SMU Singapore Management University | School of Computing and Information Systems

CS606 AI Planning and Decision Making

University Timetabling

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1. INTRODUCTION

1.Introduction

- ITC 2019: International Timetabling Competition

courses

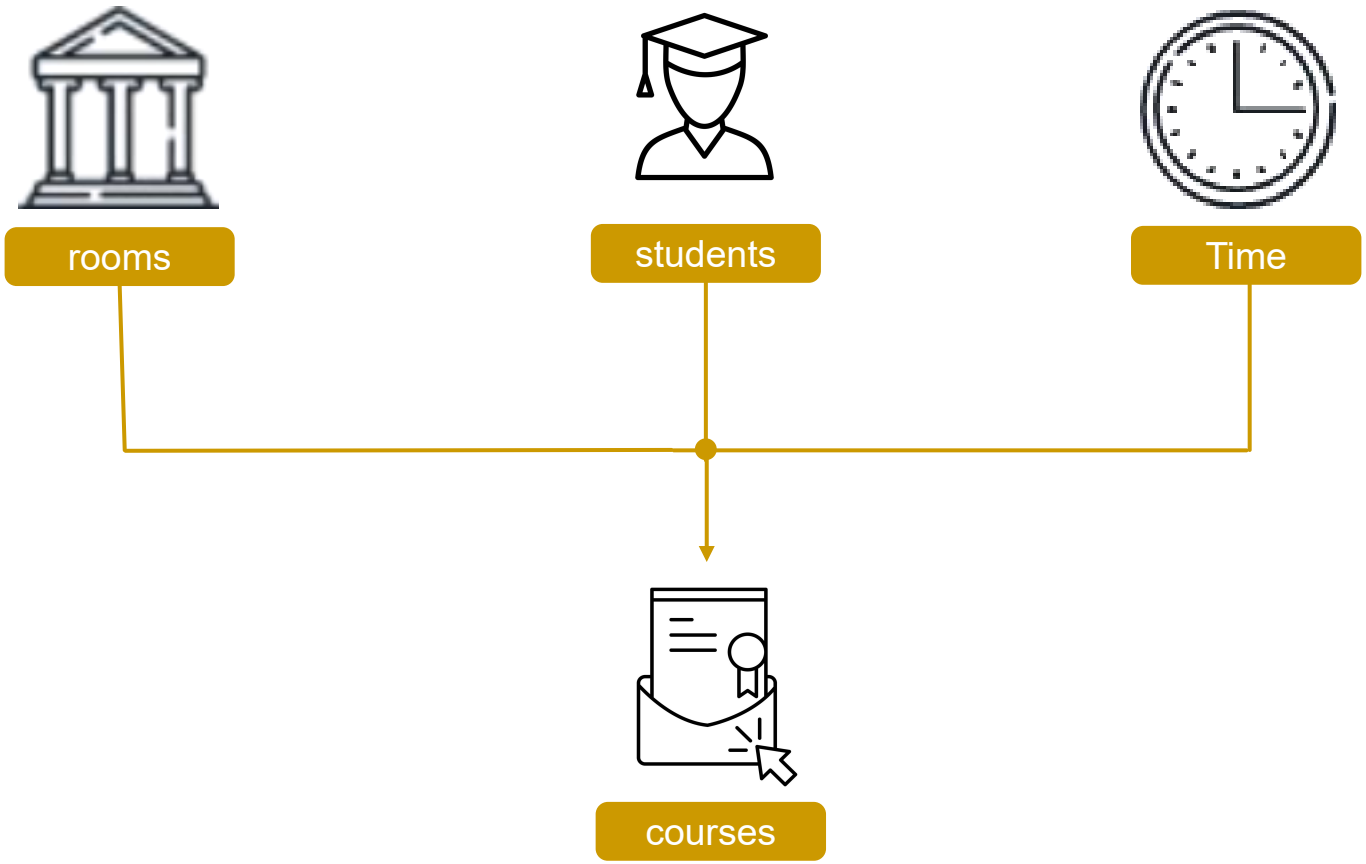
students

Goal: To find a proper time, a room and students for all the classes

https://www.itc2019.org/home

1.Introduction

Goal: find a proper time, a room and students for all the classes



https://www.itc2019.org/home

1.Introduction

- Model used by competition participants
  - Mixed Integer Programming

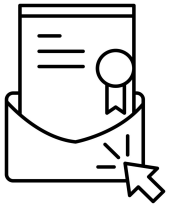
- Model used by us
  - Mixed Integer Programming
  - *Constraint Programming*

