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# Plant Growth Scheduling

Salima Jaoua and Dana Kalaaji Supervised by Jonas Racine

**EPFL** 

June 3, 2021

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# Recall: GrowthBotHub

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Association at EPFL

# Recall: GrowthBotHub

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- Association at EPFL
- Fully automated farm

## Recall: GrowthBotHub

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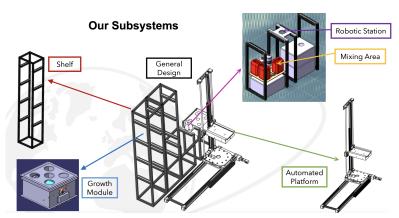
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- Association at EPFL
- Fully automated farm



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Each plant has needs that changes over time

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- Each plant has needs that changes over time
- Each module contains certain nutrients

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- Each plant has needs that changes over time
- Each module contains certain nutrients
- A plant need to be moved between modules a certain points in time

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- Each plant has needs that changes over time
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Max number of plants: What to plant? Where? When?

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- Each plant has needs that changes over time
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Max number of plants: What to plant? Where? When?

Our goal:

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- Each plant has needs that changes over time
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Max number of plants: What to plant? Where? When?

- Our goal:
  - Improve and optimize last semester's algorithm

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- Each plant has needs that changes over time
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Max number of plants: What to plant? Where? When?

- Our goal:
  - Improve and optimize last semester's algorithm
  - Re-scheduling

Reminder of the

problem

Multi-commodity flow

### Reminder of the

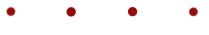
problem

# Multi-commodity flow

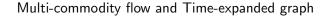
### Reminder of the

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# Multi-commodity flow and Time-expanded graph

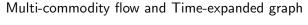


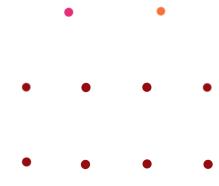
### Reminder of the



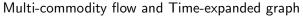


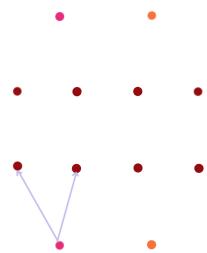
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### Reminder of the





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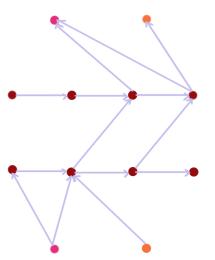
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# Multi-commodity flow and Time-expanded graph



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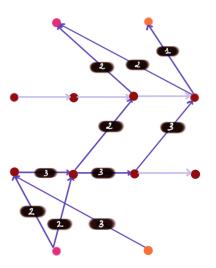
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# $\label{lem:multi-commodity flow and Time-expanded graph} \\$



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Last time: 1 node = 1 hole

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Last time: 1 node = 1 hole

• Algorithm crashes after 12h on real-sized inputs

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Tray edges	7200	720
Transfer edges	84600	846
Source edges	7220	722
Sink edges	7220	722
Total edges	106240	3010

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Last time: 1 node = 1 hole

Algorithm crashes after 12h on real-sized inputs

Our solution: reduced the size of the graph





Tray edges	7200	720
Transfer edges	84600	846
Source edges	7220	722
Sink edges	7220	722
Total edges	106240	3010

Algorithm is able to run with real-size data

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Last time: 1 node = 1 hole

Algorithm crashes after 12h on real-sized inputs



Tray edges	7200	720
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Total edges	106240	3010

- Algorithm is able to run with real-size data
- Finds a 95% optimal solution in less than 2 minutes

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Last time: 1 node = 1 hole

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## Some of our goals changed :

- We want to obtain at least one plant everyday, with different species each day
- → New diversity constraints

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## Some of our goals changed :

- We want to obtain at least one plant everyday, with different species each day
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We also need to take care of our original ones :

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## Some of our goals changed :

- We want to obtain at least one plant everyday, with different species each day
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We also need to take care of our original ones :

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## Some of our goals changed :

- We want to obtain at least one plant everyday, with different species each day
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We also need to take care of our original ones :

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And a new goal has been added :

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## Some of our goals changed:

- We want to obtain at least one plant everyday, with different species each day
- → New diversity constraints

We also need to take care of our original ones :

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And a new goal has been added :

• Total number of growth modules  $(\in [12, 16])$  unknown

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## Some of our goals changed :

