal model specification was correct. This has been achieved by discussing rules with key domain experts and by a separate role-playing exercise (see below).

3. Validation of model outputs by comparing them either to respective data from the real system or having domain experts assess the plausibility of the model-generated data.

Role-playing game as a tool for validation The AgroGame (cf. section 2.4.1) was developed in cooperation with the partners from WUT to meet the requirements of both a model validation exercise and a sociological experiment. It was used to validate the agent-based model developed by the Kassel team (section 2.3) in that the behaviour of real farmers (players in the game) could be compared with the modelled behaviour of the agents in the model. Two variables were used to measure the players' performance: wealth and reputation. Reputation is measured in special "reputation points". Players can (dis)approve of other players due to their (not) maintaining the LRS. Approval by another player earns one reputation point while disapproval loses a point. The more points a player has, the higher their reputation. At the end of the game, players are presented with game results consisting of the values of wealth and reputation for all players. The values of wealth and reputation are treated as equally important and it is up to the player to decide which variable is more significant to them.

The gaming exercise was performed three times in three different villages with invited farmers. Every player was accompanied by two students, who made observations of the process and carried out interviews with players during and after the games. This process was also documented in a video.

3. Methodologies

Of the five words in the project title (complexity, agents, volatility, evidence and scale), the most important methodological driver was intended and turned out to be *evidence*. In all three applications, each combining the development of verbal case studies and formal models based on those case studies, the models were constrained by the verbal as well as quantitative evidence.

Two of the models (those for South Africa and for Poland) were implemented with declarative, rule based agents representing individuals in the relevant communities. The third (for Scotland) was implemented with procedurally designed agents. There are three relevant differences between these types of implementations:

1. Procedural implementations effectively embody algorithms specifying the steps to be taken and the order in which they are to be taken in any set of conditions whilst declarative, rule based implementations comprise if-then rules such that when any rule fires it changes the state of the system and, usually, the set of rules that could fire. Consequently, the order in which rules fire emerges at runtime so that any sequence of actions implied by the rules also emerges at runtime. In effect, social simulation models that have declaratively implemented agents produce the social processes they simulate whilst procedurally implemented agents "select" a previously defined process at runtime.

2. In many declarative implementations, there can be rules (called meta-rules) that write rules (called object rules). there can also be meta-meta-rules that write meta-rules, and so on. Consequently, it is possible for agents to use meta-rules to define sequences of actions that were not programmed into them. It is not possible for procedural agents to define action sequences at runtime.

3. Declarative rules are logic-like constructs using symbols that can be devised for mnemonic charactersistics and specifically to couch the rules in the terminology of stakeholders. Such rules can be presented more effectively to stakeholders for them to confirm that the rules correspond to narrative descriptions of individual and social behaviour.

In practice, neither of the models with declaratively specified agents entailed meta-rules. However, both allowed social processes to emerge from social behaviour and influence networks. The agents who would influence one another were determined at runtime by virtue of their characteristics in a manner based on empirically well validated propositions from social psychology. Moreover, the rules and narratives produced by the rules were presented domain experts for confirmation (or disconfirmation) of their plausibility.

A principle of the project was that models should be validated qualitatively at micro level and by some statistical means at macro level. The micro level validation amounted to confirmation by stakeholders and domain experts without direct engagement with model development that events emerging during simulation runs as described by narrative traces were plausible. At macro level, two type of statistical evidence were investigated. One was concerned with network topology. The concern here was that the influence networks that emerged and evolved through the course of simulation runs were those we would expect from widespread studies in the social network literature. A range of statistical signatures were considered. A particular point of interest was whether small world networks emerged and how they evolved. In the studies and models of both the Odra River Valley in Poland and the village of Ga-Selala in South Africa, small world networks did emerge. In the particular case of Ga-Selala, small world friendship networks tended to disintegrate when agents "died" from HIV/AIDS related illnesses.

Micro level validation was the focus of some discussion and differences of views within the project team. The essential difference turned on whether the presentation of narrative simulation outputs to stakeholders should be structured within a protocol or, alternatively, validation by stakeholders should take the form of presentations and discussions without such protocols.

4. Achievements (State of the Art)

All of the objectives of the project were met.

4.1. Evidence

The evidence sought and obtained for constraining the model designs and validating model outputs falls into three main categories: evidence about the relevant areas of behaviour of individuals, evidence about the structure of social networks and contextual evidence such as land use patterns and life tables (incidence of death categorised by age).

4.1.1. Social networks

The clearest evidence of social networks in the project was produced by our colleagues in Wrocław. A network of social acquaintances developed from interviews with 74 families is depicted in Figure 4.1 in which the nodes represent families and the links represent acquaintanceships. The obvious clustering conforms to that of the small-world networks that have been of interest to complexity scientists. That is, within each cluster, links form triangles indicating the two acquaintances of one family are themselves acquainted with one another. Links between clusters are more sparse. In Figure 4.1, for example, the families depicted by nodes 3 and 31 are acquainted but have no other shared acquaintances. However, there are clear clusters involving each of those nodes in which all acquaintanceships are triangular. This is a part of the definition of the small world network. The other criterion for a network to have a small world topology is that the longest paths between any pairs of nodes should be short and that the network should be complete in the sense that there is a path from each node to every other node. The network depicted in Figure 4.1 is obviously not complete since there are isolated clusters among the families. It is also not obvious that the longest paths are as short as we would expect in a complete random network. However, the network produced here is based on a limited sample of data and refers only to acquaintanceships amongst the sampled families. There will be other links to families not included in the available data so that we cannot say whether the isolated clusters in Figure 4.1 have links to unsampled, clustered families that would in turn be linked back directly or indirectly to other clustered or sampled families. In general, all we can say here is that the network of sampled families meets one of the necessary conditions for a small world network. The limitation here is the size of the sample which in turn is due to the cost of surveying families in the semi-structured way required to elicit information about acquaintanceship links and the ability each node in the network has to influence the behaviour of other nodes.

None of the evidence on social relationships obtained for any of the three case studies is inconsistent with the small world network topology. This is, of course, an extremely

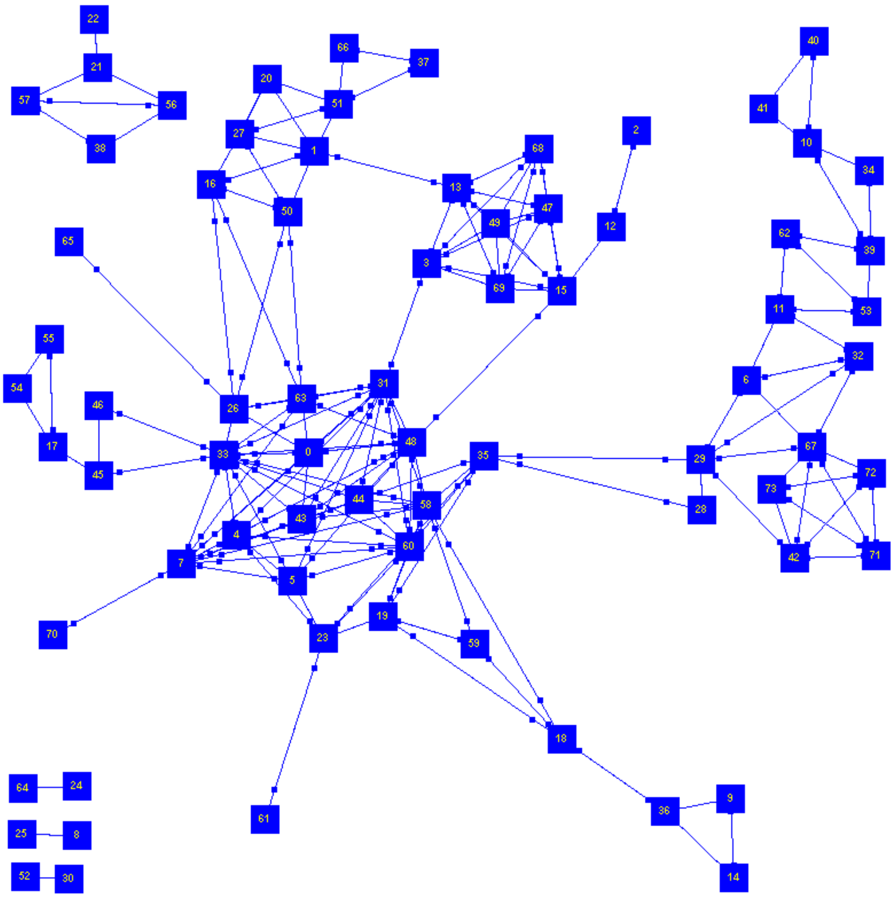

Figure 4.1.: Social acquaintances network in Odra River Valley

weak statement. It is strengthened by the results obtained from several of the models as reported in section 4.2.