2. PROBLEM DEFINITION

2.Problem Definition

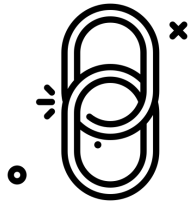
2.1 Data

rooms



courses

students



constraints

2.Problem Definition

2.1 Data

- Rooms

capacity

The max **students'** number in one room

room r

ROOM R	MON	TUE	WED	THU	FRI	SAT	SUN
08:00							
10:00							
12:00							
14:00							
16:00							
18:00							

Not available on Sat noon

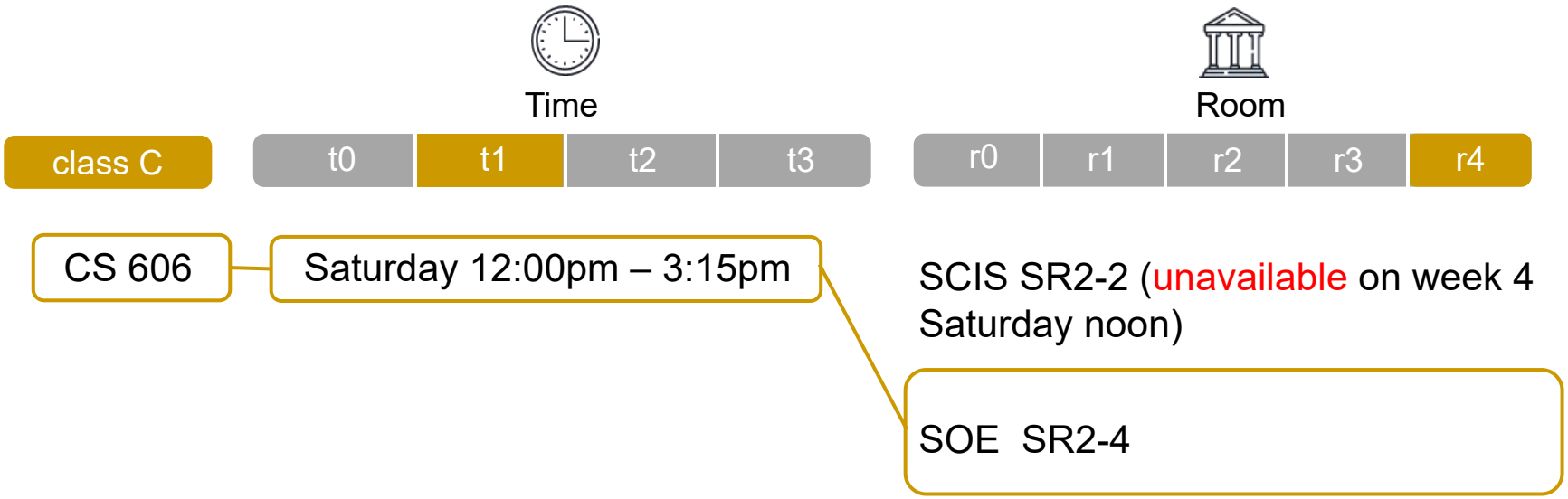
unavailable

Some rooms are **not available at some time slots**

2.Problem Definition

2.1 Data

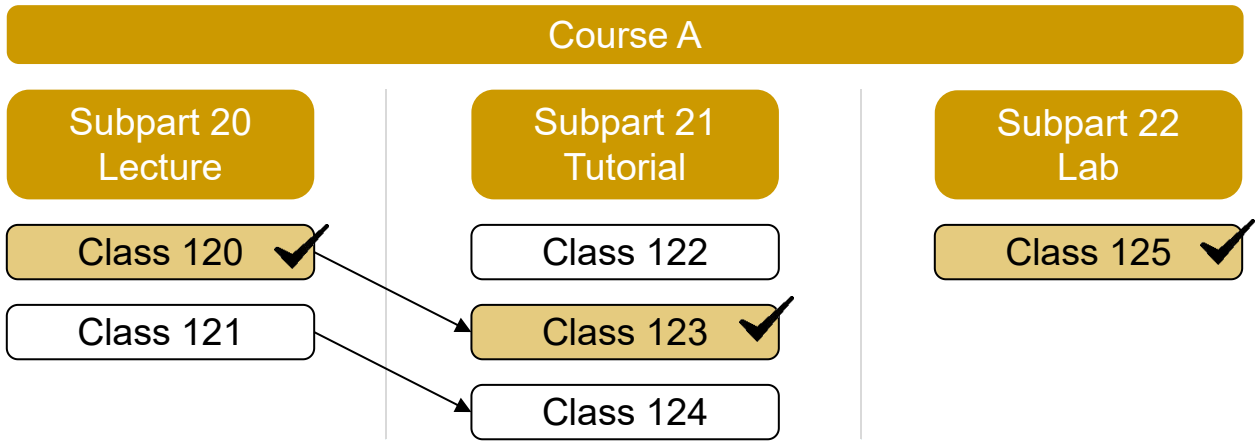
- Classes



2.Problem Definition

2.1 Data

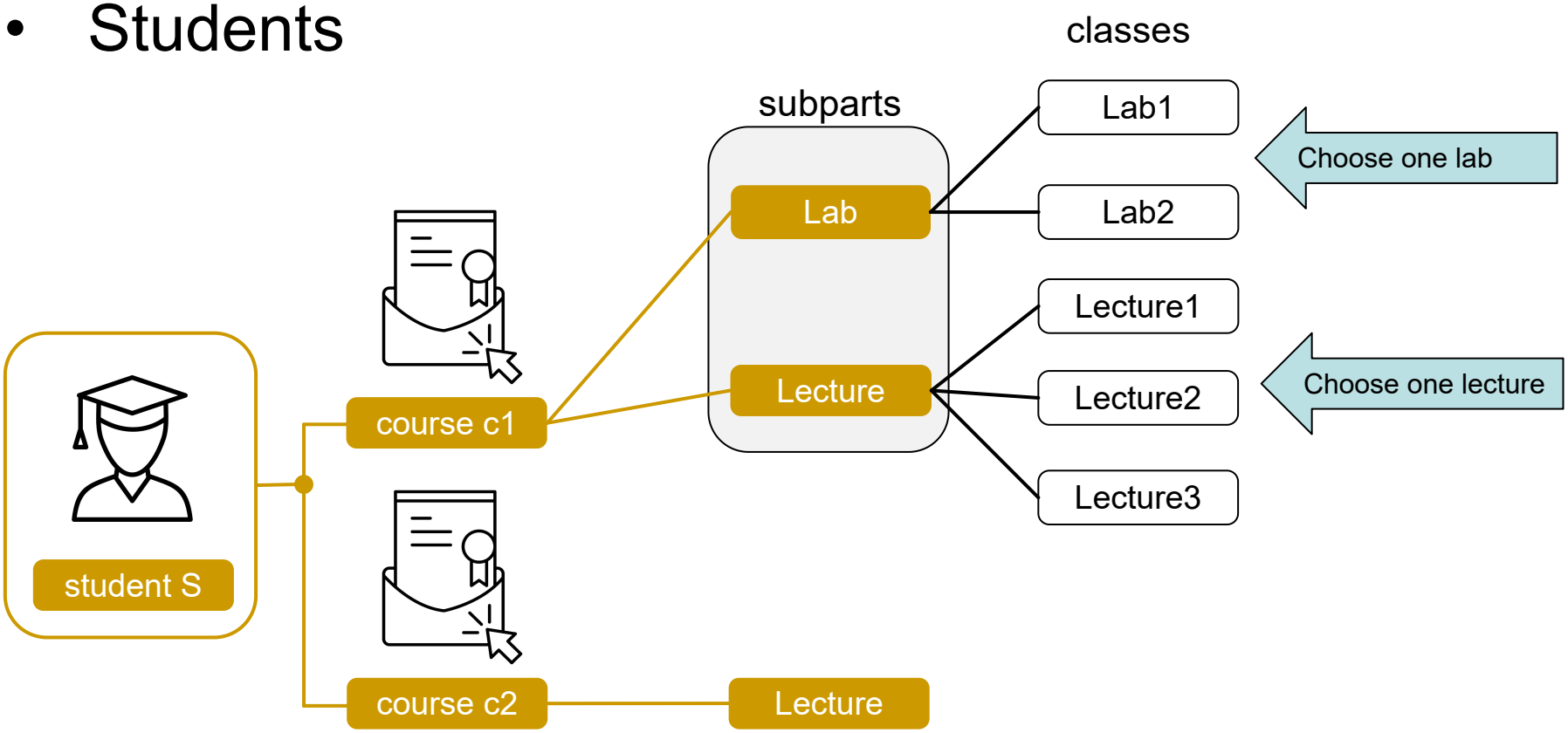
- Courses
  - Each course has multiple **subparts**
  - Each subpart has multiple **classes**
  - A student need to choose **one class in each subpart** for each course
  - Some class has **prerequisites**



2.Problem Definition

2.1 Data

- Students



2.Problem Definition

2.1 Data

- Distributed Constraints

  We only consider hard constraints: **SameAttendees** in this project

Constraint	Complementary	Time	Days	Weeks	Room	Pairs
SameStart		✓	✗	✗	✗	✓
SameTime	DifferentTime	✓	✗	✗	✗	✓
SameDays	DifferentDays	✗	✓	✗	✗	✓
SameWeeks	DifferentWeeks	✗	✗	✓	✗	✓
SameRoom	DifferentRoom	✗	✗	✗	✓	✓
Overlap	NotOverlap	✓	✓	✓	✗	✓
SameAttendees		✓	✓	✓	✓	✓
Precedence		✓	✓	✓	✗	✓
WorkDay(S)		✓	✓	✓	✗	✓
MinGap(G)		✓	✓	✓	✗	✓
MaxDays(D)		✗	✓	✗	✗	days over D
MaxDayLoad(S)		✓	✓	✓	✗	slots over S
MaxBreaks(R,S)		✓	✓	✓	✗	breaks over R
MaxBlock(M,S)		✓	✓	✓	✗	blocks over M

