Dynamic Modelling for Human-centered Systems

Lecture 1

Syllabus: chapter 1 and 2

Agenda for today

- What is a model?
- Why modelling?
- Designing models
- Growth model in Excel

Agenda for today

- **What is a model?**
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Model

- What is a model?
  - Describe the most important characteristics of model
  - With a neighbour, answer via menti.com: **5576 3918**

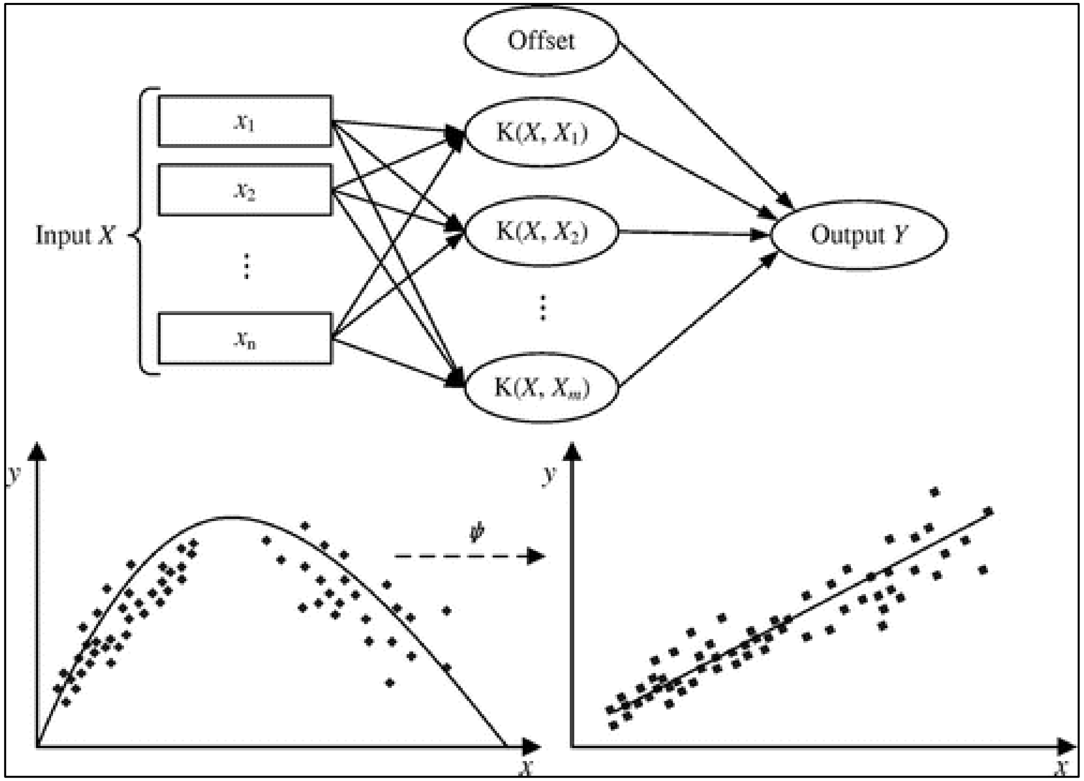
- Definitions:
  - *A representation of an object, system, or idea in some form other than that of the entity itself* **(R.F. Shannon)**
  - *A simplified representation of a system or phenomenon, as in the sciences, with any hypotheses required to describe the system or explain the phenomenon, often mathematically* **(Random House Unabridged Dictionary)**
  - *A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics* **(The American Heritage Dictionary)**

Example

- Planetarium:
  - Representation of *planets and their orbit*
  - Aim:
    - Show working of solar system
    - … and Eisinga: proof that the world will not disappear
  - Type
    - physical
    - *dynamic*

Another example

- Statistical / machine learning models
  - Representation of *correlation between input and output*
  - Aim:
    - predict output based on input
  - Type
    - numerical
    - *static*

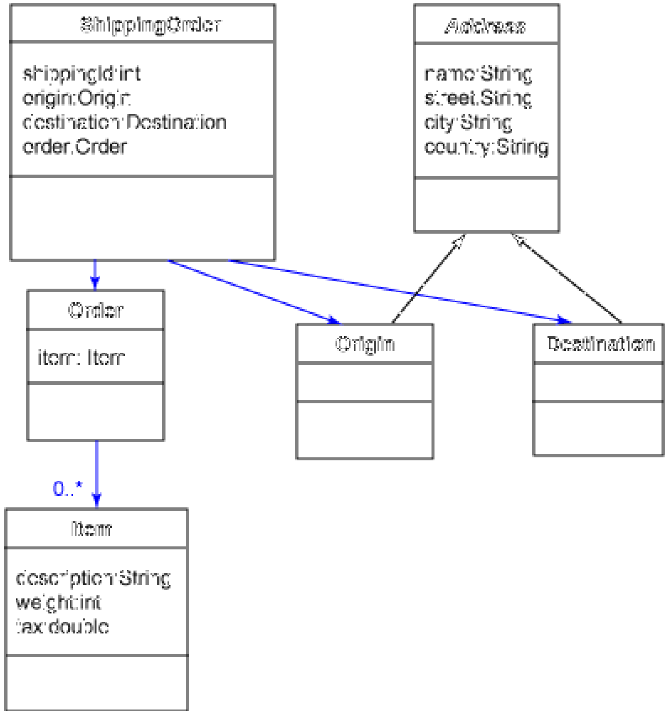


Yet another

- Marquette (scale model):
  - Representation of *spatial properties of between objects*
  - Aim:
    - study spatial aspects beforehand
  - Type
    - physical
    - *static*

