The management of environmental resources: decision making

What is a system?

- A system is composed of interrelated components, connected together in order to facilitate information, matter and energy flows
- A dynamical system is a process where the variables' values change over time

What is an environmental system?

- It is a system concerning an environmental domain (air, water, soil, land, agriculture, forests, etc.)
- It can be described by various components where different processes take place (biological, chemical, physical, etc.)

An example

- A forest stand can be considered as a system or a whole where its functions is depended on interactions of its parts, the soil, roots, stems, crowns, understory etc.
- In isolation, the parts can never be identified as a forest stand because the function of the stand is not embedded into individual parts but into the interaction among all of its parts.

Complex systems?

- Structural properties:
  - local interactions
  - non linear
  - feedbacks
  - open (difficult to find boundaries)
- Behavioural properties
  - emergent
  - self organises
  - adaptive

Environmental systems are complex systems

- huge quantities of data to manipulate
- low quality of data (uncertainty, measurement errors, missing data)
- different spatial and temporal scales (from seconds to years, from local to global)
- dynamic and stochastic behaviour
- at the crossroad among many disciplines/ domains

Environmental systems and policy resistance

- Policy resistance: the law of unintended consequences
  - US pay farmers to take soil out of cultivation to combat erosion is a waste of money (Business Week 3/18/96)
  - Road building programs to reduce congestion have increased traffic
  - ...

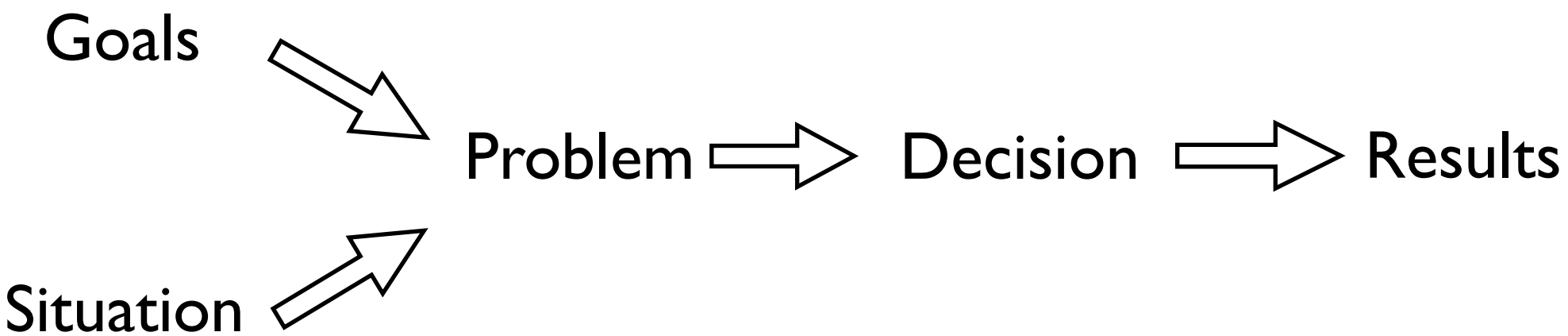
Policy resistance

- US policy on fire suppression has increased size and severity of forest fires
- Flood control efforts based on structural interventions often lead to more sever floods
- Pesticides and herbicides have stimulated the evolution of resistant pests and weeds, killed natural predators and accumulated up the food chain

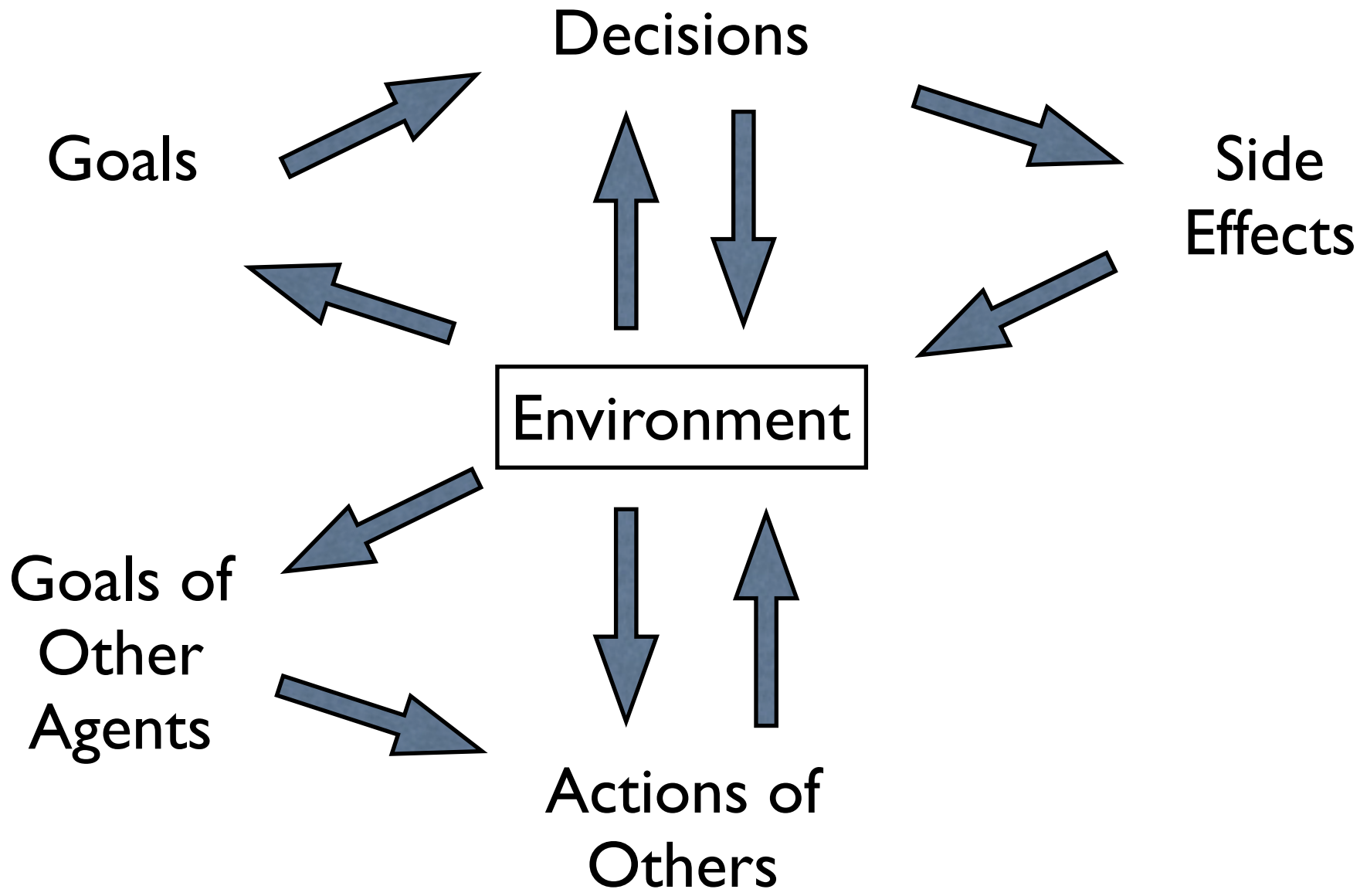
The role of the Environmental Manager

- The Environmental Manager must design policies to manage the environmental system
  - preserving the natural resources
  - protecting the environment and ecosystems
  - fostering human development
- The EM must be ‘smart enough’ to avoid policy resistance!

The wrong view



A more realistic view...



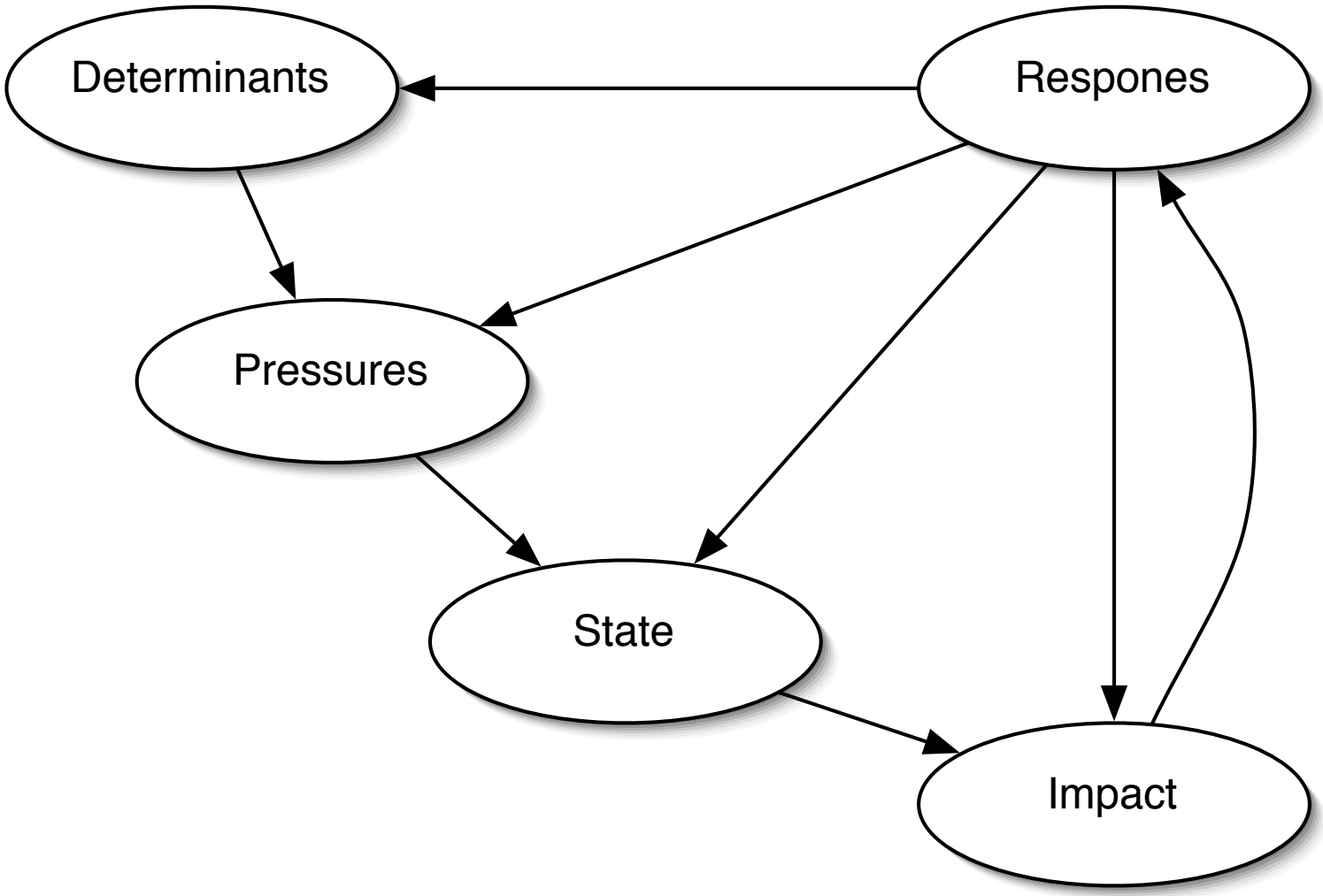
DPSIR

Determinants-Pressures-States-Impacts-Responses

The DPSIR schema

- Proposed by the European Environmental Agency (1994 and 1996)
- It can be used to describe the evolution of a natural system under human influence