- We want to obtain at least one plant everyday, with different species each day
- → New diversity constraints

We also need to take care of our original ones :

Constraint about the plant's size

## And a new goal has been added:

- Total number of growth modules  $(\in [12, 16])$  unknown
- → Goal: find best combination of growth modules

# Diversity

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We keep the current diversity constraint

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We keep the current diversity constraint

• number of plants of each species is close to the average

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We keep the current diversity constraint

• number of plants of each species is close to the average

$$\begin{aligned} & \text{maximize} & & \sum_{\rho=1}^{P} \sum_{d=1}^{\text{size}(k_{\rho})} \sum_{(i,j) \in \delta^{+}(s_{\rho})} x_{ijk_{\rho_{d}}} \\ & \text{subject to} & & \sum_{(i,j) \in \delta^{+}(n)} x_{ijk} - \sum_{(i,j) \in \delta^{-}(n)} x_{ijk} = 0 \quad \forall n \in V - \{S,T\} \\ & & \forall (i,j) \in E \quad \sum_{\rho=1}^{N} \sum_{d=1}^{\text{size}(k_{\rho})} x_{ijk_{\rho_{d}}} \leq 5 \\ & & \forall \rho \in \{1....N\} \sum_{d=1}^{\text{size}(k_{\rho})} \sum_{(i,j) \in \delta^{+}(s_{\rho})} x_{ijk_{\rho_{d}}} \geq \frac{\sum_{\rho=1}^{N} \sum_{d=1}^{\text{size}(k_{\rho})} \sum_{(i,j) \in \delta^{+}(s_{\rho})} x_{ijk_{\rho_{d}}}}{N} - \epsilon \end{aligned}$$

→ ensures that we have a long term diversity

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• Indicate if we harvest a plant on a given day

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Divide the new constraint into two smaller ones

• Indicate if we harvest a plant on a given day Add a variable  $(z_d)_{d\in\{1...D\}}$  where D is the total number of days

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Divide the new constraint into two smaller ones

• Indicate if we harvest a plant on a given day Add a variable  $(z_d)_{d\in\{1...D\}}$  where D is the total number of days

• Goal:  $z_d = 0 \ \forall d \in \{1 \dots D\}$ 

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### Divide the new constraint into two smaller ones

• Indicate if we harvest a plant on a given day Add a variable  $(z_d)_{d\in\{1...D\}}$  where D is the total number of days

$$ullet$$
 Goal:  $z_d=0 \ orall d \in \{1\dots D\}$   $\underline{\wedge}$  may be impossible

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Divide the new constraint into two smaller ones

- Indicate if we harvest a plant on a given day Add a variable  $(z_d)_{d \in \{1...D\}}$  where D is the total number of days
- Goal:  $z_d = 0 \ \forall d \in \{1 ... D\}$

 $\longrightarrow$  penalize the objective function each day where we don't harvest a plant.

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• Need to diversify the outcomes each day  $\rightarrow$  add a variable for every edge:

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 $\bullet$  Need to diversify the outcomes each day  $\to$  add a variable for every edge:

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 $\bullet$  Need to diversify the outcomes each day  $\to$  add a variable for every edge:

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$$y_{ij} = 1 \text{ if } x_{ijk} > 0 \ \forall (i,j) \in E \ \forall k$$

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• Need to diversify the outcomes each day  $\rightarrow$  add a variable for every edge:

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Limit number of days in a where we can harvest a specie

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• Need to diversify the outcomes each day  $\rightarrow$  add a variable for every edge:

Indicator of flow

$$y_{ij} = 1 \text{ if } x_{ijk} > 0 \ \forall (i,j) \in E \ \forall k$$

- Limit number of days in a where we can harvest a specie
  - ightarrow Once we harvest a plant of type p, we cannot harvest another one for the next 3 days

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• Need to diversify the outcomes each day  $\rightarrow$  add a variable for every edge:

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- Limit number of days in a where we can harvest a specie
  - $\rightarrow$  Once we harvest a plant of type p, we cannot harvest another one for the next 3 days

$$\forall d \ \forall p = 1...N \ \sum_{d}^{d+3} y_{t_{p_d}} \leq 1$$

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At least a plant per day constraint:

- More even distribution over time
- Some loss of plant but negligible

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At least a plant per day constraint:

- More even distribution over time
- Some loss of plant but negligible
- Does not affect the running time

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At least a plant per day constraint:

- More even distribution over time
- Some loss of plant but negligible
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At least a plant per day constraint:

- More even distribution over time
- Some loss of plant but negligible
- Does not affect the running time

- Really slows down the code: from 2min to +3h!
- If we limit the harvesting of a same species of plants to at least every...