4.1.2. Behaviour and social interaction

The surveys and interviews undertaken in all three case study areas provided ample evidence for realistic modelling of behaviour.

For the Ga-Selala model, we were fortunate in obtaining longitudinal survey data of financial and sexual practices in rural South Africa from a longstanding project covering microfinance, HIV/AIDS and gender abuse (RADAR, 2005). This evidence was validated specifically for Ga-Selala by interviews and role play games conducted during field trips to the village by members of the SEI team accompanied on one trip by members of the MMU team. Our colleagues from Wrocław produced interview and survey data and used role playing games related to land reclamation systems in the Odra River Valley. The Macaulay team conducted semi-structured interviews across the Upper Deeside district of the Grampian Region.

The Polish case study (with input provided by the Wrocław Institute of Technology and Wrocław University) focuses on those parts of the Odra river region that are at risk of regular flooding due to neglected or damaged dikes and the lack of maintenance of an old land reclamation system and also more generally on land use in the Odra river region. Social mobilisation or collective action by the individual farmers is required to maintain or re-establish the system of channels, ditches and dikes of the land reclamation system. Between the farmers, acquaintance or friendship links exist. When looking for collaborators to accomplish a maintenance related task however, the friendship network may serve as a starting point to build up a collaborator network, but the friendship network may not suffice to get all needed expertises together. By word of mouth, additional persons in the collaborator network (i.e. collaborators of collaborators) with the necessary expertise are sought, until the task can be solved. Such existing networks tend to be used again and again, thus leading to cliques of collaborators with complementary expertises.

The Ga-Selala model

The interviews and role play conducted in Ga-Selala provided the modelling team with evidence concerning participants' friends and the reasons they chose their closest friends, to whom they would lend food, from whom they would seek to borrow food in times of distress, their attitudes to health issues, the reasons for their choices of sexual partners, the criteria, to whom they would choose to give piece work, and similar issues. One finding was that the villagers in Ga-Selala did not distinguish between friends and acquaintances and there were not different words for the two in the local language. Consequently, they were asked in interviews who were the four to six people they with whom most enjoyed spending time and why they enjoyed spending time with them.

The Odra Valley model

Farming in the Odra River Valley has historically entailed a Land Reclamation System (LRS) consisting of channels – canals and ditches – that drain the soil directly or through a system of drainage pipes. The LRS protects each field against flooding. The LRS maintenance process mainly involves the periodic cleaning of canals and ditches, e.g. by removing vegetation and sediments from the channels' beds.

In principle, if viewed independently from other channel sections, the maintenance of the local section of the LRS serves to alleviate or even eliminate the negative effects of extreme weather conditions, especially excess water stress in the case of flooding, whereas neglecting LRS maintenance only increases these effects even more.

However, LRS maintenance must be regarded as a collective task that requires social mobilisation of the participants, i.e. the farmers whose land parcels are located along a ditch or a communicating ditch system. This is because the difficulties concerning land and water use in the Odra case study region result mainly from the fact that the conditions encountered on individual land parcels depend highly on the amount of LRS maintenance performed on other (connected) land parcels. In wet periods, for example, LRS neglect leads to a loss of yield on neighbouring land parcels upstream since the runoff of excess water is blocked, whereas LRS maintenance has the opposite, beneficial effect since it facilitates runoff. The latter effect arises even if the upstream neighbours do not themselves maintain their section of the LRS (free riding).

Maintenance of the land reclamation system thus enables farmers to overcome environmental shocks like flooding with only reduced yields or even with no losses at all, but it requires a collective effort. The asymmetrical dependency provides incentives for such problematic types of behaviour as free riding. It is expected that this hinders and in some cases prohibits the installation of a functioning LRS.

When farmers are asked about their motivations concerning LRS maintenance, they state that they would either maintain the LRS if they had sufficient economic resources or if there was enough social support for LRS maintenance. The economic dimension of LRS maintenance is mainly determined by the achieved stability in attained crop yields over years with climatic extremes (flooding/drought) but it also includes factors like buying the required equipment or paying others to do the work. Social support towards LRS maintenance may e.g. originate from observing other farmers maintain their local LRS facilities properly and gaining protection against environmental fluctuations and shocks. A second source of social influence originates from actors actively trying to initiate a working LRS. Usually, these initiators are people from local authorities. In addition, farmers can also be convinced by other persons, who are socially skilled and rather well known (high social network integration) as well as respected in the local community. For instance, farmers mention professional advisors forming Advisory Centres. As an abstraction we regard all these types of leader personalities as 'LRS initiators' in that they influence farmers in their decision to maintain the LRS and to participate in the collective action. Accordingly, LRS initiators form the second actor type that is represented in the social model.

The Grampian model

The models are based on findings from qualitative interviews with 51 agricultural land users in the Upper Deeside of the Grampian region, such as farmers and estate managers, as well as other agricultural industry members. These interviews focussed on the patterns and causes of land use change, and the role of land managers' social networks in these processes.

Through the respondent interviews, it became clear that two primary types of decision-making occur: response to opportunity, and 'needs must' (in response to shock or stress). In the case of land acquisition, the decision-making process primarily involves opportunity, rather than a formally reasoned business plan. The other decision-making process discovered in the field research can best be described as 'needs must'. This is more commonly associated with decisions to change commodity, or to sell land. Economic 'stresses', such as the high cost of inputs, labour scarcity and declining commodity prices, have resulted in circumstances under which farmers feel driven to make a change.

The concepts of system 'shocks' and 'stresses' are highly important to the CAVES case study, where it is hypothesised that long term social networks contribute to the relatively stable land-use system currently in place in the region. From the survey it became clear that change is also limited by the options perceived by farmers. Both responses to opportunities and 'needs must' occur within restrictive parameters. Farmers access opportunities within the constraints of their land suitability, current farming set-up (e.g. infrastructure, asset base and debt load), market trends, subsidy structure and other government programs.

Social networks were conceptualised utilising Bourdieu's concept of 'social capital', defined as "a durable network of more or less institutionalised relationships of mutual acquaintance and recognition – or in other words, to membership in a group" (Bourdieu, 1983). Opportunities for formal group membership include the National Farmers' Union, the Tennant Farmers Association, Grampian Farm and Wildlife Advisory Service, farm building societies, local agricultural show committees, and commodity production groups. Most farmers are members of at least one group. There are also numerous opportunities to participate in agricultural events, which do not require formal group membership: these include local and regional agricultural shows and events, farm walks and open days, agricultural auctions and judging competitions. Farmers also access information informally through travelling salespeople, who often provide information on practices on other local farms, at non-agricultural events, such as family gatherings and recreational activities, and via sources, which are not dependent on social or cultural capital (e.g. farming newspapers, government publications, paid business advisors).

