COMP9414 Artificial Intelligence

Assignment 1: Constraint Satisfaction Search

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Due Date: Week 5, Friday, October 17, 5.00pm

Objective

This assignment concerns developing optimal solutions to a scheduling problem inspired by the scenario of a manufacturing plant that has to fulfil multiple customer orders with varying deadlines, but where there may be constraints on tasks and on relationships between tasks. Any number of tasks can be scheduled at the same time, but it is possible that some tasks cannot be finished before their deadline. A task finishing late is acceptable, however incurs a cost, which for this assignment is a simple (dollar) amount per hour that the task is late.

A *fuzzy scheduling* problem in this scenario is simplified by ignoring customer orders and having just one machine and a number of *tasks*, each with a fixed duration in hours. Each task must start and finish on the same day, within working hours (9am to 5pm). In addition, there can be *constraints*, both on single tasks and between two tasks. One type of constraint is that a task can have a deadline, which can be "hard" (the deadline must be met in any valid schedule) or "soft" (the task may be finished late – though still at or before 5pm – but with a "cost" per hour for missing the deadline). The aim is to develop an overall schedule for all the tasks (in a single week) that minimizes the total cost of all the tasks that finish late, provided that all the hard constraints on tasks are satisfied.

More technically, this assignment is an example of a *constraint optimization problem* (or *constrained optimization problem*), a problem that has constraints like a standard Constraint Satisfaction Problem (CSP), but also a *cost* associated with each solution. For this assignment, we will use a *greedy* algorithm to find optimal solutions to fuzzy scheduling problems that are specified as text strings. However, unlike the greedy search algorithm described in the lectures on search, this greedy algorithm has the property that it is guaranteed to find an optimal solution for any problem (if a solution exists).

The assignment will use the AIPython code of Poole & Mackworth. You are given code to translate fuzzy scheduling problems specified as text strings into CSPs with a cost, and you are given code for several constraint solving algorithms – based on domain splitting and arc consistency, and based on depth-first search. The assignment will be to implement some missing procedures and to analyse the performance of the constraint solving methods, both analytically and experimentally.

Submission Instructions

- This is an individual assignment.
- Write your answers in **this** notebook and submit **this** notebook on Moodle under **Assignment 1**.
- Name your submission `<zid>-<firstname>-<lastname>.ipynb` where `<firstname>-<lastname>` is your **real** (not Moodle) name.
- Make sure you set up AIPython (as done below) so the code can be run on either CSE machines or a marker's own machine.
- Do not submit any AIPython code. Hence do not change any AIPython code to make your code run.
- Make sure your notebook runs cleanly (restart the kernel, clear all outputs and run each cell to check).
- After checking that your notebook runs cleanly, run all cells and submit the notebook **with** the outputs included (do not submit the empty version).
- Make sure images (for plots/graphs) are **included** in the notebook you submit (sometimes images are saved on your machine but are not in the notebook).
- Do not modify the existing code in this notebook except to answer the questions. Marks will be given as and where indicated.
- If you want to submit additional code (e.g. for generating plots), add that at the end of the notebook.
- **Important: Do not distribute any of this code on the Internet. This includes ChatGPT. Do not put this assignment into any LLM.**

Late Penalties

Standard UNSW late penalties apply (5% of the value of the assignment per day or part day late).

Note: Unlike the CSE systems, there is no grace period on Moodle. The due date and time is 5pm **precisely** on Friday October 17.

Important: You can submit as many times as you want before the due date, but if you do submit before the due date, you cannot submit on Moodle after the due date. If you do not submit before the due date, you can submit on Moodle after the due date.

Plagiarism

Remember that ALL work submitted for this assignment must be your own work and no sharing or copying of code or answers is allowed. You may discuss the assignment with other students but must not collaborate on developing answers to the questions. You

may use code from the Internet only with suitable attribution of the source. You may not use ChatGPT or any similar software to generate any part of your explanations, evaluations or code. Do not use public code repositories on sites such as github or file sharing sites such as Google Drive to save any part of your work – make sure your code repository or cloud storage is private and do not share any links. This also applies after you have finished the course, as we do not want next year's students accessing your solution, and plagiarism penalties can still apply after the course has finished.

All submitted assignments will be run through plagiarism detection software to detect similarities to other submissions, including from past years. You should **carefully** read the UNSW policy on academic integrity and plagiarism (linked from the course web page), noting, in particular, that collusion (working together on an assignment, or sharing parts of assignment solutions) is a form of plagiarism.

