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Topic Title 8: Computer Systems as Systems

ICT170: Foundations of Computer Systems

Overview

- The focus of this unit is computer systems; however, we need to think about those systems in the broader context of systems in general
  - This topic explores systems in general, what they are, how they behave, how to classify and model them
- Topics:
  - Introduction
  - Features of a system
  - The qualities of systems
  - System dynamics
  - Self-organisation

Objectives

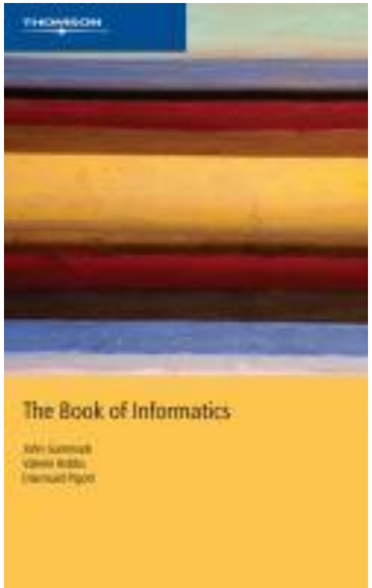
In order to achieve the unit learning objectives, on successful completion of this topic, you should be able to:

- Define the main features of a system and identify them for a given system
- Explain how feedback, regulation and learning can occur in systems
- Discuss several different ways in which systems have been classified
- Explain how systems can be modelled using system dynamics techniques such as simulation

Reading

The required reading for this topic is:

Gammack, G.J., Hobbs, V., and Piggot, D.J., 2007, *The Book of Informatics*, Thompson, Chapter 8



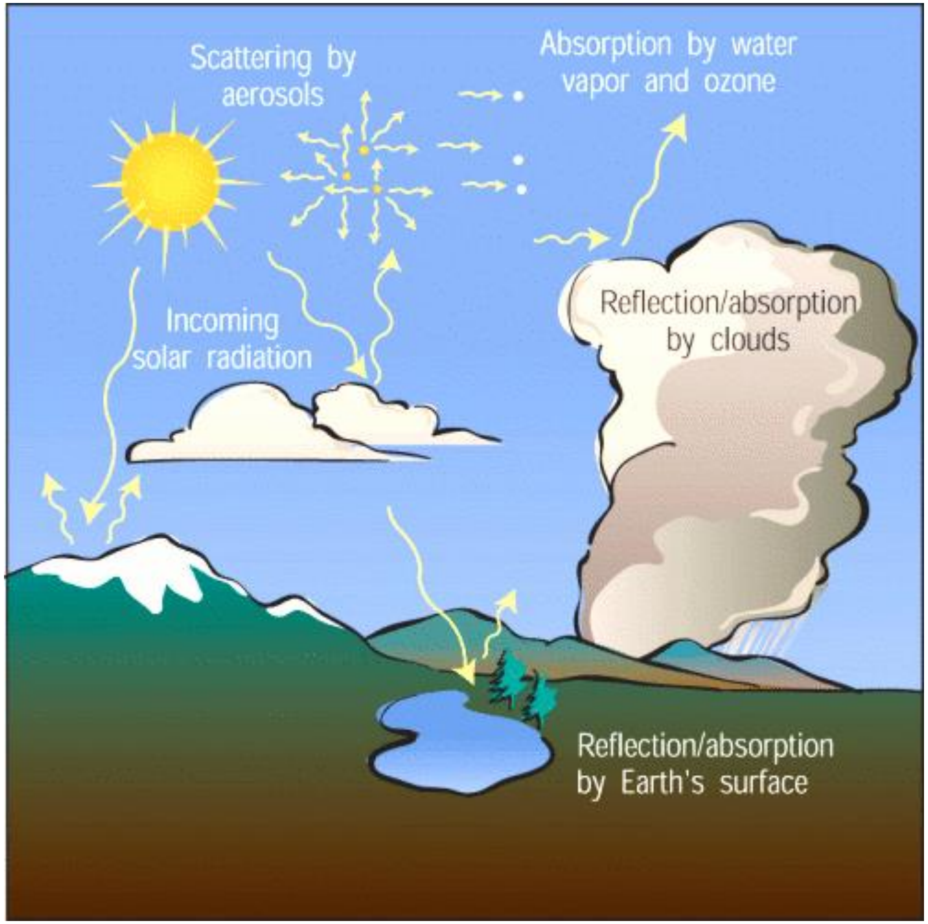
There is a 2011 edition of the book.

Computer Systems as Systems

Introduction

- Earlier in the semester you met "Systems" as being:
  - "A group of interacting, interrelation, or interdependent elements forming a complex whole" (Topic 1)
  - …and more specifically, you have explored various aspects of *computer systems*
    - in terms of input, processing, output and storage
  - The purpose of this topic is to put computer systems in a broader systems context
    - by examining systems in general and considering how computer systems fit in terms of the role they play in larger systems

Systems



- In general, systems refer to a purposive organisation of parts and how these behave and interact dynamically through time

Systems Theory

- Systems theory or **systemics** is concerned with the whole system and the qualities that relate to the system's:
  - Purposes
  - Activity
  - Selfhood
  - Connectedness
  - Environment

Just about anything can be seen as a system…

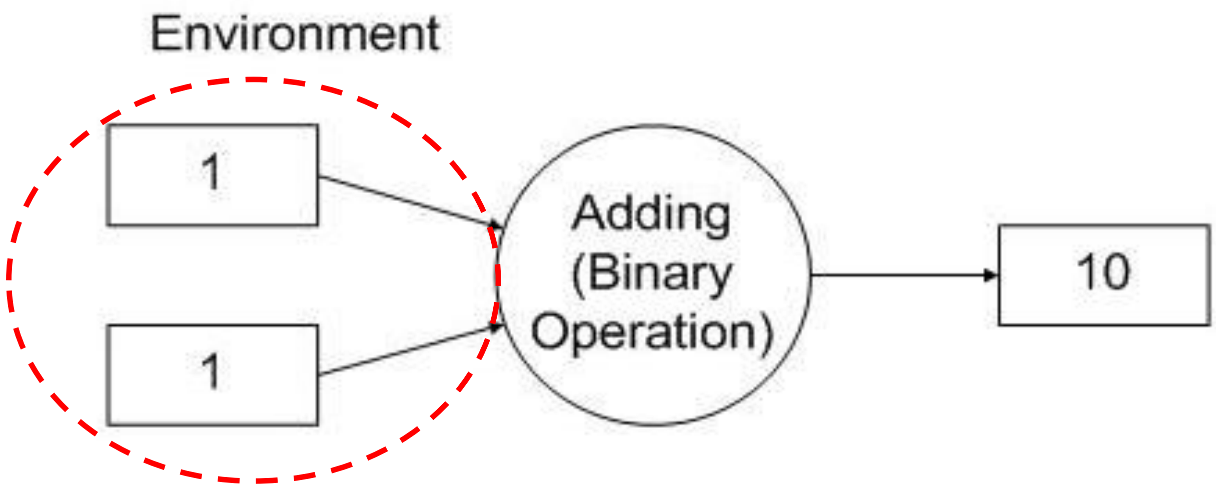
Why think about systems?

- Just as viewing a computer as a system helps us to talk about it in terms of its purpose, components, how its components work together to fulfil a given purpose, IT professionals need to understand all types of systems
  - In business systems, analysts look at the patterns of activity and work processes and see how information flows to the different parts; in effect, they view the organisation as a system
  - Games programmers and designers need to understand the system in which they are working; they need to understand its inputs, processes and outputs…

Features of a System

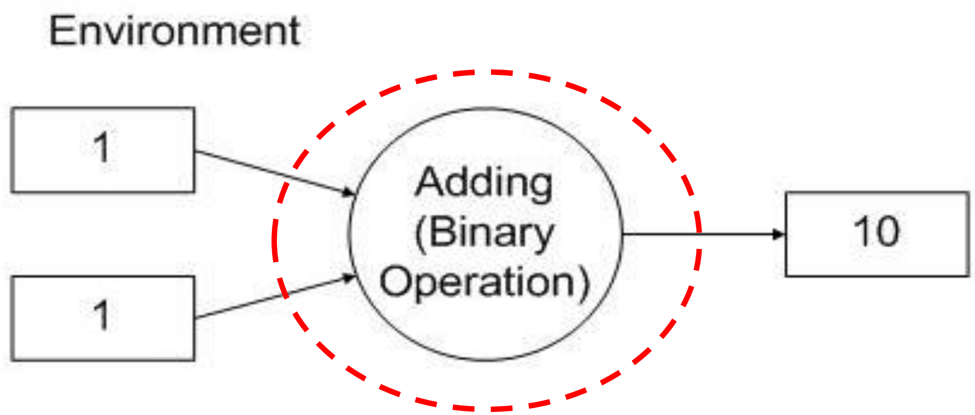
- All systems have certain attributes and the presence of these allows something to be defined or seen as a system.
- A system exists within an environment, or within a larger system. Systems generally operate within the larger environment, interacting with it.
- A system usually will take something *in* from outside, *process* it in some way and produce something that goes back to the *outside* again, usually in a different form.

