Implementation of a spatial decision support system for rural land use planning: integrating GIS and environmental models with search and optimisation algorithms

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Abstract

The implementation of a spatial decision support system (DSS) developed as a tool for rural land use planning at the management unit level is described. The DSS fulfils the need for a tool that allows rural land managers to explore their land use options and the potential impacts of land use change. The DSS is based on five components: a geographic information system (GIS); land use modules; impact assessment modules; a graphical user interface and land use planning tools. These components are implemented across two software platforms Gensym's G2 knowledge based system (KBS) development environment and Smallworld GIS. Following a review of the DSS components, the paper focuses on two aspects. First the use of the object-orientation paradigm to facilitate the integration of geospatial information. Second is the proposed use of genetic algorithms, a class of search and optimisation algorithm, to find optimum land use plans using the integrated functionality of both KBS and GIS.

Keywords: DSS, GIS integration, Genetic Algorithms

1. Introduction

1.1. Rationale behind the development of a spatial decision support system

Rural land managers, in the UK and elsewhere in Europe, are faced with an increasingly complex decision making environment where production has to be achieved within narrowing environmental and social limits. Indeed for significant land areas, particularly in marginal lands with significant environmental importance, a varied mix of financial, social and environmental goals has invariably to be achieved. Against this background it is possible to identify several factors driving land managers to seek more information. These factors include:

- **Competition** on a global scale is leading to the search for alternative land uses and land use systems. In the UK, new arable land uses include energy from biomass and chemical feed-stock crops, with the range of livestock expanding to include fine fibre sheep and goats and more exotic species such as camelids and ostriches. Alternative land use systems include the integration of traditionally separate land uses, such as livestock and timber in agro-forestry. Changes to the options for management or marketing of produce are also significant, including precision agriculture, quality assurance, niche marketing, organic produce and vertical integration of enterprises. These management systems and enterprises and can lie outwith the experience of the individual, his or her peer group and even traditional agricultural extension services and thus require information on their potential from other sources.

- **Regulation** of land use via statutory requirements for environmental impact assessments, for example impacts of land use change on biodiversity or water quality, further complicates the land use decision making process. As with alternative enterprises, environmental impact assessments often require the integration of expertise from outwith the enterprise. They may also require information from beyond the boundary of the land management unit to assess the impact on third parties.

- **Public awareness** of the issues of land use is increasing, particularly regarding land use change. The general public can also expect to influence the decision making process as significant sums of public money are invested in rural land use via grant and subsidy systems. The social consequences of land use planning add a further dimension to the complexity of the planning process.

- **Land ownership changes,** with trusts and conservation bodies becoming increasingly significant land owners in the UK, means that more diverse management goals are being pursued with social and environmental regeneration goals balanced against financial returns.

This demand for multiple objective land use planning requires sufficient information to allow the land manager to explore the options and impacts of alternative land use strategies and the structure of the trade-offs between the various objectives. Exploring such trade-offs is a complex problem especially when spatio-temporal interactions between land uses require to be addressed.

There is, however, not only an established need for more information about alternative options but also an expectation that such information can be accessed and utilised successfully.

- **Investment in information technology**, for example geographical information systems (GIS), is becoming more common. The raw spatial data required by such systems is also becoming increasingly available at acceptable cost. These spatial data include thematic (e.g. soils) and infrastructural (e.g. field boundaries) digital maps and remote sensed images from satellite, aerial and precision farming sensors. Land managers and their advisors increasingly wish to look beyond the use of GIS for inventory purposes and to add value to their investment in GIS, by using it as the basis for a land use planning tool.

- **Predictive models** such as land use systems models or evaluations of individual impact assessments exist for some systems (e.g. crop biophysical productivity and financial analyses) and can provide useful components for the land use planning tool. These models represent significant investment in research and development and the need to translate relevant models from a research to a practitioner environment is well recognised.

If the increasingly complex land use planning problems identified above are to be addressed successfully by DSS the effective integration of geo-spatial data with land use systems and impact assessment models is essential. The integrated GIS provides the component models and assessments with appropriately resolved data and in turn provides models and assessments with access to the spatial analytical capabilities. This requirement has been recognised for some time and successful examples exist of such integration (Section 1.2.1). The particular approach to GIS integration taken within this research is explored in Section 3.

To fully address land use planning problems, however, this paper proposes the addition to the DSS of land use planning tools to assist the land manager in exploring options, assessing potential impacts, experiment with alternative land use strategies and ultimately discover new knowledge. These tools are based on the rapidly developing field of evolutionary computation (see Section 1.2.2) and their implementation within the DSS is discussed in Section 4.)

The paper presents both the approach taken to GIS integration and the development of the land use planning tools in the wider context of the continuing development of a spatial land allocation decision support system (LADSS). The components of LADSS are outlined in Section 2.