While the farmers' sources of information for innovation are not limited to their neighbours, resource sharing typically occurs between close neighbours. Most farm machinery represents a high capital investment: loaning it to a neighbour creates a risk of breakage, both to the equipment, and the social connection. Farmers thought to be careless were not loaned machinery, unless a machinery operator was loaned with it. Social approval of equipment care is separate (but usually linked to) social approval of labour. Disapproval removes the opportunity to share resources. Definitions of 'good' farming vary between farmers, and so will resultant measures of social approval. Community engagement was also investigated, but not found to be particularly relevant to land-use decision-making.

4.2. Models

Agent based social models linked to biogeophysical models were developed to investigate why some external shocks to complex social networks are followed by volatile episodes and some are not. The models were based on and constrained by qualitative and statistical evidence.

4.2.1. The Ga-Selala models

Two detailed evidence-based models were developed to capture the social processes and policy issues affecting the village of Ga-Selala. One implemented agents as declarative, rule-based entities and the other implemented the agents procedurally as algorithms containing specified sequences of *if-then* statements. The advantage of the declaratively implemented agents is that the rules are couched in tokens corresponding to the terminology of the stakeholders and domain experts from academic institutions and from NGOs. The modelling process is more flexible than procedural modelling since adding rules requires the inference engine to determine the order in which the rules fire while procedural modelling effectively requires the new ordering consequent upon the addition of *if-then* statements to be undertaken by hand. Experience shows that coding mistakes are much more likely in the latter case. However, declarative programming methods are much more expensive than procedural methods in both time and memory. Consequently, the declarative version of the model could be run with many fewer agents and generally over fewer time steps than the procedural version. Insofar as it was possible, the data on which rules could fire was set procedurally directly from Java rather than declaratively by the rules themselves. This approach improved speed and memory efficiency but the declarative model was never even a close match for the procedural model in this regard.

Both of the Ga-Selala models were implemented in Java using the RePast agent modelling libraries (North and Collier, 2006). The declarative rulebased shell Jess (Friedman Hill, 2003) was used to model the agents. The procedural elements of the two models had much in common including the initialisation of household sizes and compositions, the incorporation of life tables and incidences of HIV/AIDS. Some of the key differences between the declarative and procedural agent representations were in terms of the determination of behaviour and the availability of mnemonically meaningful output traces. The declarative representation relied on an endorsements mechanism (Moss, 1998; Werth et al., 2007) in which tokens representing considerations of importance to stakeholders and their agent representations are partially ordered and then used to make choices. The the declarative Ga-Selala model, for example, one agent would value other agents more highly if they were kin, shared activities, had similar interests (in, for example, religion), attended the same church, had gone to school together, and so on. These attributes were defined on the basis of interviews with Ga-Selala villagers. In the absense of evidence about the ordering of importance of these characteristics, they can be set at random or, as Werth et al. (2007) point out, the ordering may be more appropriately determined from interview and similar evidence. The best means of ordering endorsements is an unresolved issue but will doubtless turn out to be some combination of evidence and randomness that allows for different agents (and different people) to rank importance differently but still within limits set by social norms. In the declarative model, there were rules for attaching endorsements such as reliability and shared interests to other agents, but such static endorsements as kinship were set procedurally.

The procedural model captured behaviour in less detail and perhaps less mnemonically than the declarative model, but it did incorporate a more detailed epidemiological model that supported the capture of the effects of a mining development policy in the district. This policy, designed and favoured by the local governmental authority, the Greater Tubatse Municipality, had the objective of developing mining operations to exploit substantial reserves of platinum. The problem was to explore the effects of this policy which would required migration to the region of skilled and experienced mine workers from other parts of South Africa and from neighbouring Mozambique. A key problem is that the prevalence of HIV/AIDS amongst these skilled mine workers is significantly higher than is believed to be the case amongst the population of Ga-Selala. The procedural model offered a more detailed explanation of the process of spreading infection but both models were used to explore consequences of increases in the incidence of HIV/AIDS infection and how it might result from the mining development policy. The results in relation to the evolution of social support networks are explored in section 4.3 The declarative model also produced traces that supported the production of narrative stories about individuals and households. These are considered in some detail in chapter 3.

4.2.2. SoNARe: The Odra River Valley model

The Odra River Valley model, SoNARe (Social Networks of Agents' Reclamation of land), captures core properties and processes of both the environment and the agents in the Odra scenario on an abstract level, but it is currently limited to the agents' upstream dependencies.

The SoNARe model, like the Ga-Selala declarative model, was implemented in RePast and Jess. Because of their different objectives, there were some differences in implementation strategies. In particular, the Ga-Selala model had as an objective of enquiry the effects on social support networks of HIV/AIDS. The social support and friendship networks were not distinguished because the evidence did not indicate any such differences in reality. Also, the Ga-Selala model covered long periods of time relative to individuals' lifetimes because mortality was an important feature of the policy problem. The SoNARe model did not take population change into account since that was not relevant to the Odra policy problem. Moreover, it took the friendship network as a resource for establishing collaborations – an assumption that was indicated by the case study evidence.

The implementation of the model was based on a strict distinction between the physical and the social environment of the agents. This distinction focuses on a separation between physical and social spaces both in terms of semantics and techniques used for their representation. For various reasons, the simulation of the agent's physical environment uses a traditional grid based approach. The social "location" of an agent is given by his position within a social network context, where an agent is viewed as a node and social relations are represented by edges. Since agents are considered here in more than one social context an agent's social environment generally consists of more than one network layer. The modelled agents' perceptions vary in relation to their physical or social environments.

Both perceptions are locally bounded in terms of a perceivable section of the surrounding physical space and in terms of network edges and neighbouring nodes (cf. Pujol et al., 2005). In the same way, the agents' repertoire of actions differs relating to their respective environment. In the model, the focus is on the development of the social networks and the actions related to the natural or physical environment have been reduced to abstract tasks. The agents' social environment is modelled as layers of networks. An agent may be seen as a node in different social network contexts. Technically, an agent has slots that are nodes representing potential or actual social roles in different networks, so the networks actually reside in the agents' memories. Unlike in other network modelling approaches, agents actively perceive their social environments and are able to act in their social networks. Each agent in the model has two semantically different nodes: one in an friendship or acquaintances network and one in an advisor or collaborator network.

The friendship network was initialised with an assumed small-world topology. A collaborator network does not exist initially. Once a task is assigned to an agent, it polls its social friendship network for expertise needed to accomplish the specific task additionally to its own. The search is started in the direct social neighbourhood of the agent. If the collected expertise provided by the network neighbour has been successfully applied, the agent forms an edge to the respective node in the collaborator network. Next time the agent would first poll the collaborator context when looking for collaborators. If the agent cannot find all the necessary expertise in the directly neighbouring links of the collaborator network it will pursue the search in the neighbourhood of collaborators, i.e. collaborators of collaborators to find additional expertises.

For the purpose of ensuring that the SoNARe model is as realistic as possible, including the incorporation of the social complexity inherent in the case study region, the results of interviews with farmers were compiled into a set of characteristic behavioural rules. This was done in cooperation with the work group in Wroclaw. The group in Wroclaw has also developed a biophysical model of the Odra region which realistically captures the local land and water conditions as well as their dynamics.

