Australian National University

Selecting Among Five Common Modelling approaches for Integrated Environmental Assessment and Management

29th November 2012

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Outline

- Dimensions of integration
- Modeling considerations
- 5-modelling approaches
- Take home messages

Dimensions of Integration

- Issues
  - Human, water and land-related
  - Water quantity and quality, ecosystems
- Parts of river basin
  - Land, waterway, floodplain
  - Surface water, groundwater
  - Upstream, downstream
  - Spatial and temporal scales
- Major drivers
  - Uncontrollable – e.g. climate, commodity prices
  - Controllable – e.g. policy instruments, education

Dimensions of Integration

- Disciplines
  - Economics, ecology, engineering, sociology, hydrology, earth science etc
- Stakeholders
  - Government at various levels
  - Industry groups, community, environmental sector etc
- Models, data & other info
  - Range of methodologies – participatory approaches, predictive models, MCA etc
  - Integration tools & modelling and software frameworks

Dimensions of Integration

- Scales/levels of consideration
  - Spatial (e.g. farm, local, region, state, national, international)
  - Temporal (e.g. daily, monthly, annual)
  - Decision making (e.g. individual, group, institution)
  - Intervention (e.g. measure, option, policy, strategy)

- Dimenions of integration are not mutually exclusive

Considerations for modelling choice: The rule of 7

1. Model purpose
2. Types of data available
3. Treatment of space
4. Treatment of time
5. Treatment of entities/structures
6. Treatment of uncertainty
7. Resolving the model

Considerations for modelling choice: (1) Purpose

- Prediction
  - E.g.: predicting the chance of algal bloom given there is going to be an increase in nutrient load
  - Complex vs simple model structure
  - Data for calibration and validation
- Forecasting
  - E.g.: forecasting the chance of rain tomorrow given the observed rain today
  - Assumption of continuity

Considerations for modelling choice: (1) Purpose

- Management and decision making under uncertainty
  - Simulation “what-if” vs optimization models
  - Strategic, tactical, and operational models
- Social learning
  - Interactive model-facilitated process
  - Raise awareness, gain insight, and enable change
  - Models as heuristics with focus on understanding and communication

Considerations for modelling choice: (2) Types of data available

- Types
  - Quantitative (e.g. time series) vs qualitative (e.g. expert opinion)
- Use
  - Conceptualization/formulation
  - Calibration/parameterization
  - Validation

Consideration for modelling choice: (3) Treatment of space

- Non spatial models
  - E.g. indicators of ecological abundance
- Lumped/discrete temporal models
  - E.g. average annual nutrient load to a water body
- Dynamic, quasi-continuous model
  - Over-time-behaviour
  - Time step (small vs big)
- Continuous models
  - Infinitesimally small time step

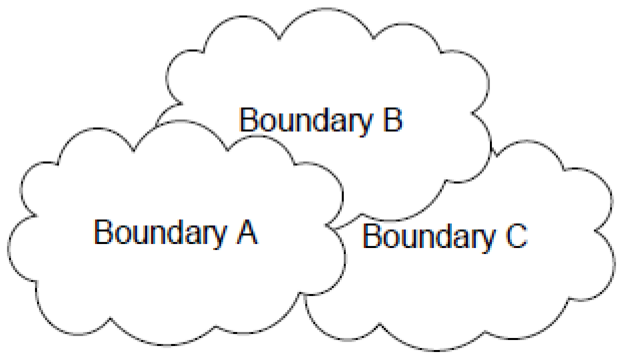
Considerations for modelling choice: (4) Treatment of time

- Non temporal, steady model
  - E.g. predator-prey model
- Lumped spatial models
  - E.g. catchment-scale model
- Compartment spatial models
  - Homogenous sub-areas
  - E.g. sub-catchment-scale model
- Grid models
  - Non-homogenous areas

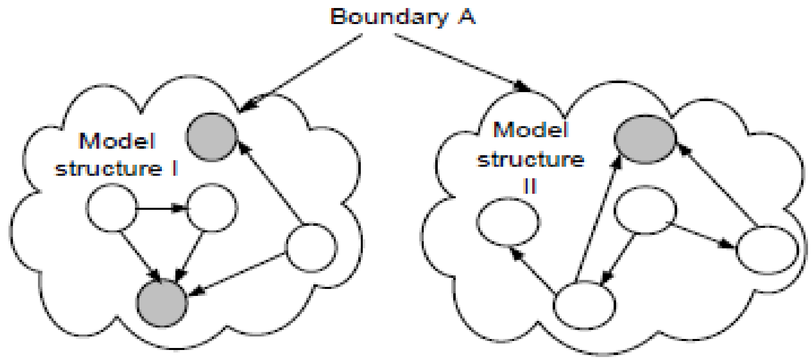
Consideration for modelling choice: (5) Treatment of entities/structures

- Aggregate level of a phenomenon or a population
- Individual level (e.g. agent based)

Consideration for modelling choice: (6) Treatment of uncertainty



Note: Based on plausible interpretations about the system, there are multiple boundaries to be modelled. Context uncertainty relates to the selection of a specific model boundary.



