TOPIC 6

Scheduling in natural resources management

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Time table

10:15-12:00	**-A- Scheduling in natural resources management**
13:15-15:00	**-B- Solve Scheduling problem** [computer lab]

Learning goals

CONCEPTUALIZE AND REPRESENT

Learn to formulate optimization models that include…

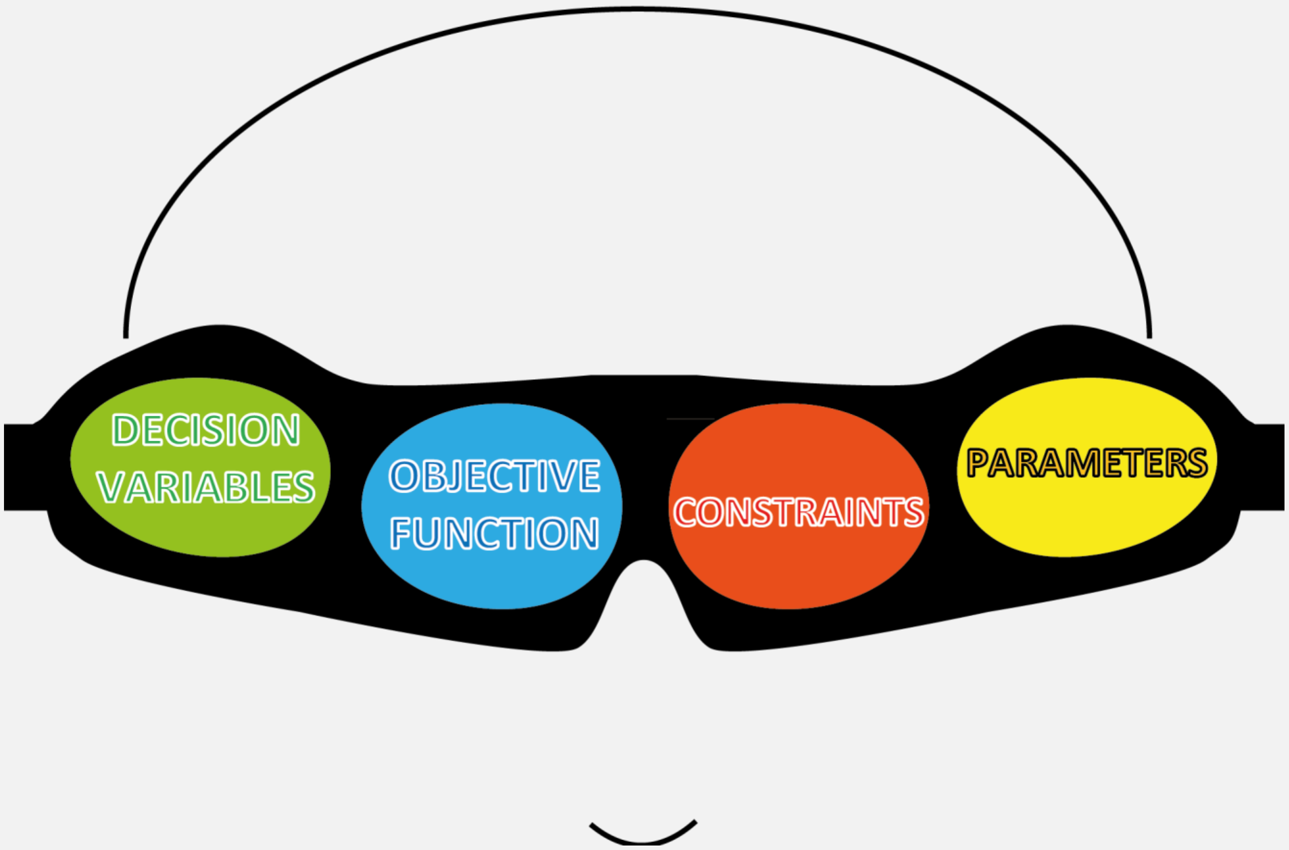
… scheduling of decisions in time

… a growth model (here: matrix population model)

IMPLEMENT

Learn to organize big matrix notation optimization models by hand (EXCEL)

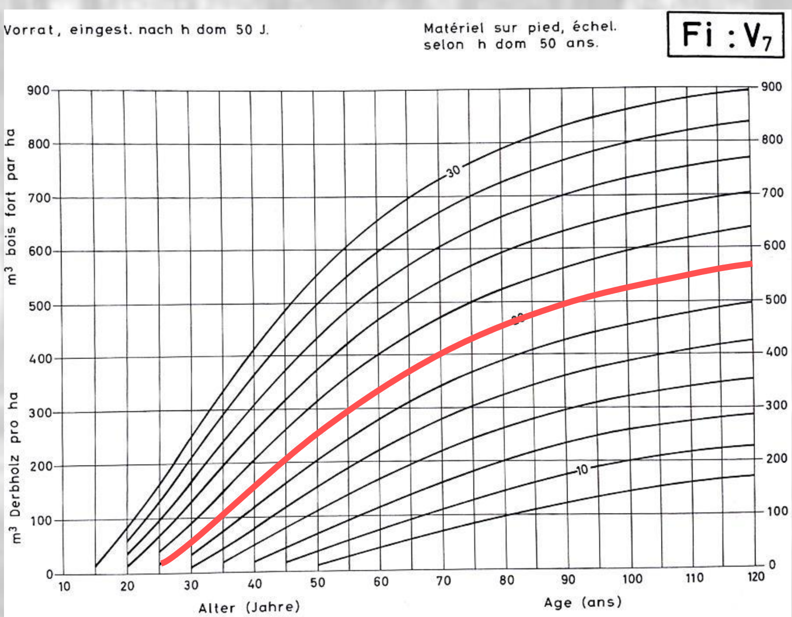
The optimizer's view of a problem



Biological natural resources…

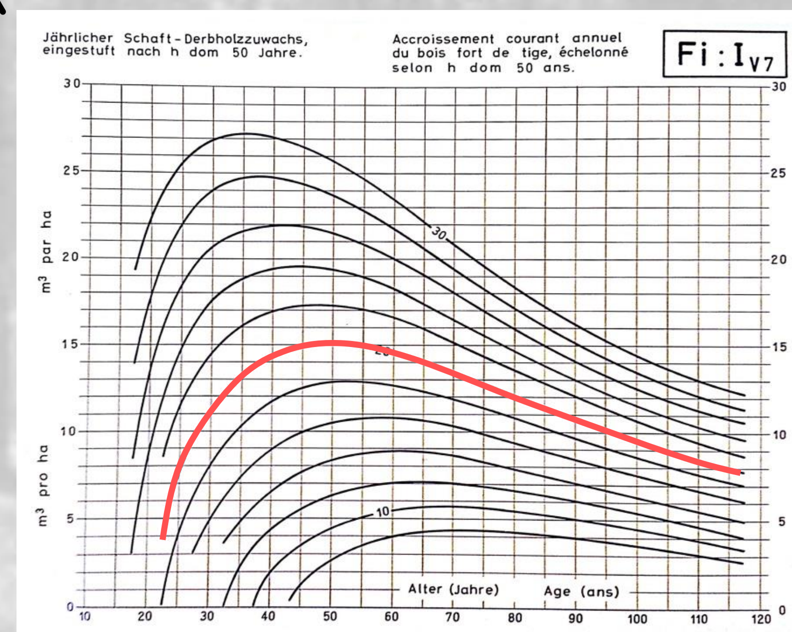
… grow!

timber volume [m³ ha⁻¹]



age [yrs]

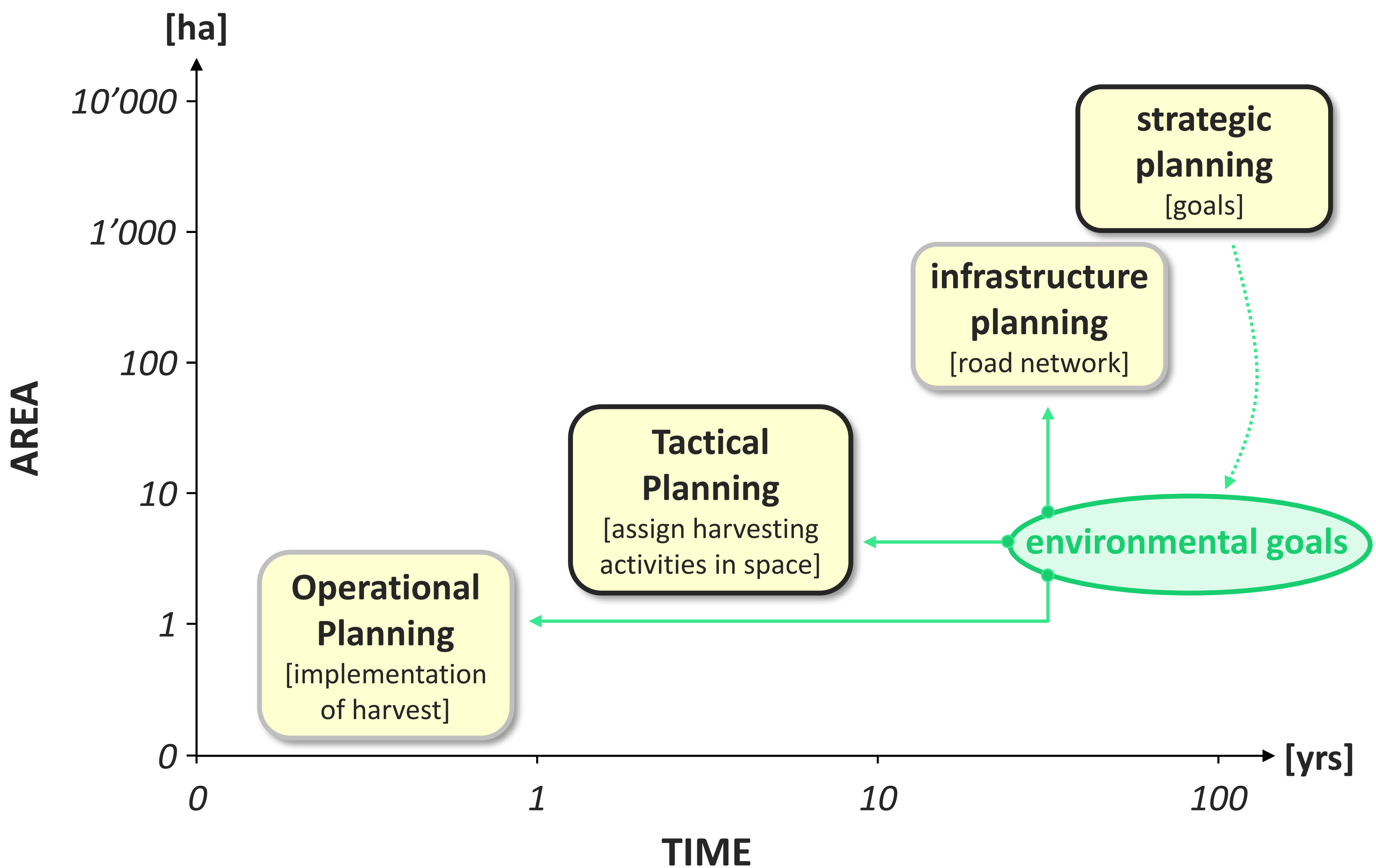
annual increment [m³ ha⁻¹yr⁻¹]



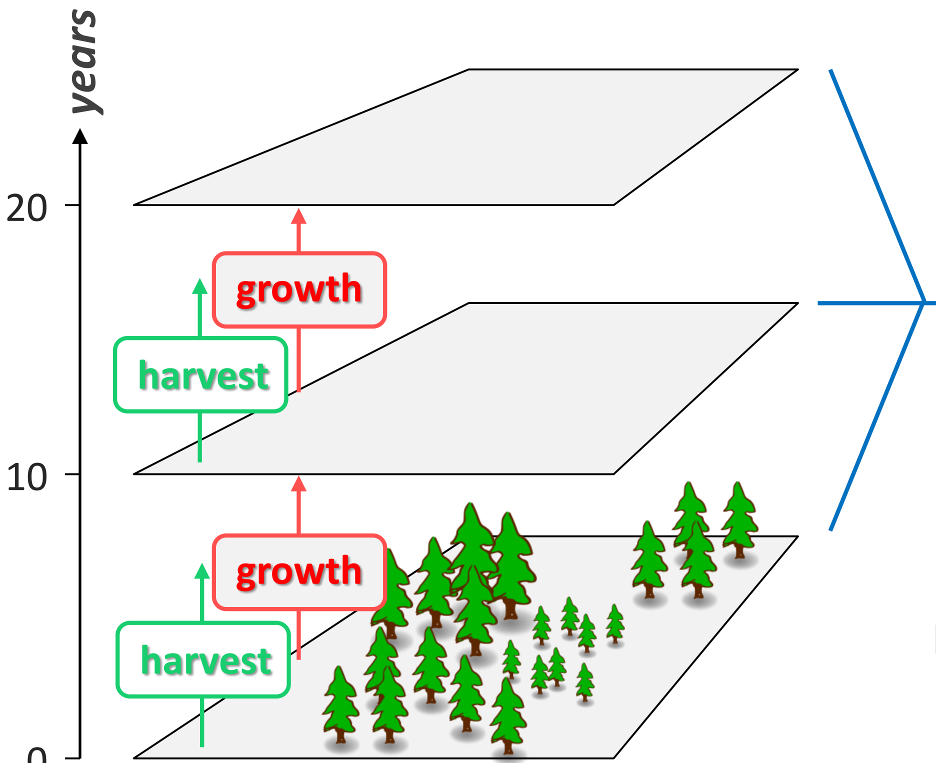
age [yrs]

Badoux E (1983) Ertragstafeln für die Fichte in der Schweiz. WSL, Birmensdorf, 3. Auflage.