The SoNARe model is coupled to the Wrocław hydro-agricultural model to simulate the hydrological dependencies that exist between farmers located along a communicating system of ditches and canals of a land reclamation system (LRS). In the model landowners decide about investing in the maintenance of their local section of the LRS and are provided with a feedback in terms of their attained crop yield under certain climatic conditions. Farmers find themselves in a twofold dilemma: First of all, a working LRS is most pertinent under unpredictable extreme weather conditions because it protects crop against excess water stress. Secondly, the beneficial effects of the LRS may only be achieved by high degrees of mobilisation of the involved farmers. The goal of the model explorations is to investigate how a structural change in terms of a collective effort of the farmers can be triggered to transform the neglected LRS presently found in the Odra region towards a collectively managed working LRS.

4.2.3. The Grampian Model

The Grampian models have been based on existing software called FEARLUS (Framework for Evaluation and Assessment of Regional Land Use Scenarios), developed at the Macaulay

Institute. It is implemented in Objective-C and Java using Swarm (Minar et al., 1996). The environment created by the FEARLUS modelling framework is populated by farmers called Land Managers (there is also a government agent). Each Land Manager owns at least one land parcel. The set of land parcels managed by one particular Land Manager is called an estate. At any particular time, each land parcel is managed by one (and only one) Land Manager, who has allocated one (and only one) certain land use in the land parcel, using a particular decision-making algorithm. Land Managers undertake various activities every time-step (which is intended to represent one year):

1. Land Managers decide a land use for each of the land parcels in their estate ("Land use decision making").

2. At the end of the year, Land Managers accumulate their annual income, which affects their wealth ("Income generation").

3. Some classes of Land Managers may approve or disapprove of other Land Managers in their social neighbourhood ("Social approval" and "social disapproval"). This social approval or disapproval can affect some Land Managers' decisions on what land use to select for certain land parcels.

4. "Learning". Whether or not this happens depends on the decision making algorithm.

5. Depending on their wealth at the end of the year, Land Managers may decide to buy land parcels ("Land parcel transfer").

Land Managers are grouped into sub-populations, which potentially make decisions in different ways. Even when two Land Managers belong to the same sub-population (i.e. have been created using the same parameter file), they can be substantially different. This is so because the sub-population files may specify probability distributions for parameter values, rather than exact values.

Most sub-population classes implement a land use decision making algorithm that can be summarised in two steps: first, a decision to reconsider land use; second, if reconsideration is undertaken, the selection of a land use (which may turn out to be the same as the former one). The decision to reconsider land use may involve an assessment of: (i) whether the Land Manager's wealth aspirations are met, (ii) whether the Land Manager's social approval aspirations are met, (iii) the period of time over which these aspirations have/have not been met. The use of aspirations mirrors Simon's theory of decision-making based on 'satisficing': beyond a certain point, people will not make changes because what they have is 'good enough' – the risk of making changes is too great relative to the perceived potential gains. Thus, Land Managers only change Land Use when Aspirations are not met (for a sufficient period of time).

The choice of new land use may be based on one of four methods: (i) An 'innovative' or 'experimental' method, which assumes the Land Manager knows of all possible land uses that might be applied, and has criteria for choosing among them heuristically; (ii) An 'imitative' method, using similar criteria but assuming only knowledge of land uses occurring in the spatial neighbourhood of the Land Manager's estate; (iii) Case-Based Reasoning (Aamodt and Plaza, 1994), a method derived from cognitive psychology allowing decisions to be based on prior experience of a land use; (iv) Advice – a method that can be integrated into the CBR approach to ask neighbouring Land Managers about their experiences with a land use when the Land Manager has none themselves.

Probability distributions are used within a sub-population to give Land Managers an individual propensity to base their decision to change on any of the three factors outlined above, and to use any of the four outlined methods to make the change. More detail on Land Manager decision-making can be found in the FEARLUS 1.0 User Guide (Polhill and Izquierdo, 2007).

The social approval model assumes that Land Managers have a set of triggers influencing whether or not they may approve or disapprove of each other. This is based on evidence from the literature that different subtypes of farmer have various set notions about management practices that do or do not indicate a 'good farmer' (Burton, 2004). Land Managers' triggers are thus effectively rules indicating whether to approve or disapprove of a neighbour using specific land uses.

Land parcel transfer is discussed in detail in (Polhill et al., 2005, 2008). Land Managers with negative accumulated wealth are assumed to be bankrupt, and put all their parcels up for sale. These parcels are then auctioned to neighbouring Land Managers, and a potential in-migrant Land Manager (the sub-population of which is chosen using probabilities that may vary over time). Land Managers have heuristic strategies for deciding which land parcels to bid for, and how much to offer.

4.3. Generalisation

The CAVES proposal called for the development of clusters of consistent models at several levels and axes of aggregation that, at the most descriptive level, capture the relevant detail of complex systems and, at the most abstract level, allow for closed-form solutions and ready comparison with models in the literature on complex systems. This was a highly ambitious aim that could not in the event be accomplished in the time and with the resources available for the project. However, a step was taken in the direction of generalisation that provides a clear link between one of our case studies and the complexity literature in relation to network topologies and their evolution (see section 4.3.1)[1]. Another step was taken regarding the comparison of models across case studies, as described in section 4.3.2.

4.3.1. Generalisation within a case study

We shall say that a model G (for general) is more general than a model S (for special) if the set of conditions in which model G is applicable is a superset of the conditions of applicability of model S. A condition of application is positive if it is the specification of circumstances in which a model is applicable or negative if it specifies circumstances in which a model is not applicable. Consequently, a model G will be more general than a model S if the negative conditions of application of the former are a subset of the negative conditions of application of the latter and the positive conditions of application model G

[1] This section is taken directly and often verbatim from Moss (2008).

are a superset of those of model S and either the negative conditions are a proper subset or the positive conditions a proper superset. In all other cases, the hierarchy of generality is ambiguous.

This criterion of genrealisation was satisfied by a process of abstraction of the Ga-Selala model. The essential objective was to abstract as much as possible from the detail of the empirical models without distorting or misrepresenting the narratives captured by the empirical model and its outputs and also without distorting or misrepresenting the macro level outputs of statistics and social network topologies and evolution.

By abstracting from the institutional detail captured in the empirical model, we learn more about the model but not *necessarily* anything more general about social processes. In the present case, the abstract model provides a story about social breakdown as a consequence of HIV/AIDS or any other epidemic that is not dependent on stokvel, funeral clubs and churches in particular.

The abstract model replaced the specific social institutions of rural South Africa with an abstract set of activities in which individual agents could choose to participate. Some activities were specified as children's activities and some as adult activities. During model initialisation, individuals were assigned to activities appropriate to their age classification but otherwise at random. Participation in activities by individuals then evolved as agents joined activities in which other agents they valued (or endorsed) most highly participated. Each agent had a randomly assigned maximum number of activities in which it could engage.[2] Religious denominations, which are important features of Ga-Selala, were left out of the abstract model but kinship was retained.

The abstract model was run over the course of a standard generation (30 years). The breaking up of the social networks over the 30 years is depicted in fig. 4.2. The isolated individuals are mainly at extreme ages. Babies have not had time to form friendships and amongst the oldest their friends tend to have died off. However, it is clear that the density of links is reduced in the 30-year friendship network and there are isolated clusters comprised by agents of moderate ages – neither infant nor extremely old.

Similar results were found in the detailed, empirical models – both procedural and declarative. Moreover, Moss (2008) demonstrated that the results on social networks were sensitive to the mortality patterns of South Africa and did not follow from a model identical in all respects except that the WHO life table for France was used instead of that for South Africa. The difference is that the French are amongst the longest lived populations in the world and South Africa amongst the least long lived. The evolving social networks corresponding to the French life tables had the small world topology but did not fragment over time.