Inputs



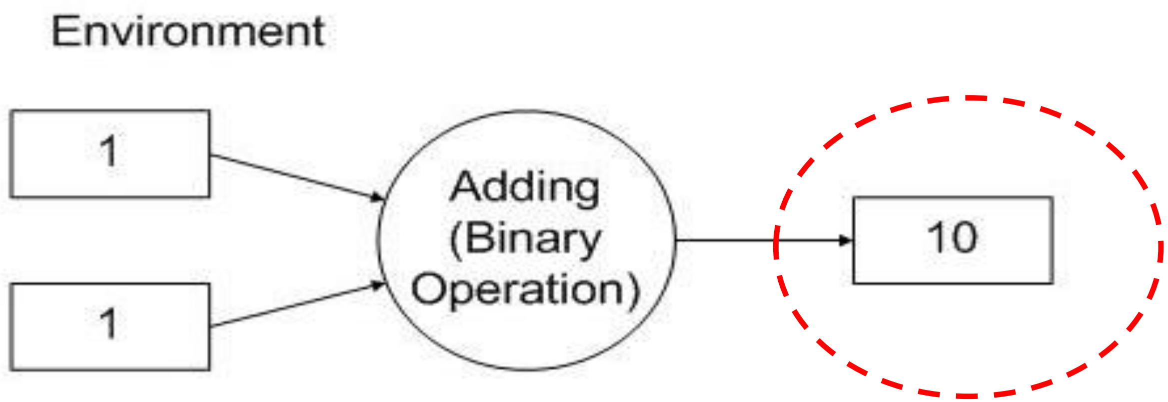
- **Inputs** are what we can identify as going into a system
  - These are typically materials or data
- Everything within a system was either present there from the start, or arrived via the inputs
- Logically these are the only sources of anything found in a system – nothing new can be created within a system boundary

Transformations



- Nothing new can be created within a system boundary, although **transformations** within the system are possible.
- Most systems, particularly organisational, have the purpose of transformation of some sort.
- he diagram on the next slide shows a simple transformation process. Normally a lot more detail of how this gets done would be modelled for a system.

Outputs



- **Outputs** are what we perceive to be leaving the system.
- Logically everything that leaves a system leaves via the outputs and as nothing new can be created, the output is some transformation of the input.
- Outputs go to **sinks**

What might be the inputs, outputs and transformations for these systems?

Feedback

Feedback

- In some systems all or part of the output from a system can be re-routed to the inputs and create a cycle. Adjusting the **feedback** to a system is the standard way of controlling it.
- Feedback is generally either **positive** or **negative**, reinforcing or inhibiting behaviour.

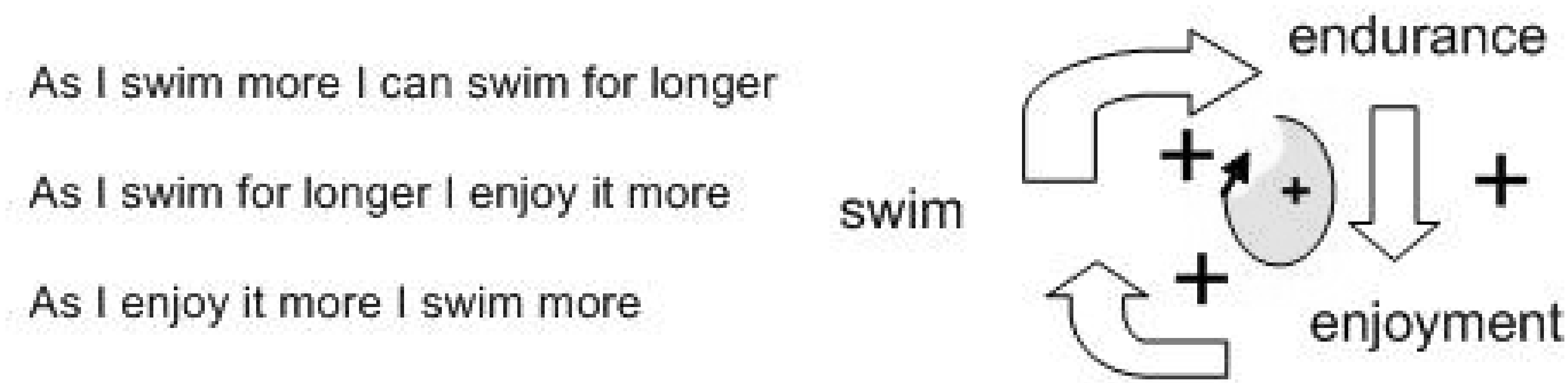
Positive feedback

- **Positive feedback** encourages more of the same behaviour – it amplifies its inputs, which, in a cyclic loop, can escalate out of control
  - A snowball rolling down a hill may gather more snow, the more snow it gathers the bigger it gets and the bigger it gets the more snow it gathers

Positive feedback – Virtuous circle

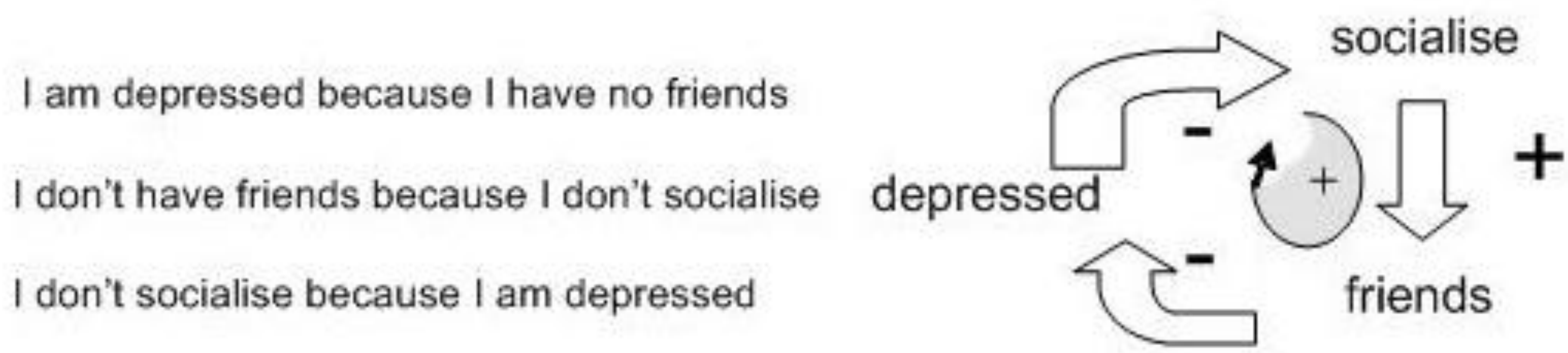
- An example of positive feedback is the **virtuous circle**, where a pattern of behaviour reinforces itself leading to *desirable* consequences.
- A loop of linked causes can be identified and this can be modelled using a **causal loop diagram**

Positive feedback – Virtuous circle



- A plus means a change in the *same* direction (more enjoyment means more swimming).
- Overall the loop is changing in the same direction – positively reinforcing the pattern. This is shown by a plus sign in the middle of the diagram.

Positive feedback – Vicious circle

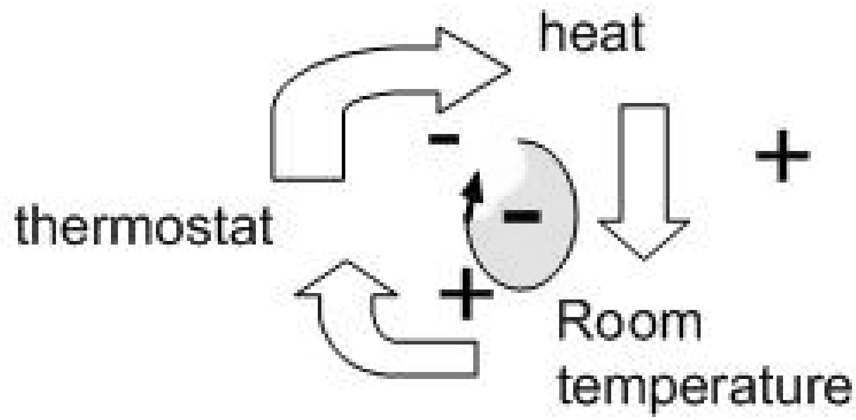


- The pattern can also be undesirable – in which case it is called a **vicious circle**
- A minus means a change in the *opposite* direction (less friends means more depressed).
- There is an *even* number of minus signs, so they cancel out, and the overall pattern is *positively* reinforcing.

Negative feedback

- **Negative feedback** discourages the behaviour that led to it
  - In most countries there are penalties for exceeding the speed limit. Therefore, drivers often watch their speedometers as they drive through speed limit zones, easing the pressure on the accelerator as the car starts to go too fast and increasing pressure if it slows down too much

Negative feedback



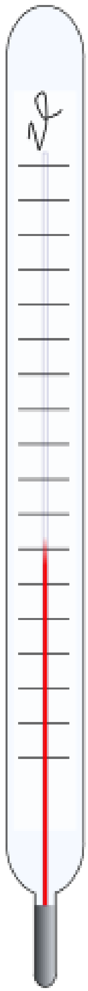
- In a **thermostat**, more heat causes more room temperature, that causes the thermostat to heat up too, which at a certain point acts to *reduce* the heat and therefore room temperature.
- There is an *odd* number of minus signs, so the loop overall is a negative feedback or **balancing loop**, shown by the minus sign in the middle.
- Negative feedback is often used to maintain **equilibrium**, a balanced state which is more or less constant and optimal
  - Artificial systems, such as cruise control or room thermostats, can be designed to work on this principle to maintain a desirable equilibrium.