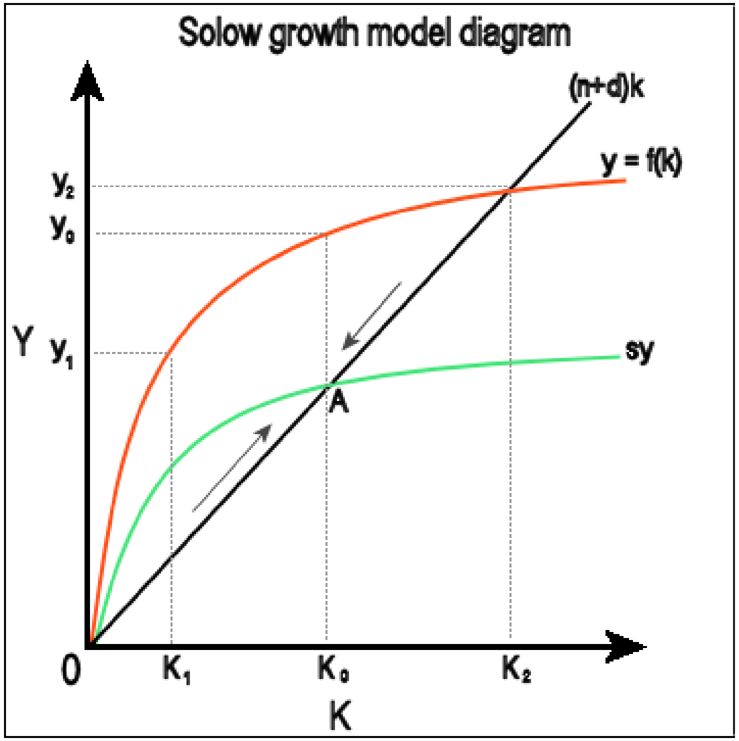
And again…

- Software model:
  - Representation of snippets of computer programs, their functions and relations
  - Aim:
    - verify program beforehand
    - simplify or automate programming
  - Type:
    - diagrams and semi-formal descriptions
    - static (or dynamic)



… another example

- Economic model:
  - Representation of economic processes
  - Aim:
    - predict aspects of economy
    - tool for determining economic policies
  - Type:
    - mathematical formuleas
    - dynamic



- Many other types exist…

Risks of using models

- Which risks do you see risks in using models?

- Important observations
  - a model is a *simplification*
  - during the design of the models, *choices* have been made
    - assumptions
  - a model is not the same as reality!

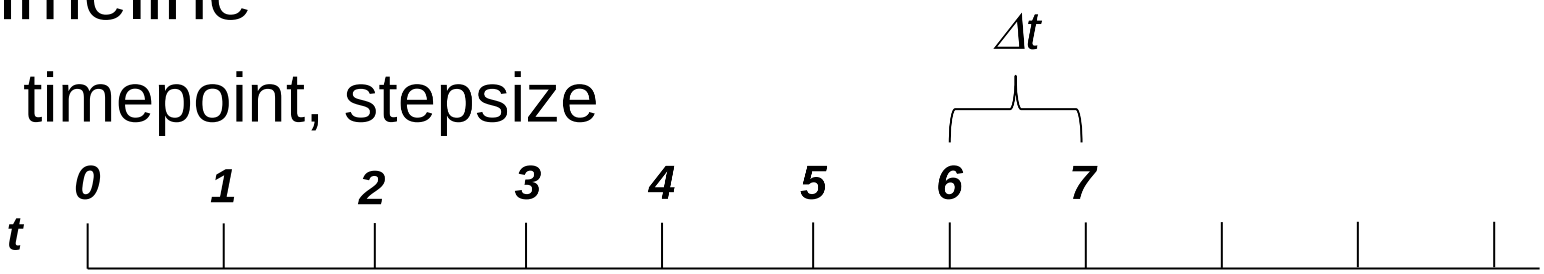
Our focus in this course

- We restrict ourselves to **dynamic models**
  - what is the most important property? Via menti.com

- A **dynamic model**:
  - describes a specific phenomenon, theory or system (i.e. a process)
  - specifies **changes over time**
    - i.e. can simulate the process

Elements of a dynamic model

- Concepts
  - represented as variables
    - temperature of an egg: *TempEgg*
- Timeline
  - timepoint, stepsize



- Rules that describe how concepts change per time step
  - $TempEgg(\mathbf{t+\Delta t}) = \beta * TempWater(\mathbf{t}) + (1-\beta) * TempEgg(\mathbf{t})$

Additional elements

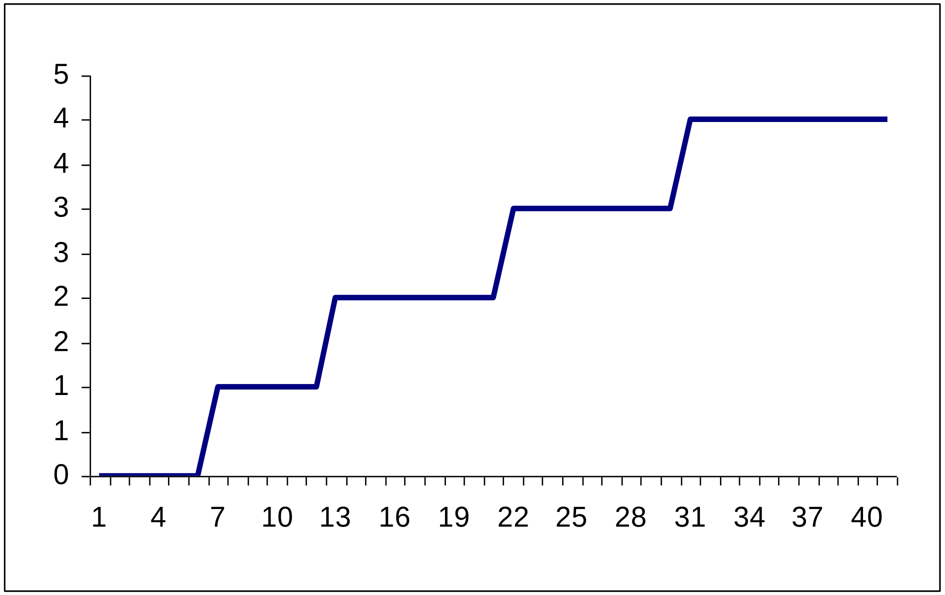
- Start values
  - $TempEgg(0) = 35$
- Optional parameters
  - $\beta = 0{,}33$
- Optional stochastic variables
  - random values

Model outcome

- How to describe the outcome of a *dynamic* model?
- List of states of a model at subsequent time points:
  - (simulation) trace
  - simulation run
- How can we show it?