Planning tasks in forestry



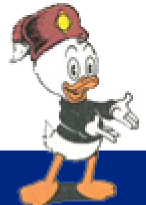
Strategic planning



Objectives

- *create steady-state*
- *constant wood-flow*
- *maximize revenues*

Highly aggregated problem representation



Use optimisation models to gain insights about the consequences of a plan

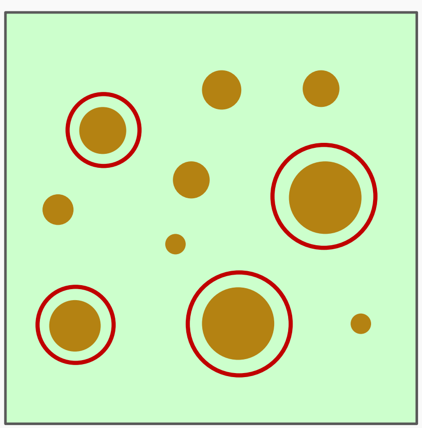
Make a forest manageable – create classes of forest types

Classification criteria

stage of development, species composition, coverage

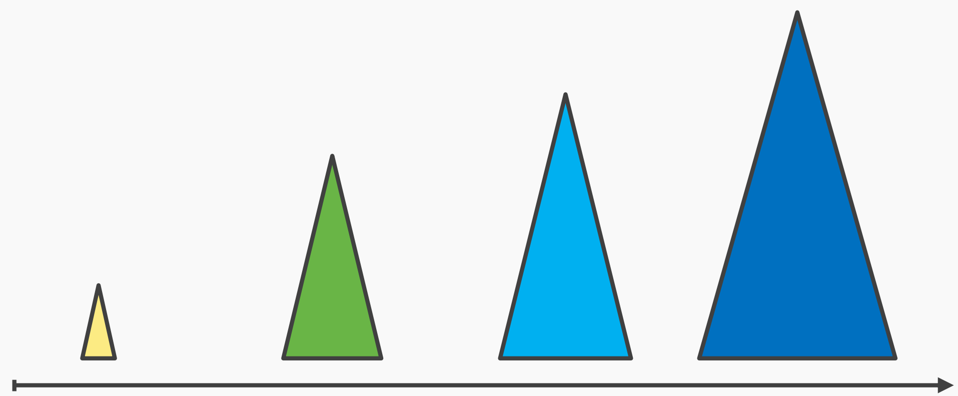
Definition

Mean diameter of the
100 tallest trees per hectare



Classes

thicket *pole* *timber* *mature timber*

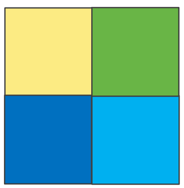


Diameter at Breast Height **DBH [cm]**

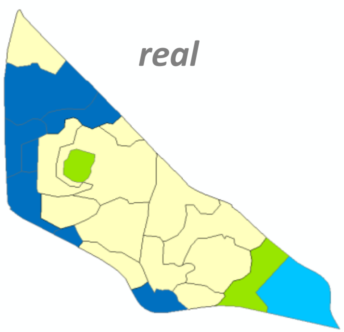
Create a steady-state [Normalwaldmodell]

stand map

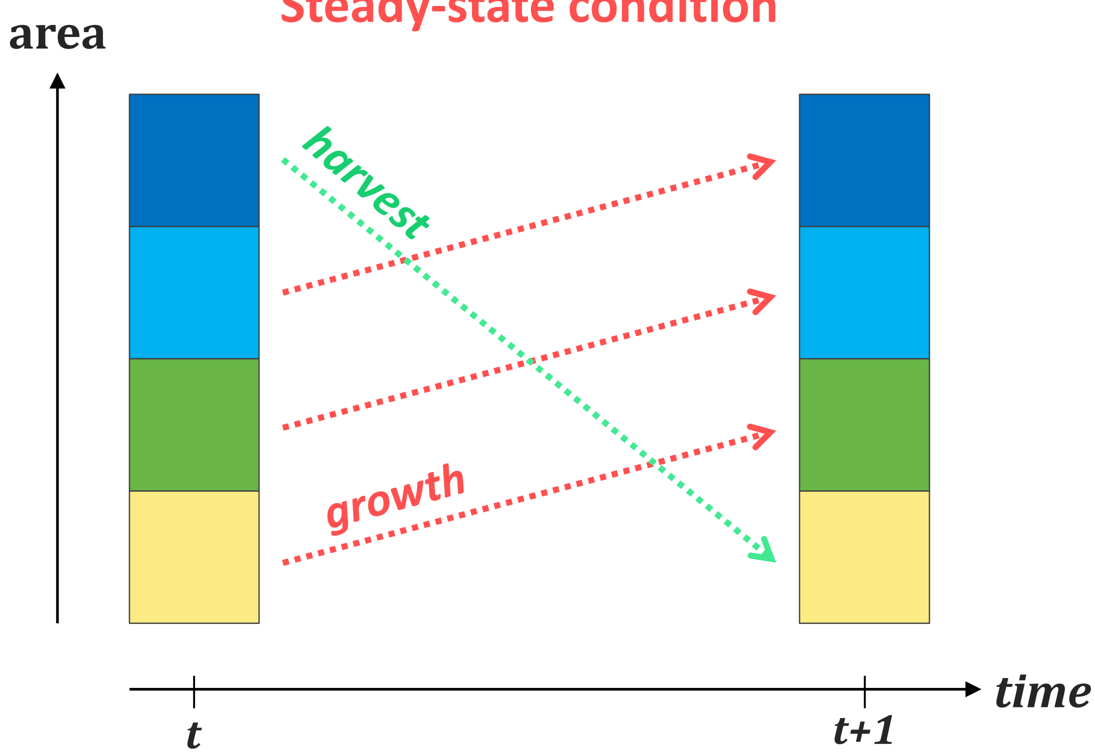
ideal



real



Steady-state condition



This also applies to Plenter forests where the focus is on "tree size" classes.

What comes next ?

Natural resources planning problem

Problem

Decision variables

Objective function

Constraints

Matrix population model

Approach for support of model formulation in EXCEL

Exercise 6
Scheduling of actions for natural resources management

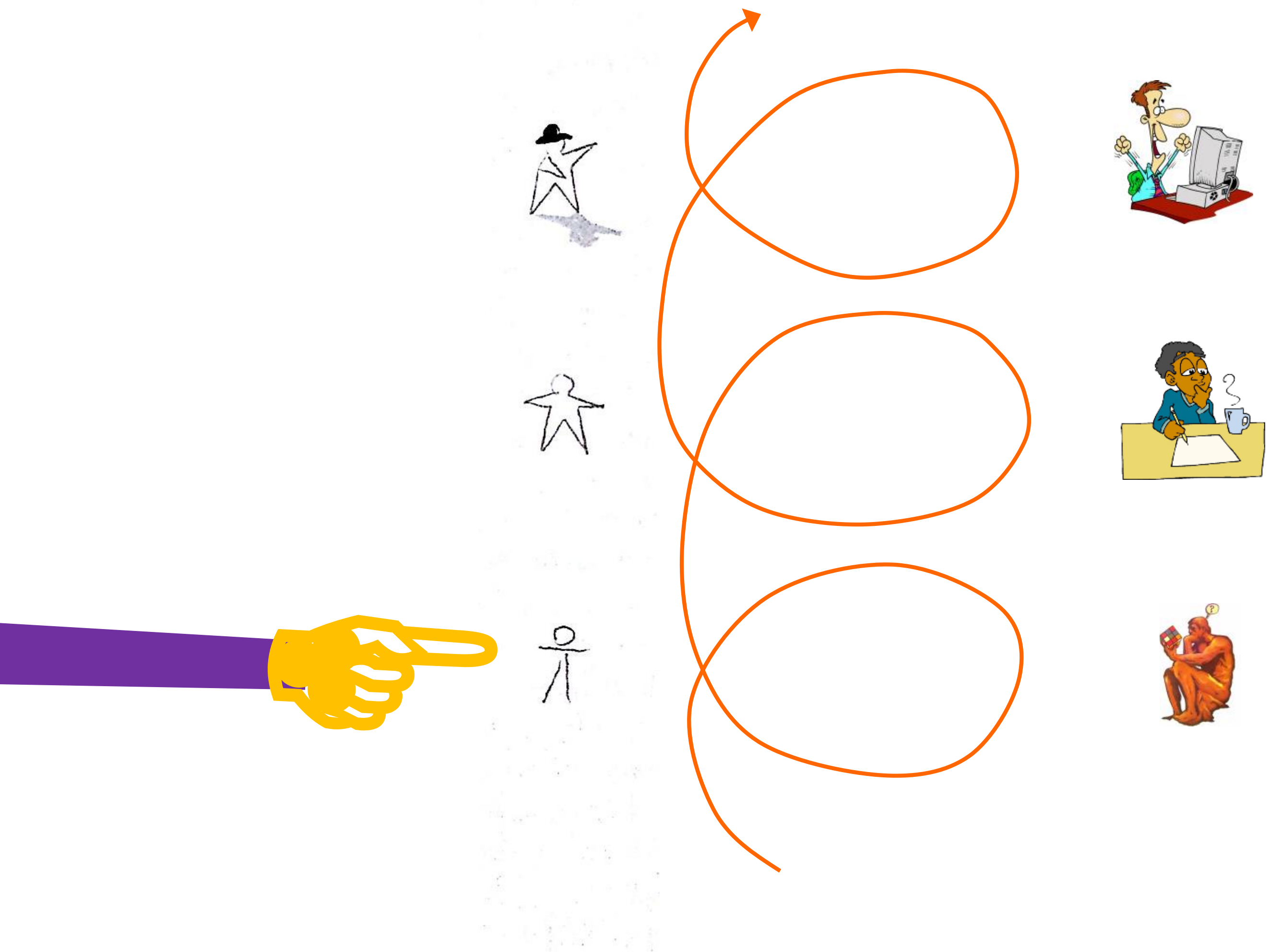
have a problem….

conceptualize & represent

implement

solve

Large optimization model



implement

conceptualize & represent

have a problem...

SCHEDULING PROBLEM

A forest company owns a forest that is composed of stands which are characterized as (1) thicket, (2) pole wood, (3) timber and (4) mature timber. Unfortunately, the percentages of those classes do not fullfill the requirements of the «steady-state» (i.e., Normalwaldmodell). The company is interested in how to schedule harvest in the future (i.e., next 3 planning periods) to transfer the forest into a steady-state and concurrently maximize revenues.