The DPSIR schema



An example (i)

- A lake, surrounded by fields and forest, a fishermen village, small tourism
- Land use practices are determinants
- They produce a flow of nutrients in the lake (a pressure)
- The trophic level in the lake increases, algal blooms (the state changes)
- The impact is a loss on tourism and fishing activities

An example (ii)

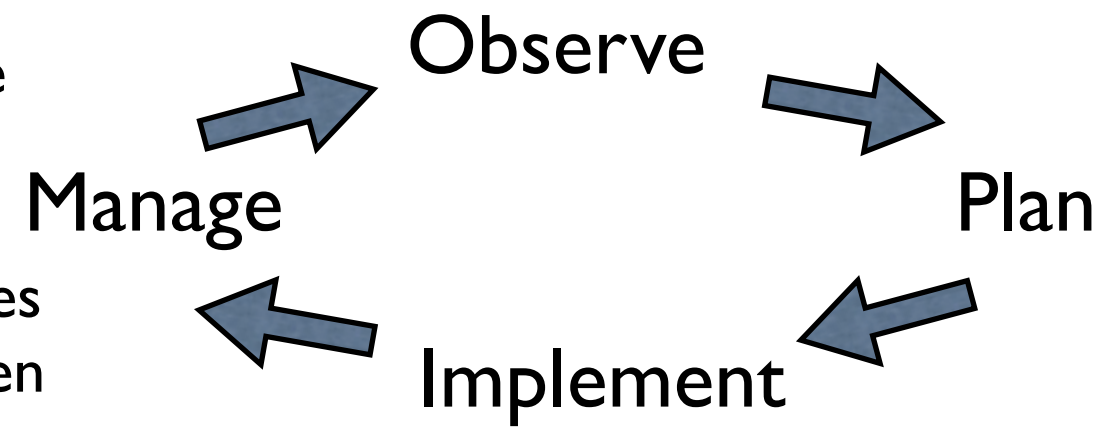
- The environmental agency can decide on alternative *responses:*
  - Regulation on use of nitrogen based fertilizers (action on pressures)
  - Harvesting algae and/or oxygen insufflation (action on state)
  - Monetary compensation for losses (action on impacts)

Making Decisions

The elements and the process of decision making

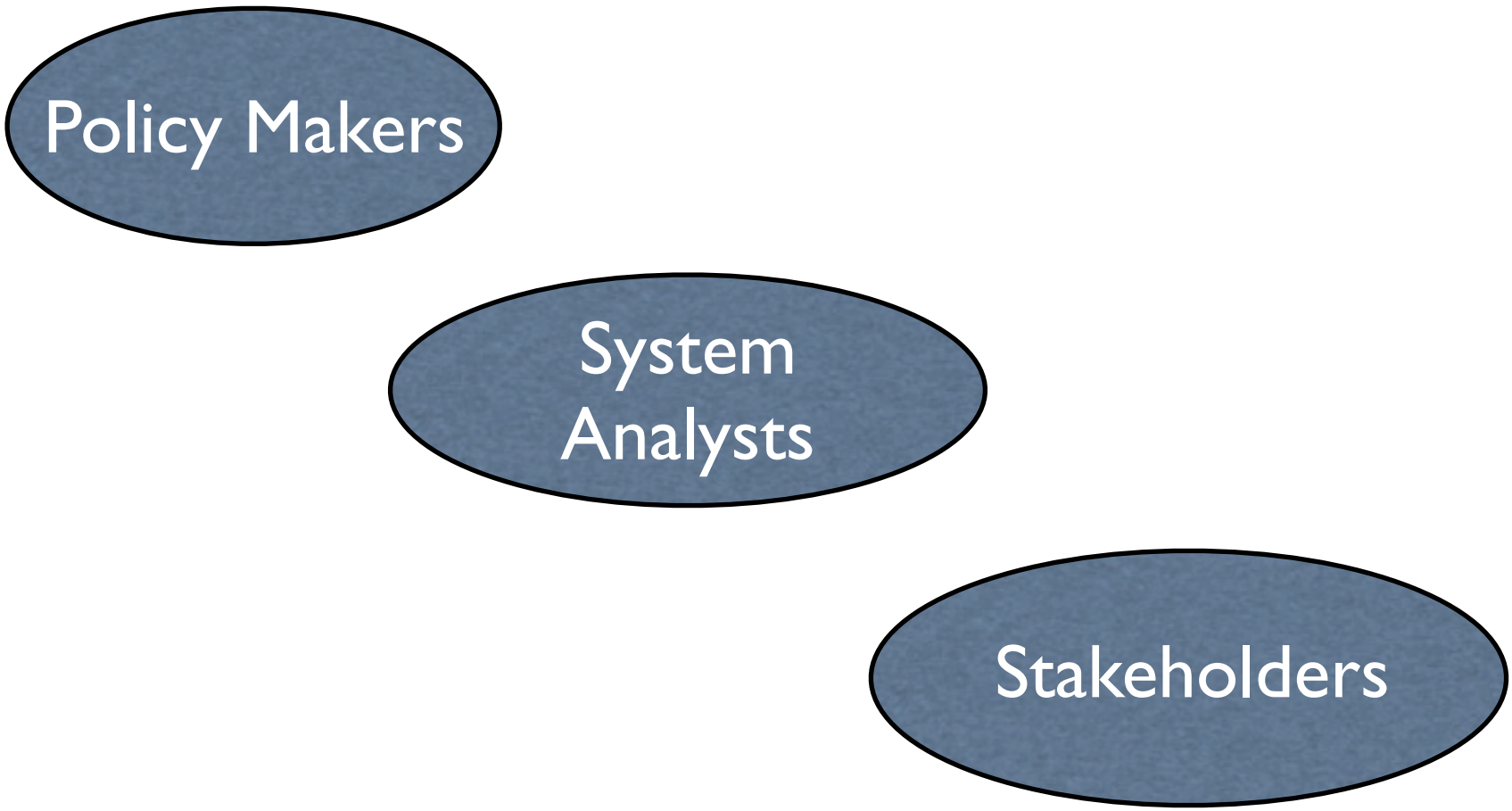
Interventions, Actions, Decisions

- Observation of the system leads to interventions which are organised in a plan of actions. The plan is implemented and defines the decisions to be taken to manage the system



- It is a feedback loop!