1.2. Review of methodologies

1.2.1. GIS linkage

The term Knowledge Based System (KBS) is employed within this paper to convey the increasingly wide range of possible approaches adopted by researchers when implementing land use systems analysis. KBS thus include models implemented as object oriented or procedural software, declarative rules based (e.g.

expert) systems and others such as neural/Baysian nets. GIS is regarded as a separate class of system due to its specialised spatial data handling capabilities

Fedra (1996), in reviewing strategies for linking GIS to environmental models to form the basis of decision support systems, identifies a continuum of intimacy of linkage from loose to deep coupling. Loose coupling of GIS with models or KBS is accomplished via the exchange of data files. File(s) of parameters required by models are created from data resident in the GIS, the models are run and their outputs returned to the GIS for mapping via other file(s). The interface between the systems is thus defined by common file formats. While this approach involves little investment in software development, it has been found to be cumbersome and potentially error prone where human intervention is required. By contrast deep coupling merges the GIS and KBS or models almost to the point that they form a single system. A deep-coupled system has a single user interface and transparent exchange of data via common systems memory. Implementation of such systems, however, requires open GIS architectures and significant amounts of software engineering. Recognising that neither of these approaches is ideal, Fedra (op. cit.) proposes an alternative integrated framework. This framework proposes that the GIS and KBS/modelling environment remain as two systems with the ability to exchange information between them. This dual-system is overlain by a common user interface with visualisation, customisation and explanation functionality.

The significant difference between the integrated and the deep-coupled system is the recognition that certain functions of GIS and KBS/modelling systems do not require to be integrated. These supporting functions are grouped into a data and information pre-processing subsystem that handles issues such as spatial data capture, model integration and knowledge-engineering. This sub-system covers a wide range of ancillary activities that support the linked systems but can be carried out independently. Fedra (op. cit.) also notes as do Livingstone and Raper (1994), that the object-oriented GIS paradigm has significant potential for simplifying the integration process, as it provides an entity definition approach common to both GIS and KBS/modelling.

Fedra (op.cit.) proposes that, by concentrating on integrating GIS processes that are core to the functionality of the DSS, the embedding of GIS in DSS becomes a more tractable problem. He suggests a DSS should support the following core GIS functionality:

1. Selection and generation of background and thematic maps in various display styles.
2. Access to spatially distributed data including model input and saved model scenarios.
3. Display of model output (or time series) as animations.
4. Support for the comparative analysis of alternative scenarios.

The GIS integration undertaken as part of the LADSS project has adopted Fedra's overall approach and has concentrated on providing the functionality required for core functions 1,2 and 3 whilst not compromising on the need to be able to undertake the comparative analysis of alternative scenarios.

1.2.2. Genetic algorithms

The land use planning tools presented within this paper are based on <u>genetic algorithms</u> (GAs), a class of search and optimisation algorithm inspired by theories of the mechanics of natural selection (Goldberg 1989, Sequeira et al. 1994). Genetic algorithms are population based search algorithms in that they maintain a fixed number of alternative candidate solutions (the <u>population</u>). Each of the individuals in a population (referred to as a <u>genotype</u>) is a complete definition of a solution, for example a land use plan. The definition is encoded within the genotype as a series of genes with each *gene* defining a small part of the solution. This encoding permits the GA to recombine or modify existing (<u>parent</u>) solutions to form new (<u>offspring</u>) solutions using a series of GA <u>operators</u>. <u>Crossover</u> operators exchange genes between two parent genotypes to form two offspring. <u>Mutation</u> operators on the other hand alter one or more genes of a single parent, for example modifying its value. Once created each genotype is tagged with a value defining its adequacy as a solution to the problem. This value, referred to as the genotype's fitness, is derived from a function or model termed the fitness function.

For land use planning purposes typical fitness metrics include the financial returns (usually to be maximised) and the impact on the environment (usually to be minimised). The fitness functions used within the authors' application are discussed in Sections 2.3 and 5.2. Selection as a parent is biased in favour of those genotypes with higher fitness. As population size is fixed, fitness is also used to determine which of the existing individuals are eliminated and replaced by higher fitness offspring from the reproductive process. The processes of selection, recombination and replacement combine to form a "survival of the fittest regime" with the fittest member of the population ultimately being an optimum or near-optimum solution.

As tools for land use planning, GAs have both advantages and limitations compared with other algorithms. GAs are notably excellent in quickly finding solutions to complex optimisation problems that may be described as good or adequate (Goldberg 1989). That is, GAs are efficient at finding solutions close to the optimum, but they cannot be guaranteed to find the optimum (De Jong 1993). To reliably find optimum solutions GAs are frequently combined with local search algorithms, such as hill-climbing to form hybrid GAs (Bramlette and Bouchard 1991). By analogy these hybrid GAs use the GA to find the hill with the optimum solution at its peak and then employ the hill-climbing algorithm to find the peak.

GAs are flexible tools as their search and optimisation mechanisms are independent of the fitness function (Goldberg 1989). All that a GA requires of the fitness function is a value to assign to genotype fitness. This flexibility is desirable as it enables the modification of the evaluation function, or even its substitution, without the need to alter the GA. Thus, a single GA may be re-used for a range of land use planning tasks. Exploiting the efficiency and flexibility of a GA search is, however, dependent on the effective design of a representation for the elements of the application (De Jong 1990) and a compatible well-parameterised set of operators (Davis 1991).