Notes: Within the same model boundary, there are multiple forms that can be modelled. Structure uncertainty relates to the selection of the variables and the interactions among them.

Consideration for modelling choice: (7) Resolving the model

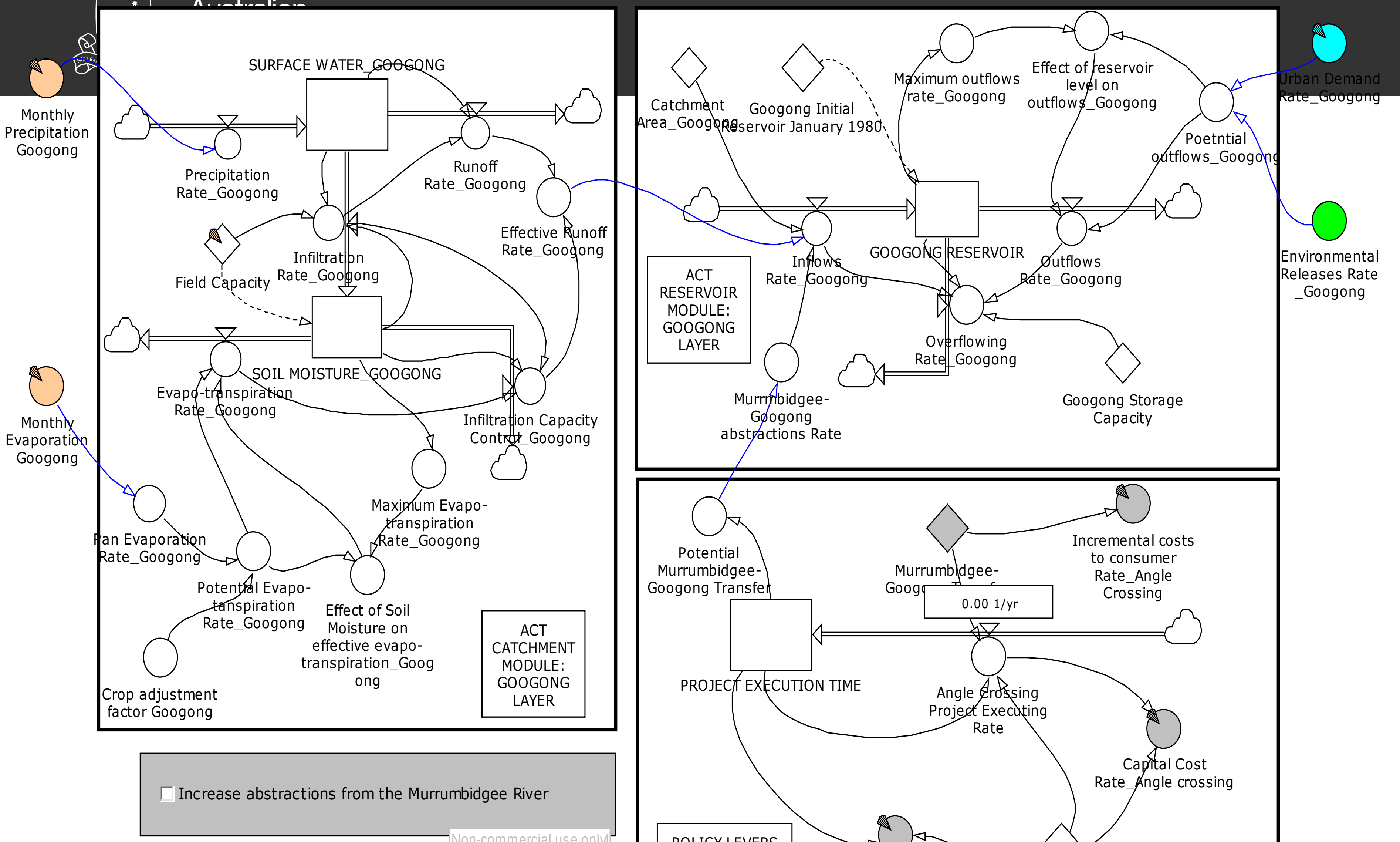
- Scenario-based approach (‘What-if?’)
- Analytical solution approach
- Optimization (single and multi-objective)
- Hybrid approach