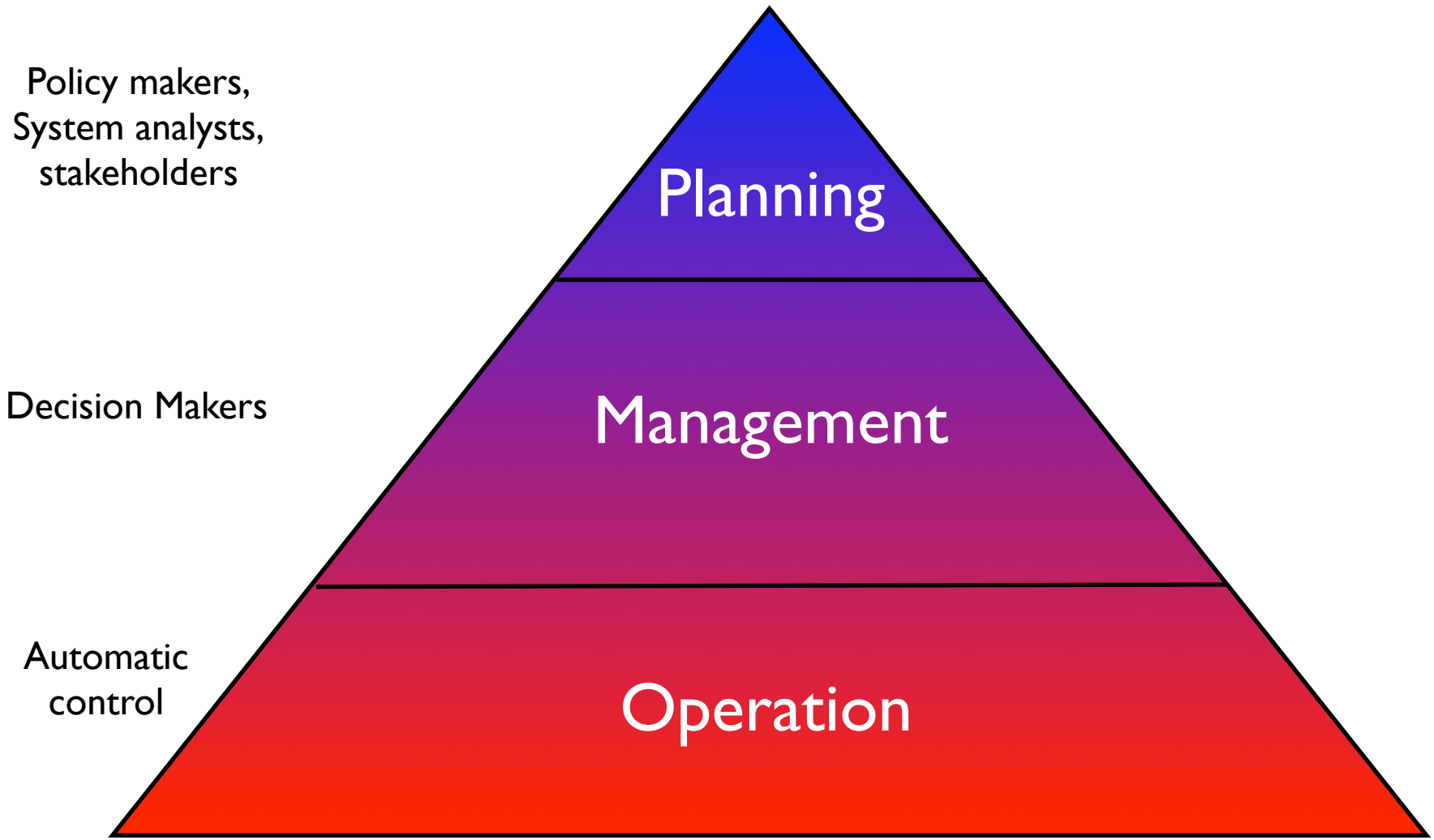
The decision makers



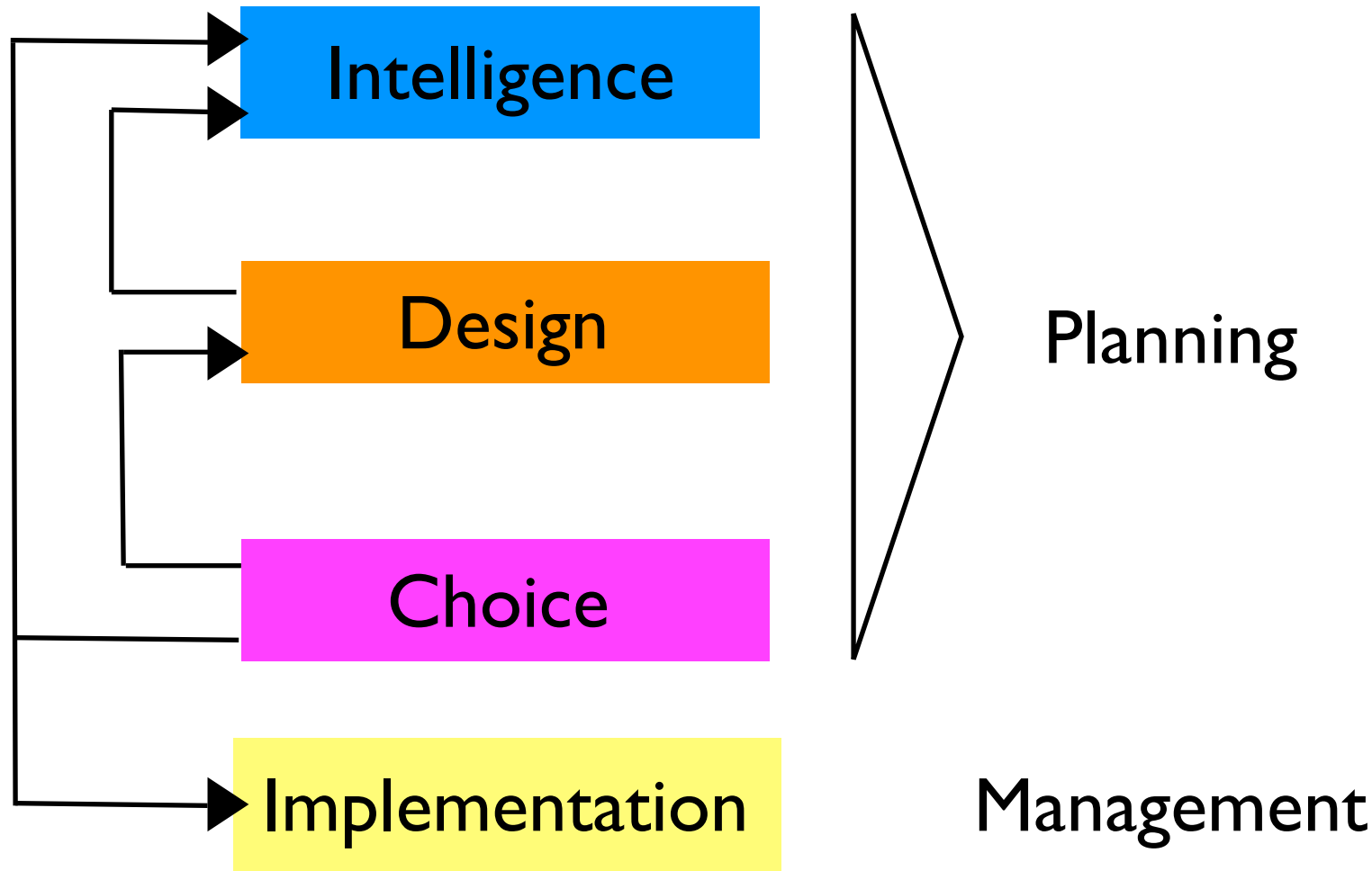
The roles of decision makers

- The technical authority which orders a project (e.g. a water authority)
- The political authority which approves/rejects a project (e.g. a local government)
- The system analyst who develops the project
- The stakeholders (local interest groups)

The levels of decision making



Decision making: an iterative process



Simon (1960)

Planning

- Planning means to define objectives and to design a policy which, applied to the system, can be judged a valid solution to achieve the objectives.
  - intelligence: objectives, criteria and indicators
  - design: alternative policies
  - choice: alternative evaluation and selection

Programmes and projects

- A project is the choice of the alternative to reach the set objectives
- A programme is a set of projects to be executed over time
- A project defines the intervention alternatives to reach given objectives
- A policy can be defined at planning, management and operational levels

Intelligence

- The “intelligence” phase of the decision making process involves
  - the definition of the objectives and the range of possible actions/interventions
  - the selection of criteria and indicators to measure the compliance to the set objectives

Design

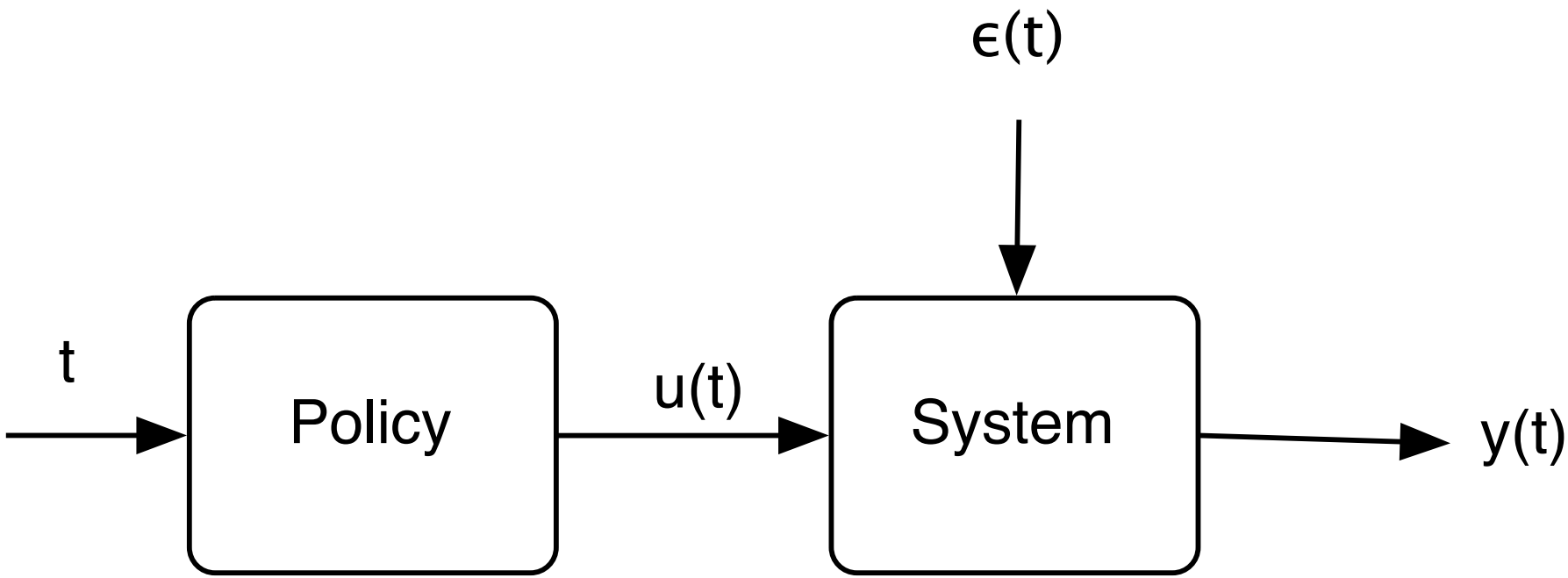
Design of alternatives

- It is the exploration of the various sets of actions to be conducted to achieve the project objectives
- The result of the design of alternatives are plans and policies

Open-loop policies

- The policy does not take into account the system state
- Such policies are often coded in laws and regulations
- They are often affected by policy resistance!

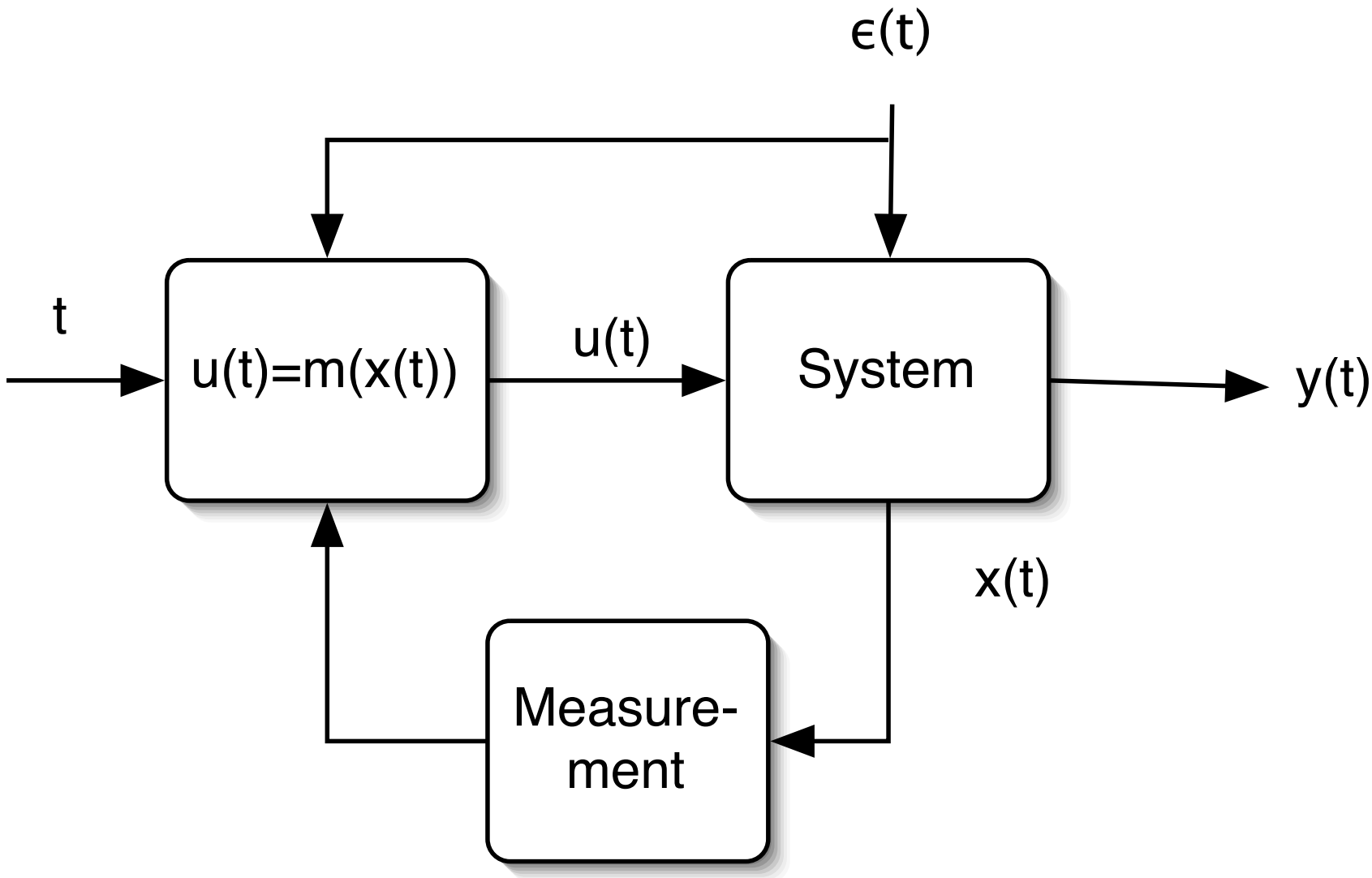
Open-loop policy



Closed-loop policies

- The decision is made on the basis of the available information at that moment
- The policy defines a *control law*
- Policy resistance is still possible but at least we know it's our fault!