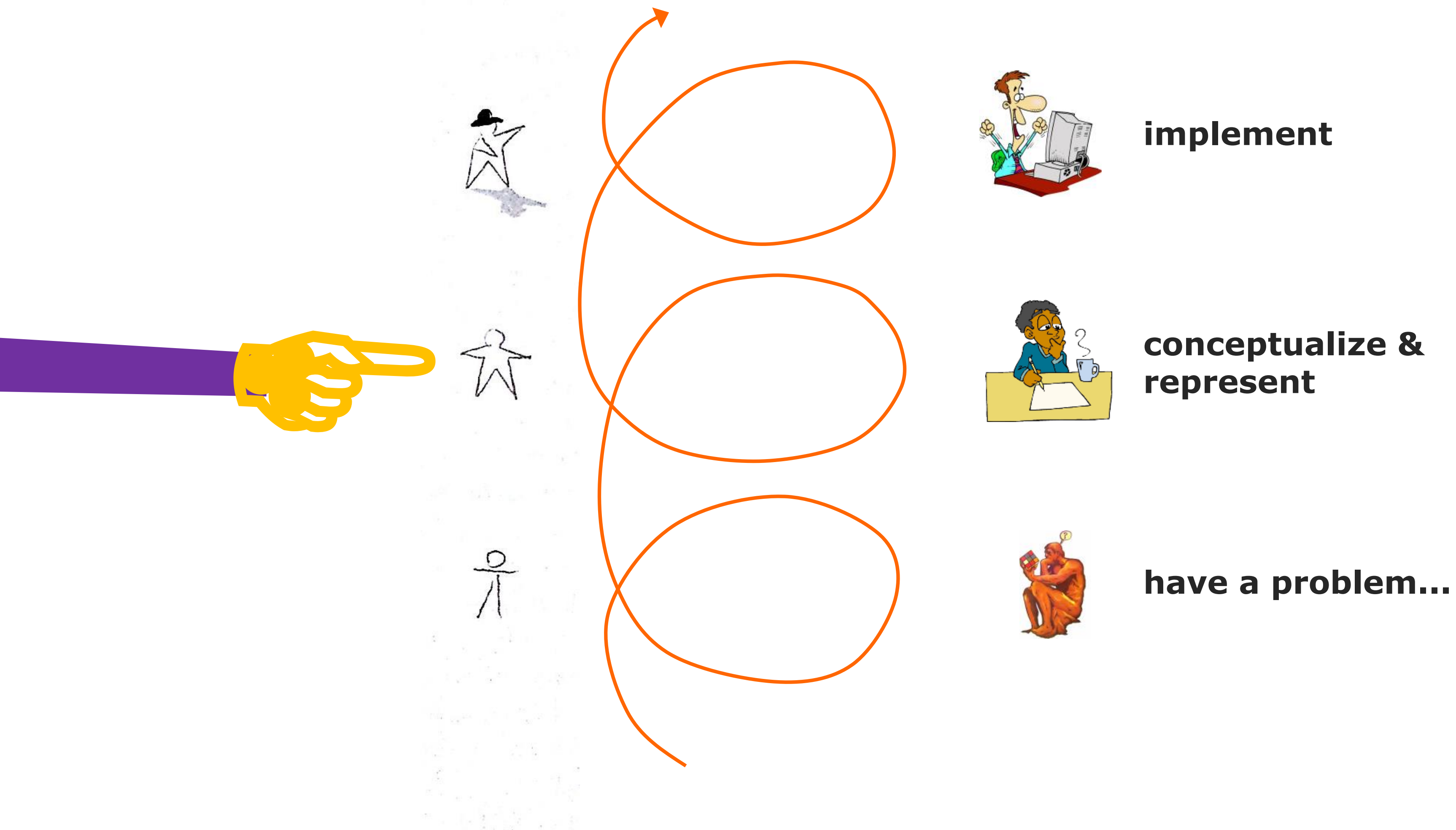
Revenue estimates
in Fr./ha

thicket	0
pole	7’500
timber	35’000
mature timber	45’000

Forest composition
in ha

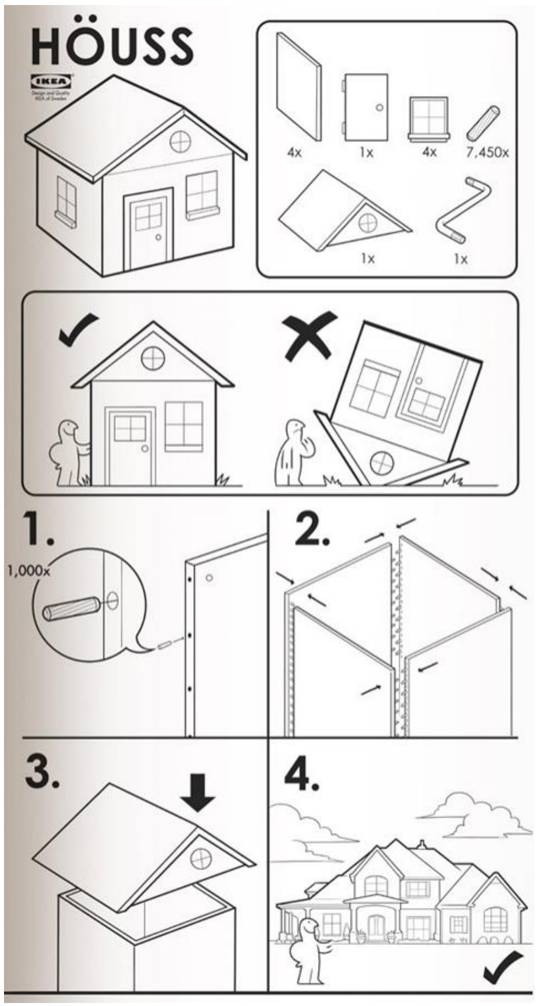
thicket:	100
pole:	200
timber:	50
mature timber:	150

«Mer muess s'Problem gärn becho!»

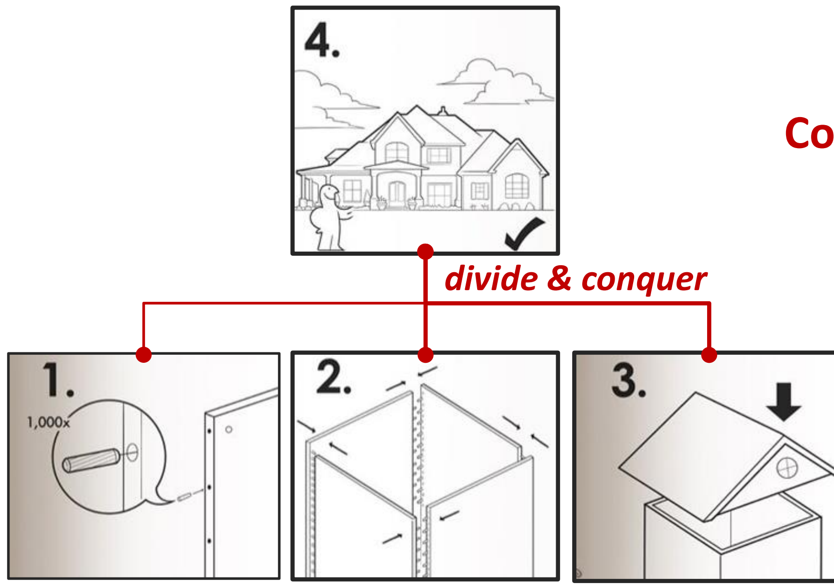

implement
conceptualize &
represent
have a problem...

We need a concept which will help us building the optimisation model

instructions available



no instructions available

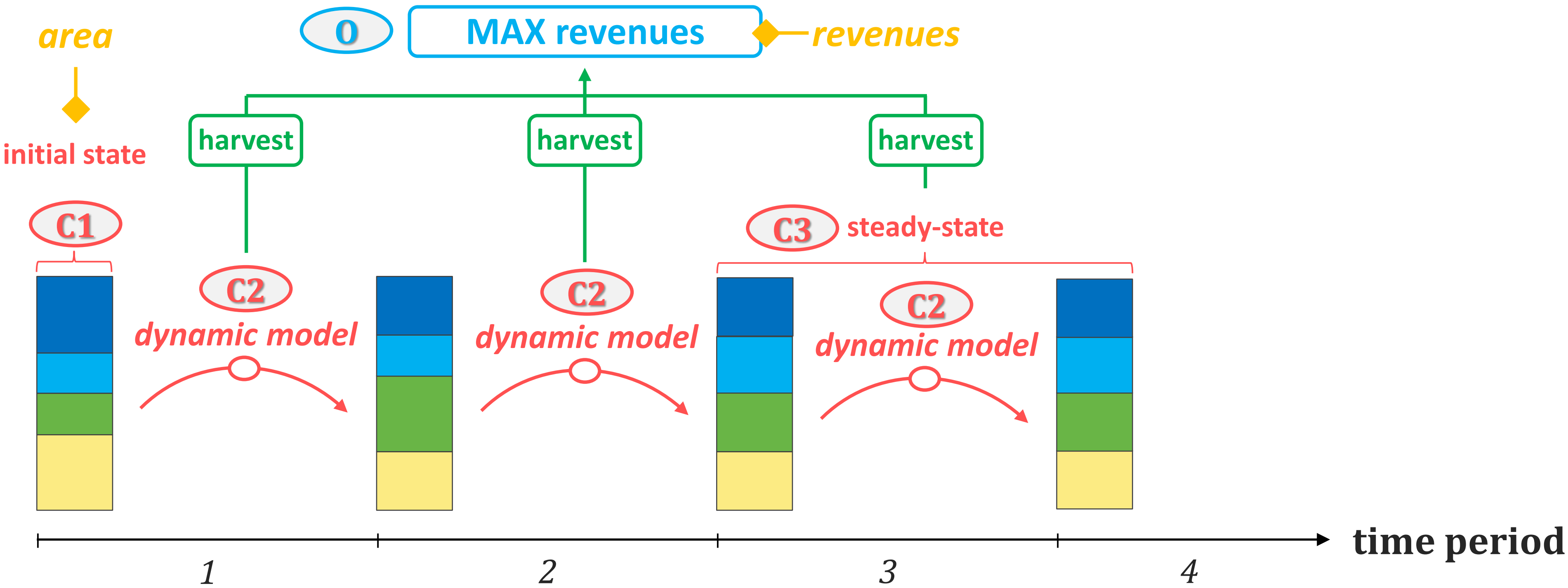


Conceptual model

Components

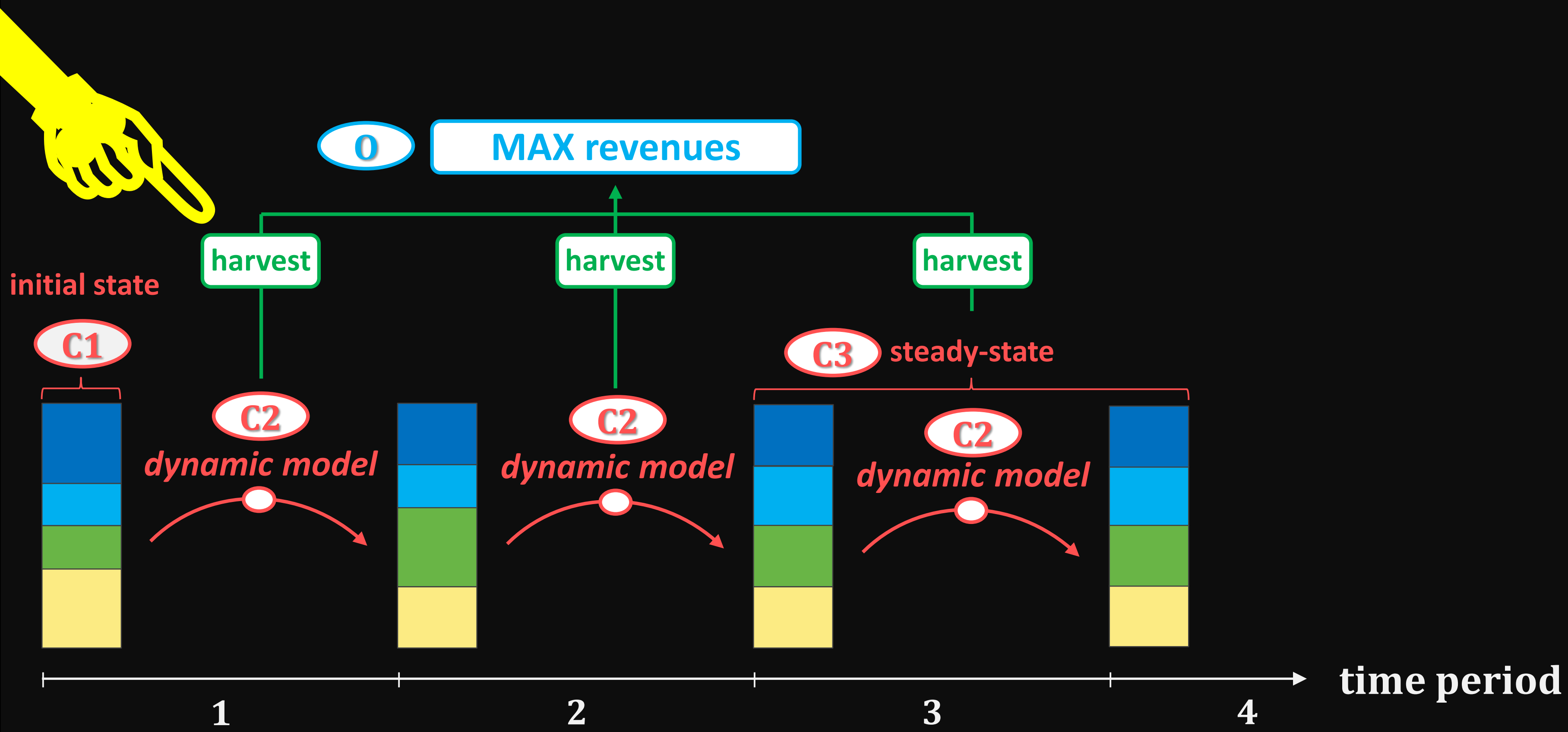
Conceptual model for the scheduling problem

Graphical problem characterization

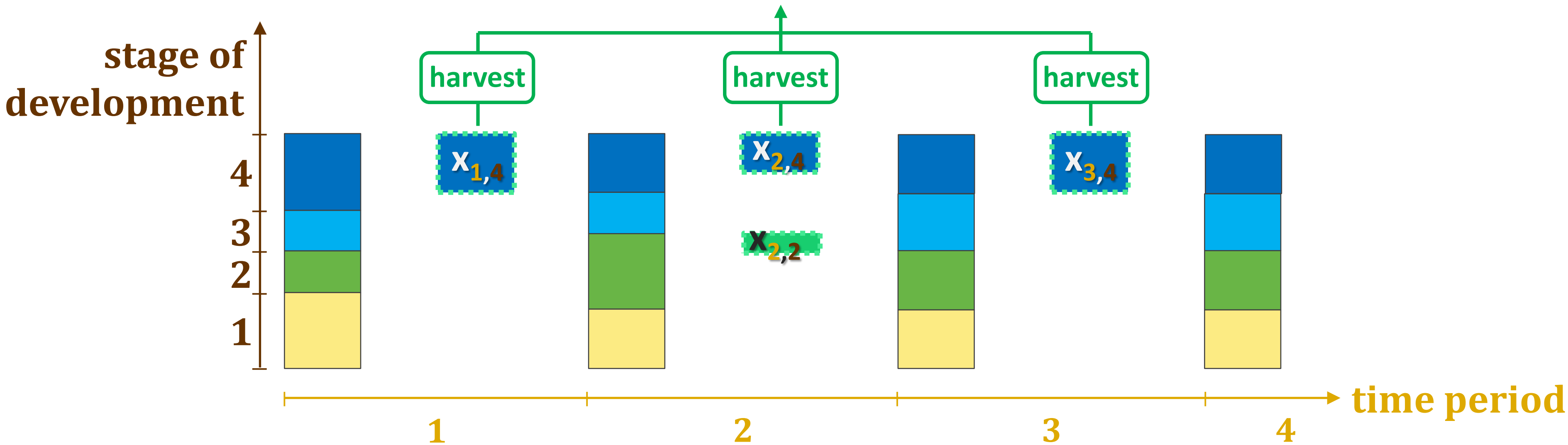


Use constraints for modeling growth!