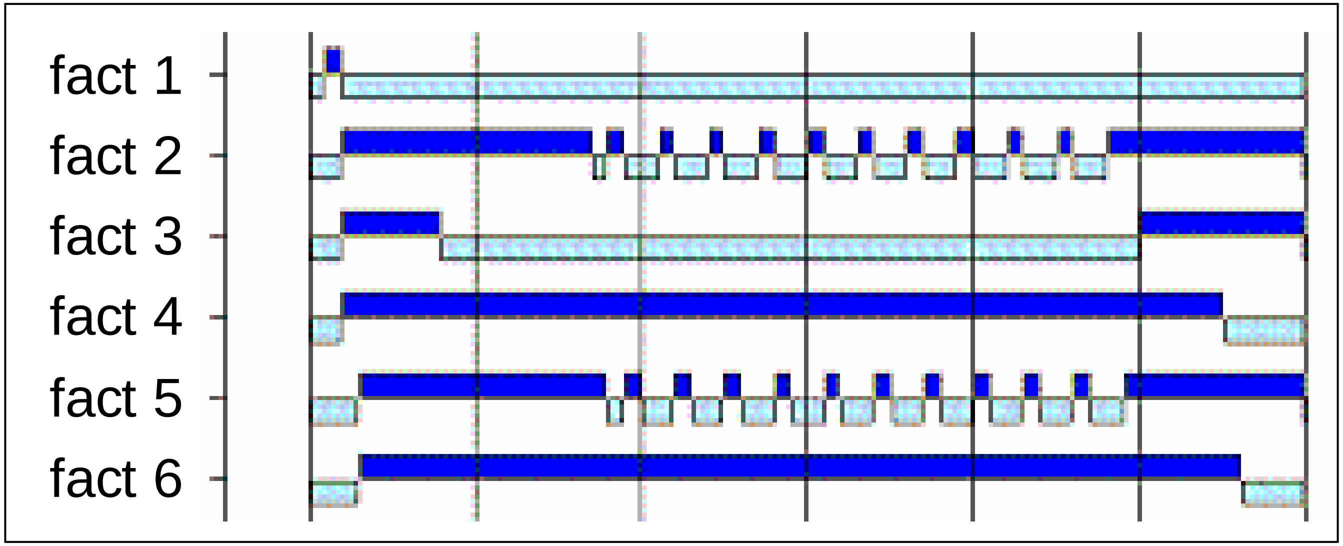
Visualisation of simulations

- Dependent on the representation of the model
  - graphical representation of values of model variables at subsequent time points



Visualisation - 2

- representation of truth values of model variables at subsequent time points (state trace)



Agenda for today

- What is a model?
- **Why modelling?**
- Designing models
- Growth model in Excel

Why modelling?

- 1. Study a process to increase understanding:
  - study the behaviour of a process over time
  - performing “what if” simulations
- 2. Basis for intelligent systems
  - models are used to understand what is happening with humans (and what to do)
  - models can make systems behave human-like

Users of models

- People:
  - researchers
  - policy makers

- Systems:
  - adaptive systems
  - human-like systems
  - ⇒ *second half of the course*

Use of models for scientific understanding

- How to use models to increase understanding?
- Scientific method:
  - research questions lead to hypotheses
  - formulate specific and precise hypotheses:
    - “if A occurs, then we observe B after some time”
  - validate hypotheses on simulation traces

Research questions

- Questions can be based on:
  - curiosity about the consistency of a scientific theory
  - curiosity about ultimate consequences of (aspects of) a scientific theory
  - questions about the long term effects of changes in policy

New term: model property

- An hypothesis about a model behavior (i.e. the outcome of a simulation given some input and parameter value) is called:

  a **model property**

Model properties

- Can be statements about
  - effects that happen over time
  - combination of inputs that lead to some output
- Examples:
  - *Jupiter and Pluto will not collide within two years*
  - *when taking a pill every 3 hours, the medication level is between 12 and 20 mg/l*
- What is essential for a property?
  - it can be tested in an unambiguous way

Validation of properties

- Run (several) simulations of the model and check the properties ⇒ scenarios
  - choose conditions / input parameters intelligently
  - be precise about what you can conclude
- Alternatively:
  - use logic / mathematics to (dis)prove the properties
    - usually quite complex

Advantages of modelling

- Processes are easier to study than in reality, because that is:
  - expensive
  - time consuming
  - hard to measure
  - hard to manipulate
  - not ethical
  - …

Use of models for intelligent applications

- Ambient Intelligence:
  - Intelligent systems support humans in their daily environment

- Requirements:
  - Systems have *knowledge* about human functioning
  - This course: making dynamic models about human functioning and incorporate them in systems

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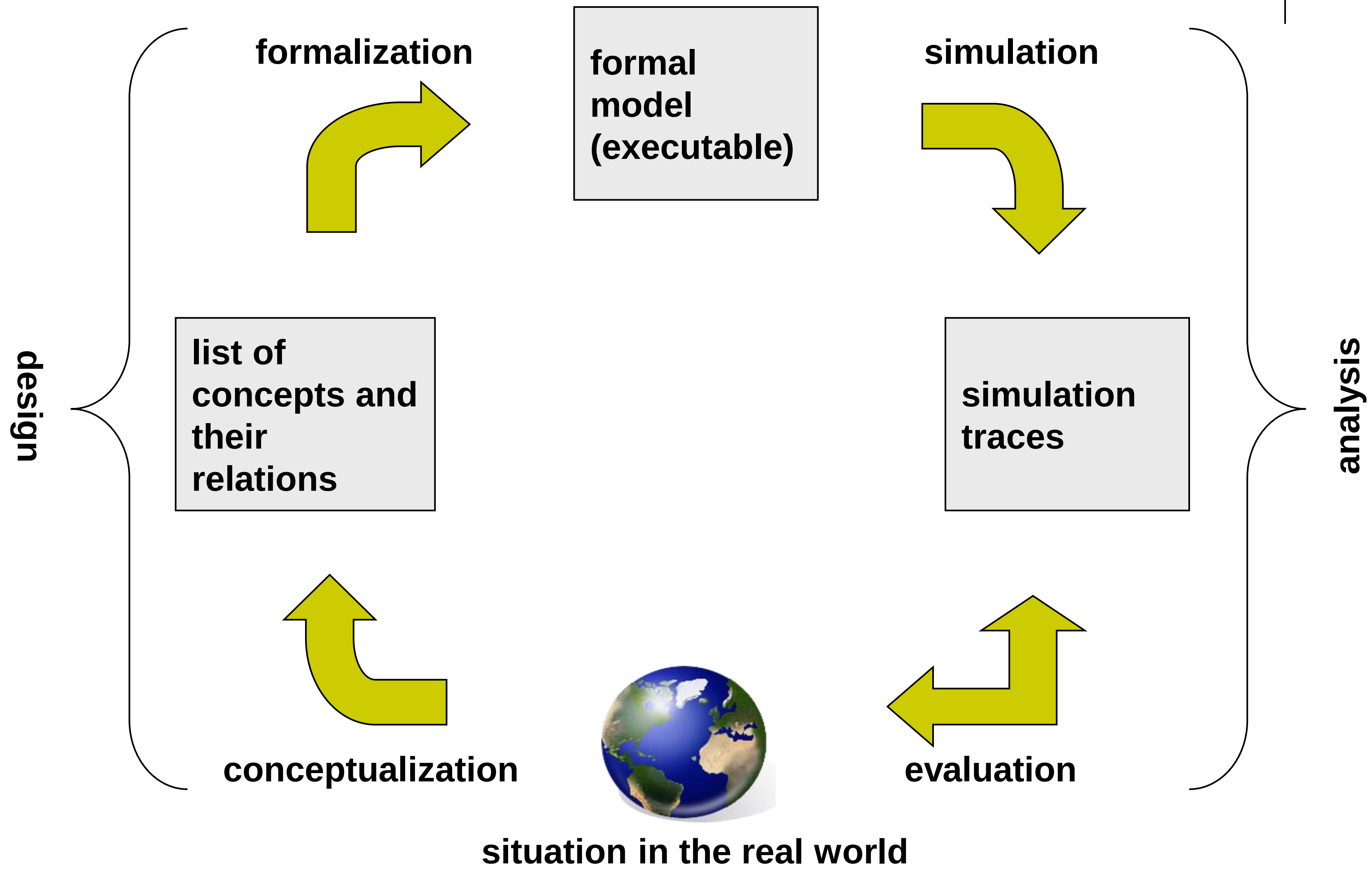
- **Designing models**
- Growth model in Excel