Finally, do not use any contract cheating "academies" or online "tutoring" services. This counts as serious misconduct with heavy penalties up to automatic failure of the course with 0 marks, and expulsion from the university for repeat offenders.

Fuzzy Scheduling

A CSP for this assignment is a set of variables representing tasks, binary constraints on pairs of tasks, and unary constraints (hard or soft) on tasks. The domains are all the working hours in one week, and a task duration is in hours. Days are represented (in the input and output) as strings 'mon', 'tue', 'wed', 'thu' and 'fri', and times are represented as strings '9am', '10am', '11am', '12pm', '1pm', '2pm', '3pm', '4pm' and '5pm'. The only possible values for the start and end times of a task are combinations of a day and times, e.g. 'mon 9am'. Each task name is a string (with no spaces), and the only soft constraints are the soft deadline constraints.

There are three types of constraint:

- **Binary Constraints:** These specify a hard requirement for the relationship between two tasks.
- **Hard Domain Constraints:** These specify hard requirements for the tasks themselves.
- **Soft Deadline Constraints:** These constraints specify that a task may finish late, but with a given cost.

Each soft constraint has a function defining the *cost* associated with violating the preference, that the constraint solver must minimize, while respecting all the hard constraints. The *cost* of a solution is simply the sum of the costs for the soft constraints that the solution violates (and is always a non-negative integer).

This is the list of possible constraints for a fuzzy scheduling problem (comments below are for explanation and do **not** appear in the input specification; however, the code we supply *should* work with comments that take up a full line):

```
# binary constraints
constraint, ⟨t1⟩ before ⟨t2⟩           # t1 ends when or before
t2 starts
constraint, ⟨t1⟩ after ⟨t2⟩            # t1 starts after or when
t2 ends
constraint, ⟨t1⟩ same-day ⟨t2⟩         # t1 and t2 are scheduled
on the same day
constraint, ⟨t1⟩ starts-at ⟨t2⟩        # t1 starts exactly when
t2 ends

# hard domain constraints
domain, ⟨t⟩, ⟨day⟩, hard                                    # t
starts on given day at any time
domain, ⟨t⟩, ⟨time⟩, hard                                   # t
starts at given time on any day
domain, ⟨t⟩, starts-before ⟨day⟩ ⟨time⟩, hard               # t
starts at or before day, time
domain, ⟨t⟩, starts-after ⟨day⟩ ⟨time⟩, hard                # t
starts at or after day, time
domain, ⟨t⟩, ends-before ⟨day⟩ ⟨time⟩, hard                 # t
ends at or before day, time
domain, ⟨t⟩, ends-after ⟨day⟩ ⟨time⟩, hard                  # t
starts at or after day, time
domain, ⟨t⟩, starts-in ⟨day1⟩ ⟨time1⟩-⟨day2⟩ ⟨time2⟩, hard  # day-
time range for start time; includes day1, time1 and day2, time2
domain, ⟨t⟩, ends-in ⟨day1⟩ ⟨time1⟩-⟨day2⟩ ⟨time2⟩, hard    # day-
time range for end time; includes day1, time1 and day2, time2
domain, ⟨t⟩, starts-before ⟨time⟩, hard                     # t
starts at or before time on any day
domain, ⟨t⟩, ends-before ⟨time⟩, hard                       # t
ends at or before time on any day
domain, ⟨t⟩, starts-after ⟨time⟩, hard                      # t
starts at or after time on any day
domain, ⟨t⟩, ends-after ⟨time⟩, hard                        # t
ends at or after time on any day

# soft deadline constraint
domain, ⟨t⟩, ends-by ⟨day⟩ ⟨time⟩ ⟨cost⟩, soft          # cost per
hour of missing deadline
```

The input specification will consist of several “blocks”, listing the tasks, binary constraints, hard unary constraints and soft deadline constraints for the given problem. A “declaration” of each task will be included before it is used in a constraint. A sample input specification is as follows. Comments are for explanation and do **not** have to be included in the input.

```
# two tasks with two binary constraints and soft deadlines
task, t1 3
task, t2 4
# two binary constraints
constraint, t1 before t2
constraint, t1 same-day t2
# domain constraint
domain, t2 mon
```

```
# soft deadline constraints
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by mon 3pm 10
```

Preparation

1. Set up AIPython

You will need AIPython for this assignment. To find the aipython files, the aipython directory has to be added to the Python path.