Regulation and learning - homeostasis

- When a system maintains itself through a feedback mechanism, it is called **homeostasis**.
  - Homeostasis is simply the idea that a system will try to stay stably balanced, at equilibrium
    - A thermostat keeps room temperature with a balanced range
    - http://brewprof.com/weekend-diy-homebrew-project-dual-stage-temperature-controller-stc-1000/
  - A **steady state** is also constant over time and may or may not be at equilibrium.
  - These ideas are applied in economics, health, astronomy and many other fields, including to the Earth itself

Homeostasis and the human body

- Homeostasis is one of the most fundamental concepts in health care: it is a principle that the human body will try to maintain homeostasis:
  - If our energy is low, we eat
  - If our temperature is cold, we shiver
  - If we have been poisoned, we may develop a fever
- Although a healthy body is more or less at equilibrium, *dynamic* processes that maintain that state are occurring all the time, without our conscious intervention.



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Systems interacting with other systems – Coupling

- **Coupling** is where systems are interdependent through the *output* of one system becoming the *input* of another
  - **Tightly coupled**
    - where the output of one system is directly linked to the input of another.
  - **Loosely coupled**
    - where the link may not be direct or complete, or may be able to be overridden.

Tightly coupled and loosely coupled systems

- In a car, the *output* of the accelerator is directly linked to the *input* of the tachometer – **tightly coupled**
- The *input* for the accelerator depends on human judgment, which is informed by the tachometer's output. These systems are more **loosely coupled**, there is less direct dependency and there is a human in the loop, allowing discretion to be exercised.
- With cruise control, the system is fully automated, though it can be overridden.
  - The distinction between fully automated and partly automated systems is important in system design
- http://www.snopes.com/autos/techno/cruise.asp (Winnebago cruise control myth)

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Regulation and learning

- When a system uses feedback to adapt to a new situation, it is a type of **learning**
- Feedback is used to reduce or lessen the difference between the *actual* state and the *intended* state to which the system is purposefully orienting itself
- This can be modelled with more complex systems of loops
- Machines that can learn in this way have been around for many years now

Deutero-learning (Bateson)

- Learning by generalising from primary experience can be modelled by a simple feedback loop.
  - Avoiding obstacles or steering a car between the edges of its traffic lane uses feedback from visual cues to allow error correction. Once we can do this, we can drive on roads we have not seen before.
- **Deutero-learning** contextualises this using a second feedback loop.
  - We are aware of ourselves driving and knowing how to drive allows us to steer off the road, perhaps to avoid causing an accident.
- The ideas of deutero-learning, or 'learning to learn', have been applied in many different fields, including the theory of learning in organisations

Double loop learning
(Argyris and Schön)

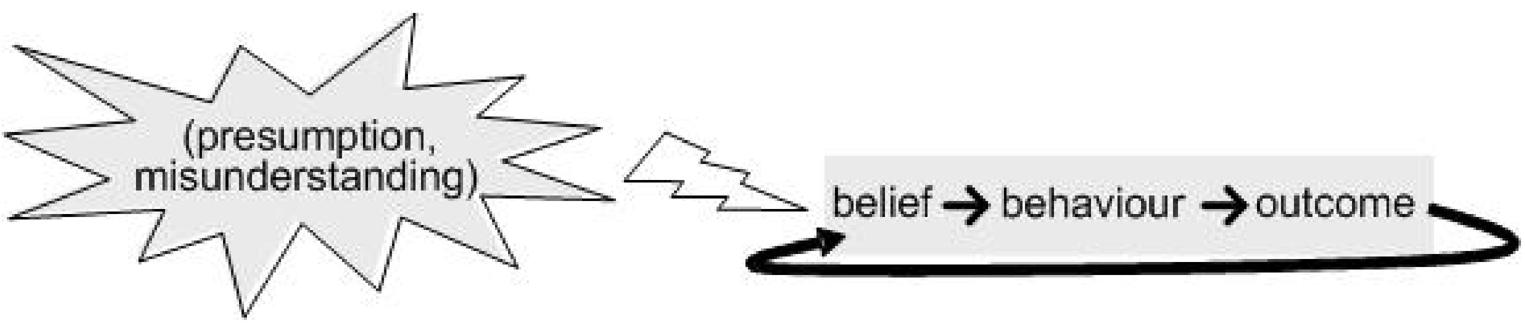
- **Single loop learning**
  - When painting a factory wall, feedback from the painter or supervisor ensures it is error free, efficien done and completed to a schedule.
  - The feedback loop involves only action and monitoring its consequences.
- **Double loop learning**
  - The whole activity of painting walls might be seen as a waste of resources ,so that system gets eliminated, replaced with an easily washed laminate wall or open brickwork.
  - The *whole system loop itself* is monitored and feedback applies to that system as a whole.

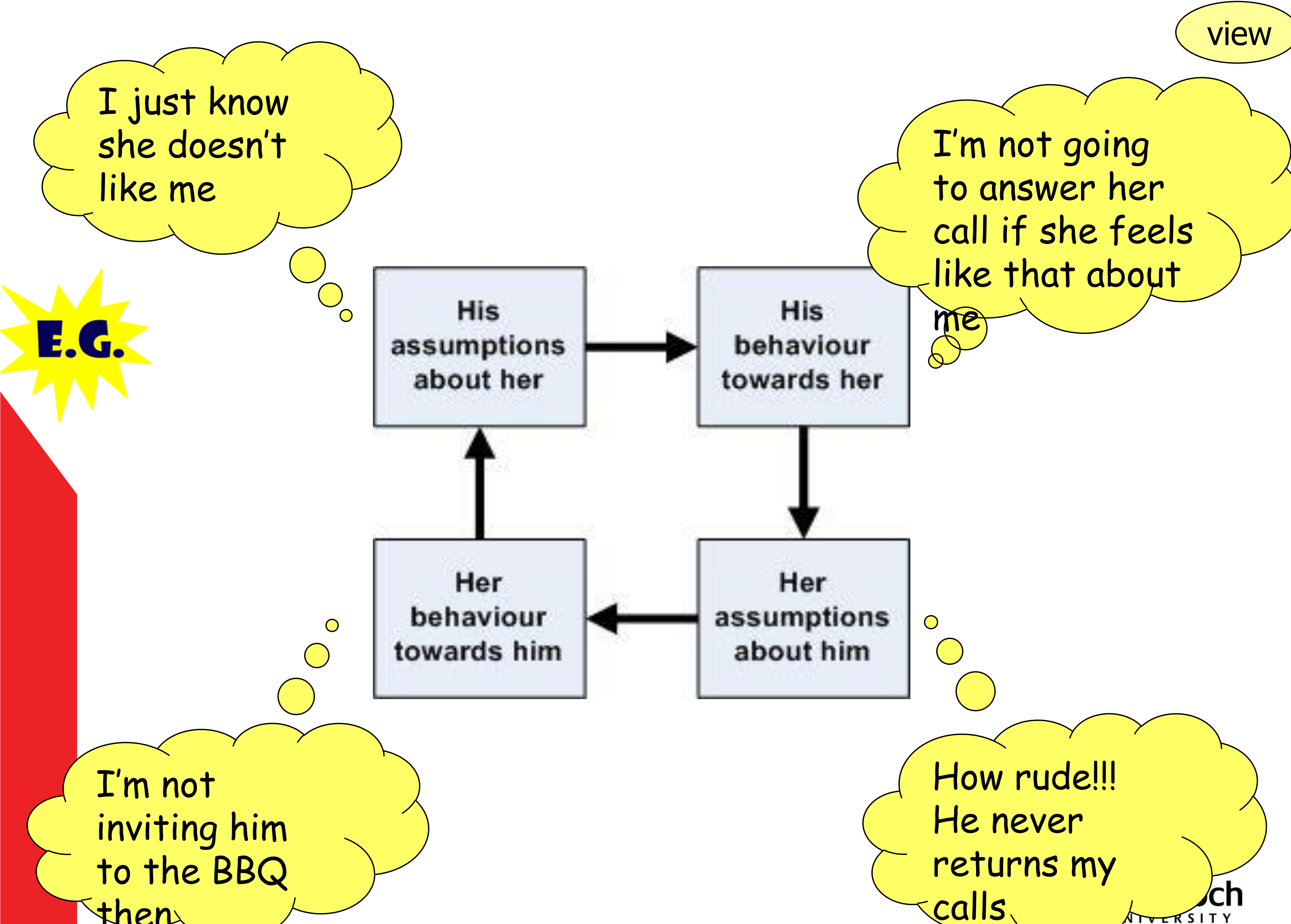
Single and double loop learning

- The difference is between simple detection and correction of errors within some task or procedure (single loop learning), and questioning the procedure itself, particularly in relation to the organisation's goals and objectives (double loop learning)

Self-fulfilling

- Some patterns of behaviour are self-reinforcing but dysfunctional
- Starting with a small misunderstanding, things can escalate into a situation both parties believe is actually the case
- Moreover, since each *acts* as if it were the case, it becomes true in the *experience* of each




view
E.G.
I just know she doesn't like me
I'm not going to answer her call if she feels like that about me
His assumptions about her
His behaviour towards her
Her assumptions about him
Her behaviour towards him
How rude!!! He never returns my calls
I'm not inviting him to the BBQ then

Cybernetics and systems

- Many systems concepts have been developed in the systemics field of **cybernetics**.
- Cybernetics differs from conventional sciences by its focus on communication and control relationships in a system and regulating or steering the system on course to its *goal*.
- Cybernetics is often associated with control mechanisms

Systems Purpose

- Most systems have a **purpose** and informatics systems are generally goal or function oriented.
  - These functions usually imply that some definite input occurs at a given moment in time and a definite output occurs at a second moment in time, e.g.
    - A ‘request for payment’ comes in at moment 1
    - The system then (typically) checks that ‘goods have been received’ and ‘records are kept on file’
    - Then a payment authorisation is issued at moment 2.
    - Alternatively, a denial of payment may be issued at moment 2, if it turns out that the records don’t tally.