This result followed from some abstraction and fewer, less detailed rules governing the behaviour of individual agents. Consequently, the conditions of application of the model subsume those of the detailed, empirical models but would also subsume any other representations of institutional settings and relationships. The abstract model was therefore, on the present definitions, more general than the Ga-Selala model in both its specification and its outputs.

[2]The maximum and minimum number of those activities are set by the user at the start of each simulation run.

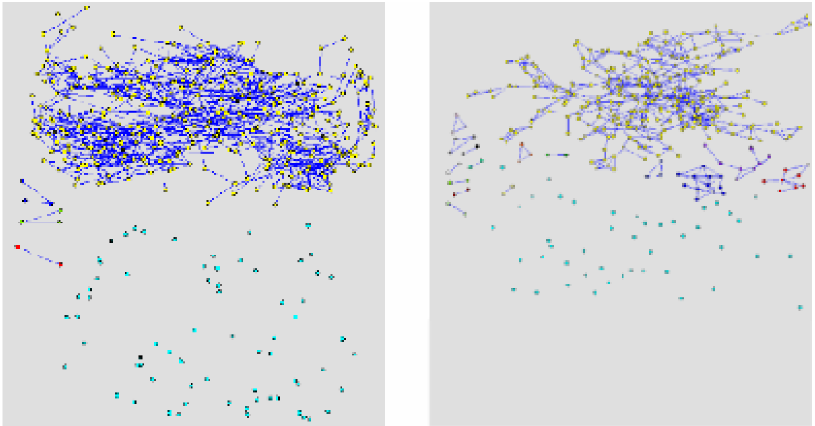

Figure 4.2.: Abstract model friendship networks; after one year (left) and after thirty years (right).

4.3.2. Generalisation across case studies

Diversity of issues and modelling paradigms do not allow for a direct generalisation of the models built for the CAVES case studies, i.e. one abstract model to cover all of the different case study models. Instead, abstract representations (concepts) of certain aspects of all CAVES case studies models were identified. This enabled the introduction of measures related to these representations, which in turn allowed to compare the same set of measures over all case study models.

All models have in common a set of agents linked in social networks interacting with other agents and/or the environment. We can therefore derive the following abstract representations (see figure 4.3):

- agents, which constitute nodes in the social networks. Their behaviour can be abstracted to decisions with regard to a set of choices, e.g. different strategies. The choice of an agent can be influenced by its own state, the states of other agents linked with it in a social network and the environment. Agents' decisions can modify the social network and/or the environment.
- links between agents. Different types of links may be distinguished, leading to layers of social networks. Some of these layers can be interpreted as groups agents belong to. Agents can rely on different layers for particular decisions.
- the environment. It can be represented through a set of environmental variables and parameters, some of which may be spatially explicit.
- interactions between (a) agents using the links of the social networks and (b) agents and the environment. Note that while the framework incorporates the full set of possible interactions not all of these may be present in one particular case study model.

The basic distinction in complexity measures as applied to the above framework lies in the focus of analysis – it can be either network based or agent-based. Network analysis

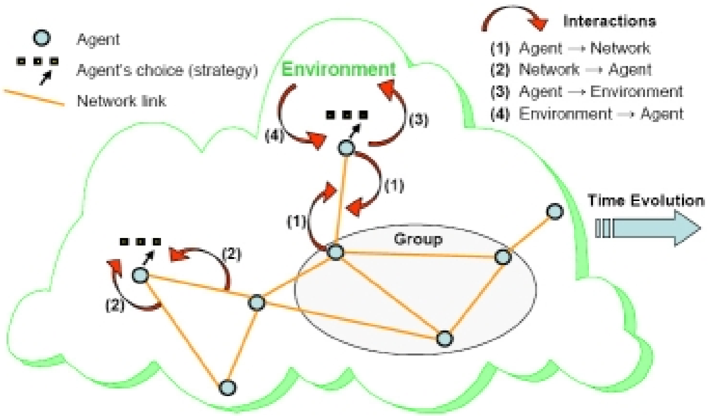

Figure 4.3.: The CAVES generalisation framework

has a long history and many of the standard network metrics such as average path length or degree centrality were used successfully in the CAVES project. Recent advances in complex networks expanded the repertoire of measures by e.g. clustering coefficient and degree correlation. Agent-focused complexity measures use agents' states as substrate for calculations. Example measures are: dynamism, polarisation or clustering as applied to agents' choices.

Both network-based and agent-based measures can be analyzed as time series. This type of analysis can focus on features such as volatility clustering or other examples of heteroscedasticity. Regarding the (in)stability of selected variables or measures over time we can apply resilience measures. This kind of analysis focuses on phase space looking for alternative stability domains and how they change in time. However, a certain level of volatility can make this type of analysis inapplicable.

5. Impact

The NEST-Pathfinder initiative under which the CAVES Project is funded was established by the European Commission to provide "early stage funding of emerging research areas." The "Tackling Complexity in Science" calls have been intended *inter alia* to

- Promote the development of techniques for the successful tackling of specific but important, complex real-world problems.
- Encourage the transfer of such techniques for tackling of complex problems from one area of science to another, where particularly promising and appropriate.

Within the framework of the funding programme, the intended impacts have been to develop and demonstrate the value of techniques that would usefully address complex real-world problems and to draw where appropriate on different areas of science. The immediate impact of the CAVES Project has been, we believe, to have produced policy analyses of direct use to policy analysts and to have identified with clarity both the promise and the problems facing the use of complexity science in the service oif social policy formation, implementation and evaluation.

The longer term impact of the CAVES Project will, we hope, turn on three questions raised as a result of our research and our demonstrations of complexity characteristics of a range of evidence based models. The questions are:

Means and procedures for validation. The appropriate means and procedures for the validation and confirmation of models is an issue that was raised by our SEI colleagues and was discussed above in chapter 3. It is essential to combine the realism and appropriateness of evidence based models developed bottom-up and as set of clear guidelines and procedures for validation which are necessarily have an important top-down element. A suitable starting point for exploring this issue is the Downing sensitivity matrix (Downing, 2004). There would need to be a procedure for identifying the appropriate dimensions or the labels for the columns of the sensitivity matrix.

Cluster chains. Both empirical investigations and simulation results produced social networks marked by clusters, as we would expect in a small world network, but the clusters were connected in chains so that the network diameters were significantly longer than would be expected in a random network or, therefore, in a small world network. These empirical and modelling results, though consistent, do not necessarily lead to the conclusion that the relevant social networks are not small world. On the other hand, we cannot assume that they are small world. It might well be that links between social clusters result from engagement in activities and that our social surveys did not cover enough activities of stakeholders to identify all of the relevant social links and that we did not allow for enough activities in the simulation models. In light of the emphasis placed on small world networks in the complexity literature, it would be appropriate to investigate further the evidence for the sources of links between clusters (further than we have done and than we find in the literature) and to use agent based social simulation to identify hypotheses about the sources of inter-cluster links and how they evolve.

Generalisation Two approaches to generalisation were reported above. One involved abstraction of a single model (in this case the Ga-Selala model) and the other involved the finding of commonality across all models. Both were successful and form the basis for an investigation into the features of models and social processes that give rise to complexity.

We claim to have developed techniques for the successful tackling of specific but important, complex real-world problems including not only land use but also epidemiological problems such as HIV/AIDS. Our models all integrated social and natural elements in the service of policy formation and analysis and, to that extent, we have transfered techniques for tackling complex problems from one area of science to another. We consider these to have been important outcomes that demonstrate benefits from the consideration of social processes as complex, dynamic phenomena. The questions we have raised are questions that need to be answered if complexity science is to develop as an effective approach to the tackling of real-world problems. If they are addressed by the policy and complexity science communities, then the long term impact of the CAVES Project will turn out to have been significant and even fundamental.