1.2.3. GA Representation

Two-dimensional grids have been used in spatial modelling (Samet 1989) and land use planning (Butcher et. al. 1996). Indeed, Cartwright and Harris (1993) proposed a grid-based genotype representation, with two dimensional crossover operators. Explicitly spatial genotype representations were rejected, however, as impractical for the land use planning application. This rejection was primarily because spatial representations increase the magnitude of the optimisation problem. For example 100 genes may define the land use for 100 parcels of land, but this only allows for an inadequate ten by ten grid across the land management unit as a whole. The second reason for rejection was the potential problems associated with translating grid-based solutions into practical land use plans. The analysis of the performance of a number of crossover operators by Eshelman et. al.(1989) also made it possible to consider adopting a conventional one-dimensional genotype representation with each gene representing a block of land, to which a land use would be allocated. This *land block focused* representation has strong similarities with that successfully adopted for multiple-parameter optimisation problems (Michalewicz 1992).

1.2.4. GA Structures and Operators

The underlying structure of the GA employed is based on Davis' Object-Oriented GA (OOGA) (Davis 1991). The GA thus employs fixed size, unstructured populations, with genotype uniqueness enforced. The enforcing of genotype uniqueness has the primary goal of maintaining the genetic diversity of the population. With homogeneous populations the GA tends to find solutions quickly but these solutions are often significantly sub-optimal.

OOGA employs rank-based selection as proposed by Whitley (1989). This selection approach has been shown to minimise the twin problems of super individuals and drift. Super individuals can excessively influence the GAs search and result in sub-optimal solutions as they are selected frequently, during the initial phases of the GA run, due to their high fitness relative to the general population. GA drift, on the other hand, is experienced when differences in fitness between genotypes are too small to effectively bias the selection process. This can reduce the GAs ability to exploit small differences in fitness necessary to make the final adjustments to genotypes. A constant *selective pressure* may be maintained across the population, during the course of the GA run, by using a normalisation function. This function sets the fitness values used in selection based only on the rank of the evaluated fitness of the genotypes.

The replacement strategy of OOGA is individual replacement. That is, once crossover or mutation has created offspring, the latter are evaluated by the fitness function and then, if fitter than the least fit member of the existing population, they replace that individual in the population. This replacement strategy is significant as it permits the use of the aggressively exploratory uniform crossover operator (Syswerda 1989).

Operators are applied independently in OOGA, with individual offspring the product of a single operator (Davis 1991). An operator’s probability of application is part of the parameterisation of the GA. Optimum GA performance depends on this parameterisation but default values may also be used, as GA performance is robust. With OOGA two operators are employed, uniform crossover and mutation, with their probabilities of application, adapted over the course of a run.

Having examined the foundations of the GIS integration and land use planning tool components of LADSS the next section describes the overall structure of the system.

2. LADSS Components

The system has five main components, (Fig. 1.), described below.

2.1. Geographical Information System

This provides the generic GIS functionality as required by the DSS. It provides facilities for spatial data storage, analysis and visualisation. The component is implemented in Smallworld GIS, an object-oriented GIS.

2.1.1. Core Spatial Data Structures

The specific spatial data structures required for the rural land use planning application are shown in Fig. 2. Four object classes make up the core of the spatial data structure. These are the enterprise, the land block, the land block fragment and the land block fragment polygon. The classes define four scales of spatial organisation within the land management unit and are organised in a hierarchical structure using relational database relationships. The spatial data structures are illustrated within the GIS component of Fig. 2.

- **Enterprise** is the level in the hierarchy at which auditing analyses that apply to the management unit as a whole (e.g. a farm) take place. Examples of such audits include balance sheets for the land management unit, the overall labour required by the system of land use or the impact of the pattern of land use on the conservation value of the unit.
- **Land blocks** are areas of homogeneous land use. It is to these units, (e.g. a field or compartment) that the land use planning tools make allocations.
- **Land block fragments** are areas defined as being bio-physically homogeneous and with a uniform management regime. The definition of the land block fragments is an exercise where the land use model designer’s knowledge of the requirements and sensitivities of the model can be combined with the design of the spatial data capture strategy and incorporate the micro-scale expert knowledge of the land manager. The land-block fragment is a representation that forces explicit decisions to be made about the acceptable levels of generalisation of biophysical properties and is thus a compromise

between the non-spatial and grid-based approaches to land use modelling. As the land-block fragments are also areas of uniform management regime they also form the lowest level elements in the productivity and financial analyses carried out. The definition of land block fragments would form one of the processes in Fedra's (op. cit.) pre-processing subsystem.
- **Land block fragment polygons** carry the geometric information. Any analysis of higher-level object properties based on size, shape or proximity are based on the geometry held at this level. The land-block fragment polygon also forms the basis for the spatial search and summary methods that set the parameters for the land block fragments.
- **Agro-climatic and Administrative Zones** are structures used to hold data derived from national scale corporate datasets.

2.1.2. Spatial Data Capture

The raw topographic and soils data required by LADSS are currently collected by field survey on a grid pattern. These point data sources are represented in LADSS as **DSS Data Points**. The attribute values for those DSS data points within the boundary of a land block fragment are summarised and used to set the attribute values of the land block fragment. It is these attributes of the land use fragments that are later used by the land use modules (Section 2.2). This process of spatial search and summary is useful as it simplifies the substitution of improved data sources or summary methods to set the land block fragment attributes. This is significant as a *layered* spatial data capture strategy is envisaged. This strategy recognises that the potential cost of spatial data capture may be commercially unacceptable and that lower cost but less reliable data may have to be substituted in certain circumstances. Thus the land block fragments should, via the spatial search and summary methods, be capable of receiving data from the expert practitioner, regional scale corporate data holdings, remote sensing, consultant survey, intensive field survey or combinations of these data.