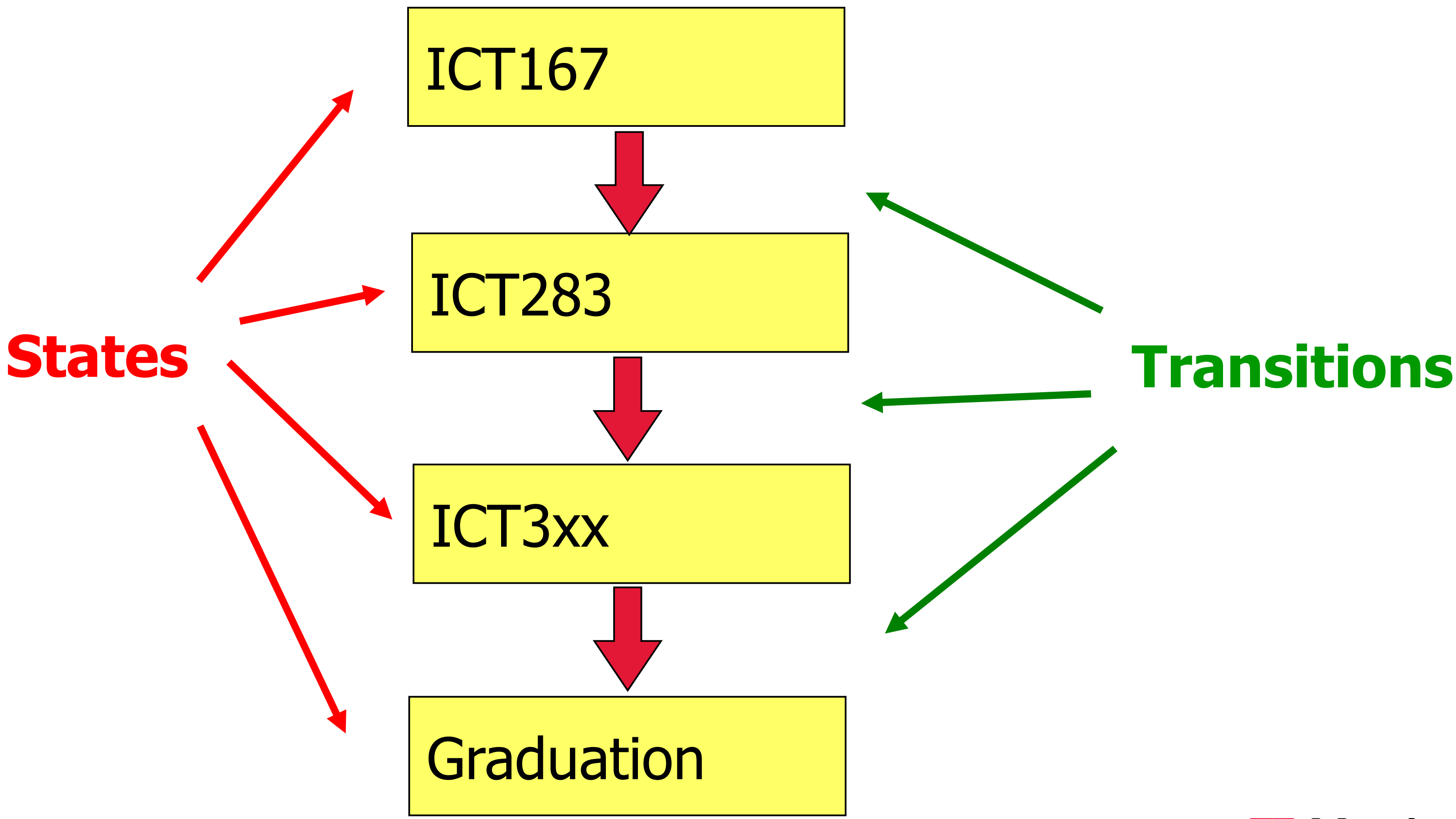
Purpose and trajectory

- The **calendar** refers to the moments, intervals or time steps where a state of the system is noted.
  - The path between the two moments is called the **trajectory**
  - These moments need not be linked to actual dates and times, but instead show an ordering in time of relevant events and states. These are generally in line with the purpose or a goal of the system, such as to transform payment requests into resolved payments.
  - **Transition** between states is a concept that can be applied very widely

State transition diagrams

- Used to represent the states and transitions in a system
- Various systems modelling languages have versions and extensions of state transition diagrams
  - Graphical forms, matrix forms
  - Commonly used in business modelling and associated software design, such as Unified Modelling Language (UML)

States in the trajectory of a three-year degree course



A three-year degree

- A student's progress through a three-year degree course may not take three years:
  - May be *faster* if summer semesters are taken
  - May be *slower* if subjects are repeated, or a gap year is taken.
- Modelling is better done in terms of the **states** along the trajectory, aiming at a completed degree
  - First level studies
  - Second level studies
  - Third level studies,
  - Graduated
- Entry to each state requires the student to have passed the previous state (eg. ICT167 is a prerequisite for ICT283) so the states must be passed through in sequential order as their requirement thresholds are met.

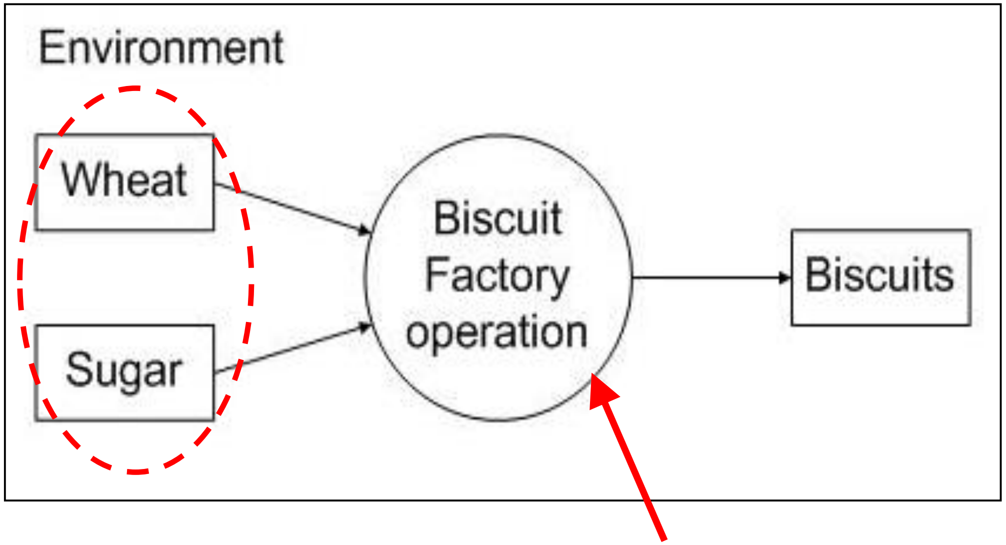
Equifinality and multifinality

- Many purposes can be achieved in different ways:
  - If you are too hot you can swim, take a cold shower or put on air conditioning or a fan.
  - The end result is the same – **equifinality**
  - The opposite is **multifinality** where similar initial conditions lead to different outcomes.
    - For example one child in a family may become a responsible citizen but their sibling becomes a bit wild, despite the same home environment

Boundary and environment

- Systems are identified by their **boundary** and exist in an **environment**, which, by definition, lies outside the boundary
- The system **interfaces** with its environment at its boundary. This is the point at which exchange takes place into, or out of the system