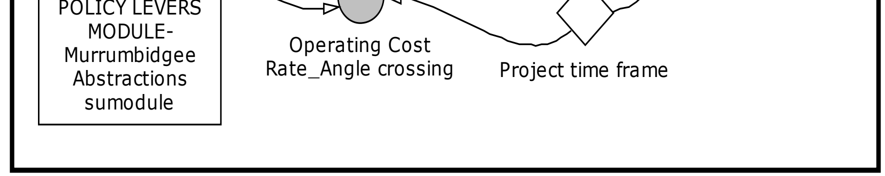
Modelling Approaches

- System Dynamics
- Bayesian Networks
- Agent Based Modelling
- Knowledge Based Modelling
- Coupled Modelling

Systems Dynamics

- A methodology for learning, communicating and decision making, where key considerations are:
  - capturing the causal structure (i.e. physical/information flows, feedback loops and delays) that generates the systemic behaviour.
  - knowledge has various sources, quality and types.
  - system knowledge and data can be updated
- Uses stocks and flows to represent system's states and causal relationships- i.e. to simulate behaviour-over-time.





El Sawah et al. *"Simply, we need to build a new dam", Is it really "Simple": A System Dynamics Approach to support Integrated Water Resource Management* (submitted to Journal of Water Resource Management).

Model considerations for system dynamics

1. Model purpose: social learning
2. Types of data available:
   - mainly qualitative in model conceptualization
   - mainly quantitative for model calibration and testing
3. Treatment of space: limited
4. Treatment of time: over-time-behaviour
5. Treatment of entities/structures: aggregate
6. Treatment of uncertainty: model structure and parameters
7. Resolving the model: what-if approach

Advantages

1. Capacity to model feedback and delays

2. A framework of techniques that improves systems thinking skills

3. Distinction between stocks and flows sharpens thinking about the processes that drive the behaviour of the system

4. Distinction between “actual” and “perceived” system conditions

Disadvantages

1. Risk of “super-elegant” but less useful models

2. Inclusion of uncertain feedback loops may model behaviour that does not correspond to real world behaviour and that is often very difficult to verify or validate

3. Propagation of uncertainties become challenging with feedback interactions

Bayesian networks

- Uses conditional probabilities as a common basis to link cause and effect – i.e. to determine likelihood of different outcomes

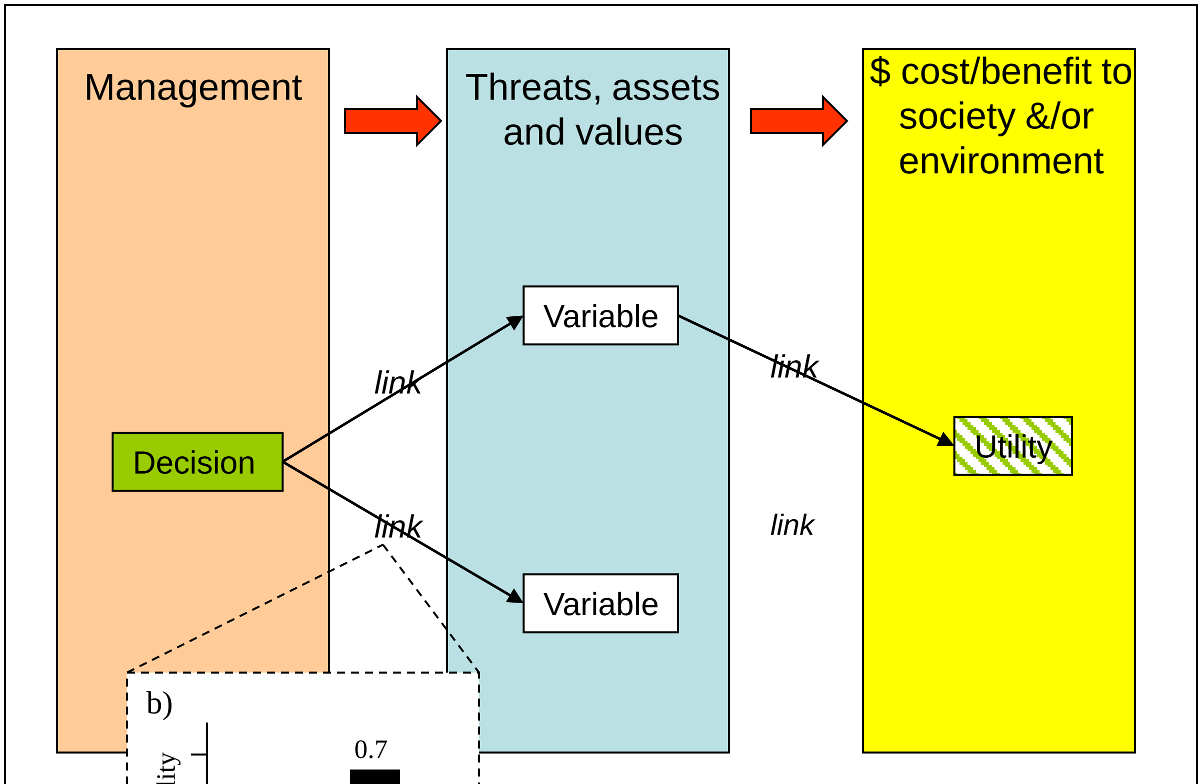
- **Conditional probabilities derived from:**
  - many (1000's) of runs of component models
  - expert elicitation
  - stakeholder surveys
  - observed data – categoric and numeric