Do this temporarily, as done here, so we can find AIPython and run your code (you will not submit any AIPython code).

You can add either the full path (using `os.path.abspath`), or as in the code below, the relative path.

In [201…
```
import sys
sys.path.append('aipython') # change to your directory
sys.path # check that aipython is now on the path
```

Out[201…
```
['/Users/yangjiashuo/PycharmProjects/AI_9414',
 '/Applications/PyCharm.app/Contents/plugins/python-ce/helpers/pydev',
 '/Applications/PyCharm.app/Contents/plugins/python-ce/helpers/jupyter_debug',
 '/opt/anaconda3/envs/AI_9414/lib/python313.zip',
 '/opt/anaconda3/envs/AI_9414/lib/python3.13',
 '/opt/anaconda3/envs/AI_9414/lib/python3.13/lib-dynload',
 '',
 '/opt/anaconda3/envs/AI_9414/lib/python3.13/site-packages',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython',
 'aipython']
```

2. Representation of Day Times

Input and output are day time strings such as 'mon 10am' or a range of day time strings such as 'mon 10am-mon 4pm'.

The CSP will represent these as integer hour numbers in the week, ranging from 0 to 39.

The following code handles the conversion between day time strings and hour numbers.

In [202…
```
# -*- coding: utf-8 -*-
```

```
""" day_time string format is a day plus time, e.g. Mon 10am, Tue 4pm, or just T
    if only day or time, returns day number or hour number only
    day_time strings are converted to and from integer hours in the week from 0
"""
class Day_Time():
    num_hours_in_day = 8
    num_days_in_week = 5

    def __init__(self):
        self.day_names = ['mon','tue','wed','thu','fri']
        self.time_names = ['9am','10am','11am','12pm','1pm','2pm','3pm','4pm']

    def string_to_week_hour_number(self, day_time_str):
        """ convert a single day_time into an integer hour in the week """
        value = None
        value_type = None
        day_time_list = day_time_str.split()
        if len(day_time_list) == 1:
            str1 = day_time_list[0].strip()
            if str1 in self.time_names: # this is a time
                value = self.time_names.index(str1)
                value_type = 'hour_number'
            else:
                value = self.day_names.index(str1) # this is a day
                value_type = 'day_number'
            # if not day or time, throw an exception
        else:
            value = self.day_names.index(day_time_list[0].strip())*self.num_hour
                + self.time_names.index(day_time_list[1].strip())
            value_type = 'week_hour_number'
        return (value_type, value)

    def string_to_number_set(self, day_time_list_str):
        """ convert a list of day-times or ranges 'Mon 9am, Tue 9am-Tue 4pm' int
            e.g. 'mon 9am-1pm, mon 4pm' -> [0,1,2,3,4,7]
        """
        number_set = set()
        type1 = None
        for str1 in day_time_list_str.lower().split(','):
            if str1.find('-') > 0:
                # day time range
                type1, v1 = self.string_to_week_hour_number(str1.split('-')[0].s
                type2, v2 = self.string_to_week_hour_number(str1.split('-')[1].s
                if type1 != type2: return None # error, types in range spec are
                number_set.update({n for n in range(v1, v2+1)})
            else:
                # single day time
                type2, value2 = self.string_to_week_hour_number(str1)
                if type1 != None and type1 != type2: return None # error: type i
                type1 = type2
                number_set.update({value2})
        return (type1, number_set)

    # convert integer hour in week to day time string
    def week_hour_number_to_day_time(self, week_hour_number):
        hour = self.day_hour_number(week_hour_number)
        day = self.day_number(week_hour_number)
        return self.day_names[day]+' '+self.time_names[hour]

    # convert integer hour in week to integer day and integer time in day
```

```
    def hour_day_split(self, week_hour_number):
        return (self.day_hour_number(week_hour_number), self.day_number(week_hou

    # convert integer hour in week to integer day in week
    def day_number(self, week_hour_number):
        return int(week_hour_number / self.num_hours_in_day)

    # convert integer hour in week to integer time in day
    def day_hour_number(self, week_hour_number):
        return week_hour_number % self.num_hours_in_day

    def __repr__(self):
        day_hour_number = self.week_hour_number % self.num_hours_in_day
        day_number = int(self.week_hour_number / self.num_hours_in_day)
        return self.day_names[day_number]+' '+self.time_names[day_hour_number]
```

3. Constraint Satisfaction Problems with Costs over Tasks with Durations

Since AI Python does not provide the CSP class with an explicit cost, we implement our own class that extends `CSP`.