Analysis

At least a plant per day constraint:

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  - ...2 days  $\rightarrow$  we obtain  $\frac{2}{3}$  of the total number of plants

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### At least a plant per day constraint:

- More even distribution over time
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- Really slows down the code: from 2min to +3h!
- If we limit the harvesting of a same species of plants to at least every...
  - ...2 days  $\rightarrow$  we obtain  $\frac{2}{3}$  of the total number of plants
  - ...3 days  $\rightarrow$  we obtain 0 plants

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Λ .....

At least a plant per day constraint:

- More even distribution over time
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- Really slows down the code: from 2min to +3h!
- If we limit the harvesting of a same species of plants to at least every...
  - ...2 days  $\rightarrow$  we obtain  $\frac{2}{3}$  of the total number of plants
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- ullet More cons than pros o dropped by the association

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Each growth module can carry up to 5 plants

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Each growth module can carry up to 5 plants

 $\rightarrow$  Constraint: each module can contain at most 2 types of plant from the same kind

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Each growth module can carry up to 5 plants

- $\rightarrow$  Constraint: each module can contain at most 2 types of plant from the same kind
- only changes the capacity per commodity of an edge

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Each growth module can carry up to 5 plants

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### Each growth module can carry up to 5 plants

- $\rightarrow$  Constraint: each module can contain at most 2 types of plant from the same kind
- only changes the capacity per commodity of an edge

### Analysis of this constraint

Does not reduce the total number of plants

# What is left to do

Analysis

### Each growth module can carry up to 5 plants

- → Constraint: each module can contain at most 2 types of plant from the same kind
- only changes the capacity per commodity of an edge

- Does not reduce the total number of plants
- Running time is the same

What is left to do

Analysis

### Each growth module can carry up to 5 plants

- → Constraint: each module can contain at most 2 types of plant from the same kind
- only changes the capacity per commodity of an edge

- Does not reduce the total number of plants
- Running time is the same
- Constraint not respected to perfection

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Each growth module can carry up to 5 plants

- ightarrow Constraint: each module can contain at most 2 types of plant from the same kind
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- Does not reduce the total number of plants
- Running time is the same
- Constraint not respected to perfection
  - → Compromise between constraint

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Each growth module can carry up to 5 plants

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- Does not reduce the total number of plants
- Running time is the same
- Constraint not respected to perfection
  - $\rightarrow$  Compromise between constraint perfectly respected or good output and running time

### Problem

Graph's architecture changed

What is left to do

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Graph's architecture changed → need to update last semester's plants' size constraint

1 node = 1 type of module

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Graph's architecture changed → need to update last semester's plants' size constraint

- 1 node = 1 type of module
- Can't control the size plants each growth module

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Graph's architecture changed  $\longrightarrow$  need to update last semester's plants' size constraint

1 node = 1 type of module

- Can't control the size plants each growth module
- We need to have control over the arrangement of a growth module

# Changing the architecture

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Change the algorithm: one node = one growth module

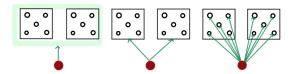
- Control over what happens inside a module
- Knowledge on what plants are inside what module

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- Control over what happens inside a module
- Knowledge on what plants are inside what module



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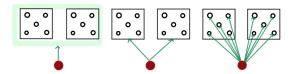
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- Control over what happens inside a module
- Knowledge on what plants are inside what module



### Analysis:

Does it run on real-sized inputs ?