Designing models

- Quotes:
  - *"Make your theory as simple as possible, but no simpler."* (Albert Einstein)
  - *"For every complex question there is a simple and wrong solution.“* (H.L. Mencken)
- Creative process!
  - requires choices and assumptions
  - not one correct solution
    - global / detailed; what to include / ignore
- Guideline provides structure to process

Modelling and Simulation Cycle



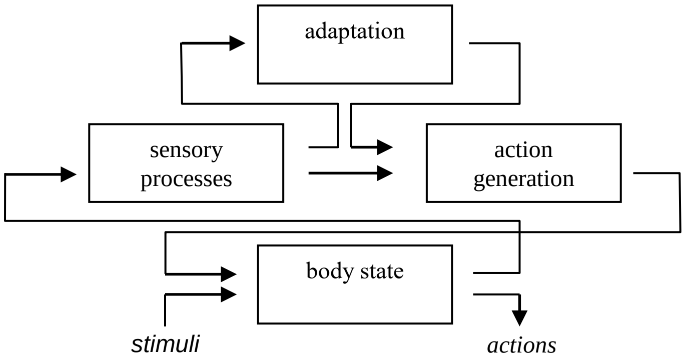
1. Conceptualisation

- Several steps
- Iterative process
  - outcome task can influence other choices

A. Characterizing the process
  - scope and boundaries
  - type of questions to answer with the model
  - expected behaviour (***characteristic patterns***)

Conceptualisation (2)

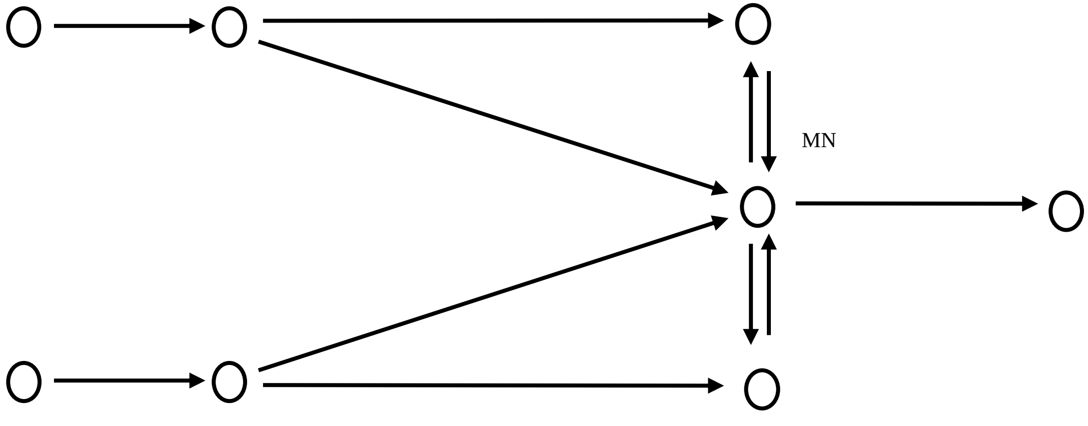
B. If necessary: describe sub processes
- identify sub processes
- determine order
- result: simple diagram
  with processes and arrows



C. Identify important concepts
- which *factors* play a role in the process
  - objects, events, principles
- result: list of concepts

Conceptualisation (3)

D. Relations between concepts
- which concepts affect each other
  - whether, not how
- most relations occur within a sub process
- result:
  - list “A affect B”
  - diagram



2. Formalisation

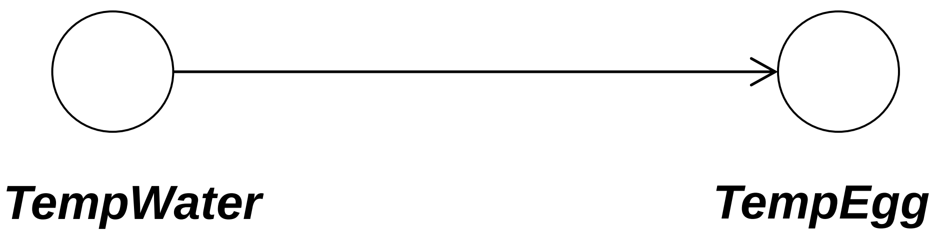
- Specification of the details of the conceptualization
  - concepts & relations
- Dependent on chosen representation
- Two main variant:
  - numerical representation
  - logical representation

Numerical representation

- Concepts:
  - variables met numerical value
    - integer, real, 0 of 1
    - example: concept “temperature” → “Temp: real”
- Relations:
  - calculation rules to determine value of concept at next time point based on values other concepts
    - in dynamic model values change over time
    - Δt (change in time) is time step between two states

Numerical representation (2)

- Suppose: model of the temperature of an egg that is boiled in a pot of water



- Example calculation rules:
  - $TempEgg(t+\Delta t) = TempWater(t)$
  - $TempEgg(t+\Delta t) = \beta * TempWater(t) + (1-\beta) * TempEgg(t)$

Logical representation

- Concepts:
  - statements (propositions) that can be *true* or *false*
    - example: medicine_taken(hiv_slowers)
- Relations:
  - Boolean rules that specify which combination of truth values is required for a concept to be true at next time point

Logical representation (2)

- Example rules:
  - $A \wedge B \rightarrow C$:
    - if A and B are true, C becomes true
  - $A \vee B \rightarrow C$:
    - If A or B or both are true, C becomes true
  - $A(X) \rightarrow B(X)$:
    - If A is true for argument value X, B becomes true for the same argument X
  - $not(A) \rightarrow B$:
    - If A is not true, B becomes true
  - $A(X) \wedge X > 52 \rightarrow B$:
    - If A is true for some value X larger than 52, B becomes true

3. Simulation

- Expected behaviour of correct model is specified as characteristic pattern ⇒ property
  - already during conceptualisation
- Define different scenarios that should be able to show properties
  - different start values
  - parameters that are different
  - stochastic variables (random factors)

4. Evaluation

- Simulations results are compared to characteristic patterns / properties
- Used to draw conclusions about correctness of model
  - validation

- Remarks:
  - Patterns ≠ direct relations:
    - about indirect relations, and / or:
    - longer period of time
  - Same process as answering research questions

Steps in brief

1. **Conceptualisation**: identification of important concepts and relations
2. **Formalisation**: describe concepts and relations in an unambiguous way
3. **Simulation**: running experiments with models to generate simulations traces
4. **Evaluation**: verify whether the simulations are in line with expectations (properties about characteristics patterns)

Wrap up:

- What is a property of model?
- Which two use cases have we seen?