2.Problem Definition

2.2 Notations

Table 1: Notation

Symbol	Definition
Sets	
$c \in C$	set of classes
$t \in T$	set of time periods
$s \in S$	set of students
$r \in R$	set of rooms
$r \in CR_c$	set of rooms each class can use
$t \in CT_c$	set of time slots each class can use
$c \in SC_s$	set of Courses that each student need to learn
$(c_i, c_j) \in SA$	set of class pairs c_i, c_j that can't overlap
Parameters	
$pr_{c,r}$	penalty of choosing room r of class c
$pt_{c,t}$	penalty of choosing time t of class c
M_r	capacity of each room r
Decision Variables	
$x_{c,t}$	binary variable that indicates whether class c is scheduled to time slot t
$y_{c,r}$	binary variable that indicates whether class c takes place at room r
$z_{s,c}$	binary variable that indicates whether student s choose class c

2.Problem Definition

2.3 Assumptions

- There's **no travel time** between two classes.
- Do not consider soft constraints and only consider **SameAttendees** in **distributed constraints**.

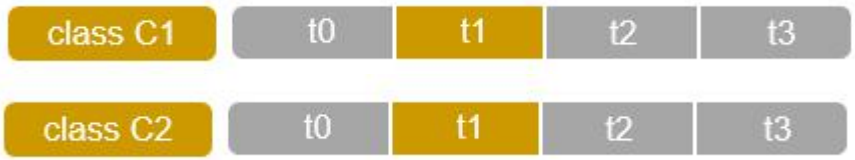
2. Problem Definition (MP)

- Decision variables

$$x_{c,t} = \begin{cases} 1 & \text{The class c takes place at time t} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{c,r} = \begin{cases} 1 & \text{The class c takes place in room r} \\ 0 & \text{otherwise} \end{cases}$$

$$z_{s,c} = \begin{cases} 1 & \text{The student s is assigned to class c} \\ 0 & \text{otherwise} \end{cases}$$



No global identifier for timeslot

2. Problem Definition (MP)

- Objective

$$\text{Min} \quad \sum_{c \in C} \sum_{r \in R} y_{c,r} pr_{c,r} \qquad \text{Room penalty}$$

$$+ \sum_{c \in C} \sum_{t \in T} x_{c,t} pt_{c,t} \qquad \text{Time penalty}$$

2.Problem Definition (MP)

- Constraints
  - H1: Every class must be assigned a time
  - H2: Every class must be assigned a room
  - H3: Every student must attend exactly one class for each subpart that he/she must attend

2.Problem Definition (MP)

- Constraints
  - H4: Prerequisite:
    - Ex: If you take AI Planning – you must take Algorithm as well
  - H5: The capacity limit of each class must not be exceeded.
  - H6: A room cannot be used when it is unavailable
  - H7: The pairs of classes in SameAttendees should not overlap in time
    - Ex: Prof Dai is teaching Algorithm & Applied ML – these 2 classes cannot happen at the same time
  - H8: Two classes can’t be at the same time and the same room

2. Problem Definition (CP)

- Decision variables

$$x_c = t, for\ c \in C \qquad \text{Domain: } t\ avail\ for\ c$$

$$y_c = r, for\ c \in C \qquad \text{Domain: } r\ avail\ for\ c$$

$$z_{s,sbp} = c, for\ s \in S, for\ sbp \in SP_s$$

Domain: c in SPs

Time for class c is t
Room for class c is r
The class choice of subpart sbp for student s is c

2. Problem Definition (CP)

- Objective

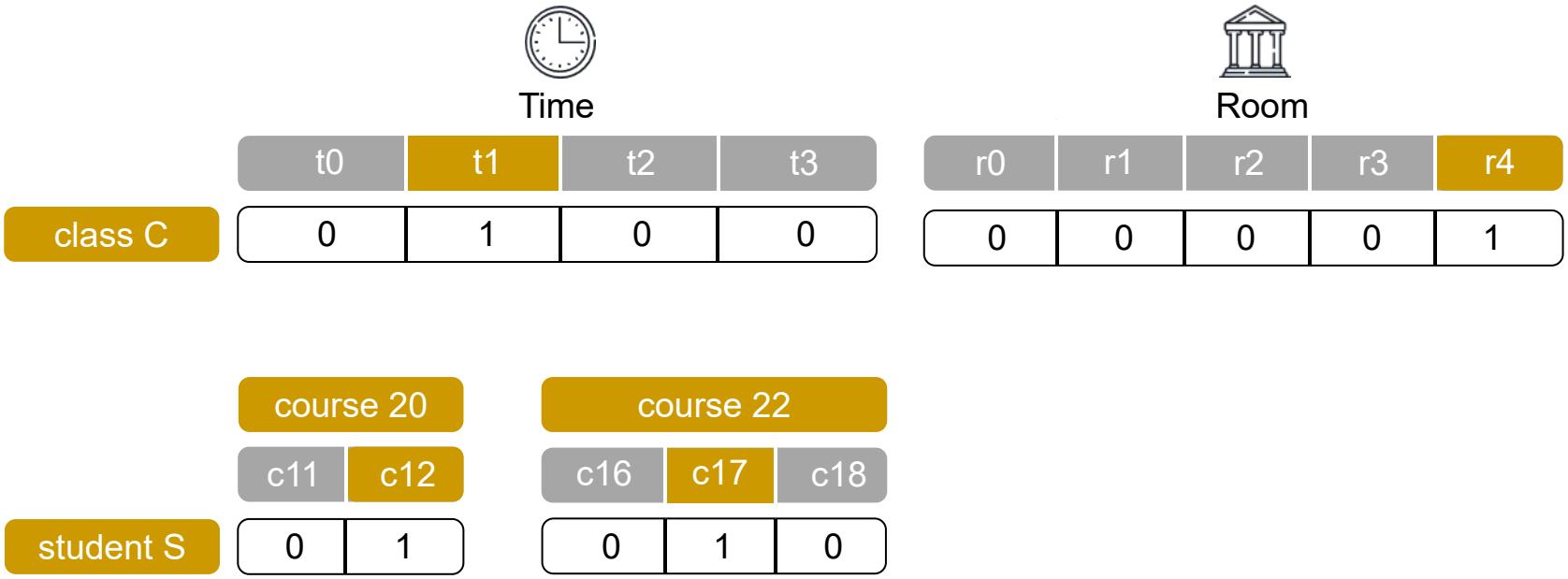
$$min \sum_c (p_{t_c} + p_{r_c})$$

- Constraints
  - H1,H2,H3 are satisfied within cp
  - H4: $if\ z_{s,sub} = c, then\ z_{s,sub`} = c.parent$
  - H5: $count(z, c) \leq limit(c)$
  - H6: $if\ x_c = t,\ then\ y_c \neq \mathrm{r}$ for t in r.avail()
  - H7: $if\ x_{c1} = t_1, then\ x_{c2} \neq t_2$ if ovl(t1,t2)
  - H8: $if\ x_{c1} = t_1, and\ x_{c2} = t_2, and\ y_{c1} = r1, then\ y_{c2} \neq r_2$ if ovl(t1,t2) and r1=r2