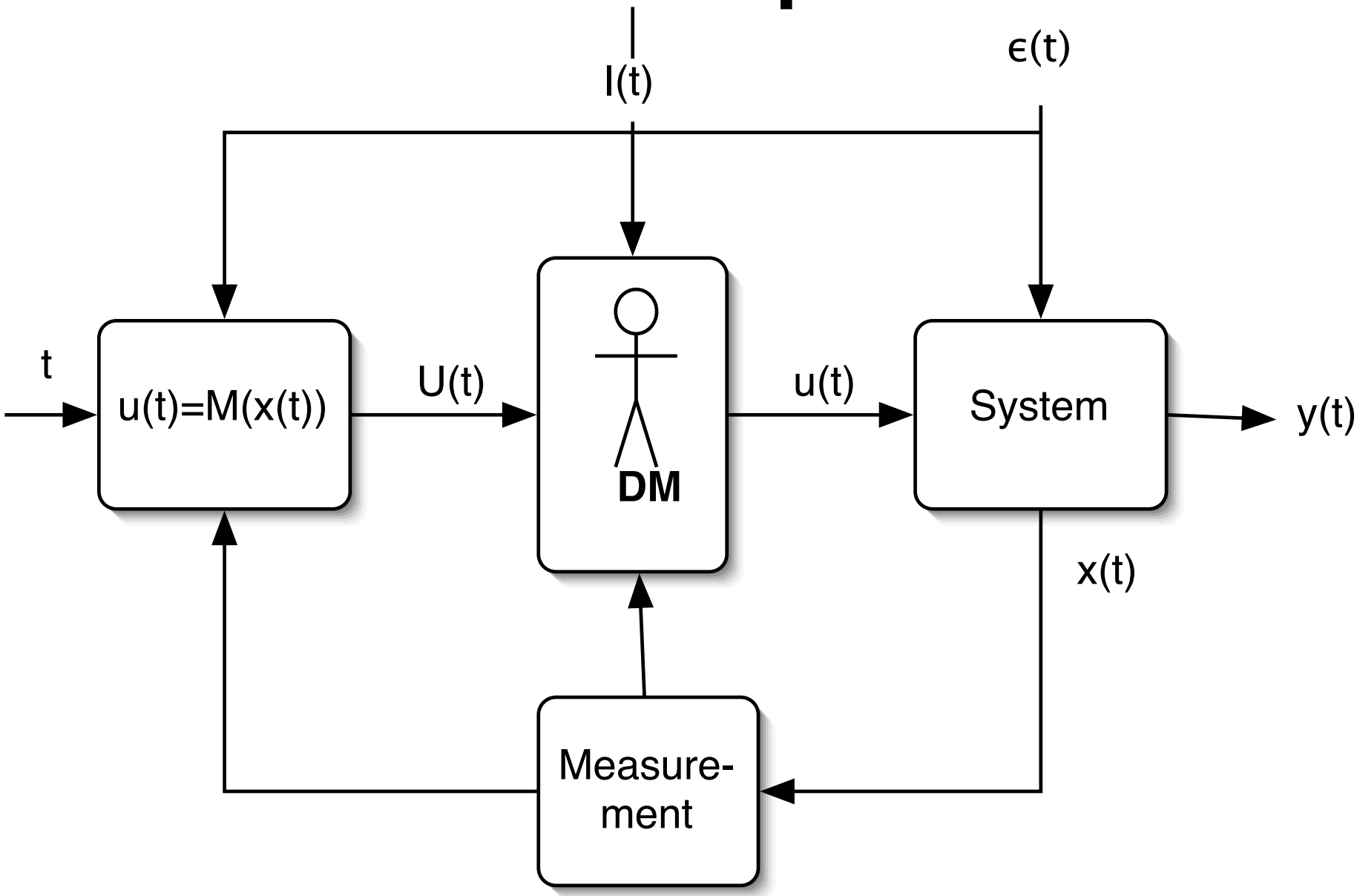
Closed-loop policy



Set-valued policies

- Closed-loop policies are designed using Control Engineering and Operations Research techniques
- Originally devised for the management and control of electro-mechanical systems
- Here, the impact of uncertainty and the role of the human decision maker are different
- We do not need ONE answer. We need a SET of possible answers

Set-valued policies



Choice

Choice of the alternatives

- The alternatives must be examined and ranked to select the best one
  - complete rationality
  - partial rationality

Complete rationality

- One objective
- One decision maker
- The problem is to find the best policy, given the objectives
- Choice is straightforward!

Partial rationality

- Multiple objectives
- Multiple decision makers
- Under-representation of stakeholders
  - The top-down approach does not put in the right perspective the role of stakeholders

Partial rationality

- Impossible to define all indicators using the same measurement unit
  - the limits of CBA
- Different criteria (and indicators) express the interests of different stakeholders
- Indicators are conflicting

Multiple objectives

- Identification of efficient alternatives
- Impact estimation
- Alternative evaluation
  - MAVT - Keeney e Raiffa, 1976
  - AHP - Saaty, 1980
  - ELECTRE - Roy, 1993
- Mitigation and compensation

Multiple decision makers

- Alternative comparison
- Negotiation
- Political choice
- Mitigation and compensation

Management

- The manager must implement the policy on the real system
- The world is more complex than our models
- The management must adapt to the situation at hand, being able to foresee the potential evolution

Multi-Attribute Value Theory

- Structuring preferences and Value Functions
- Other options are
  - analytic hierarchical process (AHP)
  - ELECTRE methods

The phases

- Scenario definition and project alternatives
- Choice of criteria and indicators
- From indicators to objectives
- Dominance
- Weight assignment
- Alternative ranking
- Sensitivity analysis

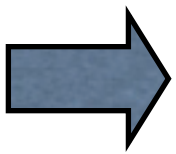
Scenario definition

A scoping example

- Egyptian water plan
- Strategic objective of the government: improve the quality of life
- Specific objective of the plan: improve the quality of life by improving water availability
- Objectives can be expressed as visions:
  - Continuous water supply, instead of 1 day in 3 from 17 to 20

An example: the Egyptian Water Plan

- Limited groundwater availability
- Most water comes from the Nile (Aswan Dam and lake Nasser)
- Expected water availability will decrease (climate change and increase in consumption)
- Water quality is decreasing



Water a limiting factor for Egypt growth

Objective: water availability

- Increment the water availability
  - Water desalinisation
  - Intercept flash floods
  - Reuse wastewater and STPs for water reuse
  - New pumping plants
  - Increase the water distribution efficiency
  - Change irrigation technology: from surface water to drip technology

Objective: environmental protection

- STP for civil, industrial and agricultural wastewater
- Combat soil salinity by improving water drainage
- New laws to protect water quality

Interventions: regulation policies

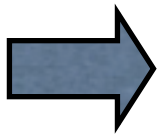
- Redefine the regulation policy for Lake Nasser
- Redefine the groundwater management policies
- Redefine the water distribution policy among districts

Interventions: affect behaviour

- Constrain and manage the agricultural expansion, the cultivation types
- Bounds on urban expansion
- Tax chemicals for agriculture
- Tariffs on water consumption
- Subsidise land reclamation from the desert

An example: managing hydrological risk

- In many regions geomorphology defines areas of high hydrological risk
- Clime and weather conditions can create risky situations
- Land use also affects risk



How to reduce the risk?

Structural interventions

- Weirs, barrages, check dams, conduits, riverbanks, flow redirection
- All these interventions affect the natural flow of the water courses
  - Discharge times have been reduced
  - Flow rate has increased
  - Downstream flood peaks have increased

New interventions

- Reduction of potential risk
  - Move out of flood areas
- Increase of water storage
  - Reforest
  - Impoundment basins
  - Increase permeability soil in urban areas
  - Expand buffer areas

New interventions

- Rebalance the geomorphological equilibrium
  - Slope stabilisation
  - Fire control
  - Forest clearing
  - Manage land uses
- Live with risk
  - Emergency management

Classification of actions

Structural

Non-structural

Planning

Management

Structural vs non-structural actions

- Structural
  - Physical interventions on the system such as new infrastructures
- Non structural
  - Modifications on the functions on the system (e.g. policies and regulations)

Planning vs management actions

- A planning action is taken "once" and then it is applied to the system
- A management action is taken every now and then, on the basis of fresh information on the system state

Examples

ACTIONS	Planning	Management
Structural	Hydropower plant station parameters	Periodical management of riverbanks
Non-structural	Environmental flows	Reservoir Release decision

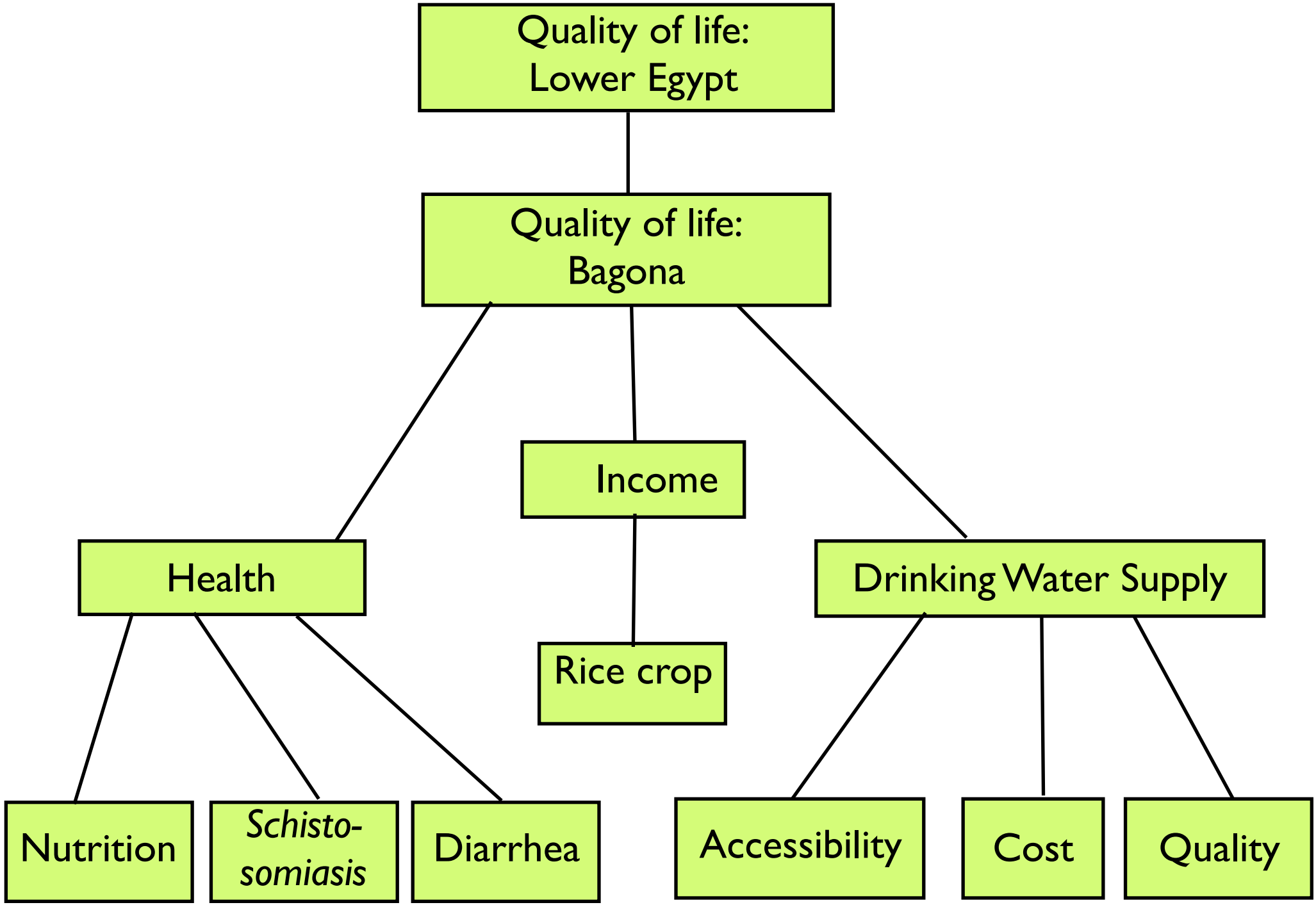
Criteria and Indicators

Criteria

- According to Keeney and Raiffa (76) they must be:
- Complete
- Operable
- Decomposable
- Not redundant
- Minimality