Bibliography

A. Aamodt and E. Plaza. Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI Communications*, 7(1):39–59, 1994.

P. Agarwal. Ontological considerations in GIScience. *International Journal of Geographical Information Systems*, 19(5):501–536, 2005.

Shah Jamal Alam and Ruth Meyer. Comparing two sexual mixing schemes for modelling the spread of HIV/AIDS, booktitle = Proc. World Congress on Social Simulation 2008 (WCSS-08), George Mason University, Fairfax, July 14-17, year = 2008, note = Also available as CPM Report No. 08-189 `http://cfpm.org/cpmrep189.html`.

Shah Jamal Alam and Ruth Meyer. Structural changes in agent-based simulations: Representing HIV/AIDS impact on social networks. In Thomas Friemel, editor, *Why Context Matters; Selected papers from the Fourth Conference on Application of Social Network Analysis (ASNA'07)*. Springer, 2008.

Shah Jamal Alam, Ruth Meyer, and Emma Norling. A model for HIV spread in a south african village. In *Proceedings 9th International Workshop on Multi-Agent-Based Simulations, May 12-13, Estoril, Portugal (MABS'08)*, 2008. `http://mabs2008.dcti.iscte.pt/revised_for_pre_proceedings/Shah.pdf`.

Shah Jamal Alam, Ruth Meyer, Gina Ziervogel, and Scott Moss. The impact of HIV/AIDS in the context of socioeconomic stressors: an evidence-driven approach. *Journal of Artificial Societies and Social Simulation*, 10(4):7, 2007. ISSN 1460-7425. `http://jasss.soc.surrey.ac.uk/10/4/7.html`.

P.S. Bearman, J. Moody, and K. Stovel. Chains of affection: The structure of adolescent romantic and sexual networks. *American Journal of Sociology*, 110(1):44–91, 2004.

Pierre Bourdieu. Ökonomisches kapital, kulturelles kapital, soziales kapital. In Reinhard Kreckel, editor, *Soziale Ungleichheiten*, Soziale Welt, Sonderheft 2, pages 183–198. Otto Schwartz, Göttingen, 1983. Translated by Richard Nice, `http://www.viet-studies.org/Bourdieu_capital.htm`.

R. Burton. Seeing through the 'good farmer's' eyes: Towards developing an understanding of the social, symbolic value of 'productivist' behaviour. *Sociologia Ruralis*, 44(2):195–250, 2004.

CAVES. CAVES Periodic Activity Report; Project Month 18, Project No. 012816 CAVES – Complexity, Agents, Volatility, Evidence and Scale. Interim report, Centre for Policy Modelling, MMU; Stockholm Environment Institute, Oxford Office; Universität Kassel; Politechnika Wroclawska; IIASA, Vienna; Macaulay Institute, Aberdeen; Uniwersytet Wroclawski, 2006. http://cfpm.org/caves/wiki/uploads/CAVESWiki.Publications/CAVES_month18_report.pdf.

Thomas E. Downing. Vulnerability in napa assessments: Guidance, examples and team exercises for developing rapid, participatory vulnerability assessments in national adaptation programmes of action. Technical report, UN Environment Programme & UN Institute for Training, Assessment and Research, 2004.

Andries du Toit and Gina Ziervogel. Vulnerability and food insecurity – background concepts for informing the development of a national FIVIMS for South Africa. Technical report, National Department of Agriculture, South Africa, May 2004. http://www.agis.agric.za/agisweb/FIVIMS_ZA.

Bruce Edmonds and Edmund Chattoe. When simple measures fail: Characterising social networks using simulation. In *Proc. of Social Network Analysis: Advances and Empirical Applications Forum, Oxford, July 16-17 2005*, 2005. Also available as CPM Report 05-158 http://cfpm.org/cpmrep158.html.

Ernest Friedman Hill. *Jess in Action: Java Rule-Based Systems*. Manning Publications Co, Greenwich, CT, USA, 2003.

N.M. Gotts and J.G. Polhill. Narrative scenarios, mediating formalisms, and the agent-based simulation of land use change. In *Proc. EPOS 2006: Epistemological Perspectives on Simulation, II Edition, University of Brescia, Italy, October 5-6, 2006*, 2006a.

N.M. Gotts and J.G. Polhill. Simulating socio-techno-ecosystems. In *Proc. First World Congress on Social Simulation, 21-25 August 2006, Kyoto, Japan*, 2006b.

M. Grüninger. Ontology of the process specification language. In S. Staab and R. Studer, editors, *Handbook on Ontologies*, chapter 29. 2004.

Paulina Hetman, Andrzej Janutka, Piotr Magnuszewski, and Andrzej Radosz. Measures of clustering in binary choice models. Technical report, Institute of Physics, Wroclaw University of Technology, 2006. http://cfpm.org/caves/wiki/uploads/CAVESWiki.KnowledgeBase/CAVES_Clustering.pdf.

Paulina Hetman and Piotr Magnuszewski. Caves generalisation framework. Technical report, Institute of Physics, Wroclaw University of Technology, 2008. http://cfpm.org/caves/wiki/uploads/CAVESWiki.KnowledgeBase/CAVES_GeneralisationFramework.pdf.

J.S. Koopman, JA Jacquez, GW Welch, CP Simon, B Foxman, SM Pollock, D Barth-Jones, AL Adams, and K. Lange. The role of early HIV infection in the spread of HIV though populations. *J Acquir Immune Defic Syndr Hum Retrovirol.*, 14(3):249–.258, 1997.

M. Kretzschmar and M. Morris. Measures of concurrency in networks and the spread of infectious disease. *Math Biosci.*, 133(2):165–195, 1996.

R. Leombruni and M. Richiardi. Why are economists sceptical about agent-based simulations? *Physica A: Statistical Mechanics and its Applications*, 355(1):103–109, 2005.

N. Minar, R. Burkhart, C. Langton, and M. Askenazi. The swarm simulation system: A toolkit for building multi-agent simulations. Working paper 96-06-042, Santa Fe Institute, Santa Fe, 1996. `http://www.swarm.org/images/b/bb/MinarEtAl96.pdf`.

S. Moss. Critical incident management: An empirically derived computational model. *Journal of Artificial Societies and Social Simulation*, 1(4), 1998.

Scott Moss. Control metaphors in the modelling of decision-making behaviour. *Computational Economics*, 8:283–301, 1995.

Scott Moss. Simplicity, generality and truth in social modelling. part 1: Epistemological issues, part 2: Demonstration. In *Proc. WCSS-08, World Congress on Social Simulation 2008, George Mason University, Fairfax, July 14-17*, 2008. Also availabe as CPM-Report No. 08-187 `http://cfpm.org/cpmrep187.html`.

Scott Moss and Bruce Edmonds. Sociology and simulation: statistical and qualitative crossvalidation. *American Journal of Sociology*, 11(4):1095–1131, 2005.

H. Neave and K. McConwa. *Distribution free methods*. Open University Press, 1987.

M. Neteler and H. Mitasova. *Open Source GIS: A GRASS GIS Approach*. Springer, New York, third edition edition, 2007.

M. E. J. Newman and Juyong Park. Why social networks are different from other types of networks. *Phys. Rev. E*, 68(036122), 2003.

M.J. North and J.R Collier, N.T. and. Vos. Experiences creating three implementations of the repast agent modeling toolkit. *ACM Transactions on Modeling and Computer Simulation*, 16(1):1–25, 2006.

N. Oreskes, K. Shrader-Frechette, and K. Belitz. Verification, validation, and confirmation of numerical models in the earth sciences. *Science*, 263(5147):641, 1994.