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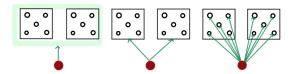
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Change the algorithm: one node = one growth module

- Control over what happens inside a module
- Knowledge on what plants are inside what module



- Does it run on real-sized inputs ? Yes !!
- Running time: from less than 2 min to more than 3h30

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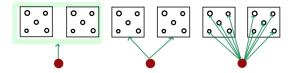
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Change the algorithm: one node = one growth module

- Control over what happens inside a module
- Knowledge on what plants are inside what module



- Does it run on real-sized inputs ? Yes !!
- Running time: from less than 2 min to more than 3h30
- Still good for its purpose

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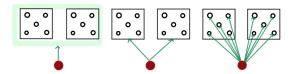
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Change the algorithm: one node = one growth module

- Control over what happens inside a module
- Knowledge on what plants are inside what module



- Does it run on real-sized inputs ? Yes !!
- Running time: from less than 2 min to more than 3h30
- Still good for its purpose → run the code once for the next 6 months

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• Best case: we know the size of each specie over time

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- Best case: we know the size of each specie over time
  - $\rightarrow$  Precise algorithm

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- Best case: we know the size of each specie over time
  - $\rightarrow$  Precise algorithm
- Problem: no experiment done by GrowBotHub

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- Best case: we know the size of each specie over time
  - $\rightarrow$  Precise algorithm
- Problem: no experiment done by GrowBotHub
  - $\rightarrow$  No data on the plant's size !

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- Best case: we know the size of each specie over time
  - $\rightarrow$  Precise algorithm
- Problem: no experiment done by GrowBotHub
  - $\rightarrow$  No data on the plant's size !
  - ightarrow Can't control the size of plants in a growth module if we have no data

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- Best case: we know the size of each specie over time
  - $\rightarrow$  Precise algorithm
- Problem: no experiment done by GrowBotHub
  - $\rightarrow$  No data on the plant's size !
  - $\rightarrow$  Can't control the size of plants in a growth module if we have no data

We still need to find some way to implement this constraint

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Determine biggest plants as they will cause problem over time How?

 $\longrightarrow$  3 out of our 6 plants will not cause problem :

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- $\longrightarrow$  3 out of our 6 plants will not cause problem :
  - Radish and Endive: small.

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- $\longrightarrow$  3 out of our 6 plants will not cause problem :
  - Radish and Endive : small.
  - Strawberries : not in the same growth module.

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- $\longrightarrow$  3 out of our 6 plants will not cause problem :
  - Radish and Endive: small.
  - Strawberries : not in the same growth module.
- ⇒ Lettuce, Fennel, Cabbage : ∧Big plants

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- $\longrightarrow$  3 out of our 6 plants will not cause problem :
  - Radish and Endive: small.
  - Strawberries : not in the same growth module.
- ⇒ Lettuce, Fennel, Cabbage : ∧Big plants
- $\longrightarrow$  they will cause problem in the growth modules of type 2

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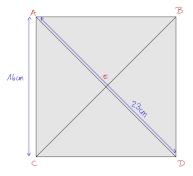


Figure: A growth module with its dimensions.

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Add a constraint to avoid having more than two big plants in one growth module.

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Add a constraint to avoid having more than two big plants in one growth module.

Plants too big only once reached modules of type 2

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Add a constraint to avoid having more than two big plants in one growth module.

- Plants too big only once reached modules of type 2
- Strawberries : ✓

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Λ ... ..

Add a constraint to avoid having more than two big plants in one growth module.

- Plants too big only once reached modules of type 2
- Strawberries : ✓

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Add a constraint to avoid having more than two big plants in one growth module.

- Plants too big only once reached modules of type 2
- Strawberries : ✓

### Analysis.

- Number of plants remains the same
- Running time

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 $\longrightarrow$  Total number of growth modules ( $\in$  [12, 16]) unknown General idea:

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- $\longrightarrow$  Total number of growth modules ( $\in$  [12,16]) unknown General idea:
  - run algorithm and output best combination

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- $\longrightarrow$  Total number of growth modules ( $\in$  [12, 16]) unknown General idea:
  - run algorithm and output best combination
  - give this as inputs to the scheduling algorithm

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- $\longrightarrow$  Total number of growth modules ( $\in$  [12, 16]) unknown General idea:
  - run algorithm and output best combination
  - give this as inputs to the scheduling algorithm

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- $\longrightarrow$  Total number of growth modules ( $\in$  [12,16]) unknown General idea:
  - run algorithm and output best combination
  - give this as inputs to the scheduling algorithm

### Implementation:

- ullet run scheduling algo on all combination of modules ightarrow output best one
- ullet Brute force o each iteration needs to run fast

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 $\longrightarrow$  Total number of growth modules ( $\in$  [12,16]) unknown General idea:

- run algorithm and output best combination
- give this as inputs to the scheduling algorithm

### Implementation:

- ullet run scheduling algo on all combination of modules ightarrow output best one
- ullet Brute force o each iteration needs to run fast
- use old algo version (1 node = 1 type of module)

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- $\longrightarrow$  Total number of growth modules ( $\in$  [12,16]) unknown General idea:
  - run algorithm and output best combination
  - give this as inputs to the scheduling algorithm

### Implementation:

- ullet run scheduling algo on all combination of modules ightarrow output best one
- ullet Brute force o each iteration needs to run fast
- use old algo version (1 node = 1 type of module)
- each iteration takes a few minutes instead of a few hours!