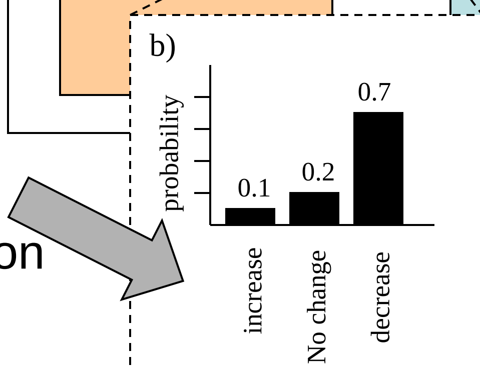
Model considerations for Bayesian network

1. Model purpose: management and decision making
2. Types of data available: both qualitative and quantitative
3. Treatment of space: lumped
4. Treatment of time: lumped
5. Treatment of entities/structures: aggregate
6. Treatment of uncertainty: probabilistic relations within BNs reflect uncertainty in model parameterization, not model structure
7. Resolving the model: what-if approach

Bayesian Networks

2 components: Structure and Probabilities





Observed data

Model simulation

Expert opinion

Literature

Outputs can be qualitative *or* quantitative

e.g. Decrease, No Change, Increase

e.g. >10 ha decrease, <10 ha decrease, No change, <10 ha increase, >10 ha increase

Advantages

1. Handle lack of data by integrating different sources of information to derive the conditional probability distribution between variables

2. Complex models are broken into components to be addressed separately

3. Easy to communicate model results to stakeholders, and non-technically trained users

Disadvantages

1. Inability to handle feedback

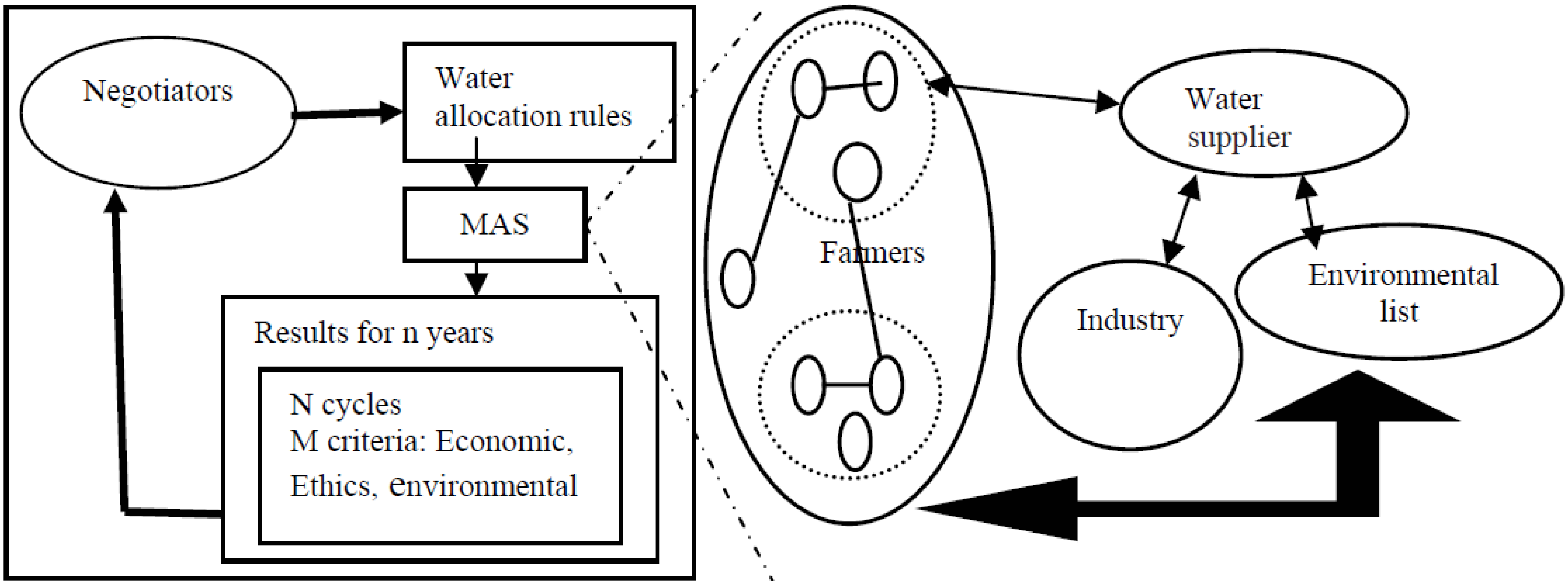
2. Because structures of BNs are relatively simple, they may be more prone to structural errors than more mechanistic models