2.2. Land use Modules

The land use modules currently implemented are spring barley, upland sheep, suckler cattle both on sown pastures, five broad-leaved tree species and two conifer species. This list of land uses reflects our interest in the uplands of the UK and is by no means exhaustive. In all cases the land use modules are implemented as procedural software within Gensym Corporation's G2 knowledge-based systems development environment. The biophysical information required is supplied by the GIS component.

The land use modules are based on a series of published land use systems models with the same generic functionality. Each module first assesses the biophysical suitability of a land block fragment. If the fragment is suitable the module then proceeds to estimate its productivity under a given management regime, defined by the land manager. This productivity is defined in terms of tonnes per ha of barley, or maximum stocking density compatible with growing sufficient winter fodder within the land management unit for livestock systems or in cubic metres per hectare per year of timber for the forestry options. Finally the land use module makes an assessment of the marginal financial productivity of the system for a given set of costs and market prices, termed the global parameters. The suitability, productivity and profitability models are linked by forward chaining rules to allow changes in bio-physical, management or global parameters to be handled.

These analyses, conducted at the level of the land block fragment, provide much of the fundamental data that are later used in the impact analyses.

2.3. Impact Assessment Modules

Three principal dimensions of impact assessment are to be considered within LADSS, economic, social and environmental. This reflects our ultimate goal of exploring multiple-objective land allocation problems. As noted previously, impact assessments integrate information from the land block and land block fragment level to give assessments for the enterprise as a whole.

The economic impact assessment is currently the most highly developed, being based on the outputs from the land use modules described above. The assessment used is the net present value (NPV) of the land management unit, calculated from the gross margins per hectare, including available grants and subsidies, discounted at a rate, and over a period, chosen by the user. NPV is used to enable comparison of the performance of land uses making annual returns such as livestock systems with those making intermittent returns over an extended period, such as forestry. Currently under development are indices of social impact based on the amount and type of employment provided by the system of land use and conservation indices based on landscape ecological measures.

The impact assessments metrics have been chosen in consultation with a technical focus group of land managers and other stakeholder groups such as non-governmental organisations and others with interests in land management such as banks. Rural employment was seen to be a key social indicator for the sustainability of rural communities as many other enterprises depend for their core business on the land use sector. The decision to provide a range of landscape ecological measures (implemented within the GIS) was taken in response to advice from conservation groups. Their preference was to use expert interpretations of the metrics for particular species or habitats outwith the software. The influence of the technical focus group discussions is further discussed in Section 5, Validation and Initial Results.

2.4. Graphic User Interface

To provide the consistent look and feel for the DSS, interaction with the GIS is controlled from the G2 environment, with the GUI being built using the toolkit provided with G2. This conflicts with Fedra's approach where the GUI is implemented as a separate subsystem overlying the GIS and KBS components. The G2 GUI toolkit does, however, permit the implementation of all the functionality suggested by Fedra.

The map windows of the GIS are manipulated, for example, to reveal or hide the map of the land management unit, using X protocols initiated by the GUI. By making method calls across the bridge software it is also possible to manipulate the user menu system of the GIS. This has been used to facilitate point and click style selection of GIS objects, with the menu being used to fire the methods required to return the identities of the objects chosen via the bridge to G2.

2.5. Land use planning tools

The land use planning tools have been implemented with the goal of supporting the search for land allocations that meet the goals of the land manager. The tools form part of an iterative system, which operates as follows. The land manager initially defines the objectives of the search (by choosing the impact assessment to be used as the fitness function in the GA) and makes any adjustments to the global or management parameters considered necessary to reflect the particular circumstances of the land managers holding. (More sophisticated facilities for handling land manager goals as a series of constraints on the optimisation are compatible with the GA search methodology and are in the process of being implemented.) The manipulation of global parameters such as grant payments and output prices also enables the land manager to analyse "what-if" scenarios. With the objective and scenario set, the land use planning tools search, using the GA, for the best allocation of land uses to land blocks. Land use allocation solutions are evaluated during the course of the GA run by the appropriate impact assessment modules. For example the NPV for an allocation can be used as the fitness function with the goal of maximising economic returns. Impact assessment modules synthesise information from the relevant land use modules or, if required, can call upon the GIS to perform any spatial analyses required. Once the GA run has terminated the land manager can view an allocation, defined by an individual genotype in the GA population, calling a GIS method to update the land allocations in the GIS. The characteristics of individual components of the allocations may also be interrogated or customised within G2. For example, individual land blocks may have their allocated land use modified by the land manager to reflect personal preferences, and the impact of such changes will be reflected in the evaluation of the land allocation. A land use plan may then be accepted or the objectives, global or management parameters modified and the search repeated.

Having described the components of LADSS it is now appropriate to examine in more detail the implementation of the GIS integration and the land use planning tools.

3. GIS Integration

The GIS integration within LADSS is based on the exploitation of the object-oriented paradigm common to Smallworld and G2. The aim was to create bridging software that would allow the GIS to pass the required information to the KBS and the KBS to access the spatial analytical functionality of the GIS. In LADSS the GIS can be viewed as a slave to the KBS.