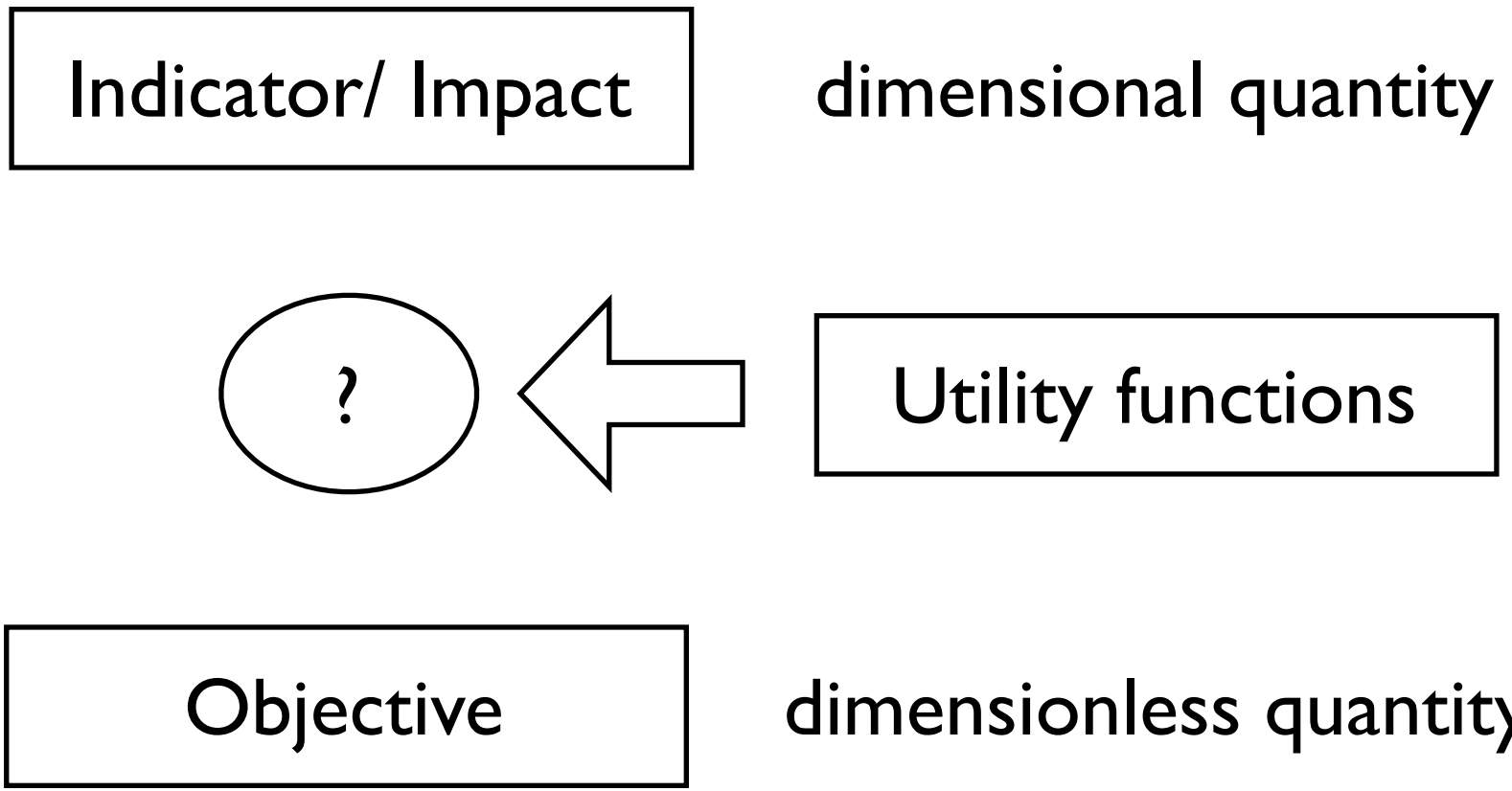
Definition of criteria and indicators

- Evaluation criteria must allow representing objectives and all expected side-effects (positive and negative)
- Criteria must be hierarchically organised
  - sector criteria
  - “leaf” criteria (are indicators)
- Indicators are functions measuring how much an alternative satisfies a criteria


Quality of life:
Lower Egypt
Quality of life:
Bagona
Income
Health
Drinking Water Supply
Rice crop
Nutrition
Schisto-somiasis
Diarrhea
Accessibility
Cost
Quality

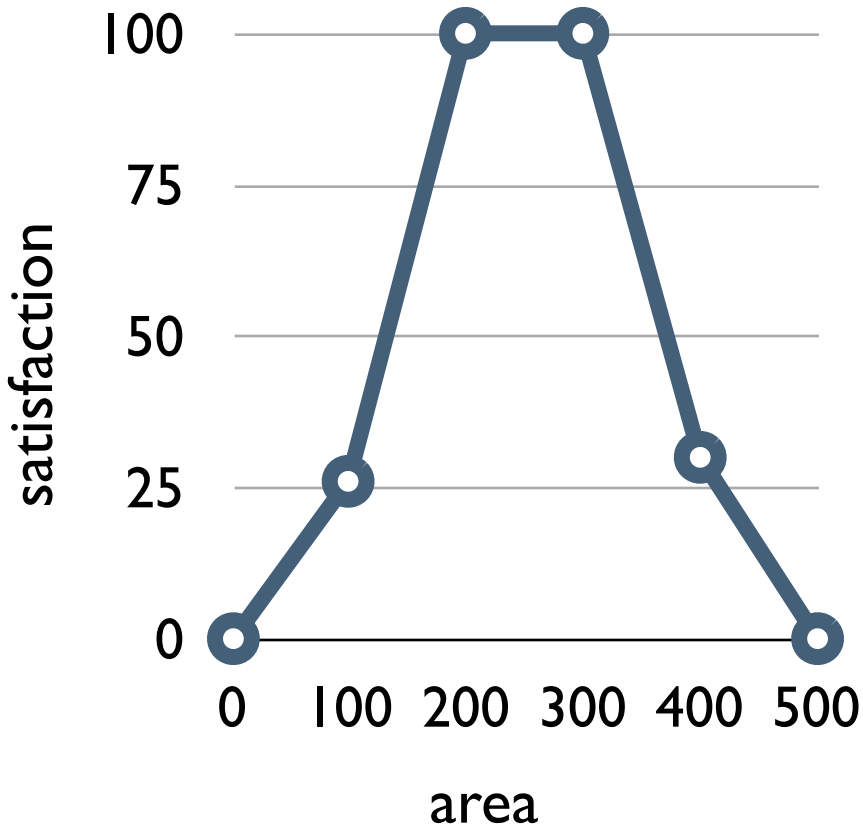
From indicators to objectives

The role of Utility functions

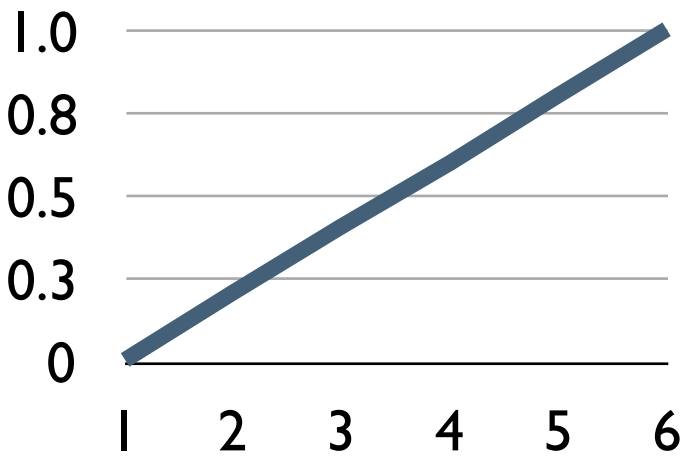


Example

- A proposed alternative reduces a wetland area
- The area is a good indicator of the reduction
- Environmentalists' satisfaction is not well represented by the area
- We need an utility function