Conceptual model



Decision variables

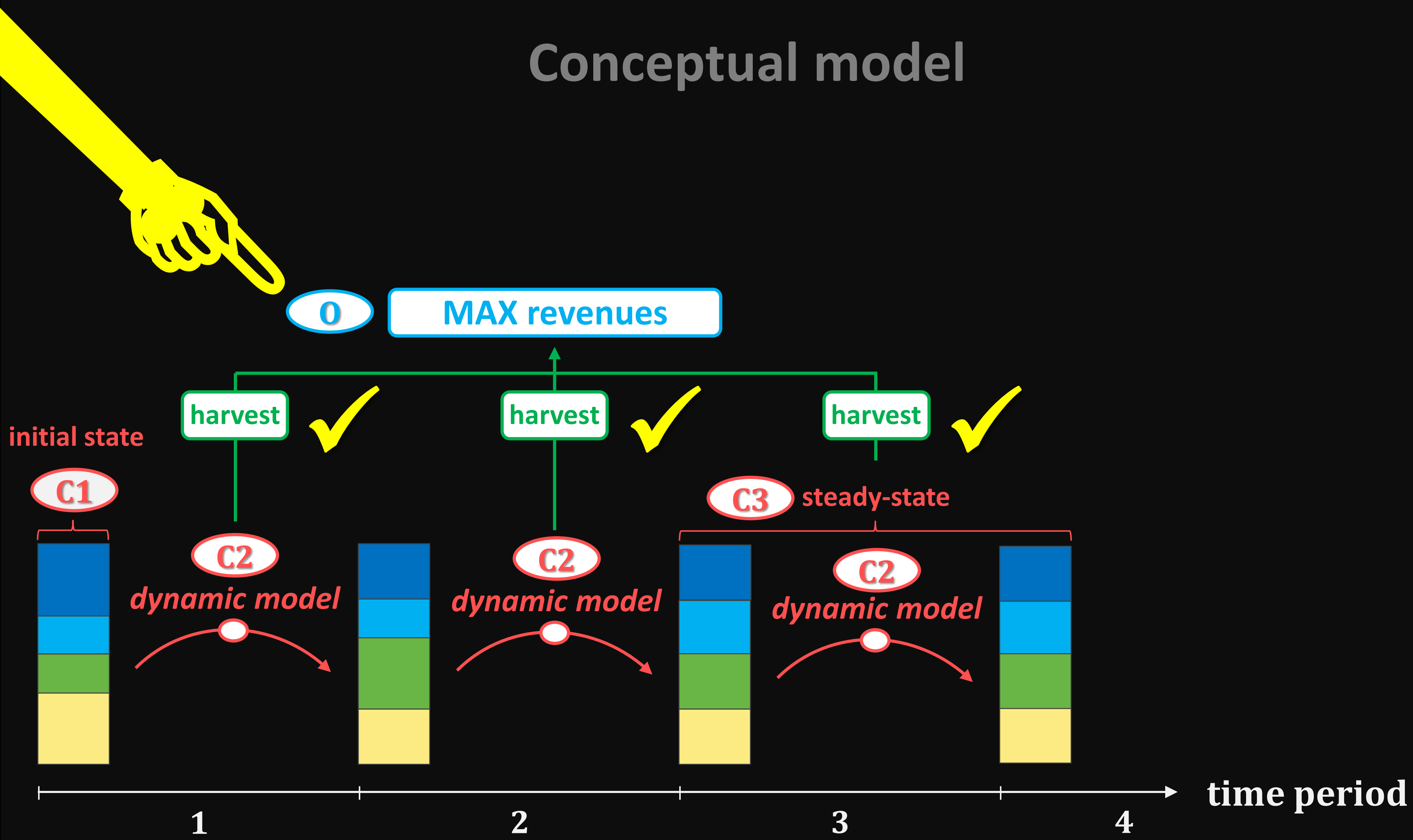


Area [ha] harvested at period *t* in stage *i*

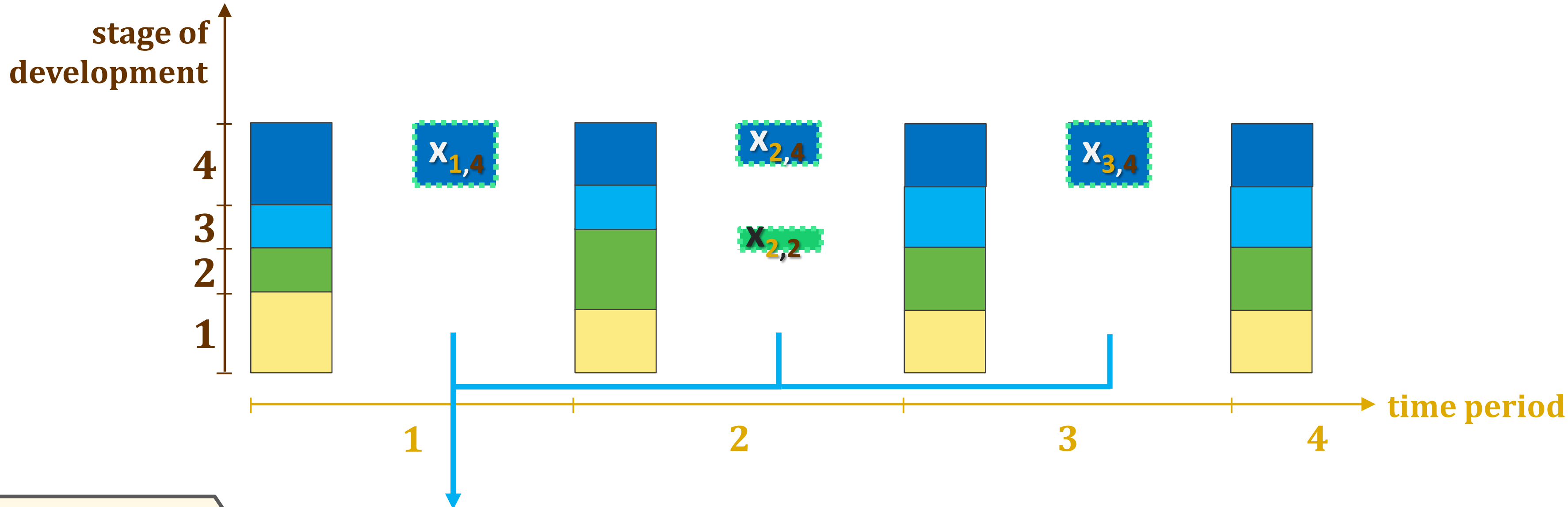
$x_{t,i}$ [ha]

Define decision variables for single time periods to represent scheduling problems!

Conceptual model



Objective function



$f_i \left[\frac{CHF}{ha}\right]$
revenue per ha
of stage ***i***

$$\text{MAX} \quad f_2 x_{1,2} + f_3 x_{1,3} + f_4 x_{1,4} +$$ ***period 1***

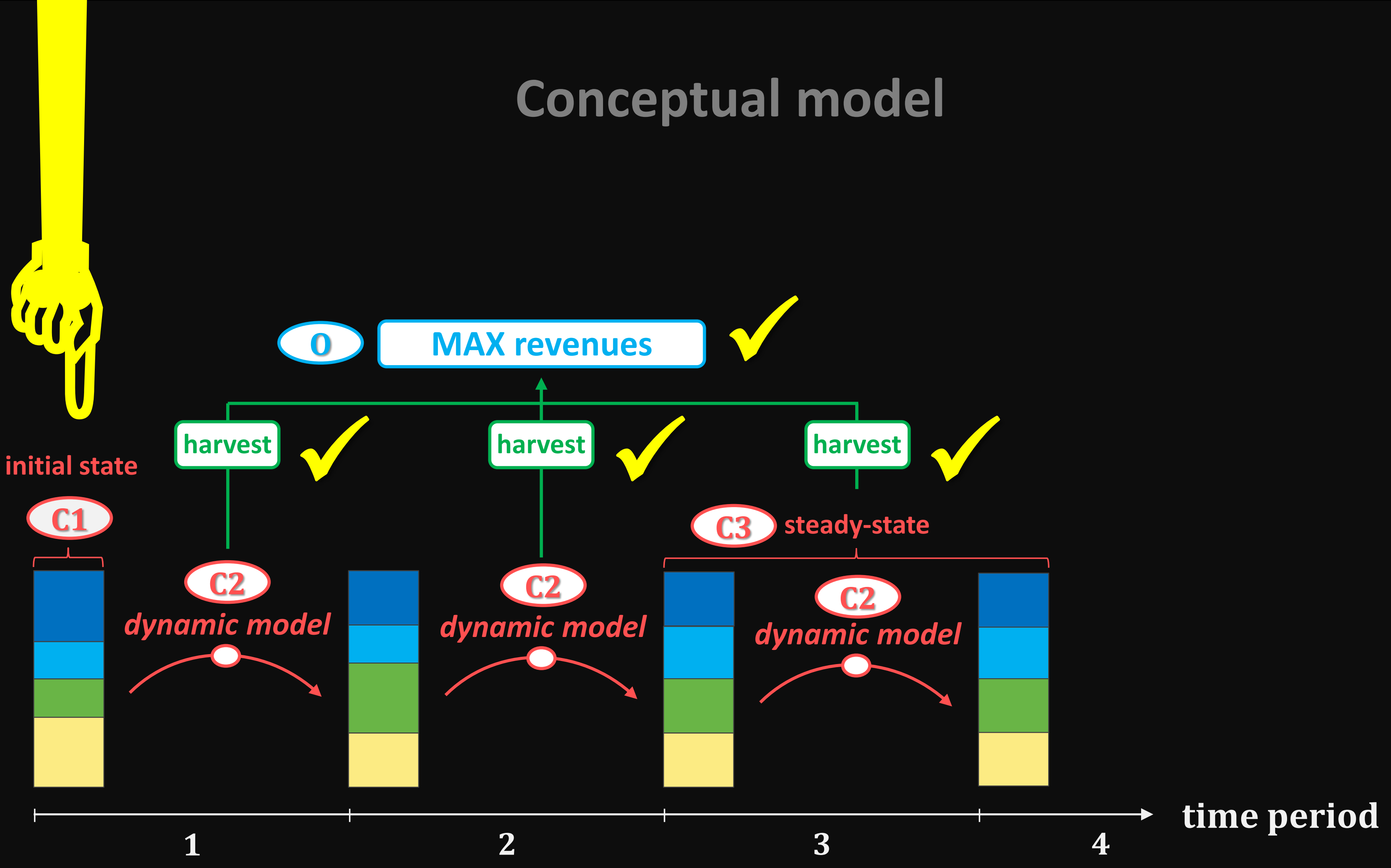
$$f_2 x_{2,2} + f_3 x_{2,3} + f_4 x_{2,4} +$$ ***period 2***

$$f_2 x_{3,2} + f_3 x_{3,3} + f_4 x_{3,4}$$ ***period 3***

or…

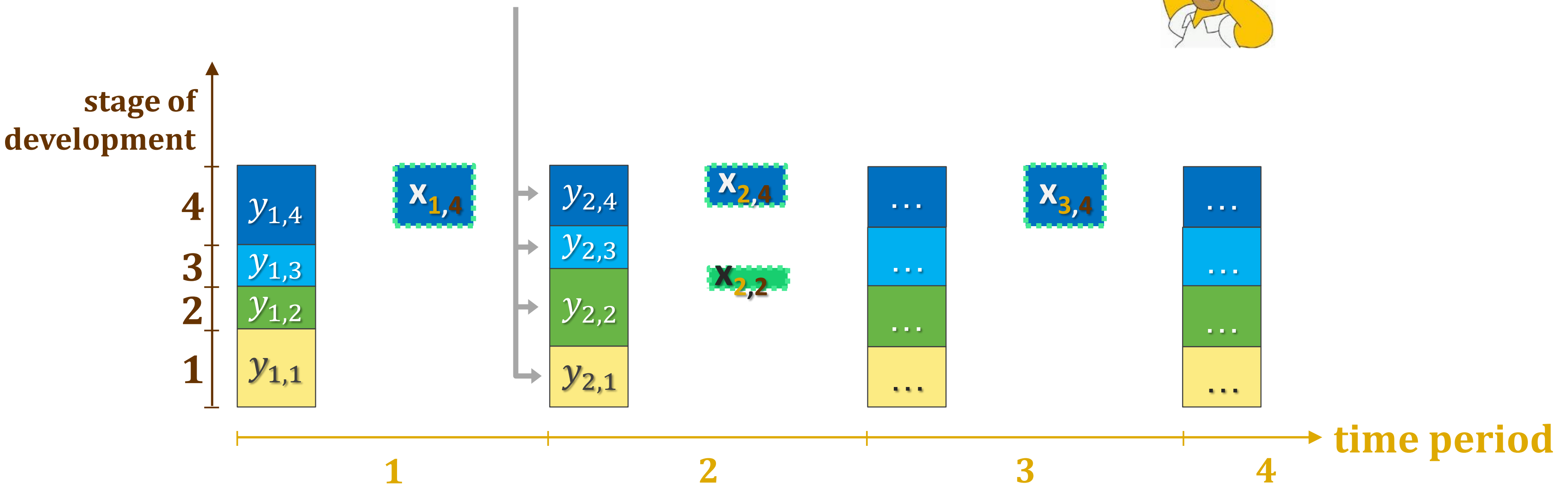
$$\text{MAX} \sum_{t=1}^{m=3} \sum_{i=2}^{n=4} f_i x_{t,i} \qquad [\text{CHF}]$$

Conceptual model



State variables – the missing ingredient

Areas depend on harvest in previous period!