The bridge between the GIS and the KBS is a bespoke C code tool that handles communications between the Gensym Standard Interface (GSI) and the Smallworld Alien Co-processor (ACP) interface.

The facility to pass data into the KBS from the GIS is used to create, within the KBS, *partially-mirrored* data structures, based on the GIS objects. That is, it passes only those entities and attributes of entities required by the KBS. The partial-mirroring process thus passes to the KBS the unique object identifiers (UID), non-spatial attributes, and relationships between the enterprise, land block, land block fragment, and the various zone classes. All spatial data remains in its native GIS environment, as do those GIS objects not required by any KBS component (Fig. 2.). The partial mirroring is also reflected in the KBS object classes where attributes, in addition to those defined as receiving values from the GIS, are defined.

The partially-mirrored data structures enable the land use module and impact assessment components to reason with these objects and to supply the information required by the land use planning tools. The KBS components may also, when necessary as part of their operation, call methods implemented within the GIS. These GIS methods are accessed by making remote procedure (RPC) calls to the GIS. A RPC takes as parameters the UID of the GIS object the method is to be sent to (from the partially-mirrored data structure within the KBS), the method name, and a list of method parameters (if any). Once the GIS has found the object identified by the UID and completed the method results are returned as values if they are simple data types or as UIDs if a GIS object.

Theoretically, in creating the partially mirrored data structures in the KBS, all that needs to be passed is the UID of the object. Any attribute data required by KBS components could then be accessed via a method call to the GIS. In practice a compromise requires to be struck between the overhead of data storage and the processing involved in repeated GIS calls. Communications across the bridge are also currently limited to sequential calls. Thus non-essential calls across the bridge are minimised.

The principal reservation in the use of a partially-mirrored approach is the greater susceptibility to error of the system compared with one based on a deep-coupled approach (Section 1.2.1). In the Smallworld to G2 bridge rigorous updating and error trapping is implemented so that incomplete or missing data is reported and dealt with in a systematic way. This does, however, impose an overhead on the communications between the two systems that could be avoided with a deeper coupling. In the continuing program of development if additional robustness is required then it is possible, with minimal reengineering of the existing structures, to use an alternative strategy based on a shared object repository. This reflects the increasing openness of GIS systems and the adoption of object oriented communications standards such as OLE and CORBA.

4. Land Use Planning Tools

As noted in Section 1.2.2, GAs are being evaluated as land use planning tools within LADSS. This section sets out the representation, the GA structures and the operators employed.

The GA implemented for land use planning has each gene representing a land block to which a land use can be allocated. The genotype structure is a one-dimensional array, with a fixed mapping defining which gene determines the land use for an individual GIS land block. Single genes are symbols defining one of the ten possible land uses (Section 2.2).

The GA employs fixed size, unstructured populations with genotype uniqueness enforced by using a unique identifier tag for each genotype. Individual replacement is used with the lowest fitness member of the current population being eliminated. Selection is rank-based with a linear normalisation function being used to set the fitness values used to bias the selection process. The standard GA performance metrics of average population fitness and maximum population fitness are employed.

The uniform crossover operator is implemented using a crossover mask, with the crossover proportion set to 0.5. This value means that offspring contain on average equal proportions of genes from each parent, maximising the operator's exploratory power. The mutation operator simply replaces the current land use of a single gene with a value chosen at random from the nine other land uses. The operators are applied independently, with their probability of application set to the default values recommend by Davis (1991). The crossover to mutation proportions are adapted over the course of the GA run from 0.65/0.35 to 0.5/0.5. For the land use planning GA a double adaption is employed. The operators application probabilities respond to both how far towards the maximum length of the GA run the GA has progressed and the number of reproductive events that have failed to result in a genotype making a fitness gain. This ensures that even if the population converges well before the maximum run length, with consequent increase in the number of non-fitness-gaining reproductive events, the mutation operators are applied at the higher rate of probabilities before the run terminates.

5. Validation and Initial Results

5.1. Validation

Validation of LADSS is taking place on several levels. First the component models of LADSS are based on peer reviewed research which includes validation. This gives a foundation level of validation, particularly of the parameterisation of models, but also provides essential meta data such as the range of conditions in which the model was developed and the temporal or spatial resolution of data the models require. Careful use is made of this meta-data to ensure that models are not applied inappropriately. The second aspect of validation being undertaken is an analysis of the sensitivity of LADSS predictions to the spatial biophysical input data. Particular attention is being paid to these data, as there are significant cost implications in the current field based survey collection methods. These costs must be minimised consistent with making acceptably reliable assessments once the system is deployed operationally. Comparison is being made between results obtained using intensive field survey, remote sensed data, regional scale corporate data holdings and expert based assessments. Our intention is to both establish the degree of confidence that can be placed in predications using each of the data sources and also to determine how best to use the expert, corporate and remote sensed data to target field based measurement most effectively. This program of research is coupled with the third validation effort, a detailed comparison of LADSS predictions against known outcomes on test sites.