Examples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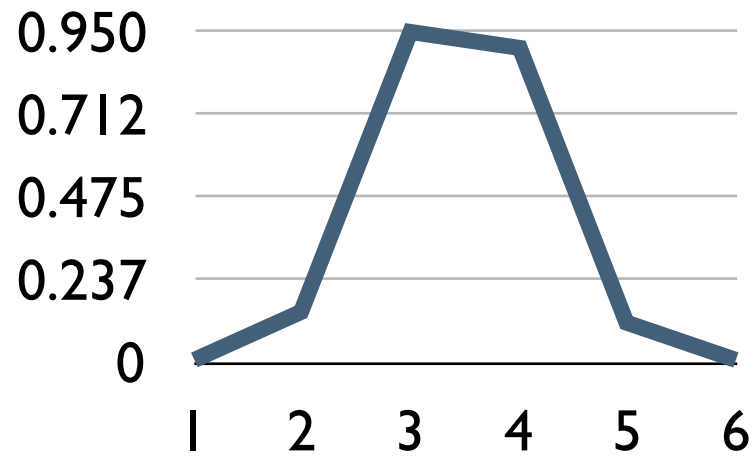
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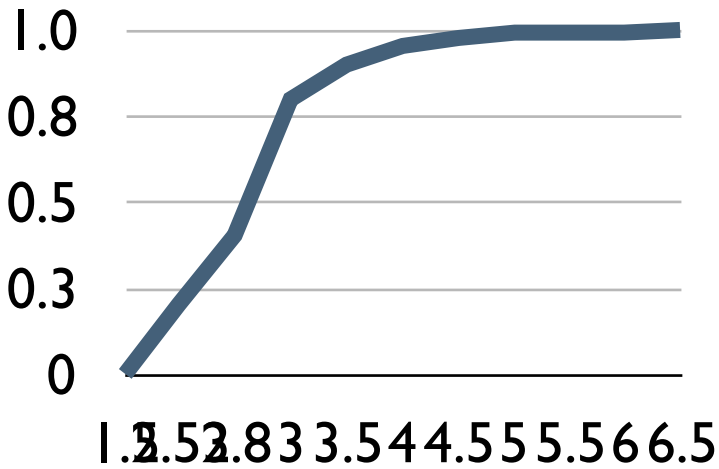
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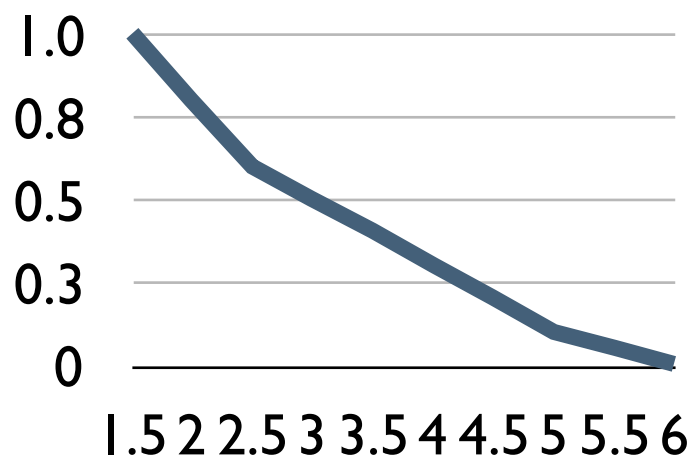
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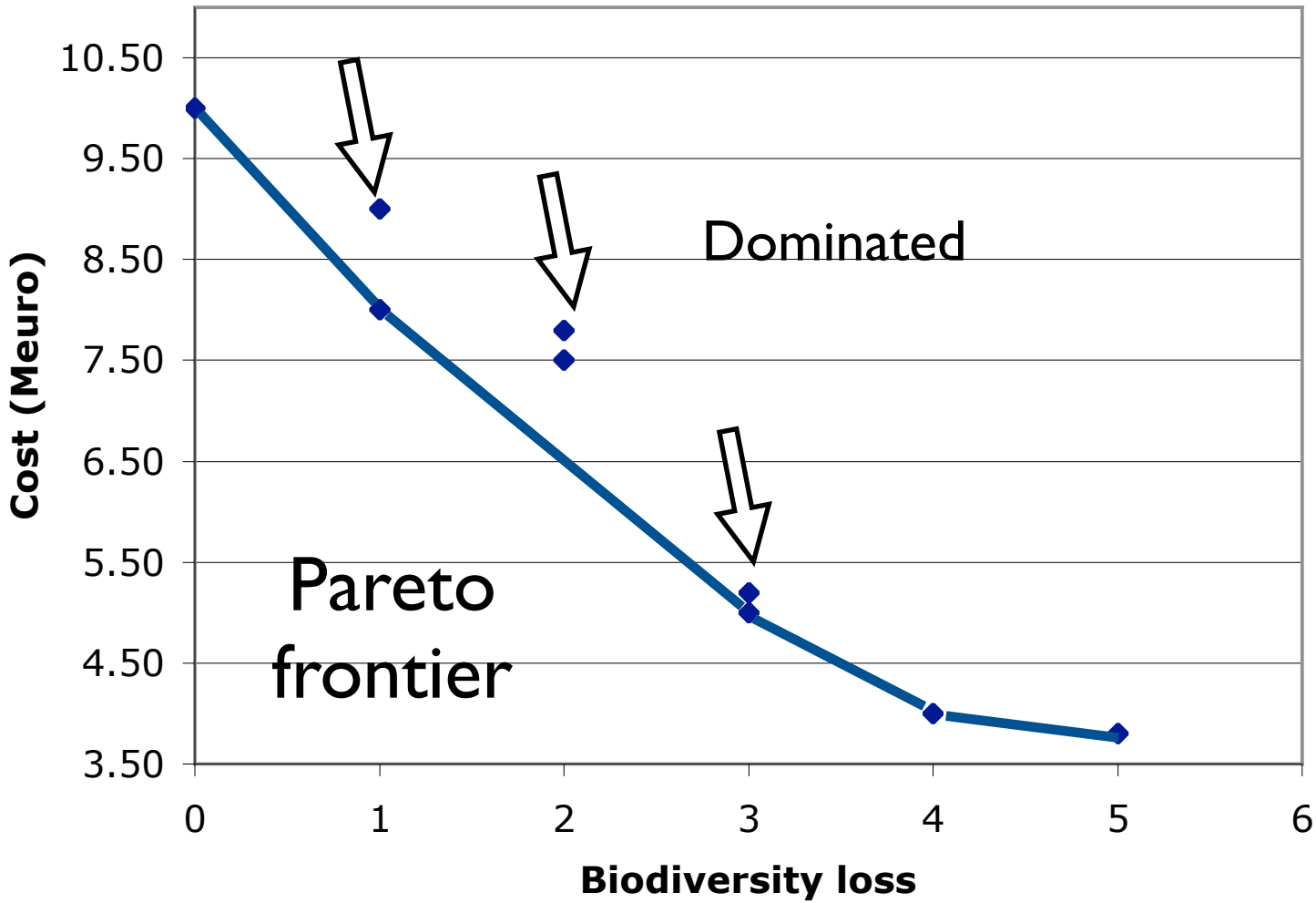
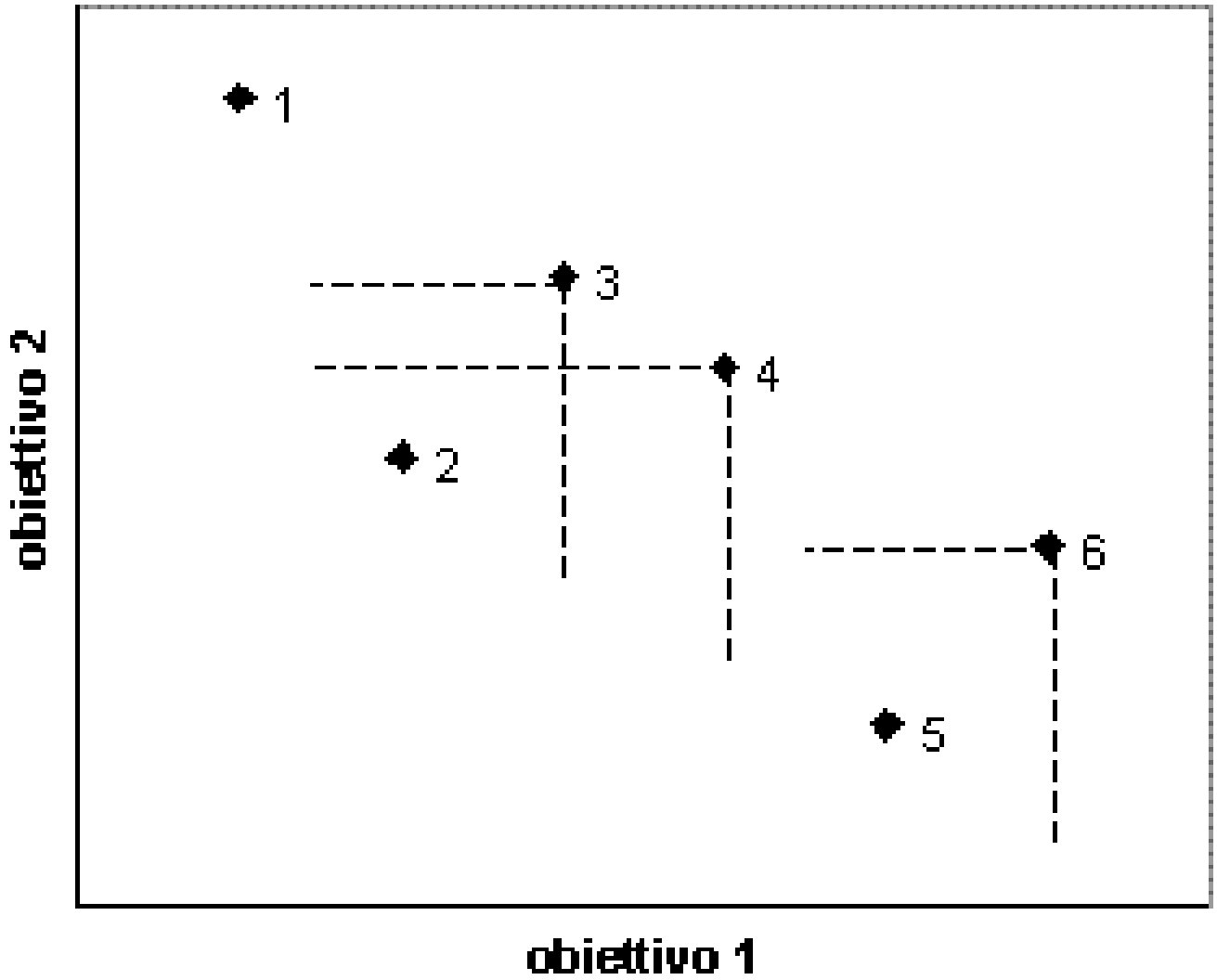
Dominance

- The management alternatives are evaluated in the objective space (possibly n-dimensional)
- The Pareto criterion allows to eliminate dominated alternatives