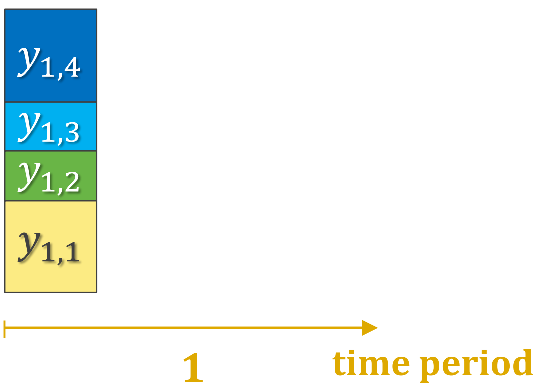


Area [ha] of stage *i*
at beginning of period *t*

$$y_{t,i} \quad \text{[ha]}$$

Introduce ***state variables*** *which characterize the* ***consequences of decisions***

Constraints C1 : INITIAL STATE



s.t.

$$
\begin{aligned}
y_{1,1} &= 100 \quad \text{[ha]}\\
y_{1,2} &= 200 \quad \text{[ha]}\\
y_{1,3} &= 50 \quad \text{[ha]}\\
y_{1,4} &= 150 \quad \text{[ha]}
\end{aligned}
$$

or…

$$y_{1,i} = b_i \quad \text{, for all i=1,..,4}$$

stage

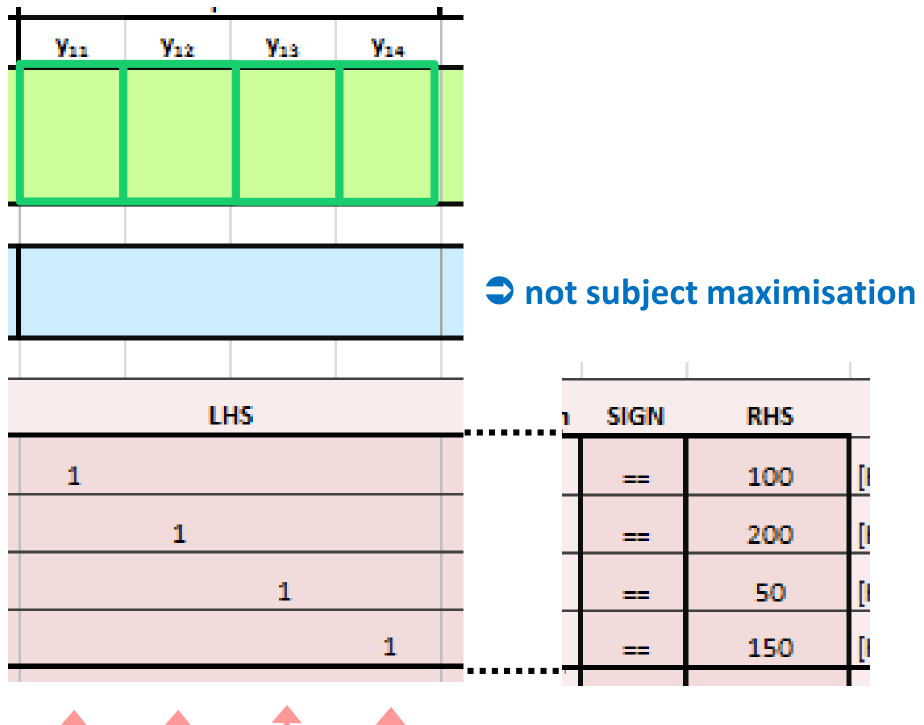
Implementation of this formula in Excel

$$1 \cdot y_{1,1} = 100$$

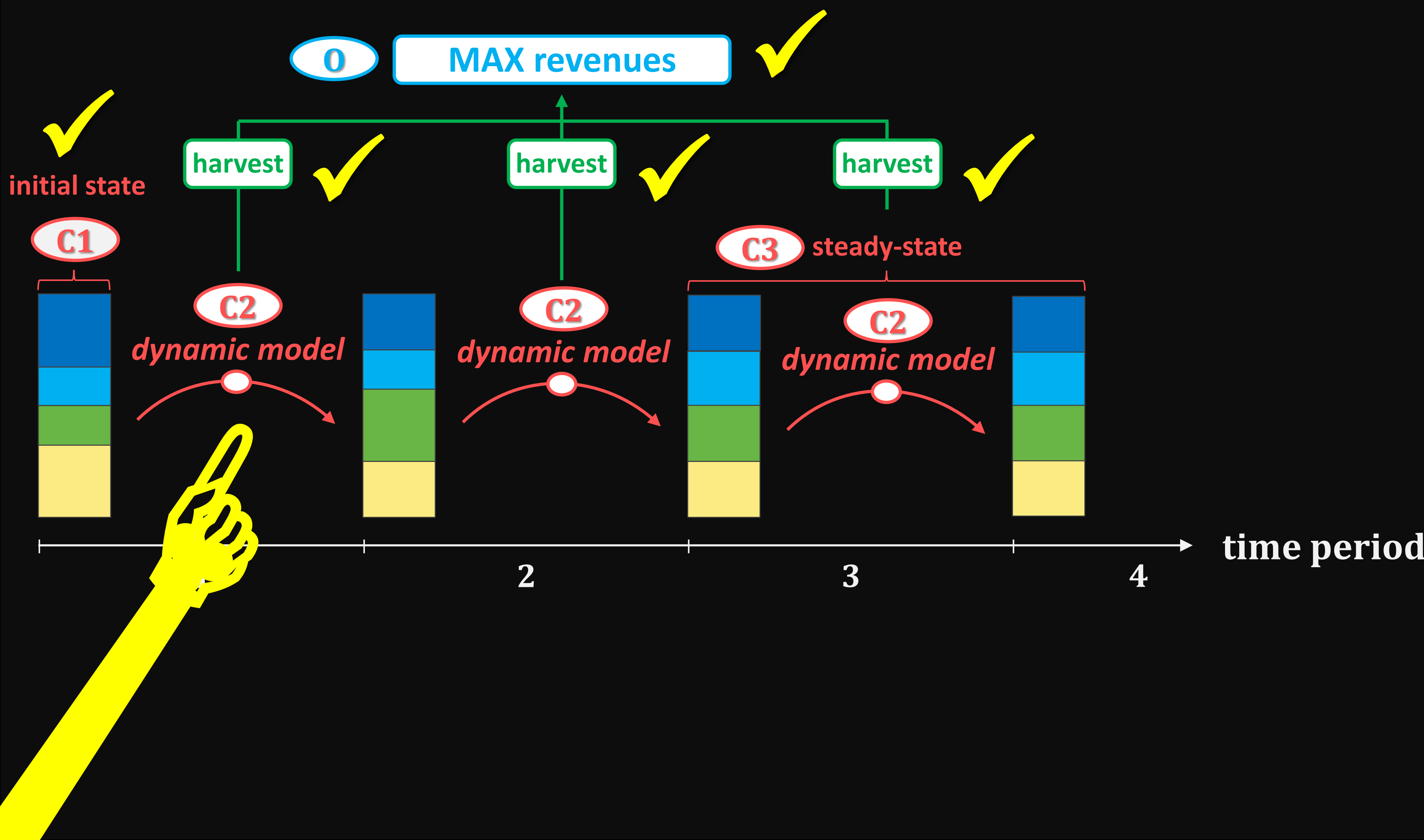
$$1 \cdot y_{1,2} = 200$$

$$1 \cdot y_{1,3} = 50$$

$$1 \cdot y_{1,4} = 150$$



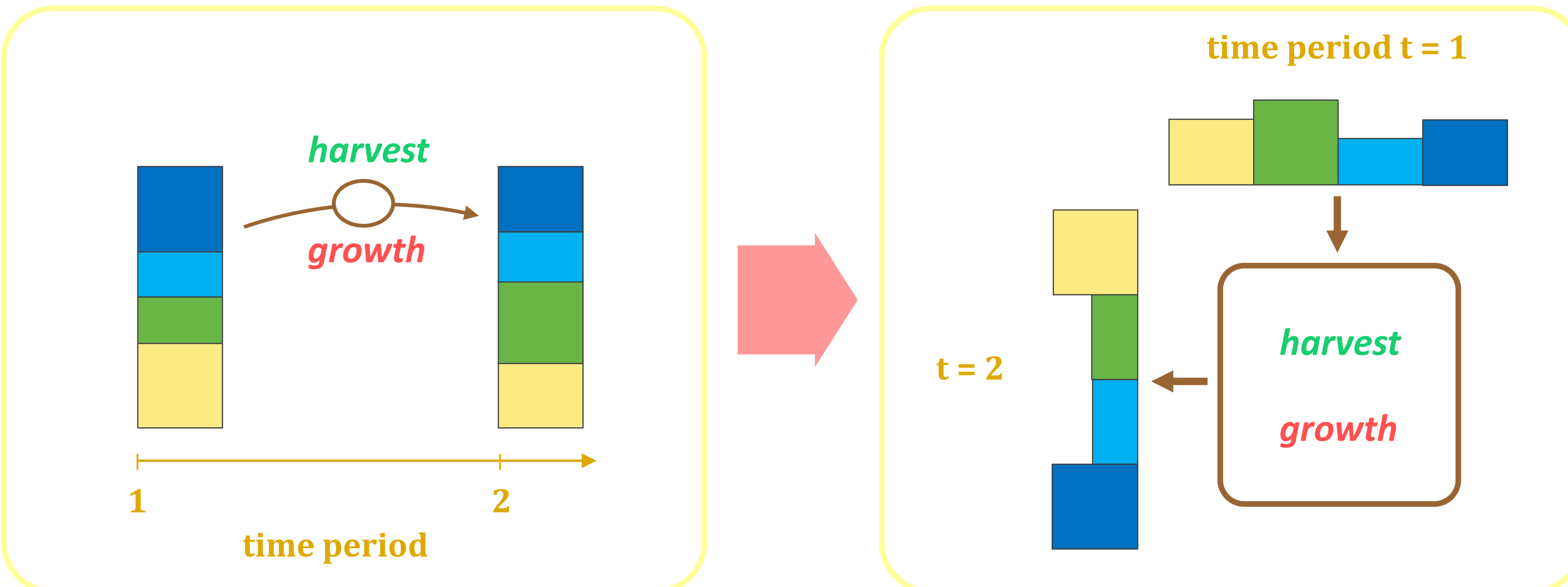
Conceptual model



Constraints C2 – forest growth and harvest

Characterize change of forest subject to growth and harvest over time

Dynamic model

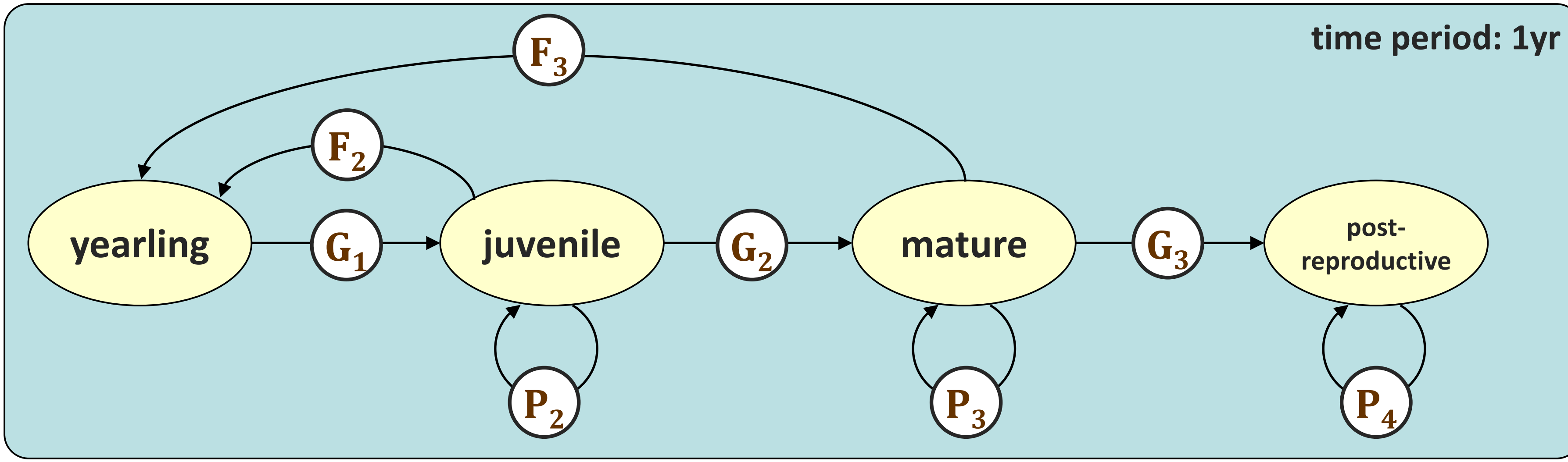


*Represent forest as a **population** which is characterized by stages*

EXAMPLE

Matrix population model of the killer whale

Represent dynamic - Matrix population model



(1) Specify stages
(2) Specify time period
(3) Specify types of turn-over
(4) Estimate turn-over rates