K. Ostasiewicz, M. Tyc, P. Goliczewski, P. Magnuszewski, A. Radosz, and J. Sendzimir. Integrating economic and psychological insights in binary choice models with social interactions. *ArXiv Physics e-prints*, (0609170), September 2006. `http://arxiv.org/abs/physics/0609170`.

J. G. Polhill and L. R. Izquierdo. FEARLUS model 1-0 user guide. Technical report, Macaulay Institute, Aberdeen, 2007. available from the authors.

J. G. Polhill, D. C. Parker, and N. M. Gotts. Introducing land markets to an agentbased model of land use change: A design. In K. G. Troitzsch, editor, *Representing Social Reality: Pre-Proceedings of the Third Conference of the European Social Simulation Association, Koblenz, September 5-9, 2005*, 2005.

J. G. Polhill, D. C. Parker, and N. M. Gotts. Effects of land markets on competition between innovators and imitators in land use: Results from FEARLUS-ELMM. In B. Edmonds, Hernandez Iglesias C., and K. G. Troitzsch, editors, *Social Simulation: Technologies, Advances, and New Discoveries*, chapter 7. 2008.

J.M. Pujol, A. Flache, J. Delgado, and R. Sangüesa. How can social networks ever become complex? modelling the emergence of complex networks from local social exchanges. *Journal of Artificial Societies and Social Simulation*, 8(4), 2005. `http://jasss.soc.surrey.ac.uk/8/4/12.html`.

RADAR. The RADAR IMAGE study — intervention with microfinance for AIDS and gender equity. `http://web.wits.ac.za/Academic/Health/PublicHealth/Radar/`, 2005.

A. Rhee. An agent-based approach to HIV/AIDS modelling: A case study of Papua New Guinea. Master of science thesis, Massachusetts Institute of Technology, 2006.

G. Robins, P. Pattison, and J. Woolcock. Small and other worlds: Global network structures from local processes. *American Journal of Sociology*, 110(4):894–936, 2005.

H. Simon.

C. Sumodhee, J. L. Hsieh, C. T. Sun, C. Y. Huang, and Arthur Y. M. Chen. Impact of social behaviors on HIV epidemic: A computer simulation view. In *Proceedings of the International Conference on Computational Intelligence for Modelling, Control and Automation and International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC'06)*, volume 2, pages 550–556. IEEE Press, 2005.

P. M. Todd and F. C. Billari. Population-wide marriage patterns produced by individual mate-search heuristics. In F.C. Billari and A. F"urnkranz-Prskawetz, editors, *Agent-Based Computational Demography: Using Simulation to Improve Our Understanding of Demographic Behavior*, pages 117–137. Physica-Verlag, 2003.

Bogdan Werth, Armando Geller, and Ruth Meyer. He endorses me – he endorses me not – he endorses me:. contextualized reasoning in complex systems. In *Proc. AAAI 2007 Fall Symposia, Washington, DC, November 8-11*, 2007.

Paul Windrum, Giorgio Fagiolo, and Alessio Moneta. Empirical validation of agent-based models: Alternatives and prospects. *Journal of Artificial Societies and Social Simulation*, 10(2):8, 2007. `http://jasss.soc.surrey.ac.uk/10/2/8.html`.

Gina Ziervogel. UNRAVEL – understanding resilient and vulnerable livelihoods in Malawi, South Africa and Zambia. Final research report, Disaster Mitigation for Sustainable Livelihoods Programme (DiMP), University of Cape Town, January 2006. Country report input from Paul Msoma, Vhonani Netshandama and Tabo Maheritona. Fieldwork undertaken by Ephraim Mzengo, Prudence Nkhumeleni and Jarvis Milimo.

Part II.

Dissemination and Use

6. Final plan for using and disseminating the knowledge

6.1. Exploitable knowledge and its use

Due to the nature of our research, the CAVES project has not generated exploitable results as per the definition of the 6^{th} Framework Programme.

6.2. Dissemination of knowledge

Table 6.1 gives an overview of all past activities concerned with the dissemination of knowledge in the CAVES project.

The *project web-site* can be found at `http://caves.cfpm.org`. It was established during the first three months of the project and since then has been updated accordingly. This internet portal is an important medium to disseminate the knowledge gained in the project. It is especially suited to share the developed software — in our case: simulation models — with a broader scientific audience.

There have been sixteen *Deliverables*: ten reports, two demonstrators (internet portal and final models) and four prototypes (models). All of them are available from the project web-site. The reports are the following:

- Deliverable 1: Initiation report
- Deliverable 3: Knowledge base (realised as integrative part of the internet portal)
- Deliverable 6: Critical examination of resilience theories and measures
- Deliverable 8: Working paper on case study structure, stakeholder/agents and validation data
- Deliverable 10: Working paper on case study validation
- Deliverable 11: Working paper on modelling and case studies in policy analysis process
- Deliverable 12: Working papers on results from each case study
- Deliverable 14: Technical reports on the final models
- Deliverable 15: Handbook on conceptual and formal models to measure resilience of complex systems
- Deliverable 16: Final report

Date	Type	Type of audience	Size of audience	Partner responsible
2005-2008	Project web-site	Research, policy analysts, general public		MMU
2005-2008	Deliverables	Research, policy analysts		all
2006-2008	Scientific publications	Research		all
04/2007	Video of Ga-Selala	Policy analysts, general public		SEI
04/2008	Final models	Research		UNIK, MLURI, MMU
23/04/08	International workshop	Research, policy analysts	18	all

Table 6.1.: Overview table

The *final models* for each of the three case studies are available as open source libraries from the project web-site. All software has been developed using open source languages and programming libraries or at least packages that are free for scientific use.

The CAVES project has been dedicated to publishing results in relevant scientific journals and conferences. Over the entire term of the project the following *scientific publications* have been written:

- S. Alam and R. Meyer, Finding Suitable Analysis Techniques for Agent-based Networks Generated from Social Processes, in Proceedings of Social Network Analysis: Second Forum on Advances and Empirical Applications, Leeds, UK, June 2006

- G. Polhill and G. Ziervogel: Using ontologies with case studies: an end-user perspective on OWL. NCESS 2006, Second International Conference on e-Social Science, 28-30 June 2006, Manchester, UK

- S. Alam: Towards better socioeconomic policies in the Sub-Saharan region, Poster at the ESRC Research Methods Festival, Oxford, UK, July 2006

- S. Alam, R. Meyer and G. Ziervogel: Modelling the Socio-Economic Impact of HIV/AIDS in South Africa. WCSS 2006, First World Congress on Social Simulation, 21-25 August 2006, Kyoto, Japan

- A. Ernst, F. Krebs and C. Zehnpfund: Dynamics of task oriented agent behaviour in multiple layer social networks. WCSS 2006, First World Congress on Social Simulation, 21-25 August 2006, Kyoto, Japan

- N. Gotts and G. Polhill: Simulating Socio-Techno-Ecoystems. WCSS 2006, First World Congress on Social Simulation, 21-25 August 2006, Kyoto, Japan

- B. Werth, S. Moss, G. Ziervogel and T. Downing: Modelling Migration in the Sahel: An alternative to cost-benefit analysis. WCSS 2006, First World Congress on Social Simulation, 21-25 August 2006, Kyoto, Japan

  This paper won the student contest at WCSS'06 in Kyoto and was awarded the gold medal for best demonstration.

- E. Norling, B. Edmonds and S.J. Alam: Complexity in Socially-Inspired Simulation. Poster presented at the annual meeting of the EPSRC NANIA project, Ambleside, 29-31 August 2006

- L.A. Small: Modelling Social Networks: An Application for Rural Sociology? Paper presented at XII International Summer School, "The Empire of Rules and the Ethics of Social Networks", August/September 2006

- L.A. Small: Introducing CAVES: Complexity, Volatility, Evidence and Scale. Poster at the Participatory Approaches in Science and Technology conference, Edinburgh, June 2006; and the Rural Sociological Society Annual Meeting, Louisville, KY, USA, August 2006.