Identification of efficient alternatives





Hp: maximise both objectives

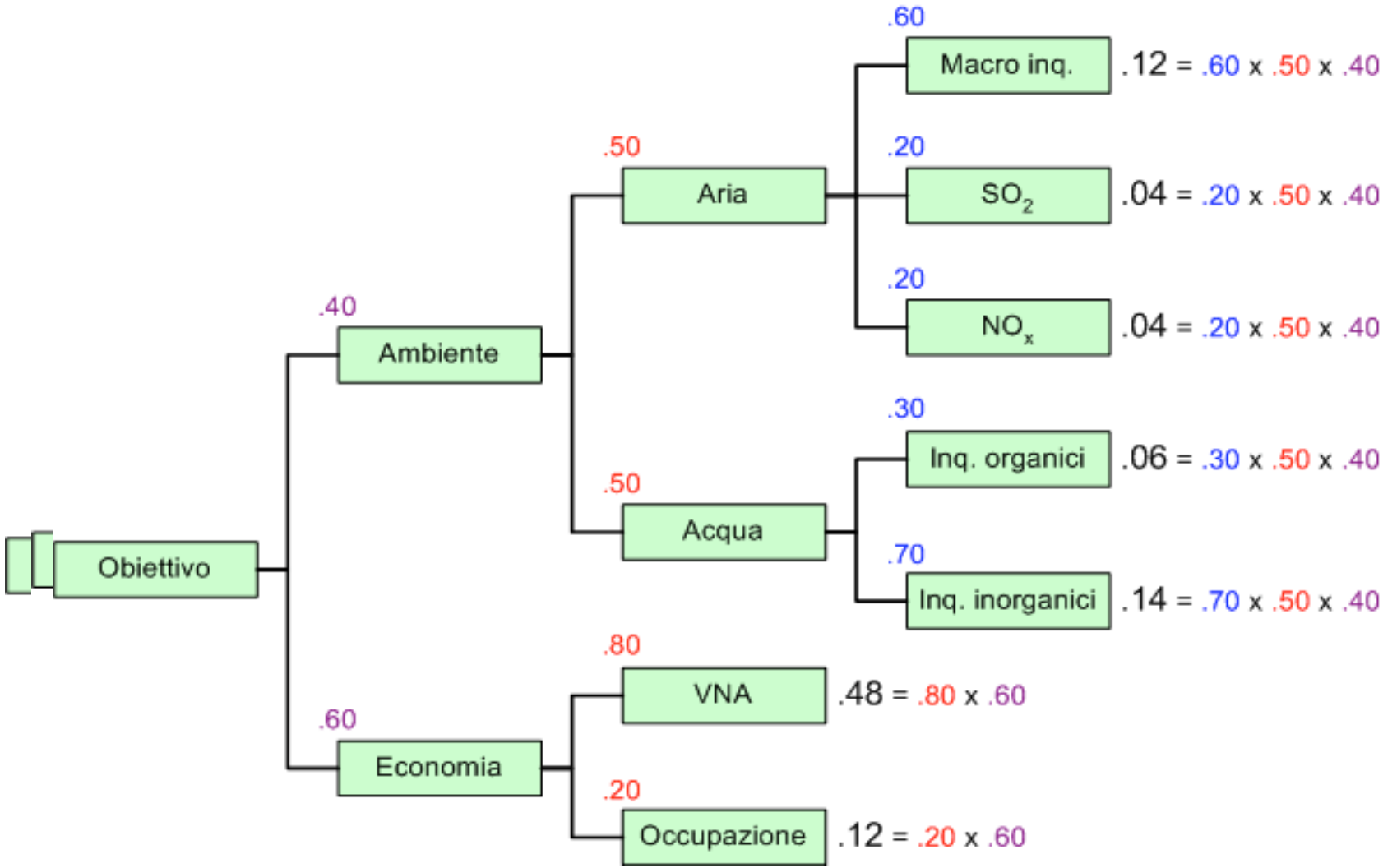
Computation of the Pareto Frontier

- Weight method
- Reference point method
- Constraint method

Weighting

- Assign weights to establish the relative importance of criteria
- Direct assignment
  - each criterion is assigned a weight indicating its relevance
- Indirect assignment
  - Criteria pairs are evaluated (marginal substitution rate)

Weights on the hierarchy



Ranking alternatives

The impact matrix

Alternatives

Objectives

$i_1(A0)$	$i_1(A1)$	...	$i_1(An)$
$i_2(A0)$	$i_2(A1)$	...	$i_2(An)$
...	...	...	...
$i_m(A0)$	$i_m(A1)$	...	$i_m(An)$

Ranking alternatives

- The ordinal paradigm assumes that the columns in the impact matrix can be compared
- The impact vectors represent an entity, not the *satisfaction* associated with the alternative
- Partial ordering w.r.t different indicators are not consistent, because of conflicts!

Alternative Ranking

Alternative k:

objective 1 * weight 1 +

objective2 * weight 2 +

…

objective n * weight n =

Total performance

1. alternative 2
2. alternative 1
3. alternative 4
4. alternative 3

Sensitivity analysis

- The solution must be ‘robust’ in front of
  - uncertainty on the indicator values
  - uncertainty on utility functions
  - uncertainty on weights

The keys to decision making

- Participate
- Integrate
- Rationalise

Participation

- Participatory decision making
  - Bottom-up, from stakeholders to policy makers
  - Spread information
  - Enhance transparency
  - Promote active involvement of stakeholders
  - Evaluation for negotiation: find the *best compromise*

Integration

- Integrate the decisional process among:
  - Decisional parties, Evaluation approaches (such as MAVT, EIA, …), Disciplines, Planning and management
- Identify the stakeholders affected by the project
- Make the impacts explicit

Rationalisation

- We need a decisional procedure able to identify the best compromise alternative
- The procedure is organised in phases
- Each phase has a well defined output and is achieved with well defined tools and techniques
- The output of each phase (but the last one) can deliver multiple viewpoints
- Facts and opinions must be kept separate
- Each phase is transparent and repeatable

Rationalisation

- The policy maker has the last word, but …
- The policy maker can make a ‘political’ choice, but using the same indicators and criteria of the stakeholders

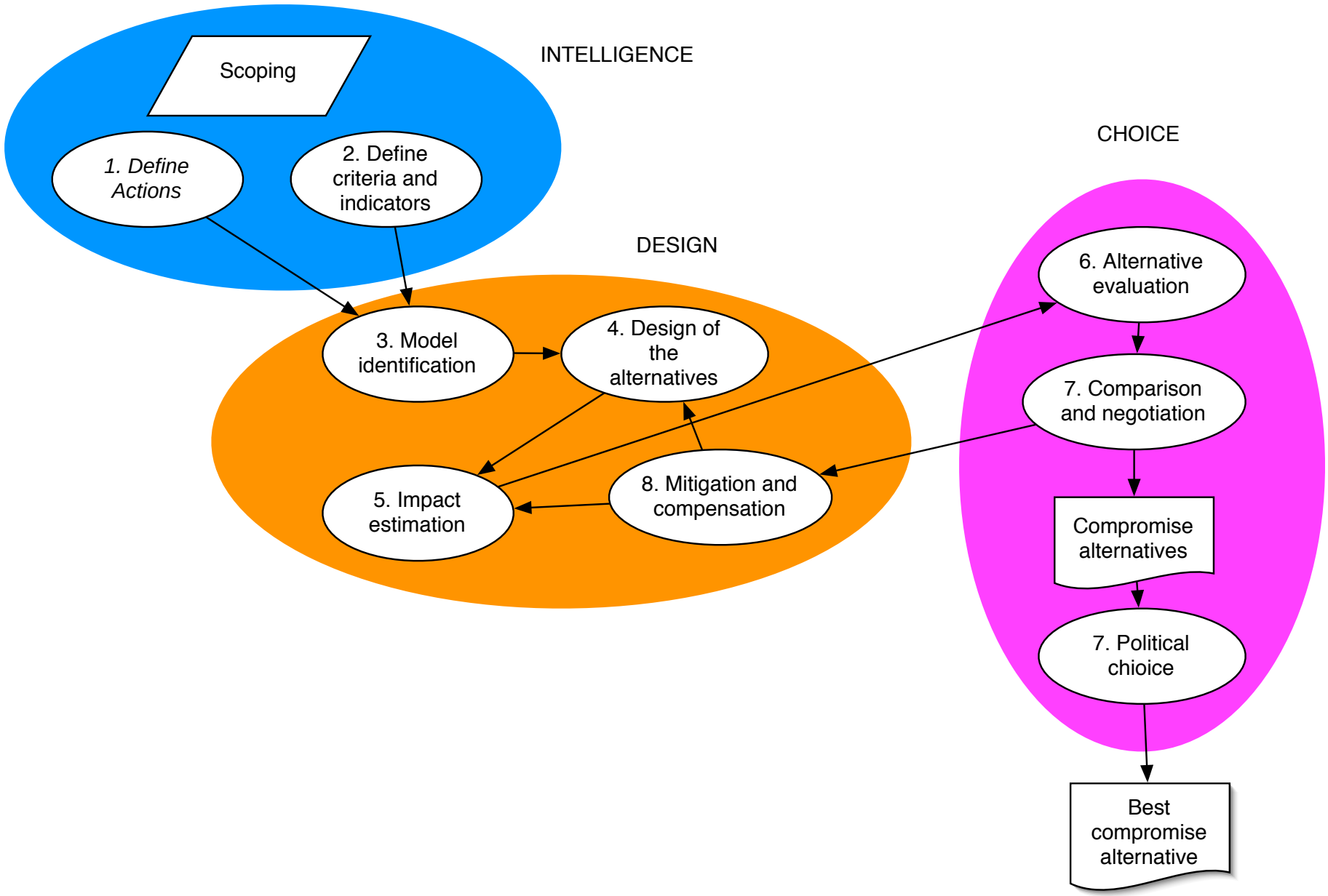
IMA-PIP

Integrated Modelling Assessment -
Participated and Integrated Planning Procedure

IMA-PIP

- IMA - PIP is a proposal for a decisional procedure
- It supports the decisional process in all its stages
- It facilitates the involvement of stakeholders
- It facilitates decision making in presence of multiple decision makers

Decision making in IMA-PIP



Scoping

- Define:
  - the Project objectives
  - the temporal and spatial scope
- Must identify:
  - Data (missing and available)
  - Stakeholders
- Classify stakeholders in sectors

Definition of Actions

- Define the intervention options to achieve the objectives
- Take into account the stakeholders' opinions (can be very varied)
- Use brain-storming techniques
- Employ a facilitator
- Converge to interventions, which are sets of actions

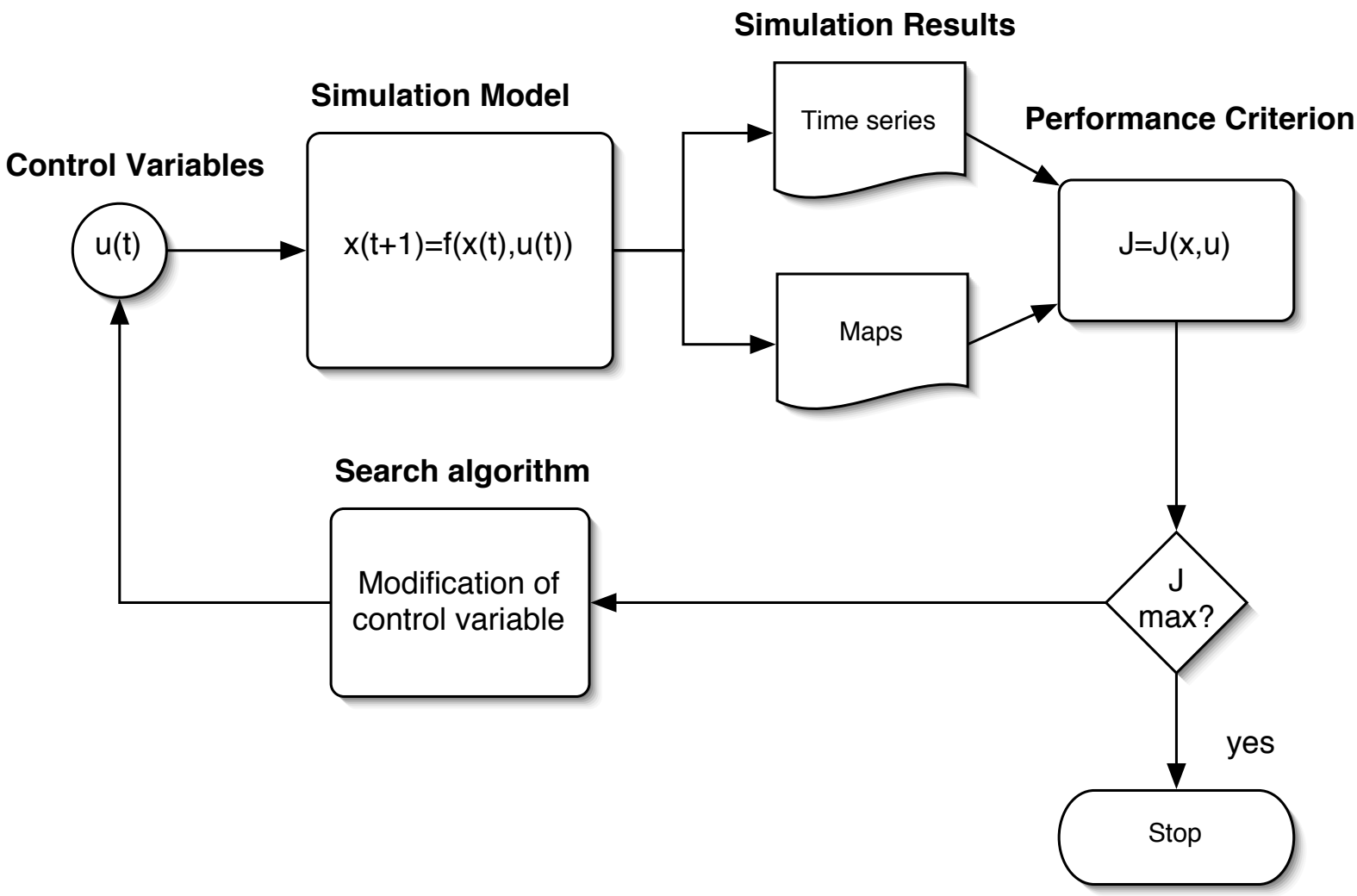
Model identification

- We must quantify the effects of the alternatives
- Models describe cause-effect relationships in the system
- Choice of the model formalism and model design takes a lot of time, is error-prone
- AI techniques can assist in this process