Boundary and environment

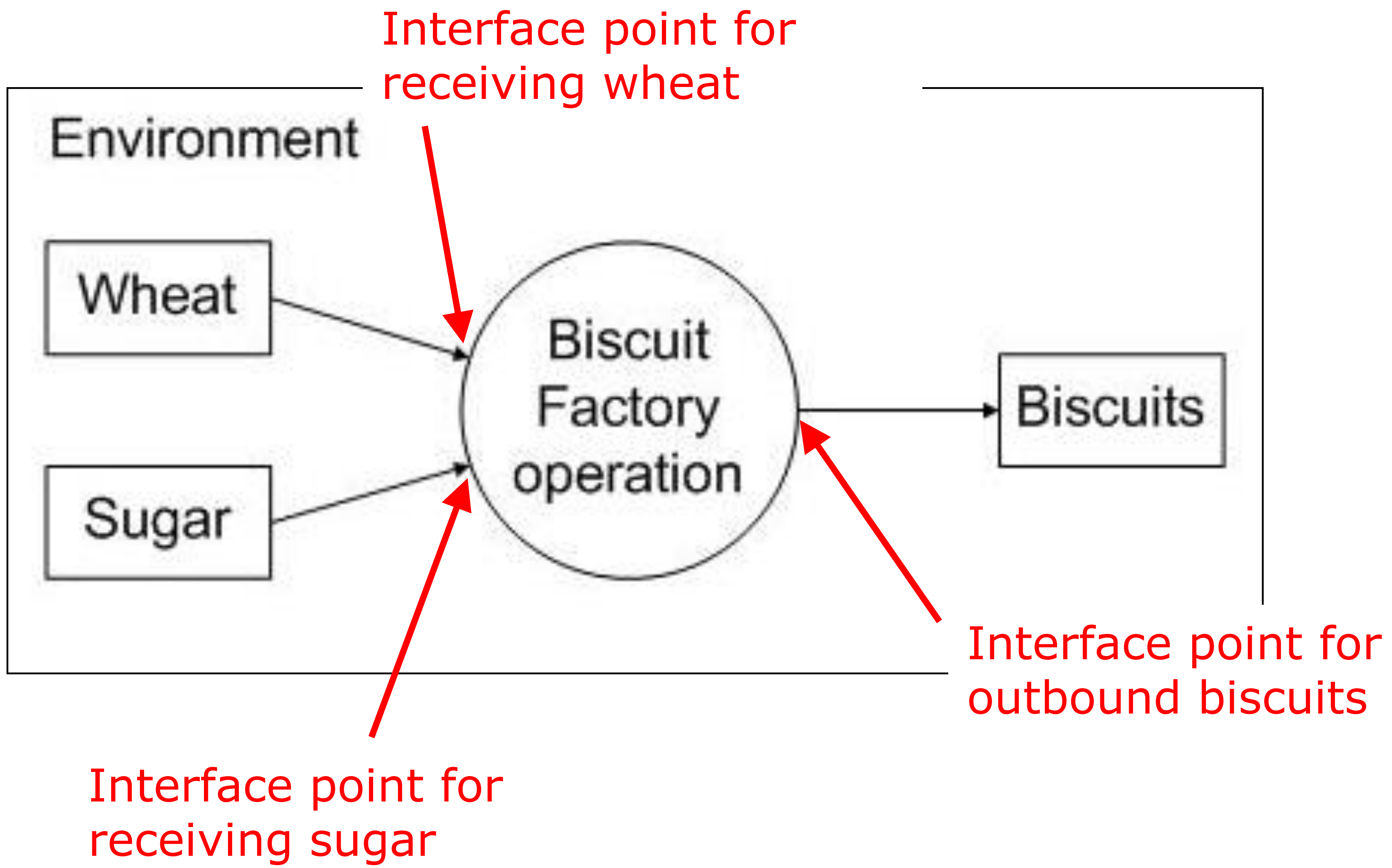


Wheat and sugar are within environment of system, but outside boundary

Boundary of system

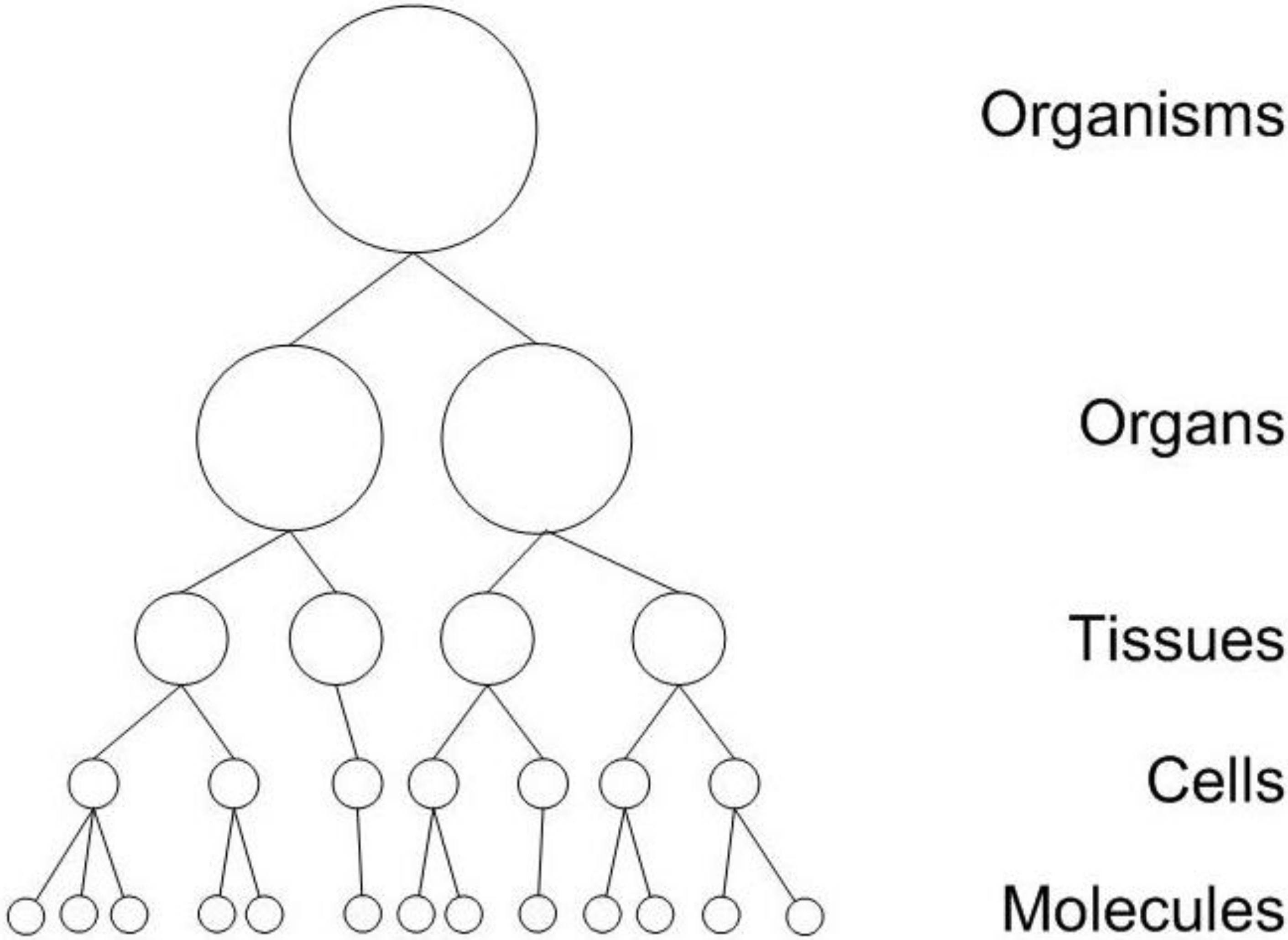
- The difference is between simple detection and correction of errors within some task or procedure (single loop learning), and questioning the procedure itself, particularly in relation to the organisation's goals and objectives (double loop learning)