In addition to these scientific validations two other initiatives are being pursued with the aim of ensuring the relevance of LADSS and prioritising future developments. The first uses a technical focus group (referred to Section 2.3, Impact Assessments) and the second wider market research. The technical focus group was formed once a prototype was available for demonstration. The best time for technical focus group formation for DSS can be debated. For LADSS it was decided that rather than form the group at the start of the project where discussions would be against a "blank sheet" it would be beneficial to have a prototype tool to demonstrate the concepts and some of the functionality. This would both give the focus group members a better idea of the capabilities of the tools and provide a focus for discussion. The risk of course is that if the prototype were entirely rejected then resources would have been wasted.

Focus group discussions have concentrated on determining the issues that LADSS could be expected to address, the identification of the impact assessments that would be required to allow evaluation of alternative solutions and additional land use modules that are required. There was significant enthusiasm for the overall approach demonstrated by the prototype and a prioritised list of further developments drawn up. The issue of operational deployment of the system was also raised and it was agreed that there were two principal user communities with contrasting DSS delivery requirements. The first desired a consultancy delivery where LADSS acts as a focus for discussion between the land manager and a consultant expert in the operation of the DSS. The managers in this group desired outcomes to be presented on paper in formats acceptable to third parties such as banks or regulators. The second was where land managers required the facility to experiment at their convenience with a DSS maintained at a central location and accessed by low cost Internet browser technology. In both cases the user group were interested in having access to the information without being responsible for the tool. The wider market research initiative is on-going.

5.2. Initial Results for the Land Use Planning GA

The site used in the development and initial testing of LADSS is the Institute's Hartwood Research Station in Lanarkshire, Scotland. The Research Station is in an area defined by the European Union as agriculturally less favoured, with a mean elevation of 200m, heavy rainfall and exposed to the prevailing westerly winds. Although used as a research station, the farm is otherwise typical of a management unit on which LADSS may be employed.

The test problem was a 62 gene long genotype with each gene representing a land block with an allocated land use (from the range of 10 possible – Section 2.2), the fitness function was provided by the economic impact assessment module. This returned an NPV calculated over a 60-year period assuming a discount rate of 3.0 percent. The goal was thus maximisation of economic returns by optimising the land allocation across the farm. This problem has the advantage that it is possible to enumerate all possible solutions and thus have a known optimum against which to test the performance of the GA. The simplicity of the problem, with no spatial interactions between land blocks, does, however, mean that the GA will require further testing on problems that appear more challenging.

Two scenarios were examined, one with EU livestock grants set to current levels, Figure 3, and the other with them set to zero, Figure 4. The fittest solution in the with-grant scenario has an NPV of £2.8M. The allocation is nearly a suckler cattle monoculture with the only other land use present being four fields of barley (the crosshatched fields). By contrast the best solution found without the grants is a mix of spring barley, suckler cattle and upland sheep (NPV of £2.0M). The horizontal hatching indicates the fields allocated to upland sheep. Comparison of the two scenarios clearly shows the important role of grants in maintaining farm values but also the potential *locking in* of patterns of rural land use into monocultures. The mix of upland sheep and suckler cattle in the without-grant scenario probably reflects the ability of the different livestock to utilise marginal differences, (of the order of 5%), in pasture production due to soil factors (given the spatial pattern of allocations). The differences between the NPV values for the two livestock systems in the without-grant scenario are, however, marginal. It would thus be possible for any mixture of upland sheep and suckler cattle to be adopted on the non-spring barley land without serious financial penalty. In a fluctuating market the mixed livestock system could be hypothesised as preferable because it increases the range of markets the land manager has available. Evaluation of this hypothesis would, however, require the use of a more sophisticated of the economic impact assessment.

6. Conclusions and Discussion

The systems integration approach to DSS design has been effectively exploited in the creation of the LADSS prototype. In particular the recognition of the wider context of GIS-KBS integration has assisted in focusing the development of the system. The exploitation of the object-oriented paradigm, through the use of partially-mirrored data structures, has been significant in simplifying the process of communication between the GIS and KBS components of LADSS. It is expected that with continuing developments in object oriented communication software (OLE/CORBA) and OpenGIS it will perhaps be possible to continue to exploit this paradigm via a more robust common object repository for the GIS and KBS. Finally the initial testing of the GA based land use planning tools demonstrates the potential of LADSS as a flexible tool for the exploration of land use planning scenarios.

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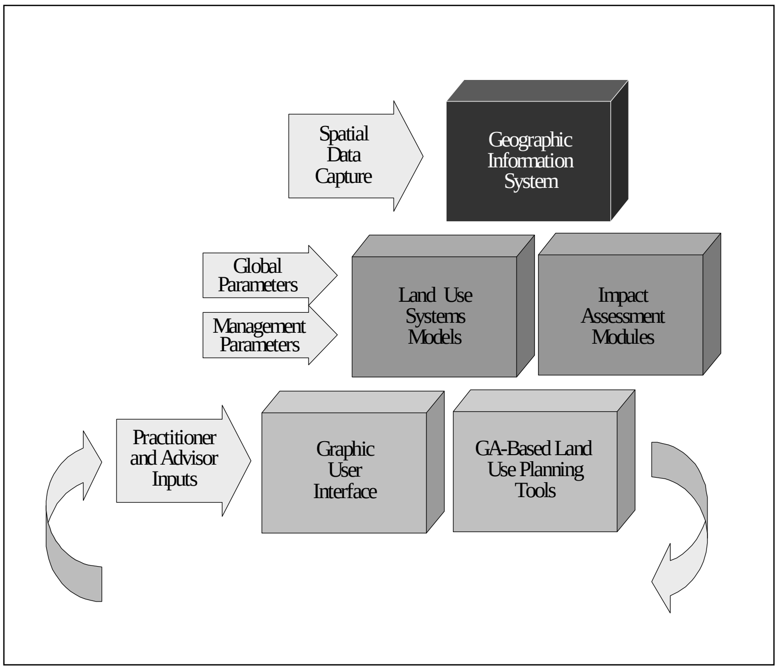