- S. Alam, A. Ernst, F. Krebs, R. Meyer, S. Moss and C. Zehnpfund: Evidence-Based Social Networks: Testing for Complexity. Submitted to MA4CS'06, a satellite workshop to ECCS'06, the European Conference on Complex Systems, Oxford, 25-29 September 2006.
- N. Gotts and G. Polhill: Narrative Scenarios, Mediating Formalisms, and the Agent-Based Simulation of Land Use Change. EPOS 2006: Epistemological Perspectives on Simulation, II Edition, University of Brescia, Italy, October 5-6, 2006
- K. Ostasiewicz, M. Tyc, P. Goliczewski, P. Magnuszewski, A. Radosz, and J. Sendzimir: Integrating economic and psychological insights in binary choice models with social interactions. ArXiv Physics e-prints 0609170, September 2006. `http://arxiv.org/abs/physics/0609170`
- S. Alam, R. Meyer, S. Moss, G. Ziervogel: Impact of HIV/AIDS in the Context of Socioeconomic Stressors: An Evidence-driven Approach. Journal of Artificial Societies and Social Simulation 10(4) 2007. `http://jasss.soc.surrey.ac.uk/10/4/7.html`
- N. Gotts: Resilience, panarchy and world-systems analysis. Ecology and Society, in press.
- S. Alam, R. Meyer and E. Norling: Agent-based Model of Impact of Socioeconomic Stressors: A DYNAMIC Network Perspective. In: Proceedings of the Sixth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'07), May 14-18, 2007, Honolulu, Hawai'i.
- S. Alam and R. Meyer: Analyzing Network Evolution in Agent-based Models using Subgraph Characteristics. In: Proceedings of the UK Social Network Conference, London, 13-14 July 2007, pp. 86-88
- S. Alam and R. Meyer: Structural Changes in Dynamical Networks Generated from Agent-based Simulation Models. In: Proceedings of the Fourth Conference on Applications of Social Network Analysis (ASNA 2007), 13-15 September 2007, Zurich, Switzerland
- S. Alam, R. Meyer and B. Edmonds: Signatures in Networks Generated from Agent-based Social Simulation Models. CPM Report No.07-176, online available at `http://cfpm.org/cpmrep176.html`
- F. Krebs, M. Elbers, A. Ernst, K. Krolikowska and G. Holdys: An Evidence-Based Model of Farmer Decision Making: Contrasting Social Support and Economic Success. Submitted to the Journal of Artificial Societies and Social Simulation (JASSS)
- F. Krebs, M. Elbers and A. Ernst: Modelling Social and Economic Influences on the Decision Making of Farmers in the Odra Region. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 - 14 September 2007, Toulouse, France

- N. Gotts: Resilience, panarchy and world-systems analysis. Ecology and Society 12(1): 24, 2007. Online available at `http://www.ecologyandsociety.org/vol12/iss1/art24/`
- N. Gotts and G. Polhill: Using Collective Rewards and Social Interactions to Control Agricultural Pollution: Explorations with FEARLUS-W. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 - 14 September 2007, Toulouse, France.
- S. Moss: Alternative Approaches to the Empirical Validation of Agent-Based Models. Online available as CPM Report No. 07-178 `http://cfpm.org/cpmrep178.html`
- G. Polhill and N. Gotts: Evaluating a prototype self-description feature in an agent-based model of land use change. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 - 14 September 2007, Toulouse, France.
- B. Werth, A. Geller and R. Meyer: He endorses me – He endorses me not – He endorses me:. Contextualized reasoning in complex systems. AAAI 2007 Fall Symposia, Washington, DC, November 8-11, 2007
- L.A. Sutherland: Farming in the Network Society: Social Capital in Grampian Agriculture. Submitted to Sociologia Ruralis in November, 2007
- S. Alam, R. Meyer and E. Norling: A Model for HIV Spread in a South African Village. MABS 2008, 9th International Workshop on Multi-Agent-Based Simulation, May 12-13 2008, Estoril, Portugal.
- S. Alam and R. Meyer: Comparing Two Sexual Mixing Schemes for Modelling the Spread of HIV/AIDS. WCSS-08, World Congress on Social Simulation 2008, George Mason University, Fairfax, July 14-17, 2008.
- A. Dunajski, M. Sieczka: Land use/cover change analysis based on historical maps — a framework for spatial error assessment. Presentation at "Methodology of landscape research" conference, Sosnowiec-Krynica, Poland, 2008
- A. Dunajski, M. Sieczka: The influence of the rectification error on the land cover change analysis results using topographic maps as an information source, 2008 (submitted publication)
- P. Hetman, P. Magnuszewski: Equilibrium properties of evolving binary choice models on networks, XXIII Max Born Symposium "Critical Phenomena in Complex Systems" 2-6 September 2007, Polanica Zdroj, Poland.
- Hetman P., Magnuszewski P., Stefanska J., Bujkiewicz L.: How groups shape social network – on assortativity of social networks; European Conference on Complex Systems, Dresden, Germany, 1-5 October 2007.
- P. Hetman, P. Magnuszewski, J. Stefanska, L. Bujkiewicz, K. Ostasiewicz: How nodes and groups properties influence assortativity in social networks; accepted for publication in Acta Physica Polonica A.

- A. Janutka, P. Magnuszewski: Dynamics of probabilistic social-impact model, XXIII Max Born Symposium "Critical Phenomena in Complex Systems" 2-6 September 2007, Polanica Zdroj, Poland.
- Janutka A., Magnuszewski P.: Structural transitions in non-equilibrium model of social impact. Submitted to European Physical Journal – Special Topics.
- Krebs, F., Elbers, M. and Ernst, A.: Modelling the social and economic dimensions of farmer decision making under conditions of water stress. Proceedings of the 1st ICC workshop on complexity in social systems, Lissabon, 2008.
- K. Krolikowska, A. Dunajski, P. Magnuszewski: The impact of institutional changes on land amelioration and land use in Odra River Valley, Poland. Presentation at the international conference "Impact Assessment of Land Use Changes", 6-9 April 2008, Humboldt University, Berlin.
- Ostasiewicz, K., Tyc, M. H., Goliczewski, P., Magnuszewski, P., Radosz, A., Sendzimir, J.: Multistability of impact, utility and threshold concepts of binary choice models; submitted to Physica A.
- S. Moss: Simplicity, generality and truth in social modelling. Part 1: Epistemological issues. WCSS-08, World Congress on Social Simulation 2008, George Mason University, Fairfax, July 14-17, 2008.
- S. Moss: Simplicity, generality and truth in social modelling. Part 2: Demonstration. Submitted to WCSS-08, World Congress on Social Simulation 2008, George Mason University, Fairfax, July 14-17, 2008.
- G. Ziervogel and A. Taylor: Feeling Stressed: Integrating Climate Adaptation with Other Priorities in South Africa. Environmental Journal, March /April 2008.
- S. Alam and R. Meyer: Structural Changes in Agent-based Simulations: Representing HIV/AIDS Impact on Social Networks. In: T. Friemel (ed.), Why Context Matters; Selected papers from the Fourth Conference on Application of Social Network Analysis (ASNA'07), Springer, 2008 (forthcoming)

The major single event for disseminating results has been an *international workshop* aimed at both academic experts and key officials involved in climate policy in general and land use issues in particular. The objective of the final workshop was both to present our results and to engage the experts and officials in exercises with the procedures developed by the CAVES project. A report of the workshop including a list of participants and speakers can be found on the project web-site.