3. SOLUTION APPROACH

3. Solution Approach

- Mixed Integer Programming
  - Binary variables
  - Linear constraints

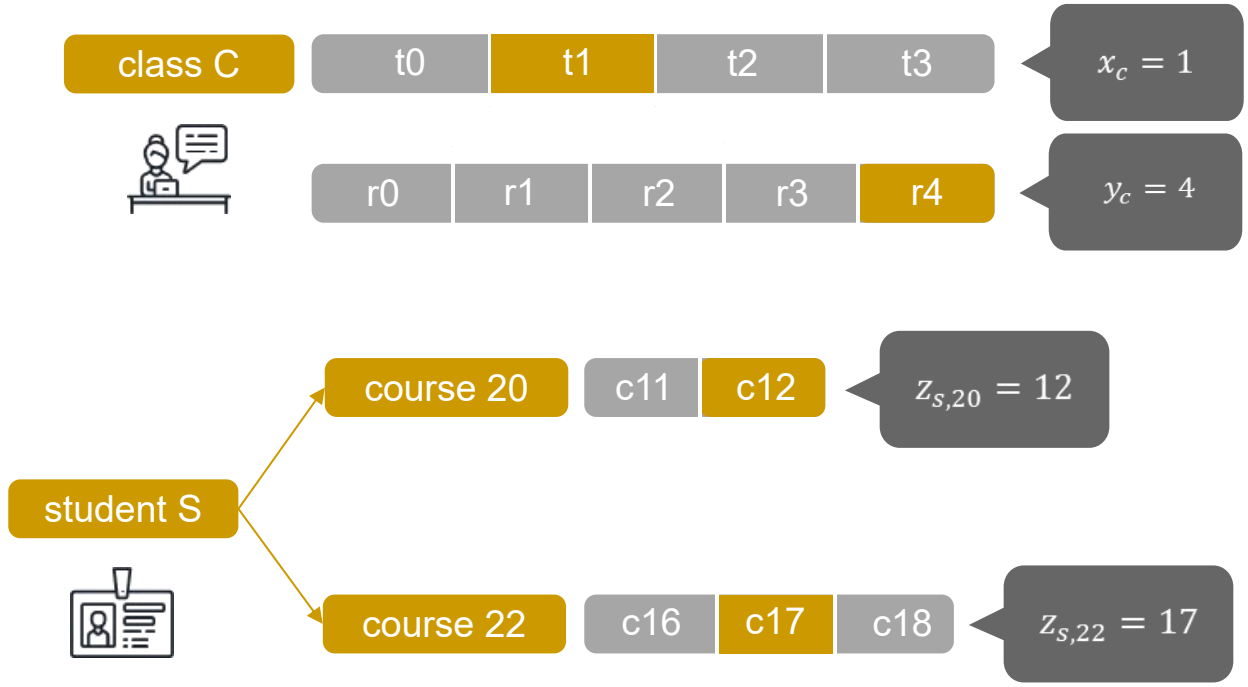


3.Solution Approach

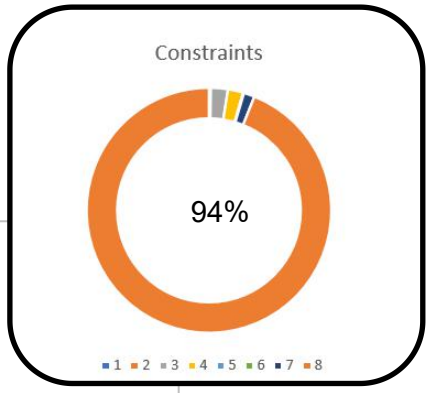
- Constraint Programming
  - Integer variables:

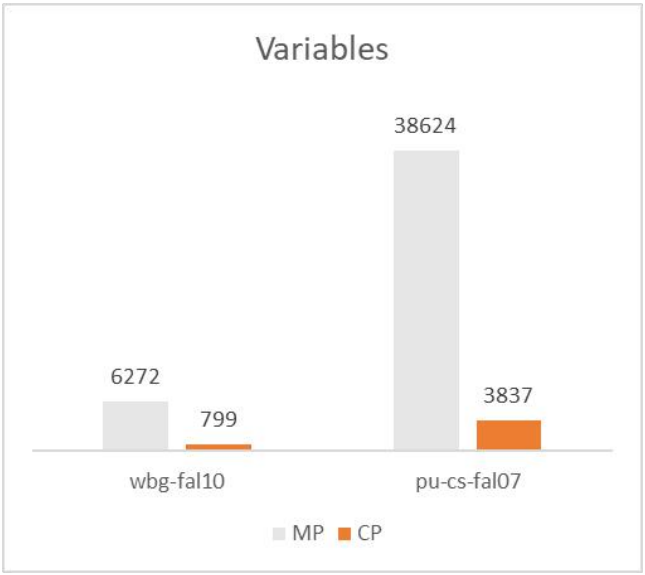
$$x_c = t$$
$$y_c = r$$
$$z_{s,sbp} = c$$

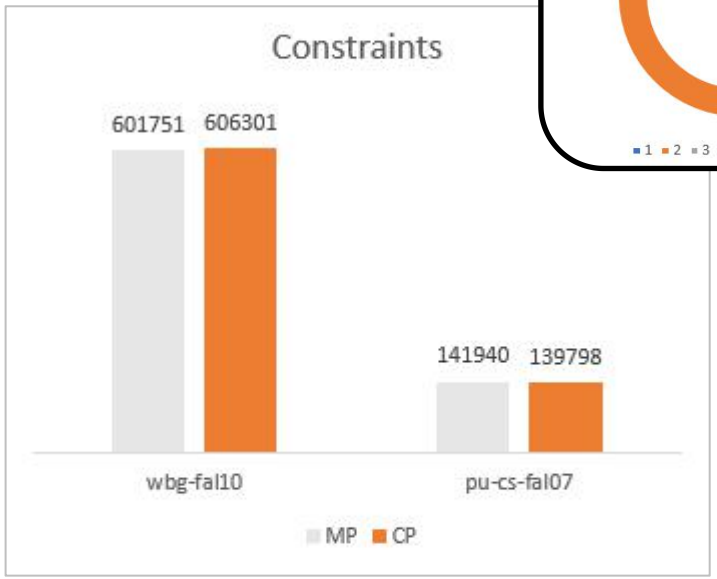
  - Logical constraints:
    - if_else
    - logical_and