Fig. 1. LADSS Components

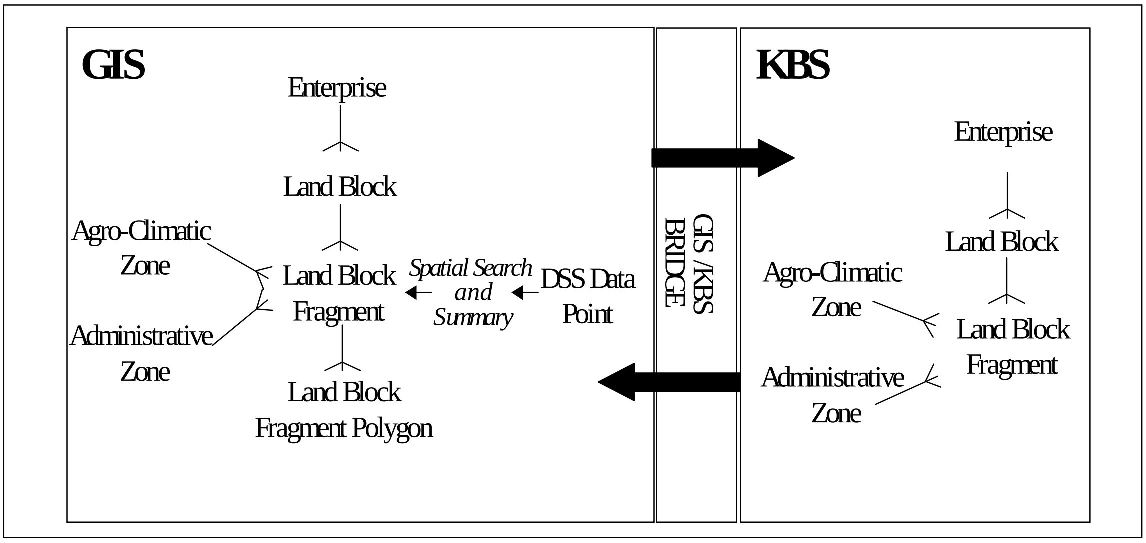

Fig. 2. Partially-Mirrored Data Structures

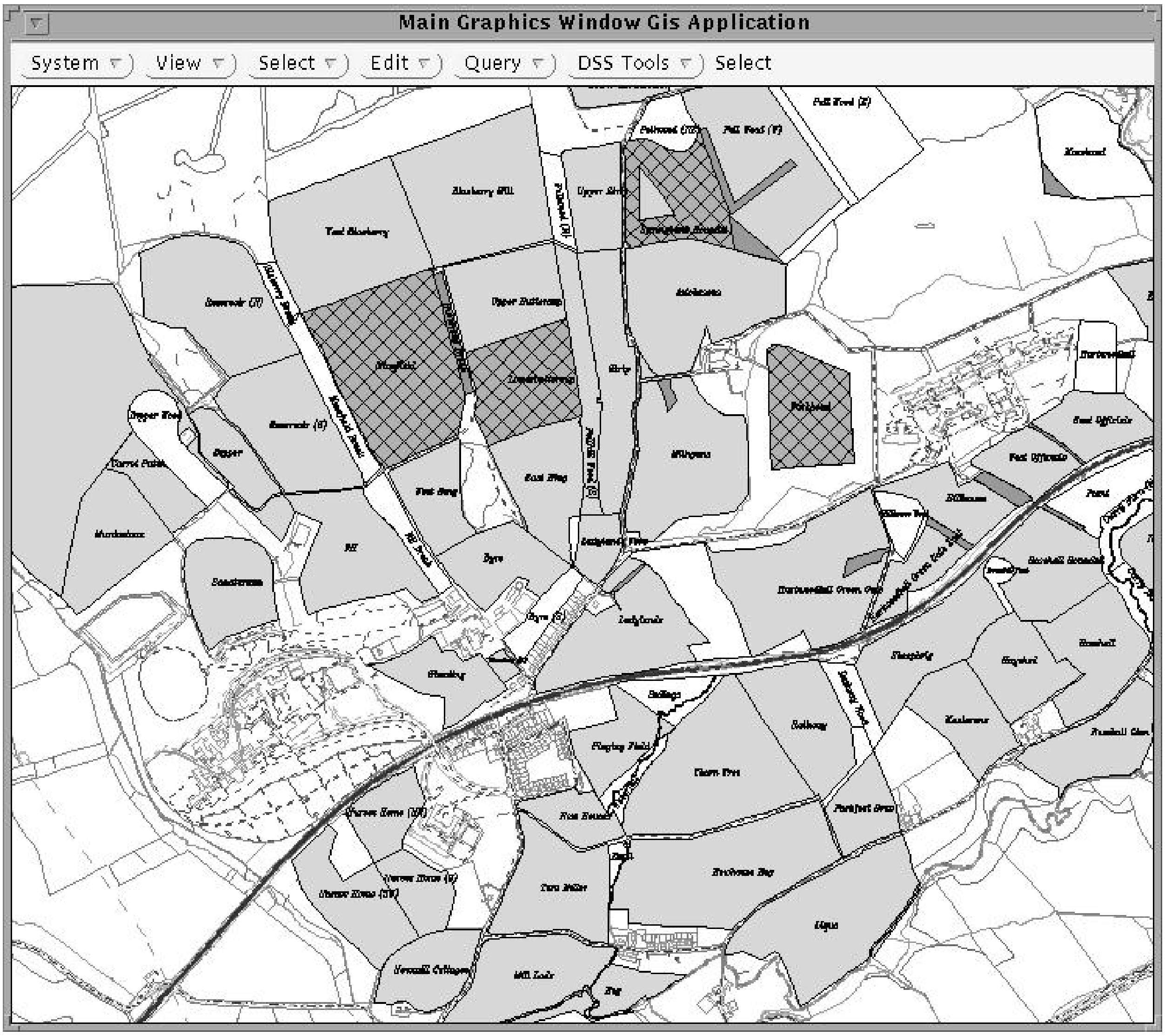