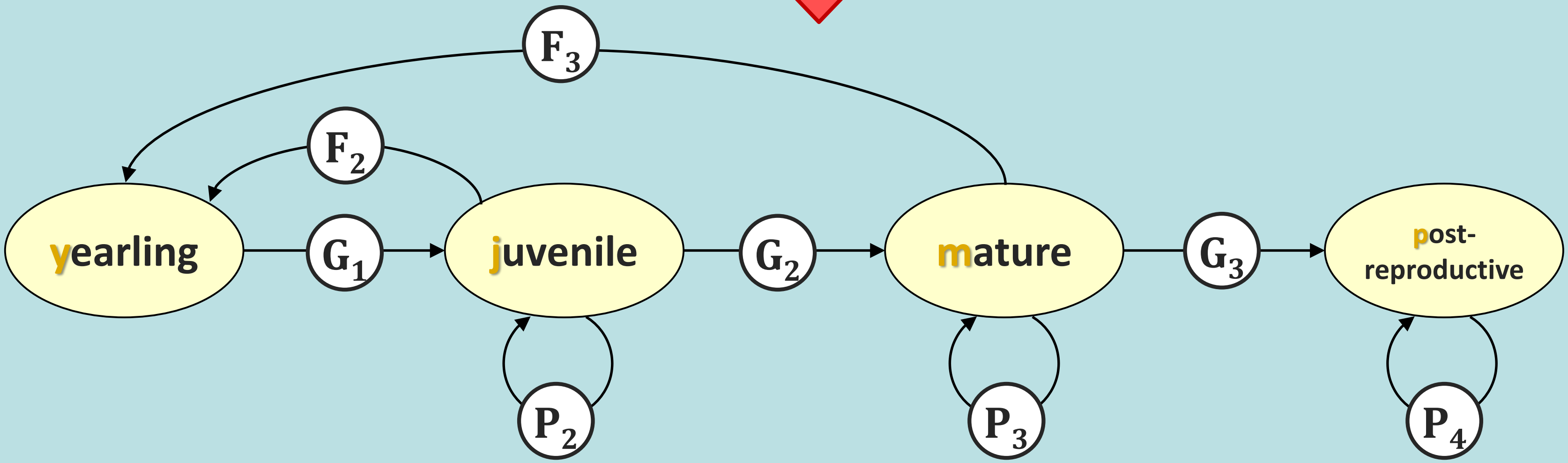
Quantify dynamic - Transition matrix

Matrix representation

period t

period $t+1$

$$\begin{array}{cc} & \begin{matrix} y & j & m & p \end{matrix} \\ \begin{matrix} y \\ j \\ m \\ p \end{matrix} & \begin{bmatrix} 0 & F_2 & F_3 & 0 \\ G_1 & P_2 & 0 & 0 \\ 0 & G_2 & P_3 & 0 \\ 0 & 0 & G_3 & P_4 \end{bmatrix} \end{array}$$



Graph representation

Applications

Method

Caswell (2001) “Matrix population models” [Book]

Forest resources management

Even-aged forests (Gleichaltrige Bestände):

Buongiorno and Gilless (2003) “Decision methods for forest resource management” [Book]

Kurz (2016) “Einsatz von Optimierungsmethoden in der Bewirtschaftung von Steinschlagschutzwäldern”

Uneven-aged forests (Plenterwald):

Buongiorno and Michie (1980) “A matrix model of uneven-aged forest management”

Sonnemann (2008) “Das ideale Plentergleichgewicht – Leitbild oder Luxus?

Wildlife (management)

Oritsland et al. (1983) “Polar bear hunt strategies evaluated by a Leslie matrix population model”

Brault and Caswell (1993) “Pod-Specific Demography of Killer Whales”

Thinkable Applications are everywhere…

Cited articles

Shiffman DS, Hammerschlag N (2016) Preferred conservation policies of shark researchers. Conservation Biology, 30: 805–815.

Simpfendorfer CA, Dulvy NK (2017) Bright spots of sustainable shark fishing. Current Biology, 27: 97-98

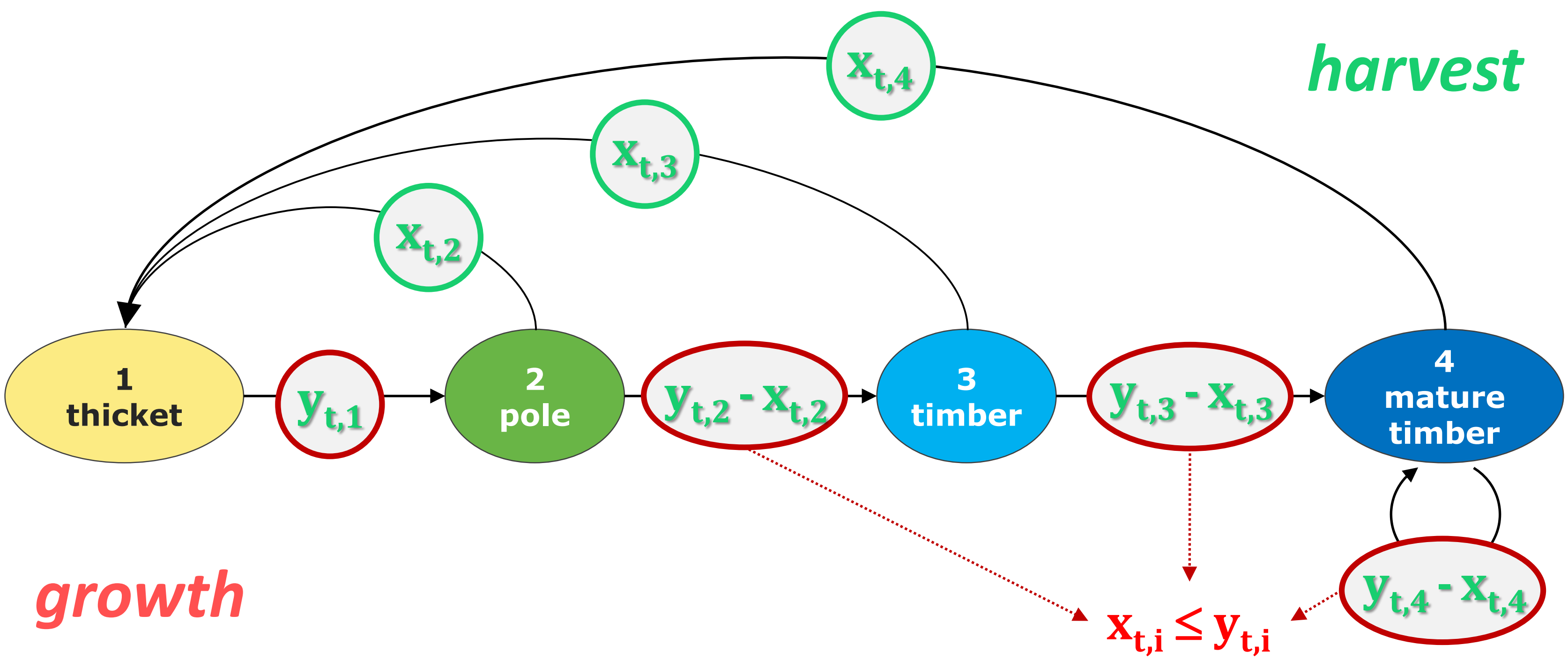
Graphical population model for even-aged forest

Stages: thicket, pole, timber, mature timber [in ha]

Time period: 10-20 years

Turn-over types: harvest, growth

Turn-over rates [in ha]: *growth* → all area grows into next stage; *harvest* → variable



Matrix population model for even-aged forest

period **t**

$$\begin{array}{cc} \begin{array}{cccc} y_{t,1} & y_{t,2} & y_{t,3} & y_{t,4} \\ = & = & = & = \end{array} & \\ \begin{pmatrix} 0 & x_{t,2} & x_{t,3} & x_{t,4} \\ y_{t,1} & 0 & 0 & 0 \\ 0 & y_{t,2}-x_{t,2} & 0 & 0 \\ 0 & 0 & y_{t,3}-x_{t,3} & y_{t,4}-x_{t,4} \end{pmatrix} & \begin{array}{l} = y_{t+1,1} \\ = y_{t+1,2} \\ = y_{t+1,3} \\ = y_{t+1,4} \end{array} \end{array}$$

period **t+1**

C2.1

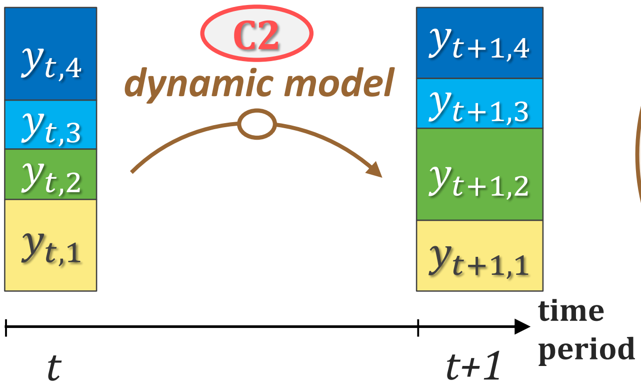
harvest

growth

Dynamic model

C2.2 and $x_{t,i} \leq y_{t,i}$

Constraints C2.1 : DYNAMIC MODEL I



$$
\begin{pmatrix}
0 & x_{t,2} & x_{t,3} & x_{t,4} \\
y_{t,1} & 0 & 0 & 0 \\
0 & y_{t,2}-x_{t,2} & 0 & 0 \\
0 & 0 & y_{t,3}-x_{t,3} & y_{t,4}-x_{t,4}
\end{pmatrix}
\begin{array}{ll}
= y_{t+1,1} & \textbf{thicket} \\
= y_{t+1,2} & \textbf{pole} \\
= y_{t+1,3} & \textbf{timber} \\
= y_{t+1,4} & \textbf{mature timber}
\end{array}
$$

	t : decision variables	t : state variables	t+1 : state variables		
s.t.	$+x_{t,2} + x_{t,3} + x_{t,4}$		$-y_{t+1,1}$	$=0$	for all t= 1,...,3
		$+y_{t,1}$	$-y_{t+1,2}$	$=0$	for all t= 1,...,3
	$-x_{t,2}$	$+y_{t,2}$	$-y_{t+1,3}$	$=0$	for all t= 1,...,3
	$-x_{t,3} - x_{t,4}$	$+y_{t,3} + y_{t,4}$	$-y_{t+1,4}$	$=0$	for all t= 1,...,3

Constraints C2.2 : DYNAMIC MODEL II

$$\begin{pmatrix} 0 & x_{t,2} & x_{t,3} & x_{t,4} \\ y_{t,1} & 0 & 0 & 0 \\ 0 & \boxed{y_{t,2}-x_{t,2}} & 0 & 0 \\ 0 & 0 & \boxed{y_{t,3}-x_{t,3}} & \boxed{y_{t,4}-x_{t,4}} \end{pmatrix}$$

area available ≥ area cut

t : decision variables	t : state variables			
$-x_{t,2}$	$+y_{t,2}$	≥ 0	for all t=1,…,3	**pole**
$-x_{t,3}$	$+y_{t,3}$	≥ 0	for all t=1,…,3	**timber**
$-x_{t,4}$	$+y_{t,4}$	≥ 0	for all t=1,…,3	**mature timber**