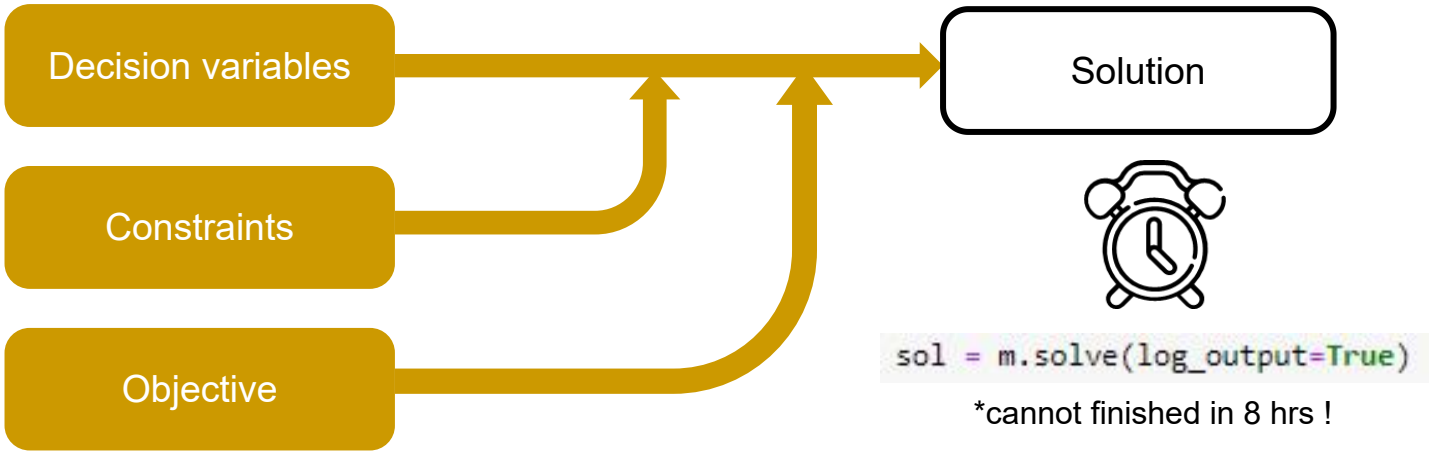
3.Solution Approach





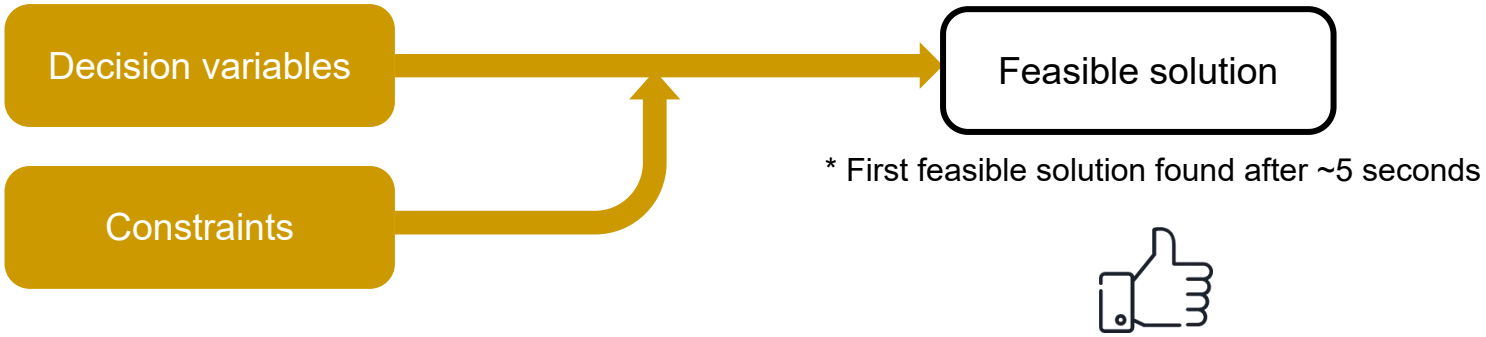


3. Solution Approach



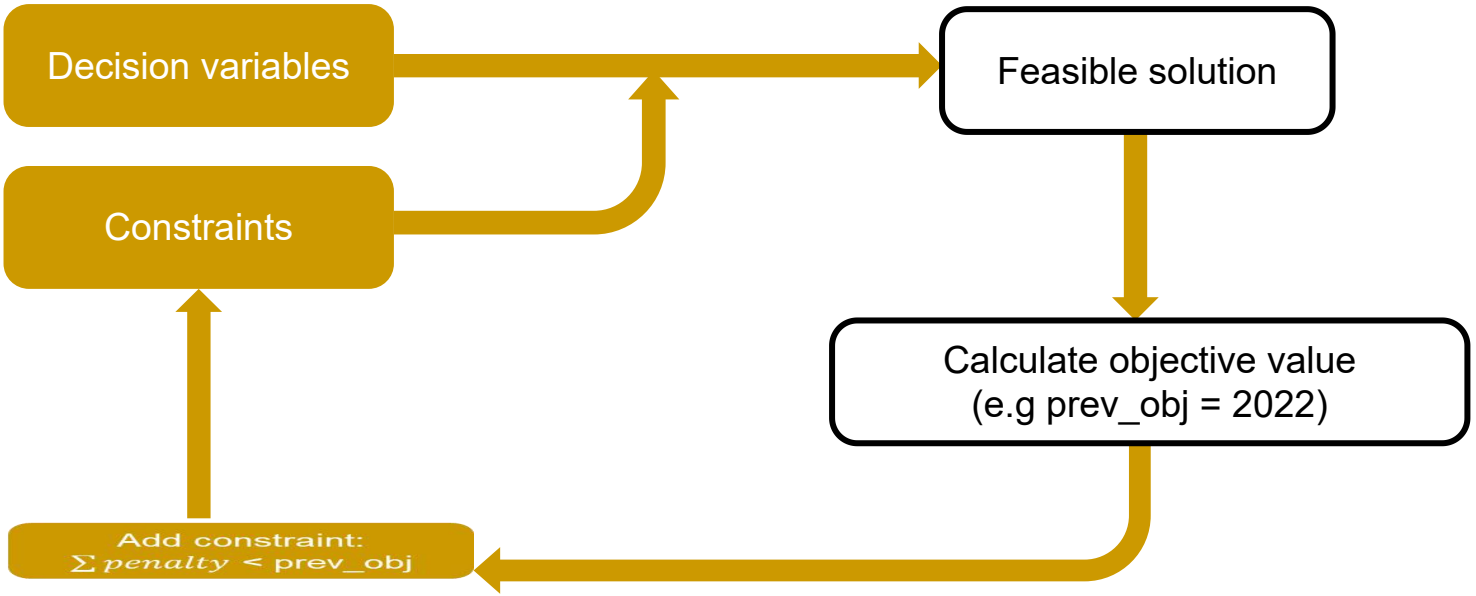
3. Solution Approach

- Mixed Integer Programming



3. Solution Approach

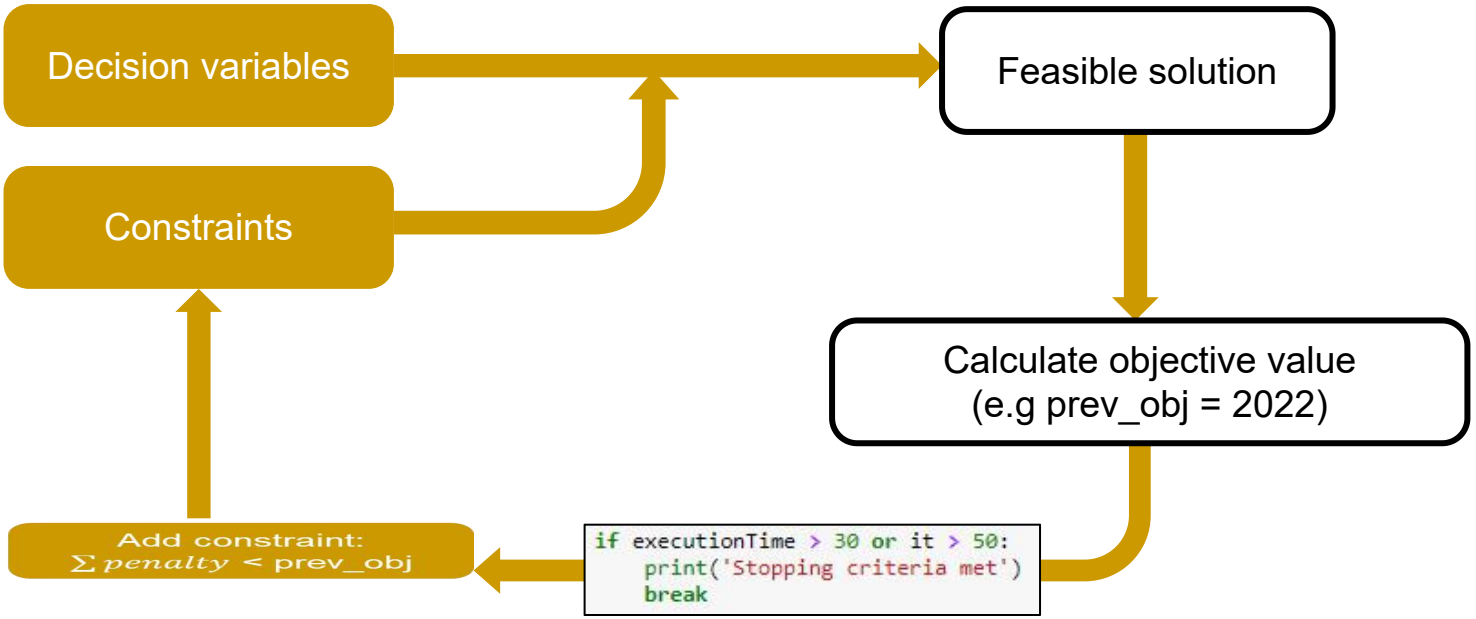
- Mixed Integer Programming




```
m.add_constraint(time_penalty + room_penalty <= sol_penalty-1)
```

3. Solution Approach

- Mixed Integer Programming



Stopping criteria: either
- number of iterations > 50
- time for an iteration exceed 30s

3. Solution Approach