Figure 3. Land Allocation - with grants

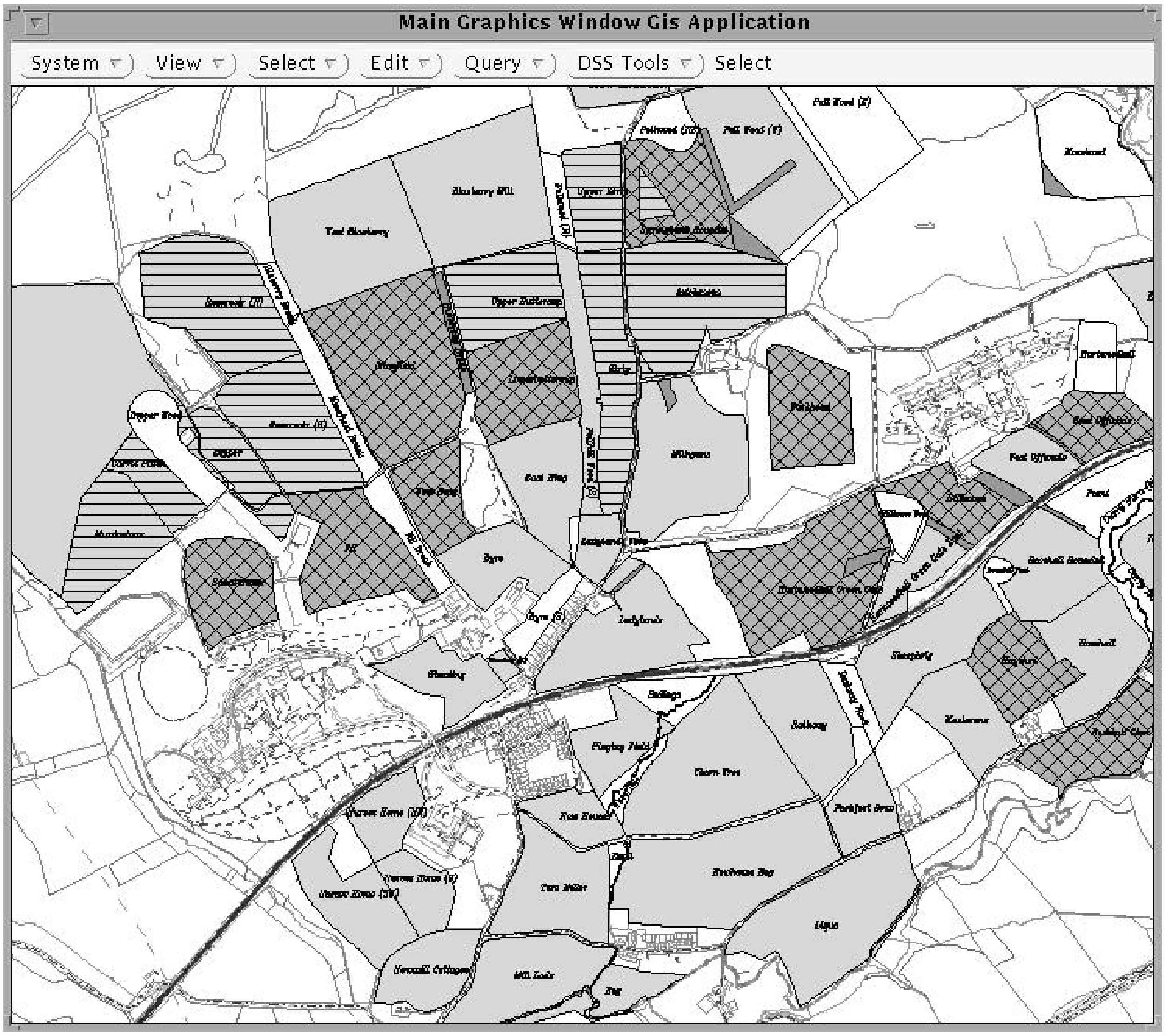

Figure 4. Land Allocation without grants