Reporting

- Structured reporting is important
  - many arbitrary choices in process
- Elements of report:
  - assumptions, choices, motivation
  - concepts, relations, expected patterns
  - scenarios used in simulation experiments
    - settings
    - input parameters
  - Verified properties, conclusions

Summary

- Dynamic models describe process in which factors change over time
- Models consists of:
  - concepts
  - rules
- Hypothesis / properties can be formulated and validated against simulation
  - for evaluating expected patterns
  - for studying the process

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- **Growth model in Excel**

Dynamic modelling for Human-centered Systems

Modelling growth

Chapter 2

Modelling “growth”

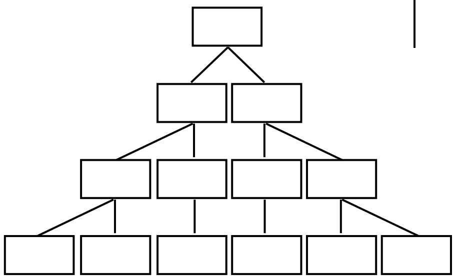
- Basic example of model of dynamic process
- At the same time: building block for models of other process in which growth plays a role
- Aim: generic model
- Inspiration from nature

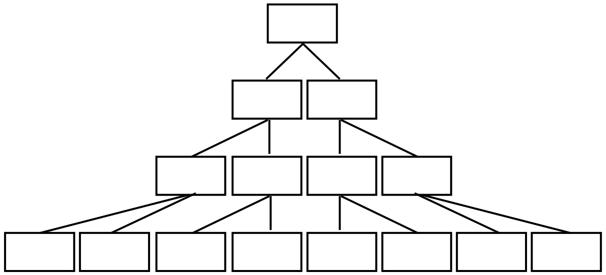
Understanding growth

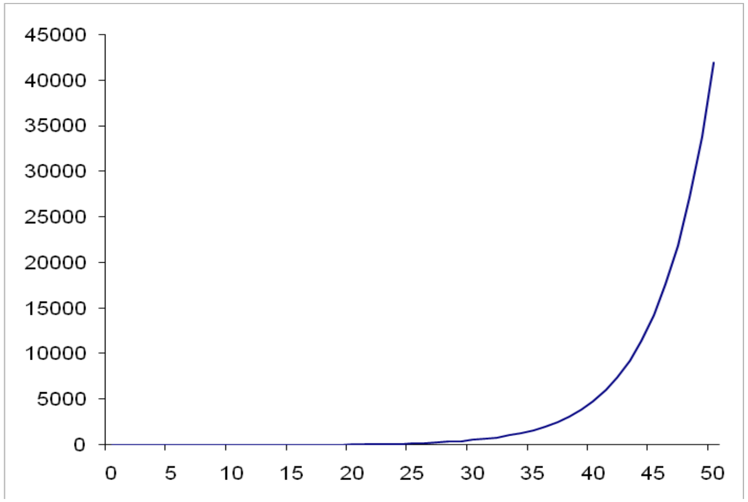
- Phenomenon growth:
  - generic process
    - economy, biology
    - relations, trust
- Inspiration: biological growth
  - two causes of growth at cell level
    - volume increase
    - cell division
  - two types of growth via cell division
    - every cell divides
    - only cells at the end divide

Generic growth patterns

- Linear growth
  - division by fixed number of cells
  - equal gain per time step
- Exponential growth
  - division by every cell
  - every time step doubling

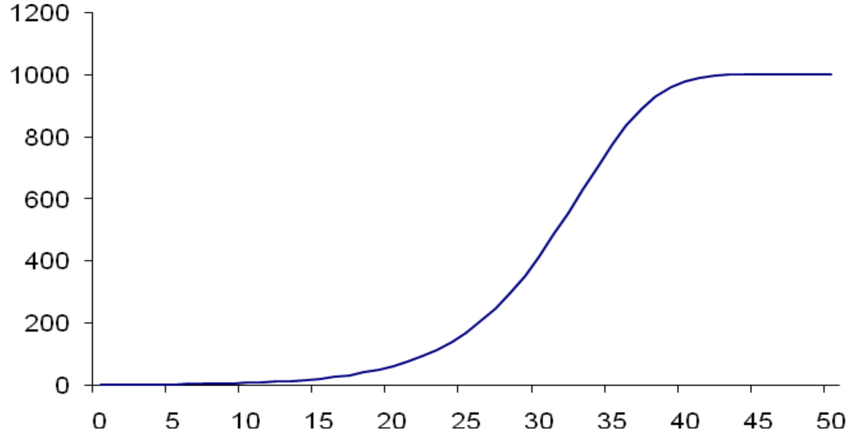






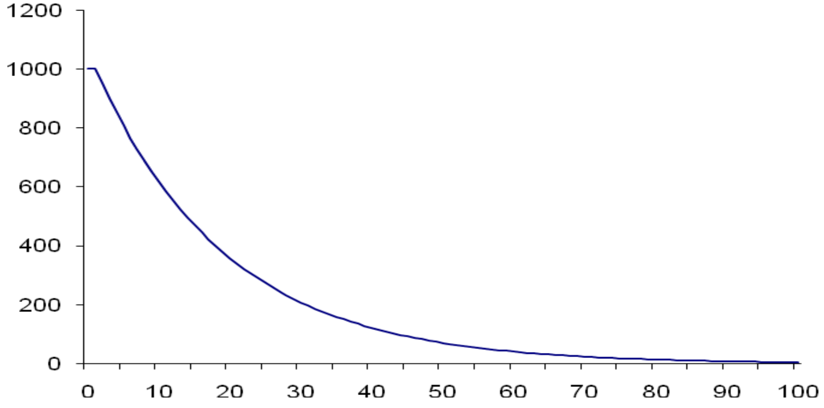
Generic growth patterns (2)