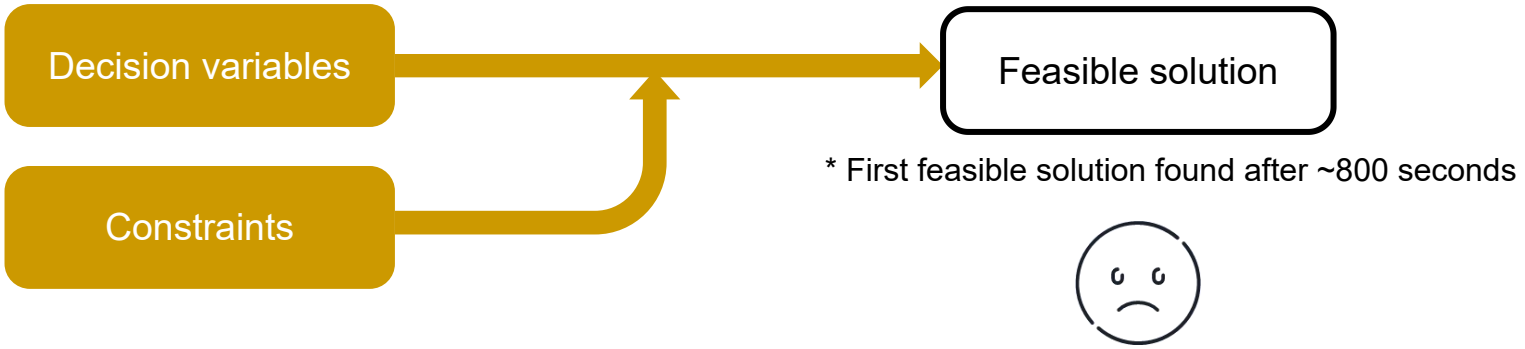
- Mixed Integer Programming

Algorithm 1 MIP approach general structure

$sol_{pre} \leftarrow None$
while not meet the stopping criteria **do**
  $sol \leftarrow model.solve()$
  if sol **then**
    $sol_{pre} \leftarrow sol$
  end if
  $penalty \leftarrow objective(sol_{pre})$
  $p_{time} \leftarrow m.sum(pt_{c,t} * x_{c,t} \ for \ c \in C, t \in CTime_c)$
  $p_{room} \leftarrow m.sum(pr_{c,r} * y_{c,r} \ for \ c \in C, r \in CRoom_c)$
  $model.add\_constraint(p_{time} + p_{room} <= penalty)$ ▷ New solution must be better than current one
end while