Boundary and environment



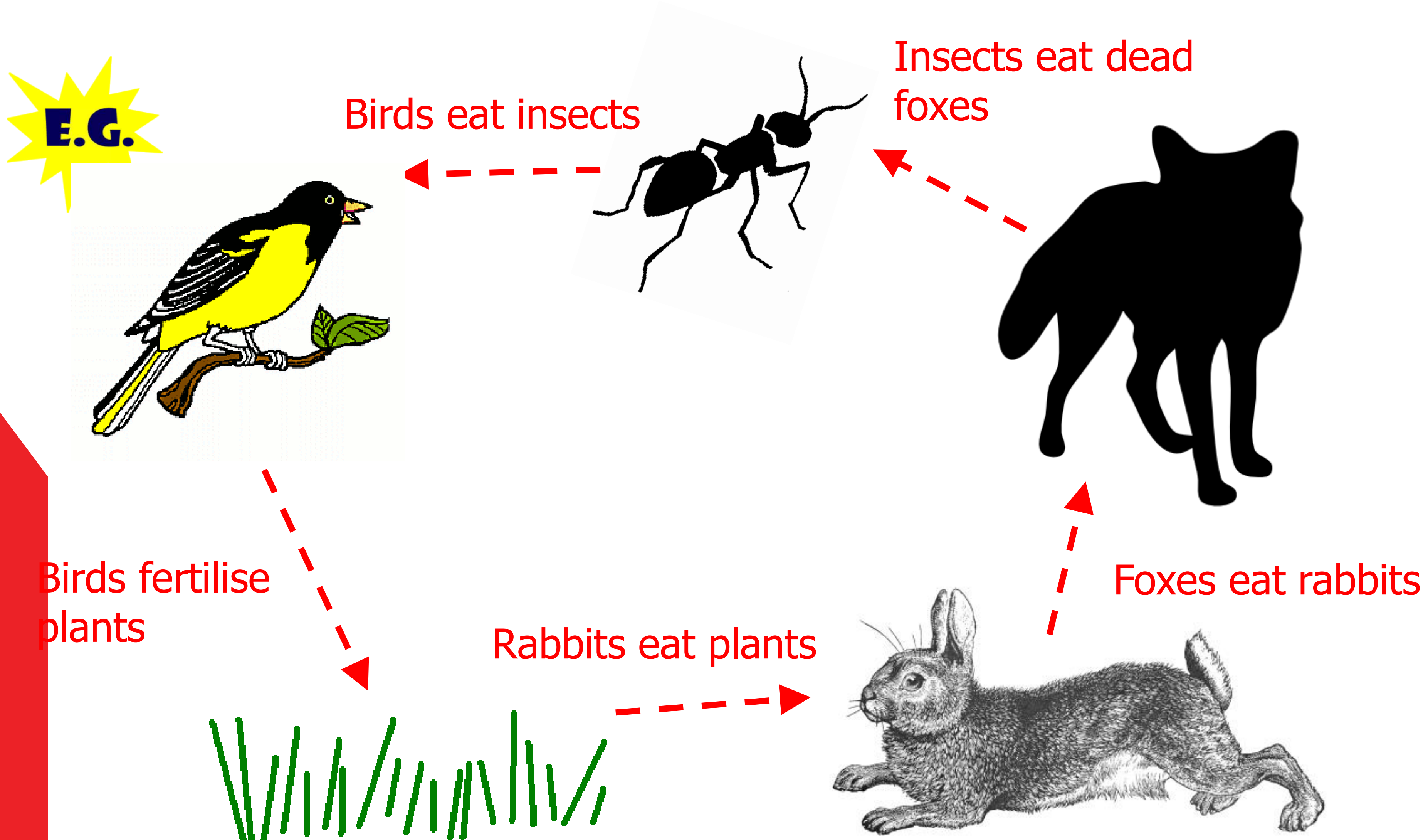
The qualities of systems

- All systems are wholes in some sense – the organised parts that make them up function with an integrity that makes them a useful level to identify by name and to build an understanding around
- Systems are themselves often parts of bigger systems, and have subsystems of their own
- At each level the system is an integral whole, or **holon**, within a **holarchy**.


Organisms
Organs
Tissues
Cells
Molecules

Connectedness and relationship

- Many systems ideas are probably familiar from the model of an **ecology** or **ecosystem**. An ecosystem is basically a community of interacting organisms and its environment.
- Ecology has supplied many ideas to computer and information systems theory, such as
  - Interdependent webs (of organisations)
  - Niche (niche marketing)
  - Symbiosis
  - Perturbation



An interdependent web…

Niche

- In ecology, a *niche* is a place within the grander scheme that is especially suited to an organism or species
- Organisations use the concept in the idea of **niche marketing** where they provide a specific product or service to consumers with those specialised tastes

Symbiosis

- Symbiosis is where two different organisms work together for mutual benefit
- Organisations can work symbiotically
  - The waste chaff from the biscuit factory might be recycled into garden mulch by another organisation

Perturbation

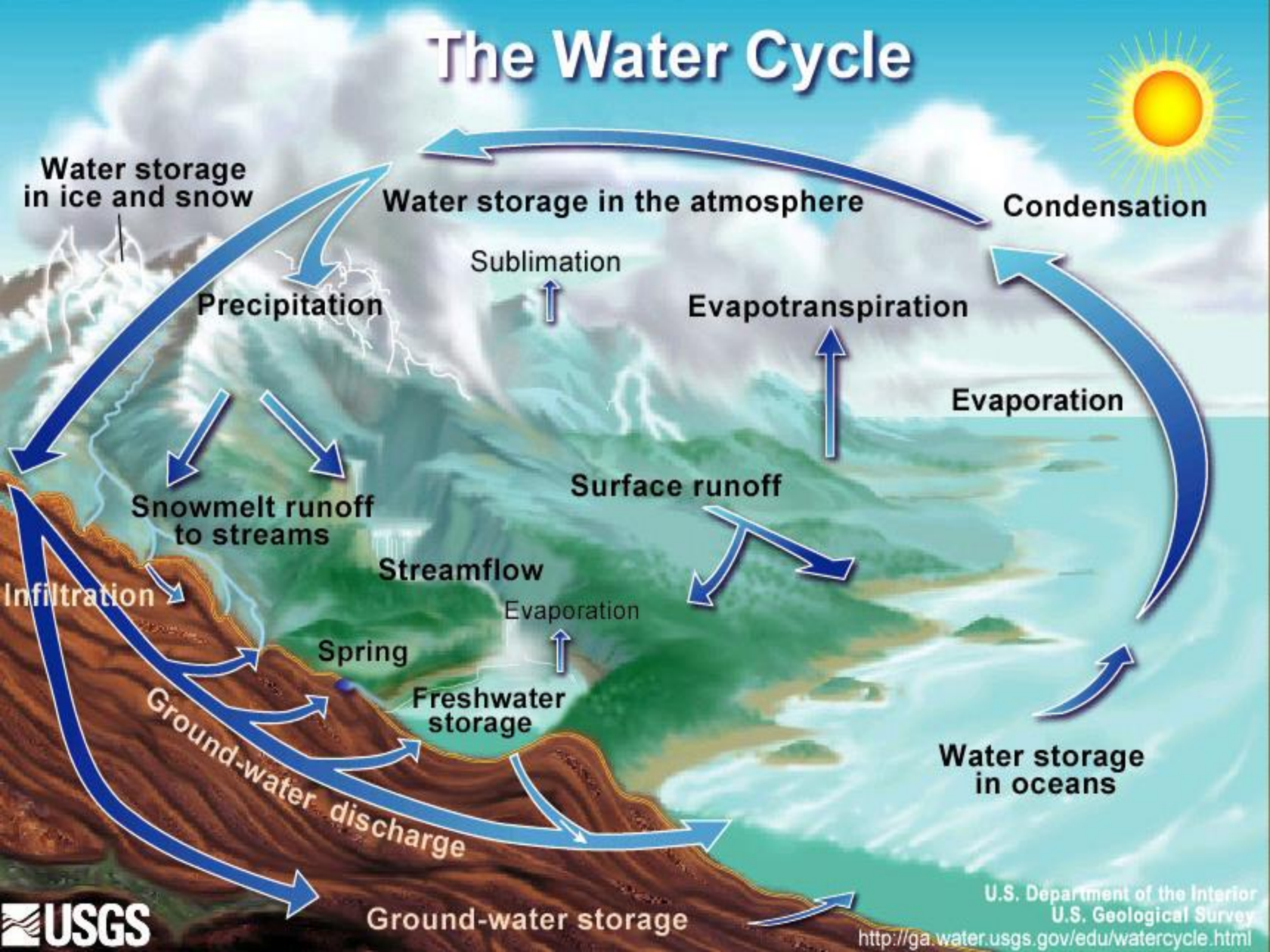
- Occurs where some disruption is introduced into an ecology or system, changing the dynamics of the system
- Systems are interconnected, so a change in one part of a system can affect the whole system
  - Pesticides targeting insects go through the food chain, increasing concentration, to threaten the survival of bird species, or ultimately human health. This may solve an immediate agri-business problem, but cause an environmental one
- Understanding the impacts of *change* and how to manage them is a key skill

Closed and open systems

- Systems can be closed or open:
  - **Closed system**
    - does not exchange materials or information with its environment
  - **Open system**
    - interacts with its environment, receiving inputs and producing outputs
- Usually parts of a system can be considered as closed for practical purposes and other parts can be considered as open

Closed systems

- A **closed system** does not exchange materials or information with its environment
- Examples of closed systems:
  - The Earth's water cycle
  - Inside a spaceship
  - The water in the pipework of a central heating or a cooling system
  - The coolant in a car engine
  - The blood circulating in your body
  - The formal languages of mathematics and computing
  - The numbers in a Sudoku puzzle
- Very few systems, other than formal ones, are completely closed
- Usually they operate in the context of other systems, with which they *interact* in some way


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
USGS
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