We also store the cost functions and the durations of all tasks explicitly in the CSP.

The durations of the tasks are used in the `hold` function to evaluate constraints.

In [203…

```
from cspProblem import CSP, Constraint

# We need to override Constraint, because tasks have durations
class Task_Constraint(Constraint):
    """A Task_Constraint consists of
    * scope: a tuple of variables
    * spec: text description of the constraint used in debugging
    * condition: a function that can applied to a tuple of values for the variab
    * durations: durations of all tasks
    * func_key: index to the function used to evaluate the constraint
    """
    def __init__(self, scope, spec, condition, durations, func_key):
        super().__init__(scope, condition, spec)
        self.scope = scope
        self.condition = condition
        self.durations = durations
        self.func_key = func_key

    def holds(self, assignment):
        """returns the value of Constraint con evaluated in assignment.

        precondition: all variables are assigned in assignment

        CSP has only binary constraints
        condition is in the form week_hour_number1, week_hour_number2
        add task durations as appropriate to evaluate condition
        """
        if self.func_key == 'before':
            # t1 ends before t2 starts, so we need add duration to t1 assignment
            ass0 = assignment[self.scope[0]] + self.durations[self.scope[0]]
            ass1 = assignment[self.scope[1]]
        elif self.func_key == 'after':
```

```
            # t2 ends before t1 starts so we need add duration to t2 assignment
            ass0 = assignment[self.scope[0]]
            ass1 = assignment[self.scope[1]] + self.durations[self.scope[1]]
        elif self.func_key == 'starts-at':
            # t1 starts exactly when t2 ends, so we need add duration to t2 assi
            ass0 = assignment[self.scope[0]]
            ass1 = assignment[self.scope[1]] + self.durations[self.scope[1]]
        else:
            return self.condition(*tuple(assignment[v] for v in self.scope))
        # condition here comes from get_binary_constraint
        return self.condition(*tuple([ass0, ass1]))

# implement nodes as CSP problems with cost functions
class CSP_with_Cost(CSP):
    """ cost_functions maps a CSP var, here a task name, to a list of functions
    def __init__(self, domains, durations, constraints, cost_functions, soft_day
        self.domains = domains
        self.variables = self.domains.keys()
        super().__init__("title of csp", self.variables, constraints)
        self.durations = durations
        self.cost_functions = cost_functions
        self.soft_day_time = soft_day_time
        self.soft_costs = soft_costs
        self.cost = self.calculate_cost()

    # specific to fuzzy scheduling CSP problems
    def calculate_cost(self):
        """ this is really a function f = path cost + heuristic to be used by th
        cost = 0
        # TODO: write cost function

        return cost

    def __repr__(self):
        """ string representation of an arc"""
        return "CSP_with_Cost("+str(list(self.domains.keys()))+':'+str(self.cost
```

This formulates a solver for a CSP with cost as a search problem, using domain splitting with arc consistency to define the successors of a node.

In [204…

```
from cspConsistency import Con_solver, select, partition_domain
from searchProblem import Arc, Search_problem
from operator import eq, le, ge

# rewrites rather than extends Search_with_AC_from_CSP
class Search_with_AC_from_Cost_CSP(Search_problem):
    """ A search problem with domain splitting and arc consistency """
    def __init__(self, csp):
        self.cons = Con_solver(csp) # copy of the CSP with access to arc consist
        self.domains = self.cons.make_arc_consistent(csp.domains)
        self.constraints = csp.constraints
        self.cost_functions = csp.cost_functions
        self.durations = csp.durations
        self.soft_day_time = csp.soft_day_time
        self.soft_costs = csp.soft_costs
        csp.domains = self.domains # after arc consistency
        self.csp = csp

    def is_goal(self, node):
```

```
        """ node is a goal if all domains have exactly 1 element """
        return all(len(node.domains[var]) == 1 for var in node.domains)

    def start_node(self):
        return CSP_with_Cost(self.domains, self.durations, self.constraints,
                             self.cost_functions, self.soft_day_time, self.soft_

    def neighbors(self, node):
        """returns the neighboring nodes of node.
        """
        neighs = []
        var = select(x for x in node.domains if len(node.domains[x]) > 1) # chos
        if var:
            dom1, dom2 = partition_domain(node.domains[var])
            self.display(2, "Splitting", var, "into", dom1, "and", dom2)
            to_do = self.cons.new_to_do(var, None)
            for dom in [dom1,dom2]:
                newdoms = node.domains | {var: dom} # overwrite domain of var wi
                cons_doms = self.cons.make_arc_consistent(newdoms, to_do)
                if all(len(cons_doms[v]) > 0 for v in cons_doms):
                    # all domains are non-empty
                    # make new CSP_with_Cost node to continue the search
                    csp_node = CSP_with_Cost(cons_doms, self.durations, self.con
                             self.cost_functions, self.soft_day_time, self.soft_
                    neighs.append(Arc(node, csp_node))
                else:
                    self.display(2,"...",var,"in",dom,"has no solution")
        return neighs

    def heuristic(self, n):
        return n.cost
```