Solve the decisional problem

- It is an ‘optimisation’ problem
- OR and AI techniques can be used in the screening and design phases

The search process



Identification of alternatives

- Alternatives are computed examining all the combinations of actions
- Their number can be huge
- The identification of the most promising alternatives can be done solving a mathematical programming problem
- Inefficient alternatives must be eliminated (Pareto Criterion)

Impact estimation

- Compute the indicators for each alternative
- For dynamic problems, an horizon must be set
- Prepare scenarios (including the historical scenario)
- Arrange the indicator values in the *Impact Matrix* (rows=criteria; cols=alternatives)

Simulation

- Deterministic simulation
  - trace-driven
  - artificial data generation
- Markovian simulation
- Monte Carlo simulation

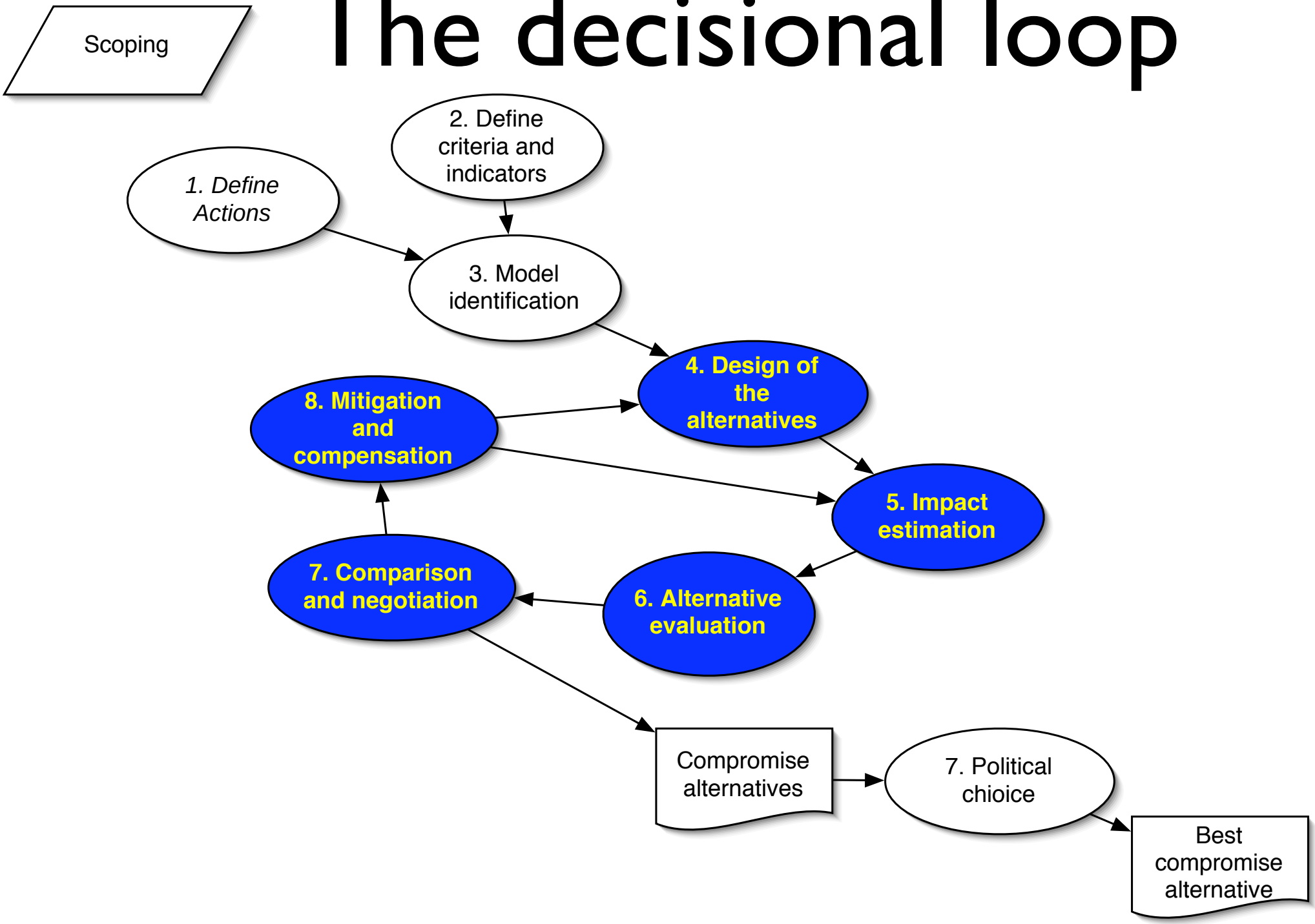
Comparison and negotiation

- A compromise alternative, accepted by everyone, must be identified
- An alternative which is better than Alt 0 for all stakeholders might not exist
- If conflict arises, this stage returns the alternatives which have found a large consensus *(compromise alternatives)*
- Different viewpoints must be shared

Mitigation and compensation

- Measures can mitigate/compensate the losses of the stakeholder who are disadvantaged by a compromise alternative
- New actions/alternatives could be identified (back to phase design and impacts): feedback loop
- Result are: *compromise alternatives*

The decisional loop



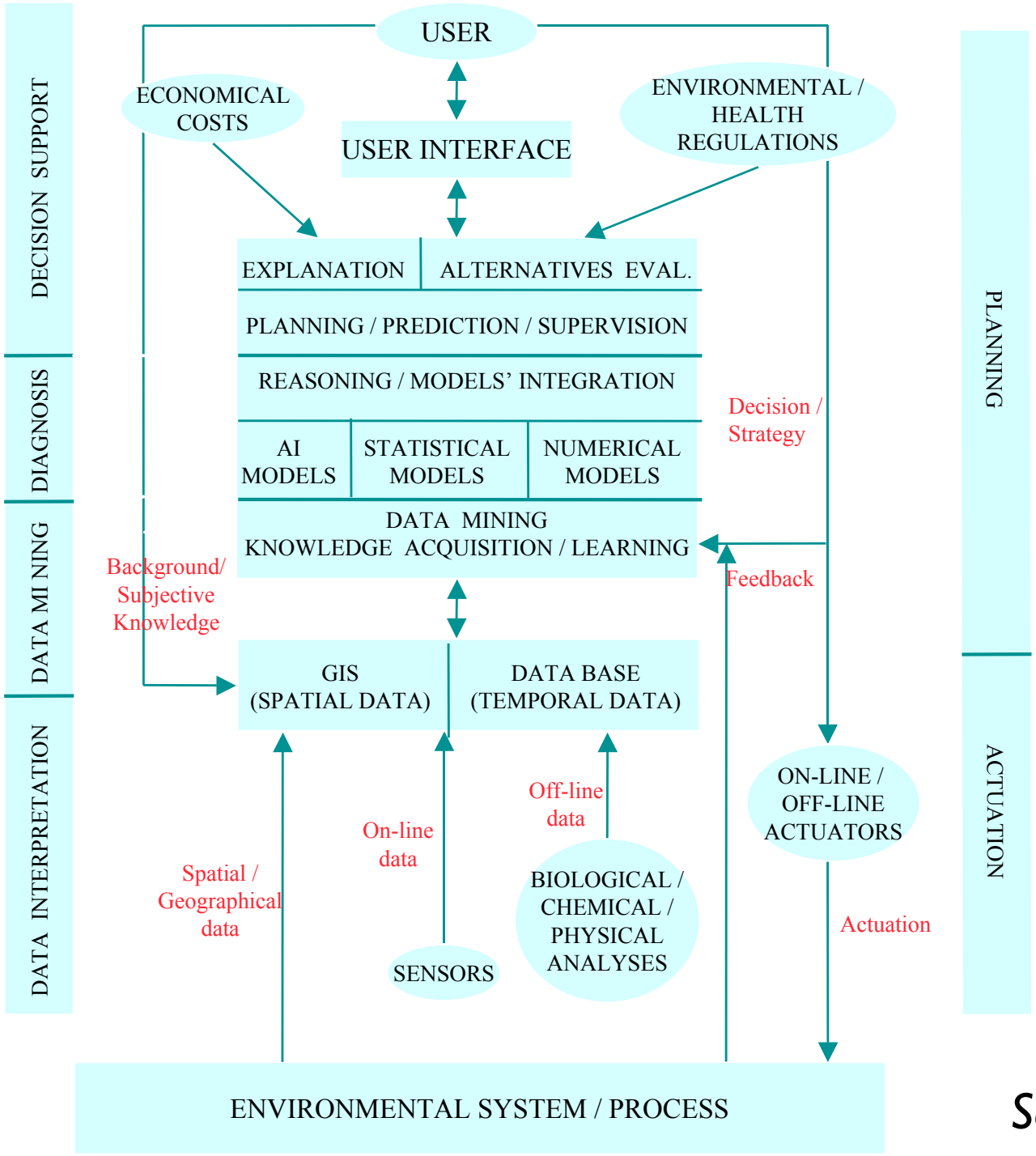
Political choice

- From the *Compromise Alternatives* to the Best Compromise Alternative

End of part I

What's next?

How do we support the decisional procedure?



EDSS

We need a software system to assist us in the decision making process

Sànchez i Marrè et al. 2003

The next topics

- Fundamentals of:
  - Modelling
  - Operations Research
  - Artificial Intelligence
  - Software architecture and design of EDSS

Why modelling

- In the design phase (part of planning)
  - to explore the alternative space and to evaluate the impacts
- In the implementation phase (in management and operational control)
  - to foresee the short/mid term system evolution in front of our decisions

Why operations research & systems analysis

- In the planning phase
  - provides assistance in scenario analysis and in the search of the optimal alternatives
- In the management and control phase
  - provide tools to simulate and forecast

Why artificial intelligence

- In the planning phase
  - when the policy is learnt from experience
- In the management phase
  - to provide support in the choice of the most appropriate decision in front of the situation at hand (diagnosis and expert control)

Why software engineering

- To create EDSS which are
  - modular
  - reusable
  - expandable