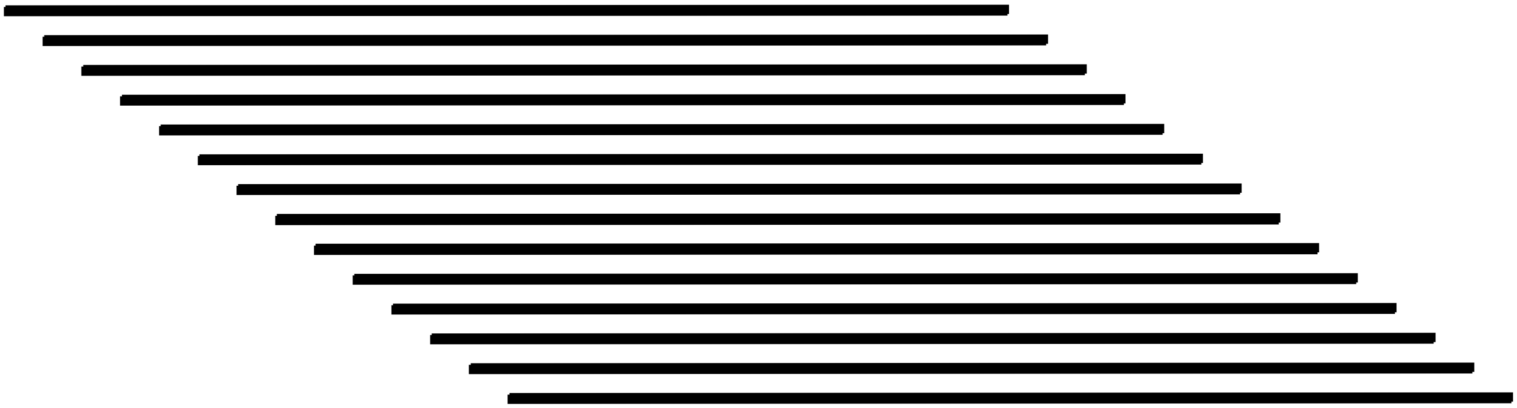
Open systems

- **Open systems** are those that interact with their environment. They receive inputs and produce outputs.
- Organisations are a good example of open systems: they take inputs and do something with them, to produce outputs.
  - The biscuit-making organisation takes wheat as input and produces biscuits as output.
  - In between it has processes that transform wheat (and other inputs) into biscuits, which can then become an input to a biscuit-retailing system.
- Organisations thus transform the inputs, usually to add value to them, or to make them useful as inputs to another system.

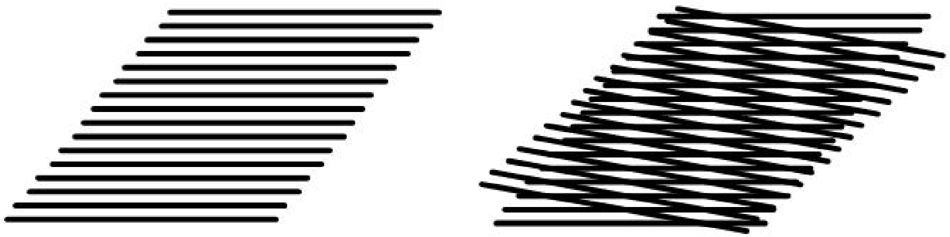
Emergence

- The counterpart to the concept of holarchies is the notion of **emergence**.
- Although systems may sometimes be broken down into parts, they have the properties of organised wholes.
  - These wholes have properties that are *not* the properties of their parts, nor are they simply derived from them. Such properties are known as **emergent properties** and result from the quality of the system design
- Emergence often occurs through interactions between parts, to produce something that was not there before.

view



Moire patterns emerge when patterns interact



Emergence

- A racing car is made up of, among other things, wheels, an engine, a fuel system and perhaps red paint.
  - None of these components is 'fast' or especially 'attractive'.
- Put together in the appropriate way, though, the car as a whole is fast, attractive and aerodynamic. These are *emergent* properties of the whole, not of the parts and the car, as a whole system, defines the parts and their role in the design.
  - The red paint is functionally no different from pink paint, but some believe red cars look as though they are faster. In systems thinking the whole *is* greater than the sum of its parts.

Components and subsystems

- Much of IT systems development uses components that can be assembled in various ways and reused, like Lego™ bricks
- Often a good way to model systems involves identifying **subsystems**, which can be looked at as replaceable components
- When subsystems can be isolated like this, it allows for different combinations to be *tested* by replacing parts of the system and observing performance

Black box and white box testing

- Both black box and white box testing are used in informatics, particularly software testing
- In **black box** testing you provide an input and get a functional output, but don't know what goes on inside the thing being tested – if the required outcome is achieved that's all that matters
- In **white box** testing the internal functioning is known and explicitly tested.

Systems thinking

- In systems thinking, the **interactions**, as much as the quality of the components themselves, are a key feature of the systems view.
- When components can act upon one another, as humans do, new outcomes can emerge and these may not be computable or simply predictable
- It is therefore an art (or a special type of science) to design a netball team (or a racing car/driver combination) from whose interactions particular outcomes emerge, some of which are unpredictable from just analysing the properties of the components.

Systems thinking

- Analytic or **reductionist** thinking concentrates on breaking things down into parts
  - But a disassembled racing car misses its essence!
- **Systems thinking** is much more interested in the qualities of the *whole* racing car –
  - speed, aerodynamics, safety, racing fast without falling apart…
    - And in this the concepts and activities of interaction, purpose, function and emergence are needed to complement the analysis of components and structure.
- A system's behaviour in its environment must also be considered
  - If the racetrack is wet, different tyres are needed.
  - Adjustments are made to the car depending on who is driving

Systems thinking

- *Whereas classical, discipline-specific science "tried to isolate the elements of the observed universe … now we have learned that for an understanding not only the elements but their interrelations as well are required"*

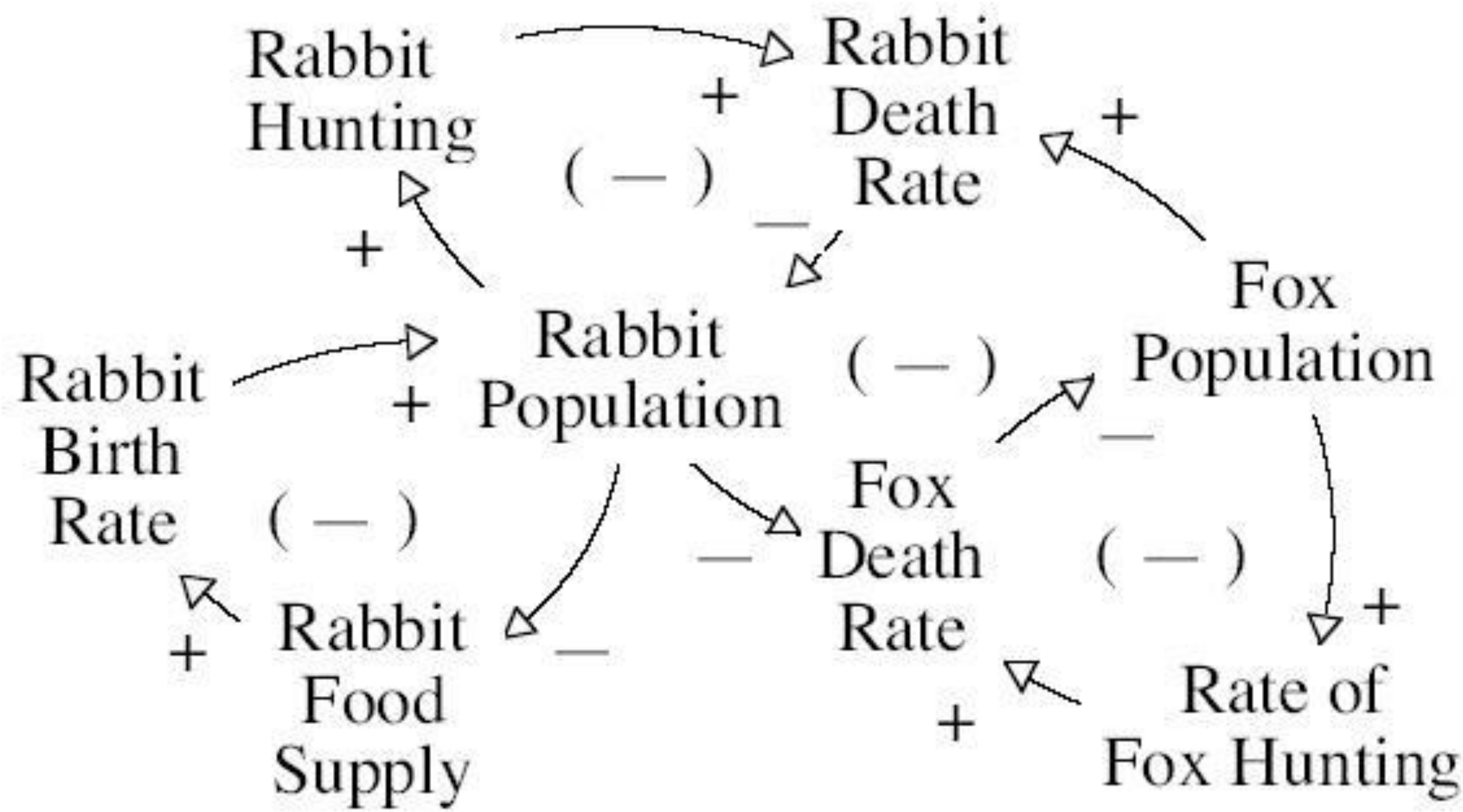
  (Ludwig von Bertalanffy)
- Bertalanffy was an early systems researcher who investigated the principles that are true for systems in general, whether these are biological systems, social, engineered or other.
- His work was described as **General Systems Theory** and it provides one of the foundations for contemporary system sciences, or systemics.