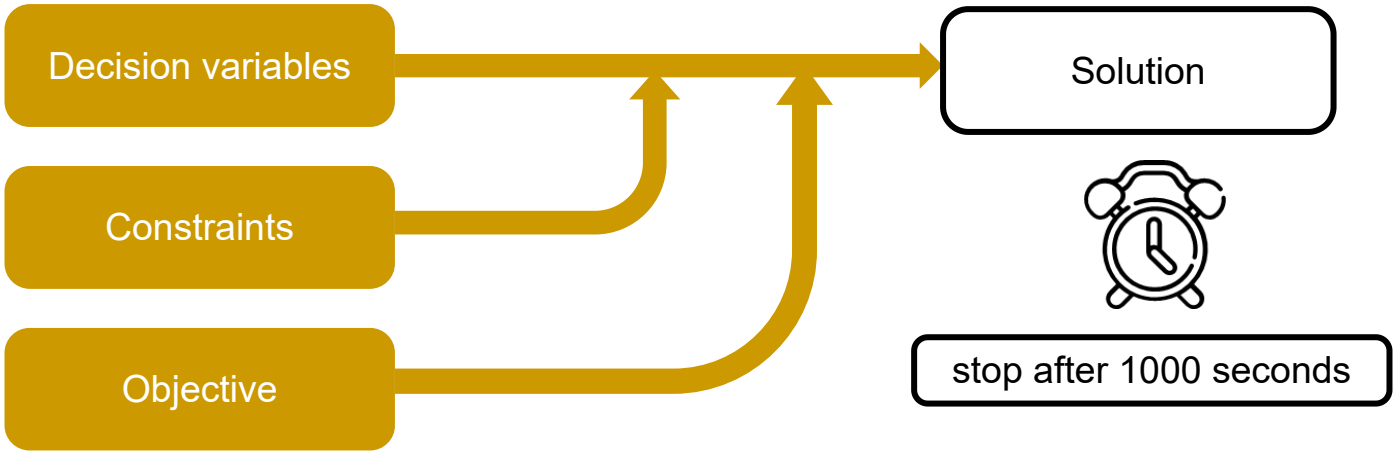
3. Solution Approach

- Constraint Programming



3. Solution Approach

- Constraint Programming

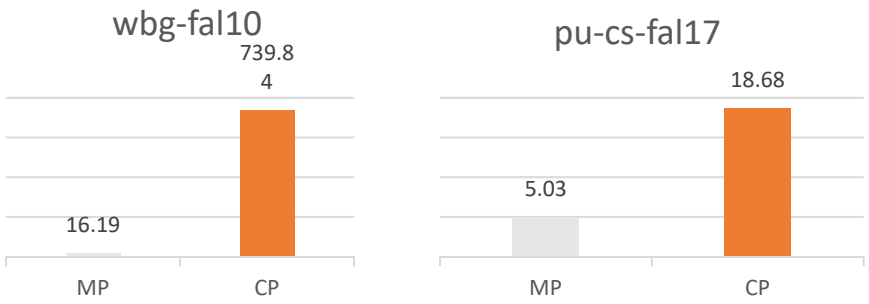


4. RESULTS

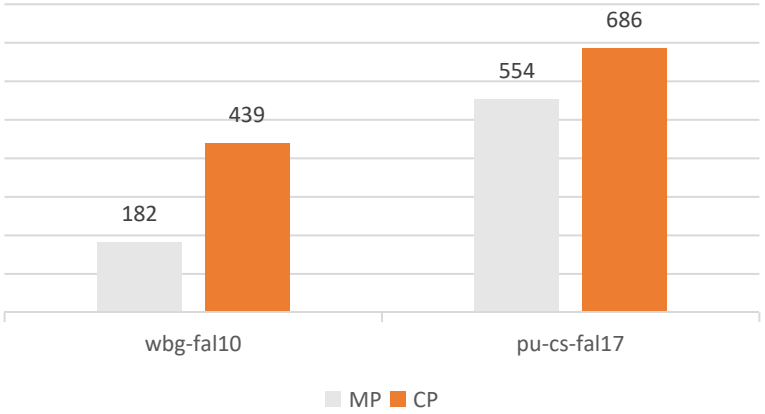
4.Results

First feasible solution

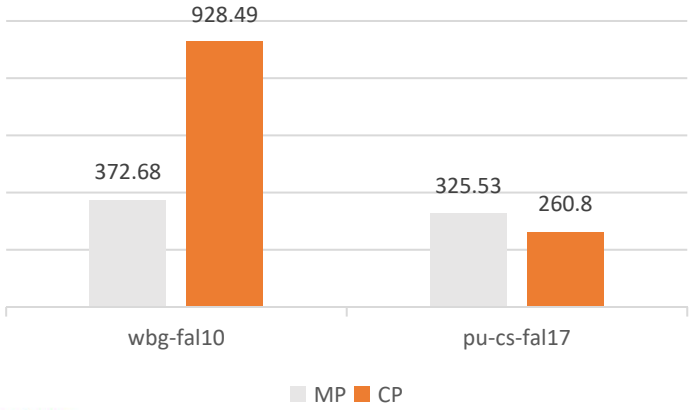
Runtime

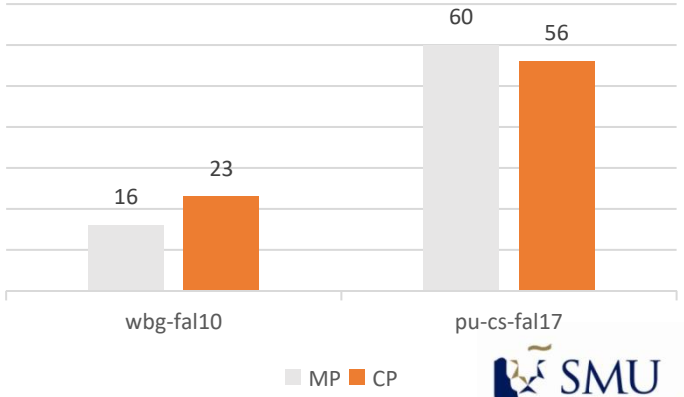


Objective



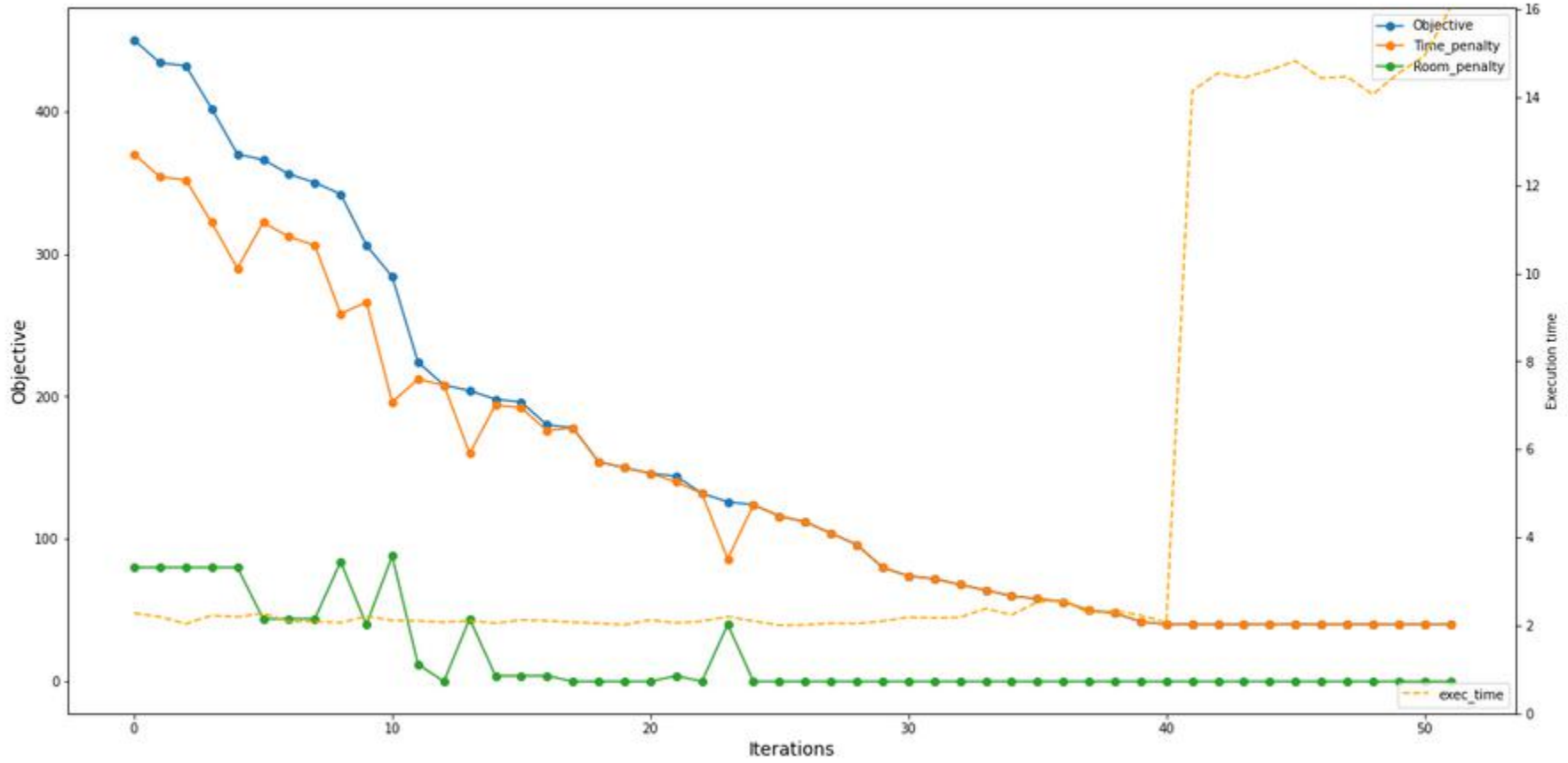
Optimal solution





MIP approach result

```
Total runtime: 249.4854 seconds
Objective value: 40.0
```