4. Fuzzy Scheduling Constraint Satisfaction Problems

The following code sets up a CSP problem from a given specification.

Hard (unary) domain constraints are applied to reduce the domains of the variables before the constraint solver runs.

In [205…

```
# domain specific CSP builder for week schedule
class CSP_builder():
    # list of text lines without comments and empty lines
    _, default_domain = Day_Time().string_to_number_set('mon 9am-fri 4pm') # sho

    # hard unary constraints: domain is a list of values, params is a single val
    # starts-before, ends-before (for starts-before duration should be 0)
    # vals in domain are actual task start/end date/time, so must be val <= what
    def apply_before(self, param_type, params, duration, domain):
        domain_orig = domain.copy()
        param_val = params.pop()
        for val in domain_orig: # val is week_hour_number
            val1 = val + duration
            h, d = Day_Time().hour_day_split(val1)
            if param_type == 'hour_number' and h > param_val:
                if val in domain: domain.remove(val)
            if param_type == 'day_number' and d > param_val:
                if val in domain: domain.remove(val)
            if param_type == 'week_hour_number' and val1 > param_val:
```

```
                if val in domain: domain.remove(val)
        return domain

    def apply_after(self, param_type, params, duration, domain):
        domain_orig = domain.copy()
        param_val = params.pop()
        for val in domain_orig: # val is week_hour_number
            val1 = val + duration
            h, d = Day_Time().hour_day_split(val1)
            if param_type == 'hour_number' and h < param_val:
                if val in domain: domain.remove(val)
            if param_type == 'day_number' and d < param_val:
                if val in domain: domain.remove(val)
            if param_type == 'week_hour_number' and val1 < param_val:
                if val in domain: domain.remove(val)
        return domain

    # day time range only
    # includes starts-in, ends-in
    # duration is 0 for starts-in, task duration for ends-in
    def apply_in(self, params, duration, domain):
        domain_orig = domain.copy()
        for val in domain_orig: # val is week_hour_number
            # task must be within range
            if val in domain and val+duration not in params:
                domain.remove(val)
        return domain

    # task must start at day/time
    def apply_at(self, param_type, param,domain):
        domain_orig = domain.copy()
        for val in domain_orig:
            h, d = Day_Time().hour_day_split(val)
            if param_type == 'hour_number' and param != h:
                if val in domain: domain.remove(val)
            if param_type == 'day_number' and param != d:
                if val in domain: domain.remove(val)
            if param_type == 'week_hour_number' and param != val:
                if val in domain: domain.remove(val)
        return domain

    # soft deadline constraints: return cost to break constraint
    # ends-by implementation: domain_dt is the day, hour from the domain
    # constr_dt is the soft const spec, dur is the duration of task
    # soft_cost is the unit cost of completion delay
    # so if the tasks starts on domain_dt, it ends on domain_dt+dur
    """
    <t> ends-by <day> <time>, both must be specified
    delay = day_hour(T2) - day_hour(T1) + 24*(D2 - D1),
    where day_hour(9am) = 0, day_hour(5pm) = 7
    """
    def ends_by(self, domain_dt, constr_dt_str, dur, soft_cost):
        param_type,params = Day_Time().string_to_number_set(constr_dt_str)
        param_val = params.pop()
        dom_h, dom_d = Day_Time().hour_day_split(domain_dt+dur)
        if param_type == 'week_hour_number':
            con_h, con_d = Day_Time().hour_day_split(param_val)
            return 0 if domain_dt + dur <= param_val else soft_cost*(dom_h - con
        else:
           return None # not good, must be day and time
```

```
    def no_cost(self, day ,hour):
        return 0

    # hard binary constraint, the rest are implemented as gt, lt, eq
    def same_day(self, week_hour1, week_hour2):
        h1, d1 = Day_Time().hour_day_split(week_hour1)
        h2, d2 = Day_Time().hour_day_split(week_hour2)
        return d1 == d2

    # domain is a list of values
    def apply_hard_constraint(self, domain, duration, spec):
        tokens = func_key = spec.split(' ')
        if len(tokens) > 1:
           func_key = spec.split(' ')[0].strip()
           param_type, params = Day_Time().string_to_number_set(spec[len(func_ke
           if func_key == 'starts-before':
              # duration is 0 for starts before, since we do not modify the time
              return self.apply_before(param_type, params, 0, domain)
           if func_key == 'ends-before':
               return self.apply_before(param_type, params, duration, domain)
           if func_key == 'starts-after':
              return self.apply_after(param_type,params,0,domain)
           if func_key == 'ends-after':