System dynamics

- The systems tradition provides concepts relevant to theorising about processes, functions, changes, control mechanisms and other dynamic aspects of systems as they act, adapt and transform in time
- **System dynamics** is a modelling approach that allows prediction of the states of a system and given points in time, and whether it is tended towards stable equilibrium or catastrophe

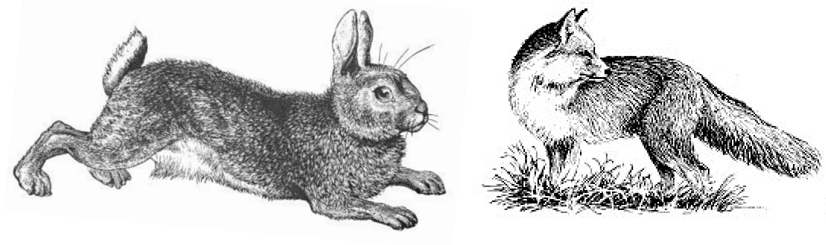
Rabbits and foxes

+ increase in one causes an increase in the other
- increase in one causes a decrease in the other



(–) negative feedback loop

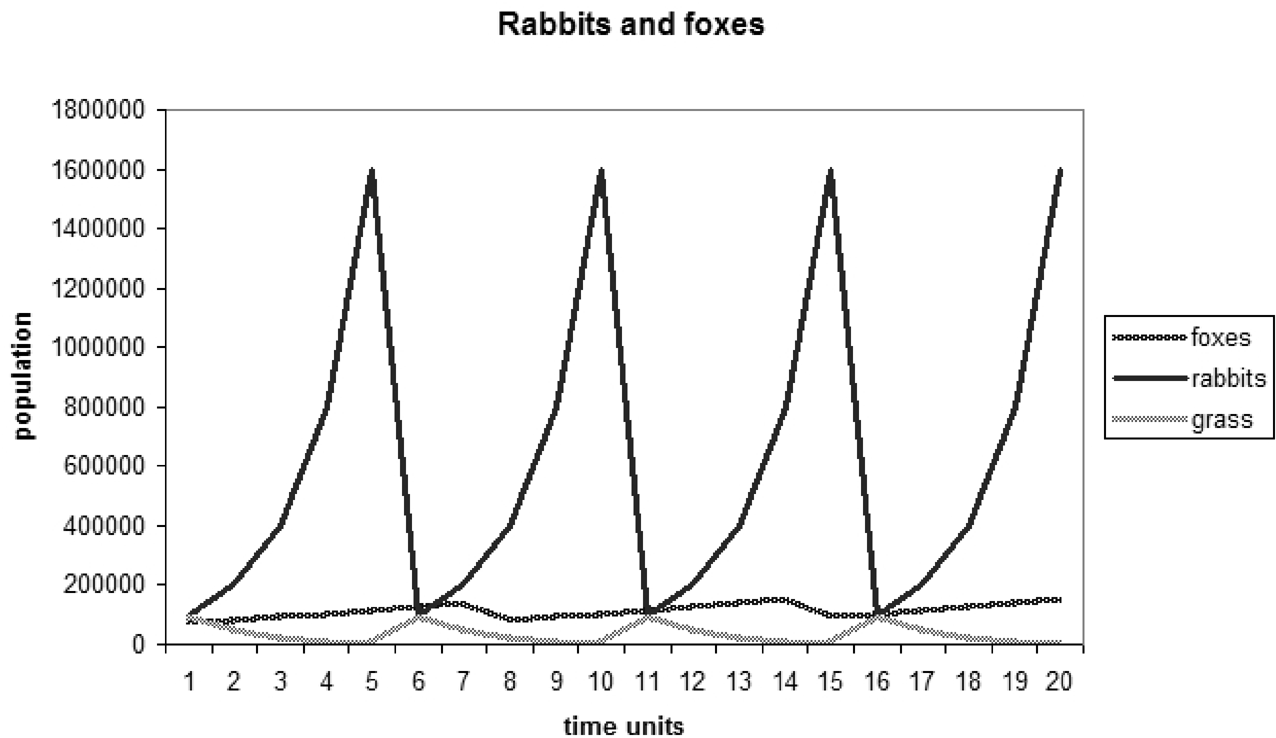
Rabbits and foxes



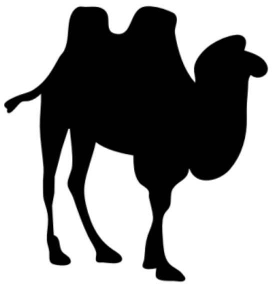
- The causal loop model shows several negative feedback loops (-)
- Thus the populations of both rabbits and foxes is under control
  - An overpopulation of rabbits impacts on their food supply, which in turn means a decrease in the birth rate
- Forrester extended these causal loop systems to include *quantities* and *time*
- Systems dynamics can then simulate what happens to the stocks of rabbits and foxes over a period of time

Initial population of rabbits	100 000
Initial population of foxes	80 000
Initial grass area for rabbits to eat	100 000
Rabbit breeding rate	2 (that is, doubling) per time step
Fox breeding rate	1.1 per time step
Grass available	100 000/current rabbit population

Possible initial assumptions for the rabbits and foxes model (top) and possible output from a simulation model using these assumptions



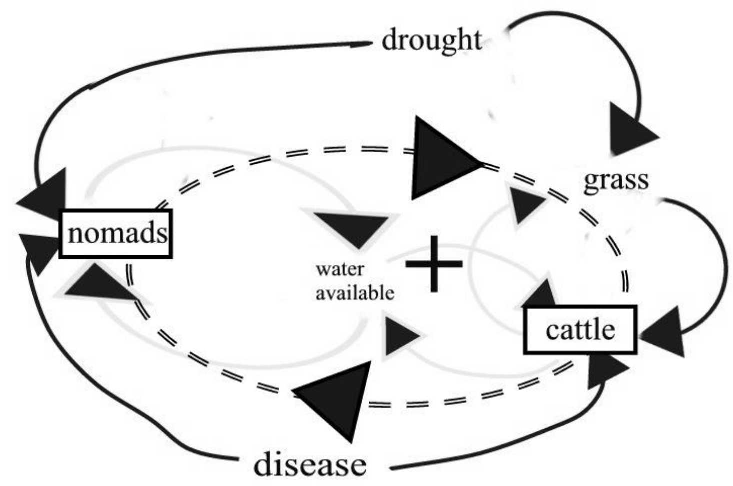
Dynamical systems

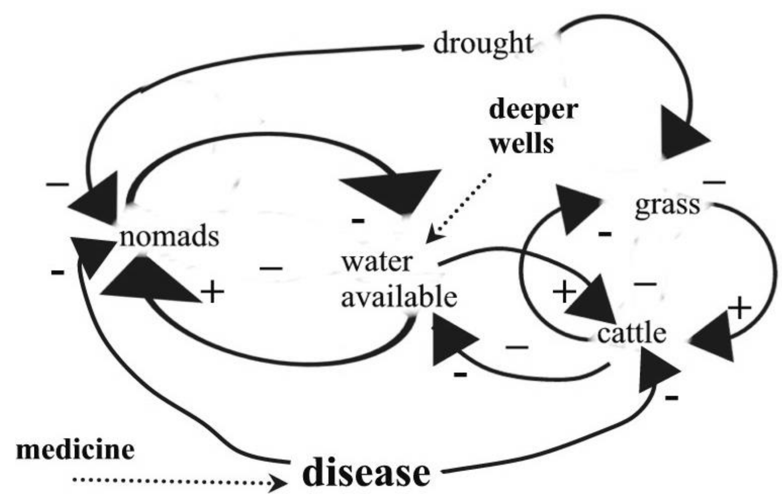


- **Tipping points** are phenomena of crowd behaviour when at a point in time, their behaviour shifts from one state to another
  - Sudoku becomes an international craze
  - A few people have a disease; suddenly there is an epidemic
  - Suddenly everyone seems to be saying “awesome”
  - The last straw breaks the camel’s back
- Below a certain **threshold** nothing changes, but only a tiny change in the input then leads to the behaviour switching **catastrophically**

Tragedy of the commons

- Initially, the traditional influences of drought and disease kept numbers of cattle under control in the Sahel
- When deeper wells and modern medicine were introduced, however, there were fewer deaths, expansion of herds – and overgrazing and desertification





Self-organisation

- Many systems adapt intelligently to their environments.
- Others may select their actions to change towards an internal equilibrium.
    - This can mean changing how their parts are organised to be closer to where they want to be, a bit like trying to find a comfortable sleeping position when camping.

Self-organisation

- Self-organising systems display the intelligence to reorganise their components into forms that allow them to adapt to changes in the environment
  - Artificial neural networks can change the weighting within the system as they learn and incorporate feedback
  - The human brain is plastic and its constructions of reality are adaptable
  - Insects can rapidly generate new forms of body more suited to changed circumstances

Self-organisation

- One of the requirements that helps a system to reorganise itself is a mutual awareness among components, which have some autonomy over their activity
- Traffic flows are a good example of how a self-organising system can work
  - Every day in our cities we see traffic moving along, more or less at the speed of surrounding traffic and usually without crashing into other vehicles.

Summary

Subtitle if required

Summary

- This topic really only scratches the surface of systems theory
- It is important to address systems theory in this unit because computers and computer systems are systems themselves, and, in turn, are component parts of larger systems
- All areas of IT have to deal with systems; their design, creation and maintenance
- Topics:
  - Introduction
  - Features of a system
  - The qualities of systems
  - System dynamics
  - Self-organisation

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