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	Last semester	Now
Size of the graph	(14412, 212'490)	(2892, 38'280)
Number of modules	8	16
Running time	MemoryError	5h30
Constraint Diversity	8	✓
Plant's size	✓	<b>✓</b>
Number of plants	MemoryError	206

Table: Comparison of the scheduling algorithm before and after our project

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$$\begin{array}{ll} \text{maximize} & \sum_{p=1}^{P} \sum_{d=1}^{\text{size}(k_p)} \sum_{(i,j) \in \delta^+(s_p)} \mathbf{x}_{ijk_{p_d}} - \sum_{d=1}^{D} \mathbf{z}_p - \mathbf{v} \sum_{(i,j) \in E} \mathbf{y}_{ij} \\ \text{subject to} & \sum_{(i,j) \in \delta^+(n)} \mathbf{x}_{ijk} - \sum_{(i,j) \in \delta^-(n)} \mathbf{x}_{ijk} = 0 \ \ \forall n \in V - \{S,T\} \\ & \forall (i,j) \in E \ \sum_{p=1}^{N} \sum_{d=1}^{\text{size}(k_p)} \mathbf{x}_{ijk_{p_d}} \leq 5 \\ & \forall p \in \{1....N\} \sum_{d=1}^{Size(k_p)} \sum_{(i,j) \in \delta^+(s_p)} \mathbf{x}_{ijk_{p_d}} \geq \frac{\sum_{p=1}^{N} \sum_{d=1}^{\text{size}(k_p)} \sum_{(i,j) \in \delta^+(s_p)} \mathbf{x}_{ijk_{p_d}}}{N} - \alpha \ \ \alpha \geq \\ & z_d \geq 0 \\ & z_d \geq 1 - \sum_{p=1}^{N} \mathbf{x}_{t_{p_d}} \\ & \forall (i,j) \in E \ \ \forall p \ \ \forall d \ \ \mathbf{x}_{ijk_{p_d}} \leq 5 \\ & \forall d \ \ \forall p = 1....N \ \ \sum_{d}^{d+3} \mathbf{y}_{t_{p_d}} \leq 1 \\ & \mathbf{x}_{ijk_{p_d}} \leq 2 \end{array}$$

### The inputs

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- 4 types of growth module
  - 6 trays of module 1 ("seedling")
  - 6 trays of module 2 ("vegetative")
  - 2 trays of module 3 ("flowering")
  - 2 trays of module 4 ("development")
- Total number of days: 180 (6month)
- 6 types of plants
  - Lettuce: 30 days in module 1, 25 days in module 2
  - Endive: 20 days in module 1, 40 days in module 2
  - Cabbage: 20 days in module 1, 30 days in module 2
  - Fennel: 20 days in module 1, 30 days in module 2
  - Raddish: 15 days in module 1, 15 days in module 2
  - Strawberry: 49 days in module 1, 21 days in module 2, 28 days in module 3, 19 days in module 4

# Graph of the optimal solution of the scheduling problem

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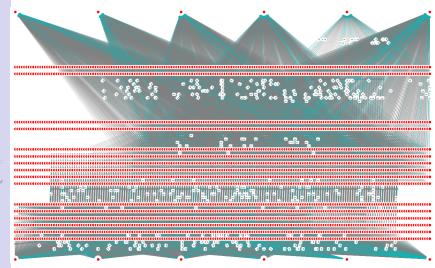
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- Total number of lettuces:
- Total number of endives:
- Total number of cabbages:
- Total number of fennels:
- Total number of raddishes:
- Total number of strawberries:
- $\longrightarrow$  Total number of plants: 168

# Snippet of the instruction file

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# Snippet of the content of a module on a given day

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