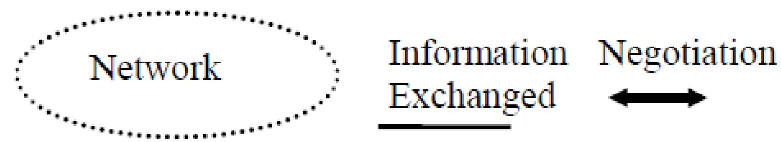
3. Practical implementation requires discretization of continuous variables

Agent Based Models

- Agent based models, multi-agent systems …
  - Simulate the dynamics of individuals or groups of animals or humans (‘agents’)
- Agents
  - Has their own goals and uses the environment to achieve these goals (according to pre-defined rules)
  - Reacts to changes in the “perceived” changes in environment
  - Agent share resources and communicate together
  - E.g. landholder, MDBA, water supplier, sheep, crop, climate
- Often used in participatory modelling process

Le Bars et al. (2005)





Agents	Number	Type
Farmers	n	Cognitive
Water supplier	1	Cognitive
Information supplier	1	Reactive
Crops	n	Reactive
Climate	1	Reactive

Le Bars, M., Attonaty, J.M., Pinson, S., and Ferrand, N. (2005). An agent-based simulation testing the impact of water allocation on farmers collective behaviors, Simulation, 81:223-235.

Model considerations for agent based modelling

1. Model purpose: social learning
2. Types of data available:
   - mainly qualitative in model conceptualization
   - mainly quantitative for model calibration and testing
3. Treatment of space: very flexiable
4. Treatment of time: over-time-behaviour
5. Treatment of entities/structures: individual and aggregated
6. Treatment of uncertainty: Agent rules
7. Resolving the model: what-if approach

Advantages

1. A framework of techniques that promotes thinking about elementary system structures, and their interactions

2. Suitable for theory-testing

Disadvantages

1. High number of parameters and significant resource requirement

2. Complexity of agents, and interactions make it difficulty to explain emergent behaviour

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Knowledge based

- Knowledge is encoded into a knowledge base and then an inference engine uses logic to infer conclusions

- Knowledge-based models need to be ‘learned’ based on the experience of the user (i.e. human-supervised learning)

- Knowledge systems:
  - Rule-based models, where the model is formalised by a set of “if-then-else” rules
  - Logic-based models, where the models is expressed as a series of logic statements, called facts

Model considerations for knowledge systems

1. Model purpose: system understanding
2. Types of data available: qualitative and quantitative
3. Treatment of space: non-temporal, lumped
4. Treatment of time: non-spatial, lumped
5. Treatment of entities/structures: aggregate
6. Treatment of uncertainty: Fuzzy set theory to account for uncertainty in experts rules
7. Resolving the model: what-if approach

Advantages

- Expert knowledge provides rich source of data

Disadvantages

- All knowledge need to be elicited and coded beforehand
- In some cases, it may be computationally expensive

Coupled modelling

- Combining complex models from different approaches
- Coupling types
  - – Loose coupling
  - – Tight coupling, (with feedback)
- The integrated model does not necessarily work on the same temporal/spatial scale as components

Advantages

- Leverage the strengths of coupled approaches

Disadvantages

- Extensive levels of skills and resources
- Challenging to propagate and assess uncertainties through the integrated model

Take home messages

- End user requirements should drive model selection (not vice versa)
- Good understanding of theory is what distinguish good and “not good” modellers
- Uncertainty assessment is ongoing modelling activity
- Balance model complexity and learning outcomes is key (but not always the case!)