- Limited growth
  - growth decreases when some maximum is approached
  - growth is linear or exponential at start, then decreasing gain per time step



Generic growth patterns (3)

- Negative growth
  - loss is larger than the gain
  - exists in several variants
    - linear
    - exponential…



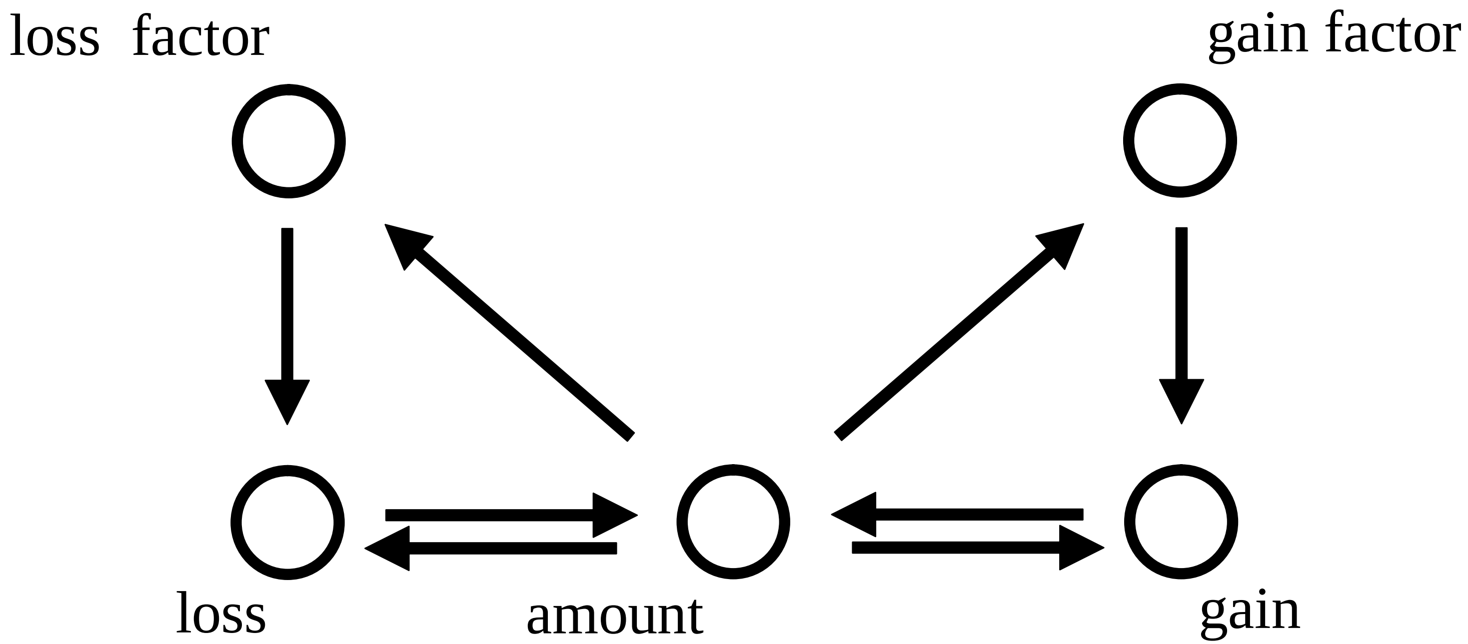
Which concepts?

- What would be useful concepts for a dynamic model of growth?
  - answer via menti.com

Conceptualisation of basic version

- Important concepts
  - amount
  - gain per time step
  - loss per time step
  - gain factor = gain as proportion of the total amount
  - loss factor = loss as proportion of the total amount

Visual representation of model



Formalisation

- **Amount and gain factor affect gain**

  Gain is calculated by multiplying the gain factor by the amount:

  *Gain(t) = GainFactor(t)*Amount(t)*

- **Amount and loss factor affect loss**

  Loss is calculated by multiplying the loss factor by the amount:

  *Loss(t) = LossFactor(t)*Amount(t)*

Formalisation - 2

- **From gain and loss to amount**

  Gain adds to the amount and loss subtracts from the amount, both taken over the time interval that is passing.

  $$Amount(t+\Delta t) = Amount(t) + (Gain(t) - Loss(t)) * \Delta t$$

- **Gain factor**

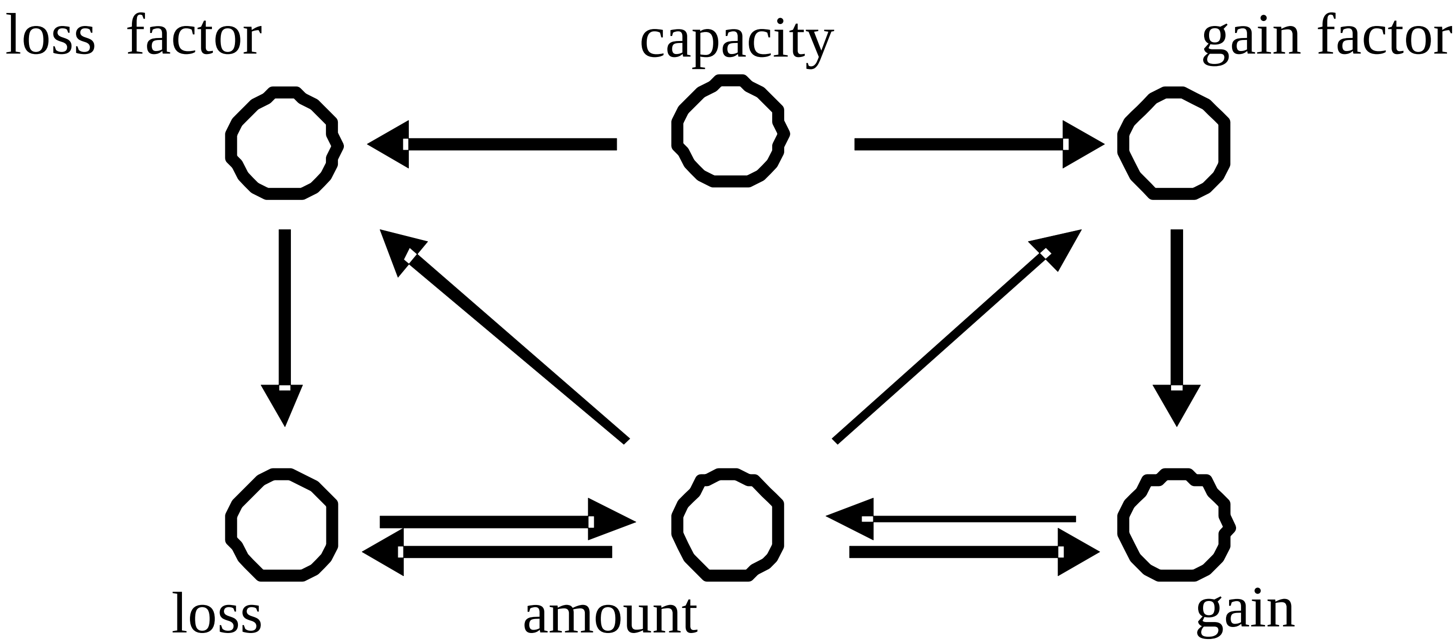
  Constant *factor* for exponential growth

  $$GainFactor(t) = \alpha$$

Limitation

- Model only allows linear and exponential growth
- Limited growth can not be represented
- Which change is needed?