              return self.apply_after(param_type, params, duration, domain)
           if func_key == 'starts-in':
               return self.apply_in(params, 0, domain)
           if func_key == 'ends-in':
               return self.apply_in(params, duration, domain)
        else:
           # here we have task day or time, it has no func key so we need to par
           param_type,params = Day_Time().string_to_week_hour_number(spec)
           return self.apply_at(param_type, params, domain)

    def get_cost_function(self, spec):
        func_dict = {'ends-by':self.ends_by, 'no-cost':self.no_cost}
        return [func_dict[spec]]

    # spec is the text of a constraint, e.g. 't1 before t2'
    # durations are durations of all tasks
    def get_binary_constraint(self, spec, durations):
        tokens = spec.strip().split(' ')
        if len(tokens) != 3: return None # error in spec
        # task1 relation task2
        fun_dict = {'before':le, 'after':ge, 'starts-at':eq, 'same-day':self.sam
        return Task_Constraint((tokens[0].strip(), tokens[2].strip()), spec, fun

    def get_CSP_with_Cost(self, input_lines):
        # Note: It would be more elegant to make task a class but AIpython is no
        # CSP_with_Cost inherits from CSP, which takes domains and constraints f
        domains = dict()
        constraints = []
        cost_functions = dict()
        durations = dict() # durations of tasks
        soft_day_time = dict() # day time specs of soft constraints
        soft_costs = dict() # costs of soft constraints

        for input_line in input_lines:
            func_spec = None
            input_line_tokens = input_line.strip().split(',')
```

```
            if len(input_line_tokens) != 2:
                return None # must have number of tokens = 2
            line_token1 = input_line_tokens[0].strip()
            line_token2 = input_line_tokens[1].strip()
            if line_token1 == 'task':
                tokens = line_token2.split(' ')
                if len(tokens) != 2:
                    return None # must have number of tokens = 3
                key = tokens[0].strip()
                # check the duration and save it
                duration = int(tokens[1].strip())
                if duration > Day_Time().num_hours_in_day:
                    return None
                durations[key] = duration
                # set zero cost function for this task as default, may add real
                cost_functions[key] = self.get_cost_function('no-cost')
                soft_costs[key] = '0'
                soft_day_time[key] = 'fri 5pm'
                # restrict domain to times that are within allowed range
                # that is start 9-5, start+duration in 9-5
                domains[key] = {x for x in self.default_domain \
                                if Day_Time().day_number(x+duration) \
                                == Day_Time().day_number(x)}
            elif line_token1 == 'domain':
                tokens = line_token2.split(' ')
                if len(tokens) < 2:
                    return None # must have number of tokens >= 2
                key = tokens[0].strip()
                # if soft constraint, it is handled differently from hard constr
                if tokens[1].strip() == 'ends-by':
                    # need to retain day time and cost from the line
                    # must have task, 'end-by', day, time, cost
                    # or task, 'end-by', day, cost
                    # or task, 'end-by', time, cost
                    if len(tokens) != 5:
                        return None
                    # get the rest of the line after 'ends-by'
                    soft_costs[key] = int(tokens[len(tokens)-1].strip()) # last
                    # pass the day time string to avoid passing param_type
                    day_time_str = tokens[2] + ' ' + tokens[3]
                    soft_day_time[key] = day_time_str
                    cost_functions[key] = self.get_cost_function(tokens[1].strip
                else:
                    # the rest of domain spec, after key, are hard unary domain
                    # func spec has day time, we also need duration
                    dur = durations[key]
                    func_spec = line_token2[len(key):].strip()
                    domains[key] = self.apply_hard_constraint(domains[key], dur,
            elif line_token1 == 'constraint': # all binary constraints
                constraints.append(self.get_binary_constraint(line_token2, durat
            else:
                return None

        return CSP_with_Cost(domains, durations, constraints, cost_functions, so

def create_CSP_from_spec(spec: str):
    input_lines = list()
    spec = spec.split('\n')
    # strip comments
    for input_line in spec:
```

```
        input_line = input_line.split('#')
        if len(input_line[0]) > 0:
            input_lines.append(input_line[0])
            print(input_line[0])
    # construct initial CSP problem
    csp = CSP_builder()
    csp_problem = csp.get_CSP_with_Cost(input_lines)
    return csp_problem
```