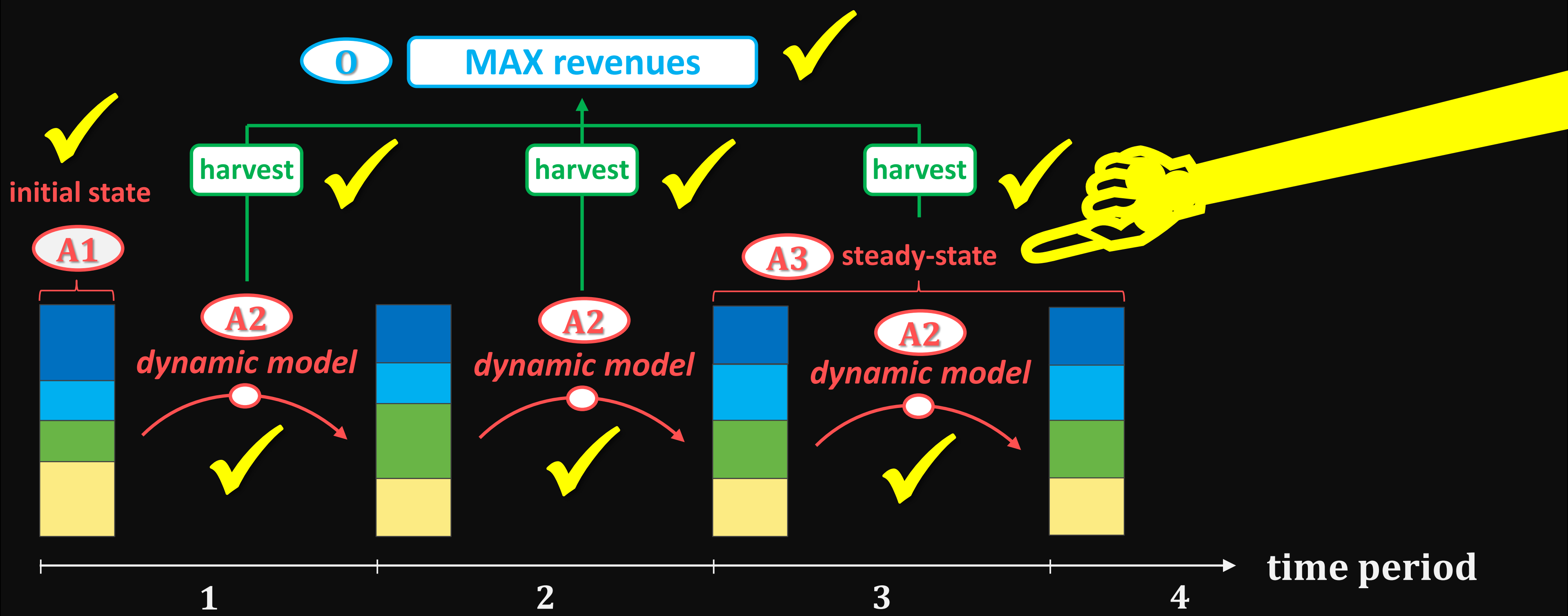
s.t.

or…

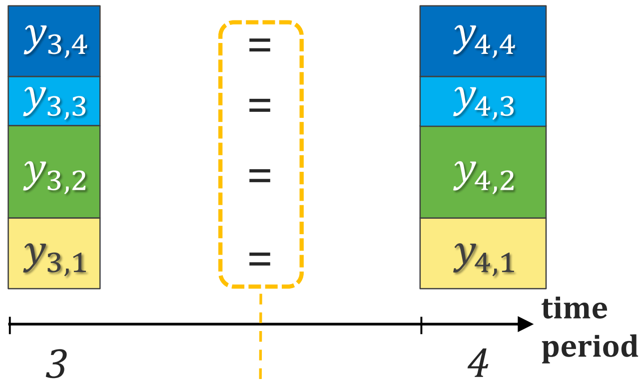
$$-x_{t,i} + y_{t,i} \geq 0$$

for all t=1,…,3
and all i=2,…,4

Conceptual model



Constraints C3 : Steady-state condition



area at period 3 = area at period 4

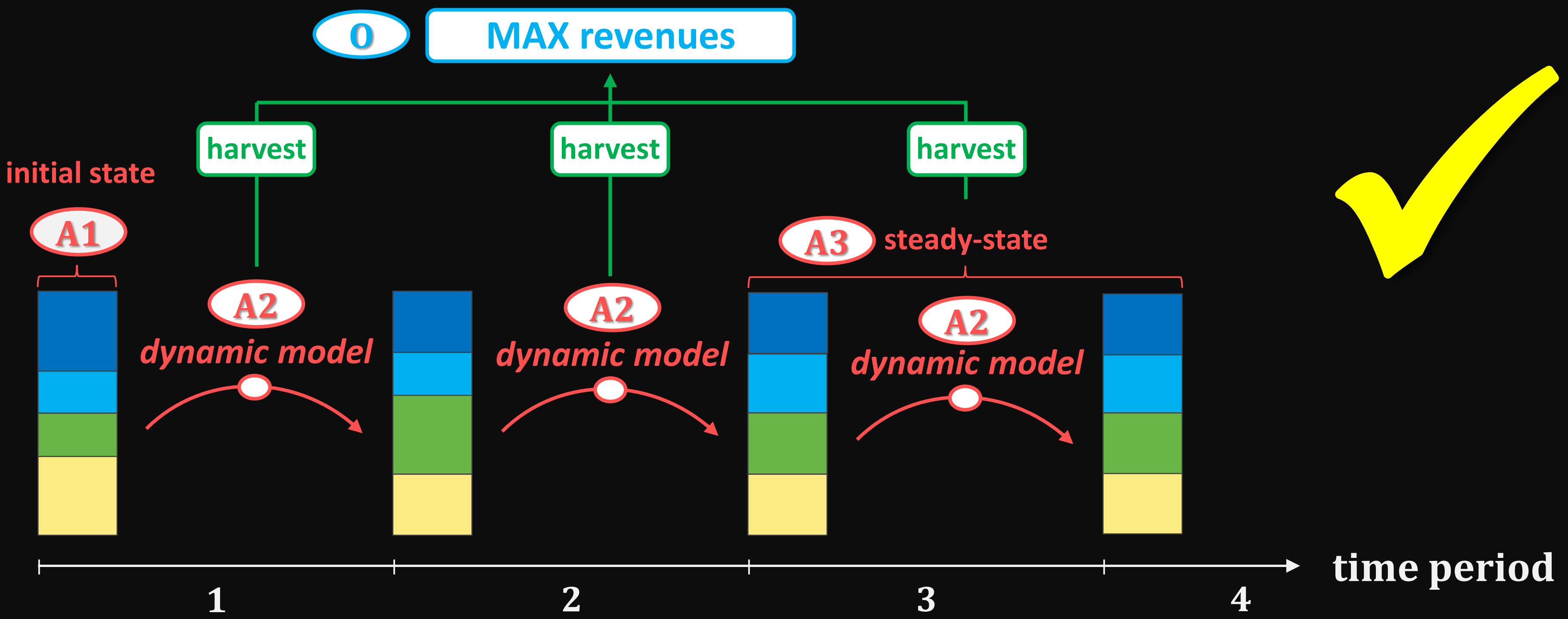
s.t.

$$
\begin{array}{rrrrrrrrl}
-y_{3,1} & & & & +y_{4,1} & & & & = 0 \quad \text{thicket} \\
& -y_{3,2} & & & & +y_{4,2} & & & = 0 \quad \text{pole} \\
& & -y_{3,3} & & & & +y_{4,3} & & = 0 \quad \text{timber} \\
& & & -y_{3,4} & & & & +y_{4,4} & = 0 \quad \text{mature timber}
\end{array}
$$

or…

$$-y_{3,i} + y_{4,i} = 0 \qquad \text{for all } i=1,\ldots,4$$

Conceptual model



Mathematical optimization model

O MAX $$\sum_{t=1}^{m=3}\sum_{i=2}^{n=4} f_i x_{t,i} + \sum_{t=1}^{m+1}\sum_{i=1}^{n=4} 0 y_{t,i}$$

initial state

C1 $y_{1,i} = b_i$ for all i=1,...,n

dynamic model

C2.1

$$+x_{t,2}+x_{t,3}+x_{t,4} - y_{t+1,1} = 0 \quad \text{for all t= 1,...,m}$$

$$+y_{t,1} - y_{t+1,2} = 0 \quad \text{for all t= 1,...,m}$$

$$-x_{t,2} + y_{t,2} - y_{t+1,3} = 0 \quad \text{for all t= 1,...,m}$$

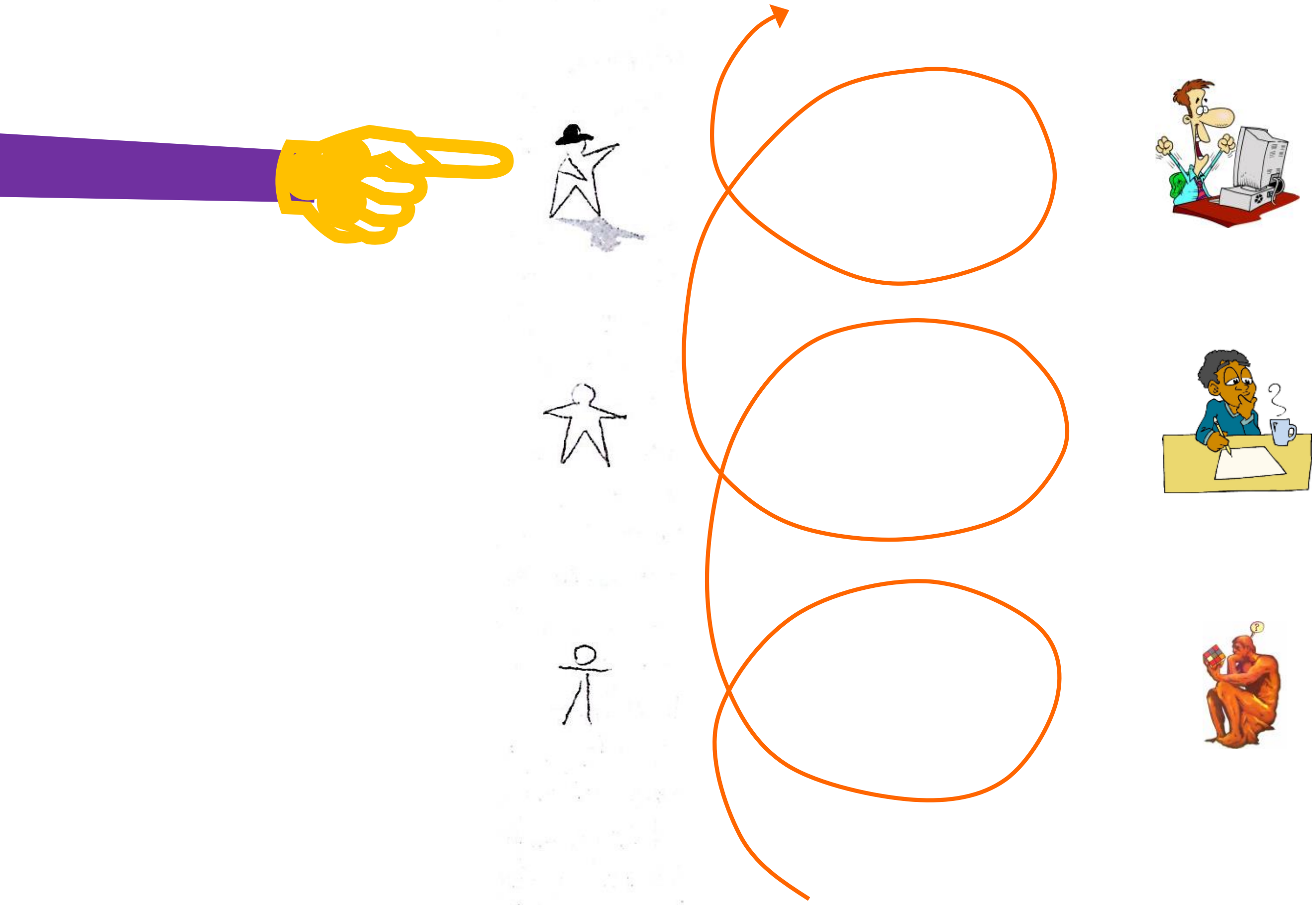
$$-x_{t,3}-x_{t,4} + y_{t,3}+y_{t,4} - y_{t+1,4} = 0 \quad \text{for all t= 1,...,m}$$

C2.2 $-x_{t,i} + y_{t,i} \geq 0$ for all t=1,...,m and all i=2,...,n

steady-state

C3 $-y_{3,i} + y_{4,i} = 0$ for all i=1,...,n

$$x_{t,i}, y_{t,i} \in \mathbb{R}_0^+$$



implement

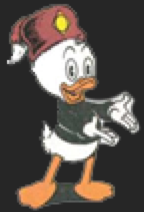
conceptualize &
represent

have a problem...

How can we manage the implementation of that model?

Divide and conquer!