Limited growth model

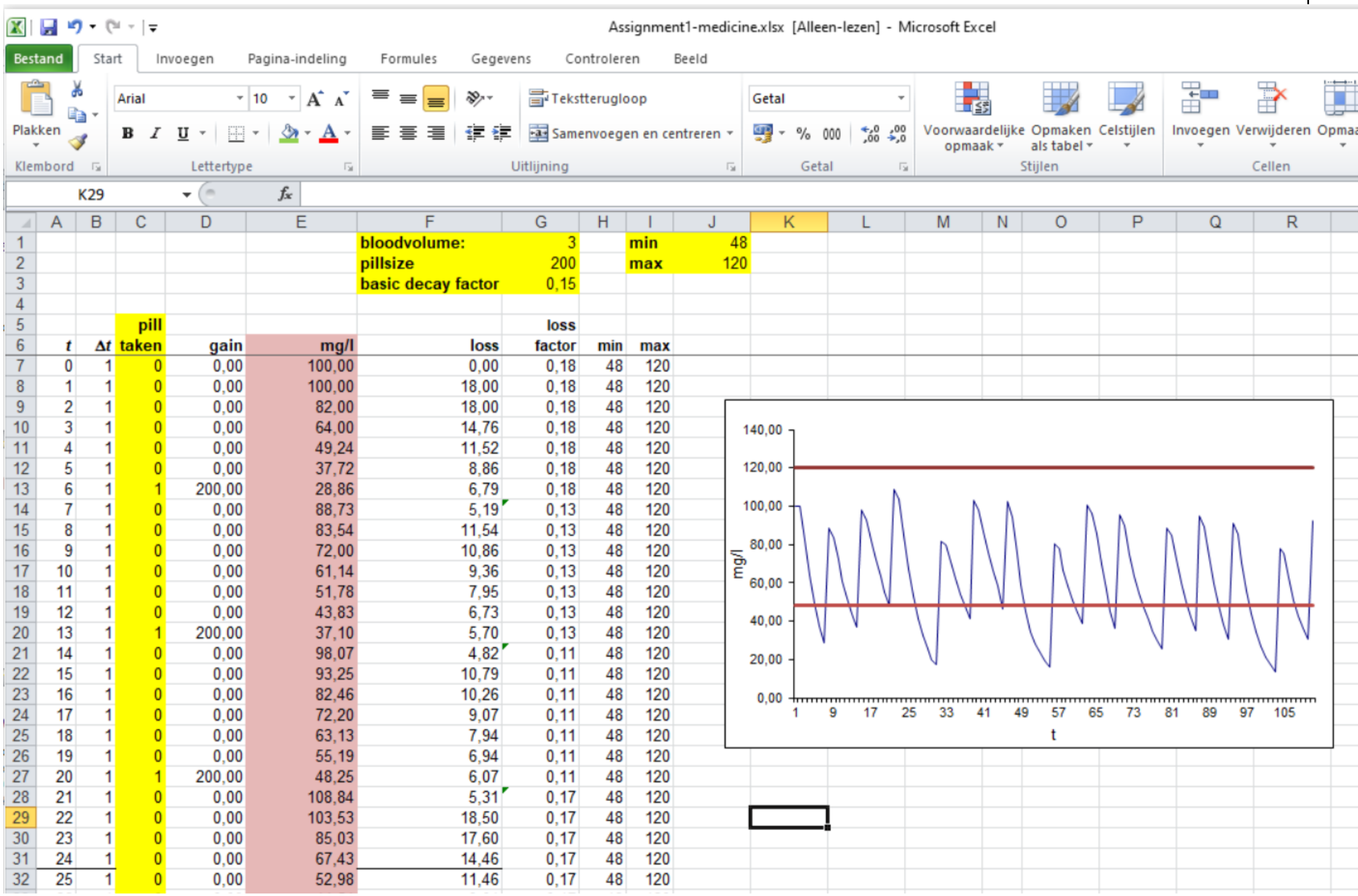


Adapted formalisation

- Limited *gain:*
  - proportional to distance to maximum capacity (C)
    - when close to C, the gain is also small

      $(\ C - Amount(t)\ )\ /\ C$
  - thus:
    - $GainFactor(t) = \alpha * (\ (\ C - Amount(t)\ )\ /\ C\ )$
  - results in "logistic" growth

Modelling in Excel



bloodvolume:	3		min	48
pillsize	200		max	120
basic decay factor	0,15			

t	Δt	pill taken	gain	mg/l	loss	loss factor	min	max
0	1	0	0,00	100,00	0,00	0,18	48	120
1	1	0	0,00	100,00	18,00	0,18	48	120
2	1	0	0,00	82,00	18,00	0,18	48	120
3	1	0	0,00	64,00	14,76	0,18	48	120
4	1	0	0,00	49,24	11,52	0,18	48	120
5	1	0	0,00	37,72	8,86	0,18	48	120
6	1	1	200,00	28,86	6,79	0,18	48	120
7	1	0	0,00	88,73	5,19	0,13	48	120
8	1	0	0,00	83,54	11,54	0,13	48	120
9	1	0	0,00	72,00	10,86	0,13	48	120
10	1	0	0,00	61,14	9,36	0,13	48	120
11	1	0	0,00	51,78	7,95	0,13	48	120
12	1	0	0,00	43,83	6,73	0,13	48	120
13	1	1	200,00	37,10	5,70	0,13	48	120
14	1	0	0,00	98,07	4,82	0,11	48	120
15	1	0	0,00	93,25	10,79	0,11	48	120
16	1	0	0,00	82,46	10,26	0,11	48	120
17	1	0	0,00	72,20	9,07	0,11	48	120
18	1	0	0,00	63,13	7,94	0,11	48	120
19	1	0	0,00	55,19	6,94	0,11	48	120
20	1	1	200,00	48,25	6,07	0,11	48	120
21	1	0	0,00	108,84	5,31	0,17	48	120
22	1	0	0,00	103,53	18,50	0,17	48	120
23	1	0	0,00	85,03	17,60	0,17	48	120
24	1	0	0,00	67,43	14,46	0,17	48	120
25	1	0	0,00	52,98	11,46	0,17	48	120