5. Greedy Search Constraint Solver using Domain Splitting and Arc Consistency

Create a GreedySearcher to search over the CSP.

The *cost* function for CSP nodes is used as the heuristic, but is actually a direct estimate of the total path cost function *f* used in A* Search.

In [206…

```
from searchGeneric import AStarSearcher

class GreedySearcher(AStarSearcher):
    """ returns a searcher for a problem.
    Paths can be found by repeatedly calling search().
    """
    def add_to_frontier(self, path):
        """ add path to the frontier with the appropriate cost """
        # value = path.cost + self.problem.heuristic(path.end()) -- A* definitio
        value = path.end().cost
        self.frontier.add(path, value)
```

Run the GreedySearcher on the CSP derived from the sample input.

Note: The solution cost will always be 0 (which is wrong for the sample input) until you write the cost function in the cell above.

In [207…

```
# Sample problem specification

sample_spec = """
# two tasks with two binary constraints and soft deadlines
task, t1 3
task, t2 4
# two binary constraints
constraint, t1 before t2
constraint, t1 same-day t2
# domain constraint
domain, t2 mon
# soft deadlines
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by mon 3pm 10
"""
```

In [208…

```
# display details (0 turns off)
Con_solver.max_display_level = 0
Search_with_AC_from_Cost_CSP.max_display_level = 2
GreedySearcher.max_display_level = 0

def test_csp_solver(searcher):
```

```
    final_path = searcher.search()
    if final_path == None:
        print('No solution')
    else:
        domains = final_path.end().domains
        result_str = ''
        for name, domain in domains.items():
            for n in domain:
                result_str += '\n'+str(name)+': '+Day_Time().week_hour_number_to
        print(result_str[1:]+'\ncost: '+str(final_path.end().cost))

csp_problem = create_CSP_from_spec(sample_spec)
solver = GreedySearcher(Search_with_AC_from_Cost_CSP(csp_problem))
test_csp_solver(solver)
```

```
task, t1 3
task, t2 4
constraint, t1 before t2
constraint, t1 same-day t2
domain, t2 mon
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by mon 3pm 10
t1: mon 9am
t2: mon 12pm
cost: 0
```

6. Depth-First Search Constraint Solver

The Depth-First Constraint Solver in AIPython by default uses a random ordering of the variables in the CSP.

We need to modify this code to make it compatible with the arc consistency solver.

Run the solver by calling `dfs_solve1` (first solution) or `dfs_solve_all` (all solutions).

In [209…

```
num_expanded = 0
display = False

def dfs_solver(constraints, domains, context, var_order):
    """ generator for all solutions to csp
        context is an assignment of values to some of the variables
        var_order is a list of the variables in csp that are not in context
    """
    global num_expanded, display
    to_eval = {c for c in constraints if c.can_evaluate(context)}
    if all(c.holds(context) for c in to_eval):
        if var_order == []:
            print("Nodes expanded to reach solution:", num_expanded)
            yield context
        else:
            rem_cons = [c for c in constraints if c not in to_eval]
            var = var_order[0]
            for val in domains[var]:
                if display:
                    print("Setting", var, "to", val)
                num_expanded += 1
                yield from dfs_solver(rem_cons, domains, context|{var:val}, var_

def dfs_solve_all(csp, var_order=None):
```

```
    """ depth-first CSP solver to return a list of all solutions to csp """
    global num_expanded
    num_expanded = 0
    if var_order == None:    # use an arbitrary variable order
        var_order = list(csp.domains)
    return list(dfs_solver(csp.constraints, csp.domains, {}, var_order))

def dfs_solve1(csp, var_order=None):
    """ depth-first CSP solver """
    global num_expanded
    num_expanded = 0
    if var_order == None:    # use an arbitrary variable order
        var_order = list(csp.domains)
    for sol in dfs_solver(csp.constraints, csp.domains, {}, var_order):
        return sol  # return first one
```

Run the Depth-First Solver on the sample problem.