Validation

ITC 2019

Summary

Variables assigned:	150/150
Enrollment problems detected:	0
Total time penalty:	0
Total room penalty:	16
Total distribution penalty:	13
Total student conflicts:	58
Valid solution:	true
Total penalty:	737

```
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     <student id="2"/>
   </class>
  ▼<class id="2" days="1111100" start="138" weeks="1111111111111111" room="6">
     <student id="7"/>
     <student id="12"/>
   </class>
  ▼<class id="3" days="0101000" start="90" weeks="1111111111111111" room="6">
     <student id="4"/>
     <student id="5"/>
     <student id="6"/>
     <student id="8"/>
   </class>
  ▼<class id="4" days="0101000" start="102" weeks="1111111111111111" room="6">
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     <student id="14"/>
     <student id="15"/>
     <student id="16"/>
   </class>
```
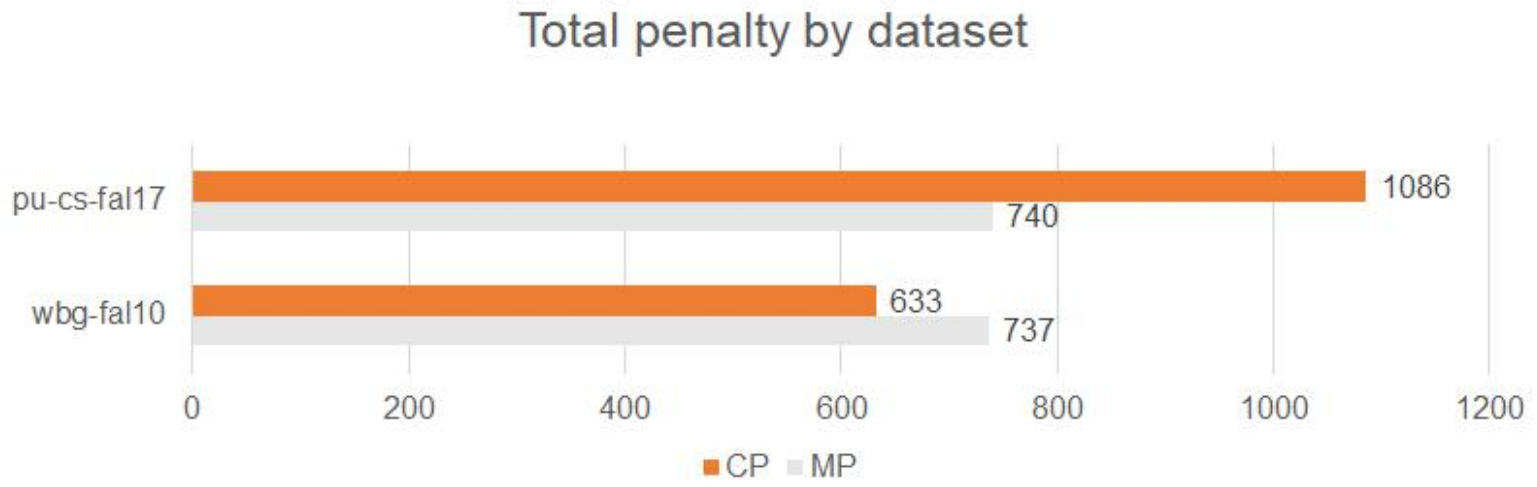
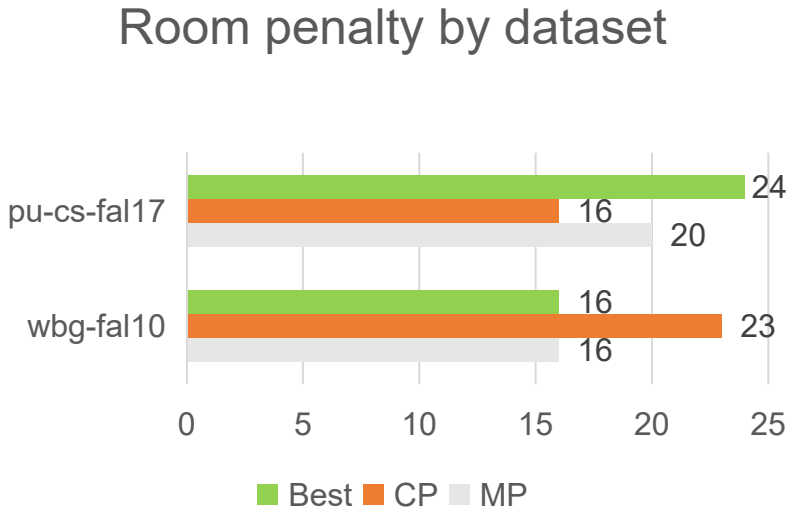
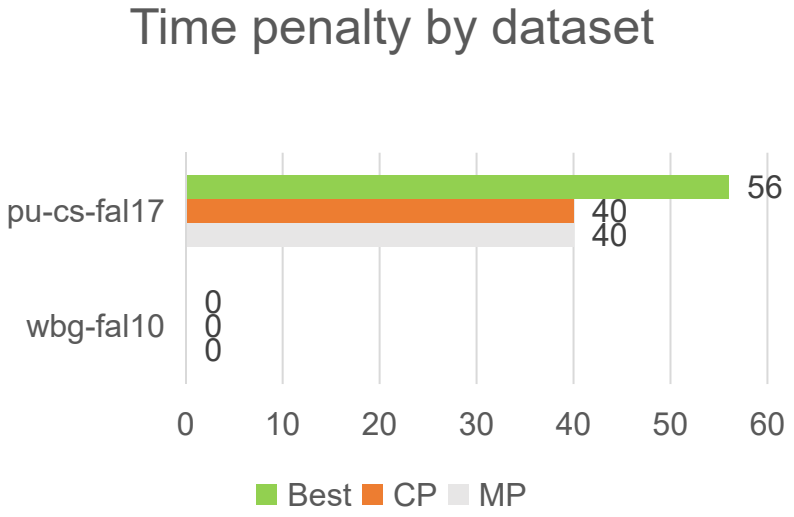

Validation


Total penalty by dataset
pu-cs-fal17
wbg-fal10
1086
740
633
737
0
200
400
600
800
1000
1200
CP
MP


Room penalty by dataset
pu-cs-fal17
wbg-fal10
24
16
20
16
23
16
0
5
10
15
20
25
Best
CP
MP


Time penalty by dataset
pu-cs-fal17
wbg-fal10
56
40
40
0
0
0
0
10
20
30
40
50
60
Best
CP
MP

5. Demo

- Colab: MIP
- Colab: CP

Q&A