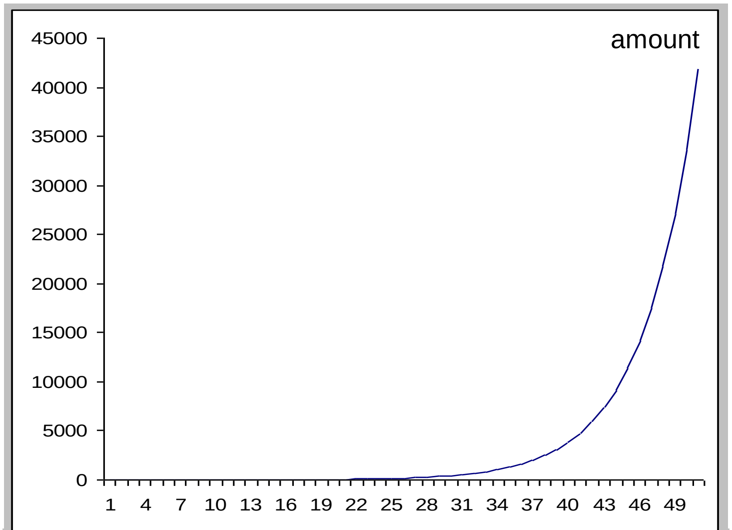
How to make dynamic models in Excel?

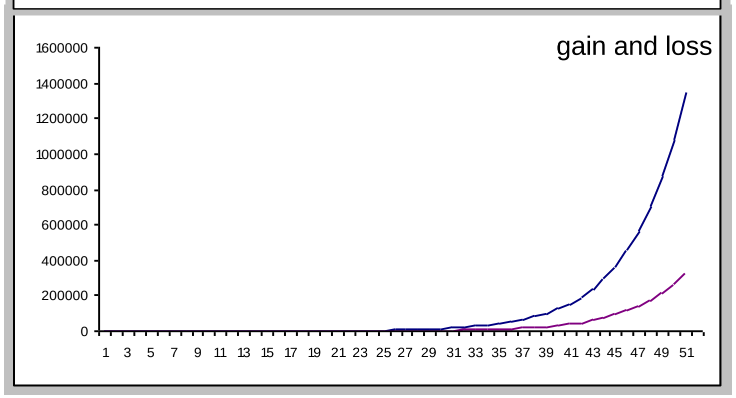
- Excel can be used to represent dynamic models
  - concepts → columns
  - timeline → subsequent rows
  - calculation rules → formulae in columns of cells
  - parameters → some specific cells

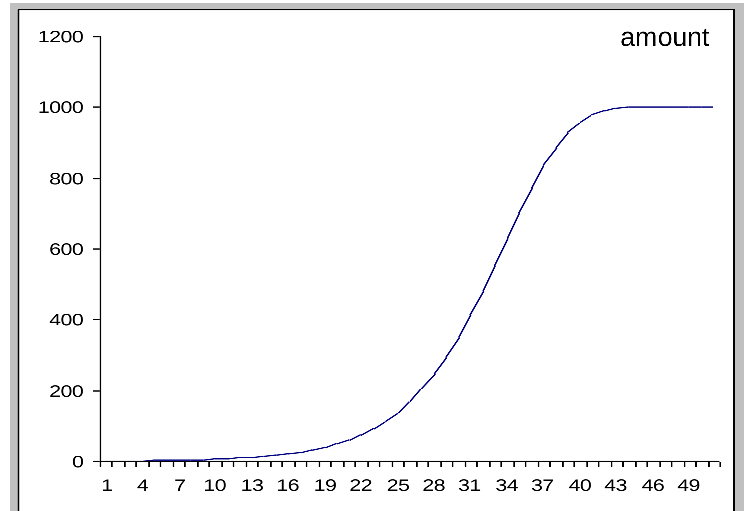
Example

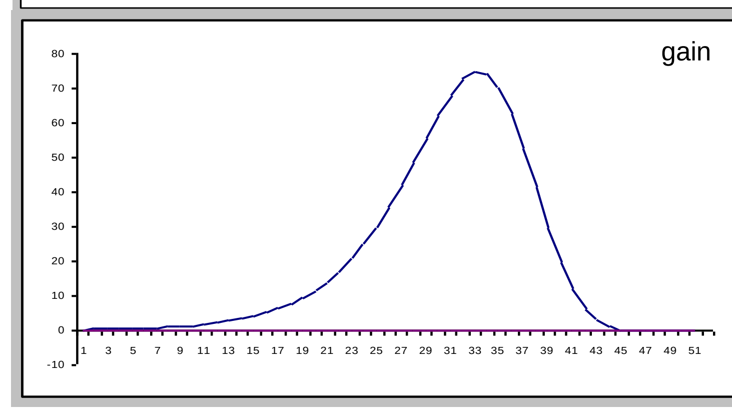
t	loss factor	loss	amount	gain	gain factor
0	0.1	10	100	40	0.4
1	0.1		130		0.4
2	0.1				0.4
3	0.1				0.4
4	0.1				0.4

Results simulations









exponential

logistic

Assignment 1

- Understand specific model in Excel
- Make changes
- Formulate hypothesis about simulation result
- Validate hypothesis by comparing simulation outcomes

Model for assignment

- Prediction of drug level in blood
  - when taking medication, it is important to keep the drug level in the blood between certain limits
- Model
  - based on growth model
  - time steps of one hour
  - taking a pill increases medication level in blood
  - medication is slowly removed from body (decay factor)
  - decay factor depends on stochastic variable (mimics “unpredictable” physical activity)

What are good hypothesis?

- It can be tested!
  - unambiguous & precise
- What do you think?
  - sit with three neighbours
  - formulate one
  - submit some examples via menti.com
- Examples:
  - the amount is always below 600 mg/l
  - when taking medication, the gain is larger than the loss
  - for a given activity level, the drug level never goes below 200 mg/l

Instructions for assignment

- Hand in a self-contained report
  - explain & illustrate
  - sketch context, discuss consequences
- Subtraction of points if the following is not done:
  - unambiguousness in the formulation of hypotheses;
  - precise, complete and logically correct description of the interpretation of the simulation results;