Disassemble problem into smaller ones that you can manage. But ***keep order****!*



Create a tool that supports you doing disassembling

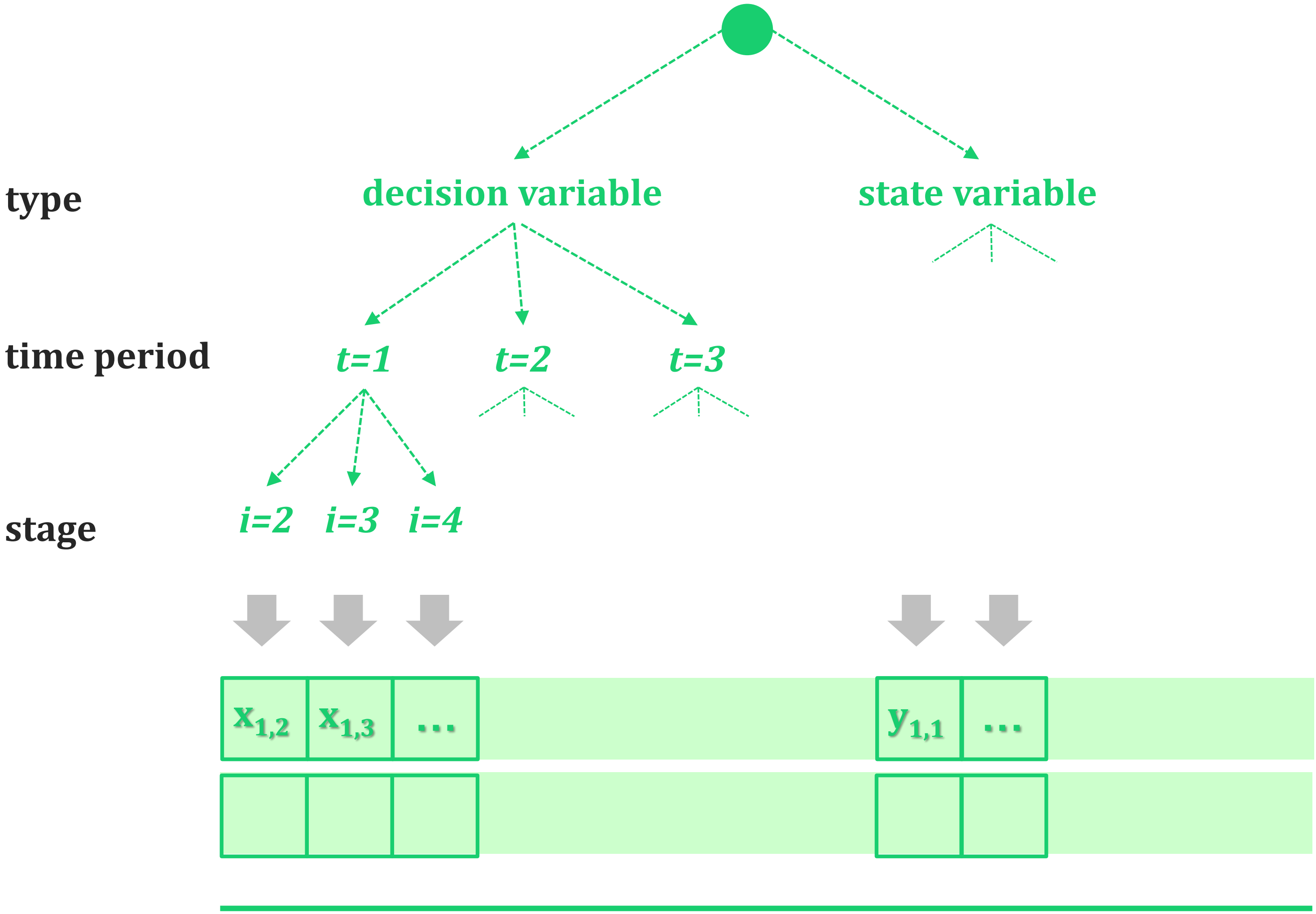
Plan the tool – how to start

Get count of variables!

Get count of constraints!

Plan the tool – variables

Hierarchical Order

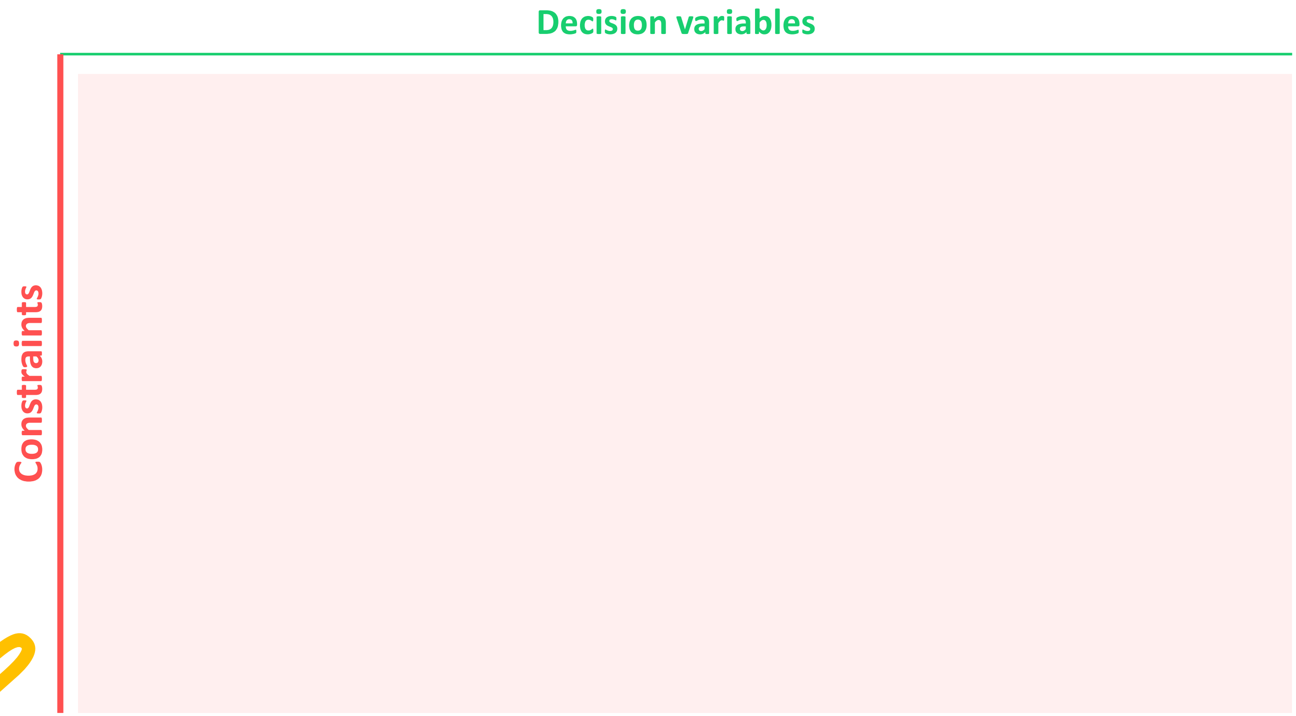


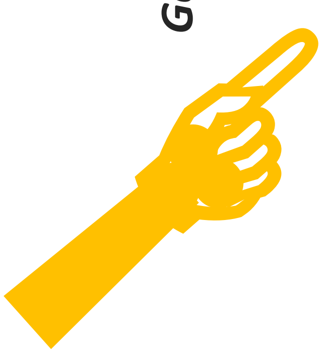
Implementation

Plan the tool – how to start

Get count of variables!

Get count of constraints!

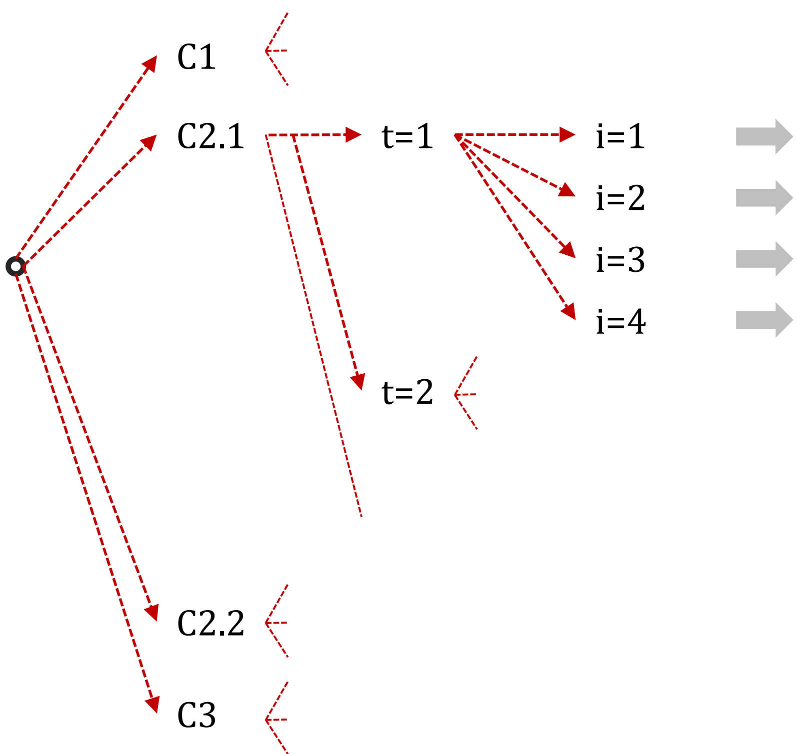




Plan the tool – constraints

Hierarchical order

constraint type | *time period* | *stage*

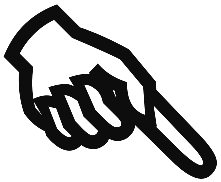


Implementation

constraint type	*time period*	*stage*
C1		
C2.1	period 1	stage 1
		stage 2
		stage 3
		stage 4
	period 2	...
		...
		...
		...
C2.2		
C3		

Plan the tool - final layout

	Decision variables			State variables				sign	rhs
Variables	t=1	…	…	t=1	…	…	…		
	$x_{1,2}$ … …	… … …	… … …	$y_{1,1}$ … … …	… … … …	… … … …	… … … …		
Objective function	f_2 … …	… … …	… … …	… … … …	… … … …	… … … …	… … … …		
C1 Initial state i=1	0	0	0	1	0	0	0	=	100
i=2				1				=	200
i=3				1				=	50
i=4				1				=	150
C2 Dynamic model									
C3 Steady-state									



have a problem....

conceptualize & represent

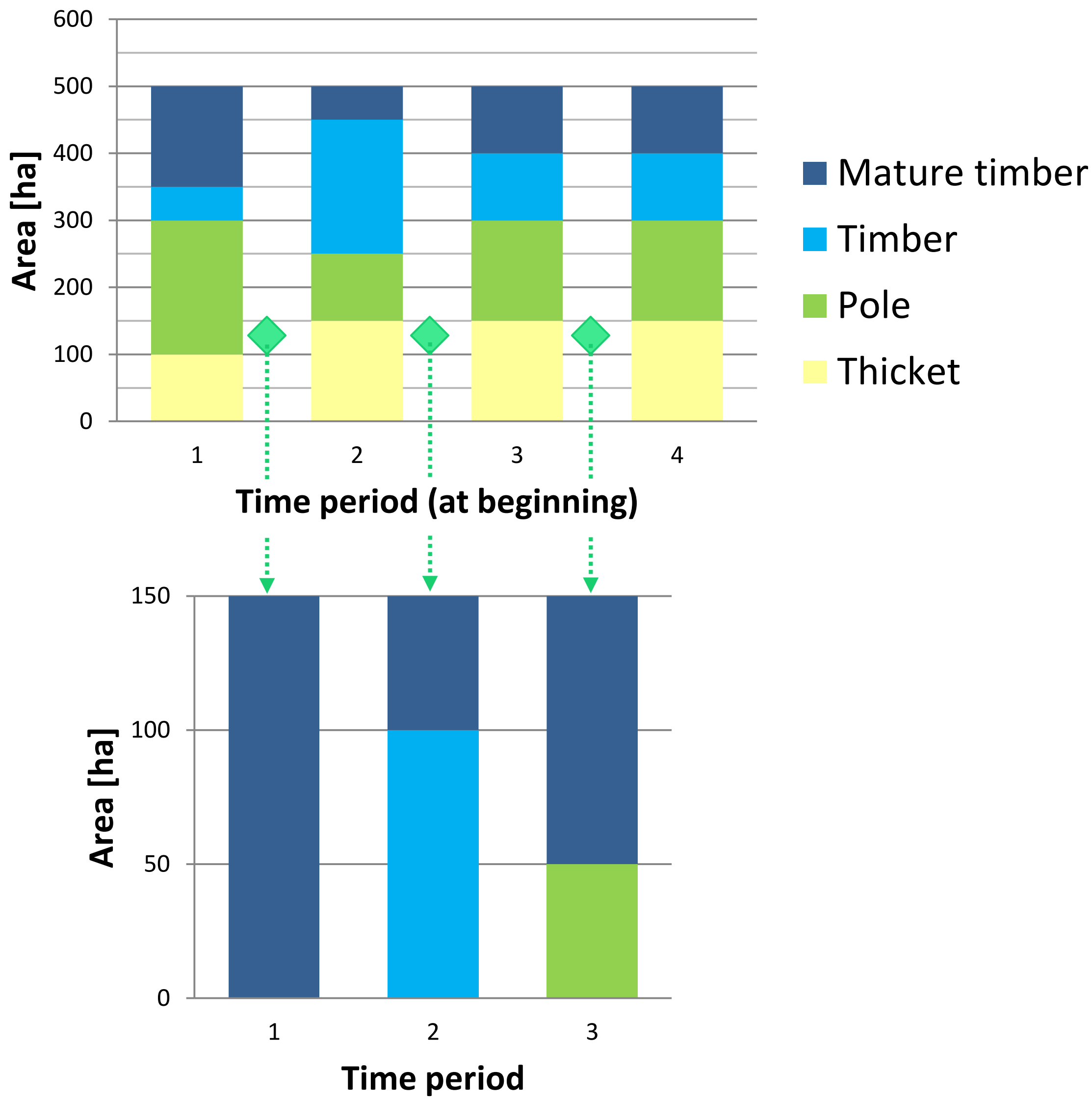
implement

solve

Solution

Forest composition

Harvested area



A choice of possible improvements

Include

- losses because of calamities (e.g., storm events)
- add interest rate (future revenues less valuable)

Reformulate

- stages of development
- conditions of an ideal state (sustainability)

Literature

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