Note: Again there are no costs calculated.

In [210…

```
def test_dfs_solver(csp_problem):
    solution = dfs_solve1(csp_problem)
    if solution == None:
        print('No solution')
    else:
        result_str = ''
        for name in solution.keys():
            result_str += '\n'+str(name)+': '+Day_Time().week_hour_number_to_day
        print(result_str[1:])

# call the Depth-First Search solver
csp_problem = create_CSP_from_spec(sample_spec)
test_dfs_solver(csp_problem) # set display to True to see nodes expanded
```

```
task, t1 3
task, t2 4
constraint, t1 before t2
constraint, t1 same-day t2
domain, t2 mon
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by mon 3pm 10
Nodes expanded to reach solution: 5
t1: mon 9am
t2: mon 12pm
```

7. Depth-First Search Constraint Solver using Forward Checking with MRV Heuristic

The Depth-First Constraint Solver in AIPython by default uses a random ordering of the variables in the CSP.

We redefine the `dfs_solver` methods to implement the MRV (Minimum Remaining Values) heuristic using forward checking.

Because the AIPython code is designed to manipulate domain sets, we also need to redefine `can_evaluate` to handle partial assignments.

In [211…

```
num_expanded = 0
display = False

def can_evaluate(c, assignment):
    """ assignment is a variable:value dictionary
        returns True if the constraint can be evaluated given assignment
    """
    return assignment != {} and all(v in assignment.keys() and type(assignment[v

def mrv_dfs_solver(constraints, domains, context, var_order):
    """ generator for all solutions to csp.
        context is an assignment of values to some of the variables.
        var_order is a list of the variables in csp that are not in context.
    """
    global num_expanded, display
    if display:
        print("Context", context)
    to_eval = {c for c in constraints if can_evaluate(c, context)}
    if all(c.holds(context) for c in to_eval):
        if var_order == []:
            print("Nodes expanded to reach solution:", num_expanded)
            yield context
        else:
            rem_cons = [c for c in constraints if c not in to_eval] # constraint
            var = var_order[0]
            rem_vars = var_order[1:]
            for val in domains[var]:
                if display:
                    print("Setting", var, "to", val)
                num_expanded += 1
                rem_context = context|{var:val}
                # apply forward checking on remaining variables
                if len(var_order) > 1:
                    rem_vars_original = list((v, list(domains[v].copy())) for v
                    if display:
                        print("Original domains:", rem_vars_original)
                    # constraints that can't already be evaluated in rem_cons
                    rem_cons_ff = [c for c in constraints if c in rem_cons and n
                    for rem_var in rem_vars:
                        # constraints that can be evaluated by adding a value of
                        any_value = list(domains[rem_var])[0]
                        rem_to_eval = {c for c in rem_cons_ff if can_evaluate(c,
                        # new domain for rem_var are the values for which all ne
                        rem_vals = domains[rem_var].copy()
                        for rem_val in domains[rem_var]:
                            # no constraint with rem_var in the existing context
                            for c in rem_to_eval:
                                if not c.holds(rem_context|{rem_var: rem_val}):
                                    if rem_val in rem_vals:
                                        rem_vals.remove(rem_val)
                        domains[rem_var] = rem_vals
                        # order remaining variables by MRV
                        rem_vars.sort(key=lambda v: len(domains[v]))
                    if display:
                        print("After forward checking:", list((v, domains[v]) fo
                if rem_vars == [] or all(len(domains[rem_var]) > 0 for rem_var i
                    yield from mrv_dfs_solver(rem_cons, domains, context|{var:va
                # restore original domains if changed through forward checking
                if len(var_order) > 1:
```

```
                    if display:
                        print("Restoring original domain", rem_vars_original)
                    for (v, domain) in rem_vars_original:
                        domains[v] = domain
            if display:
                print("Nodes expanded so far:", num_expanded)

def mrv_dfs_solve_all(csp, var_order=None):
    """ depth-first CSP solver to return a list of all solutions to csp """
    global num_expanded
    num_expanded = 0
    if var_order == None:    # order variables by MRV
        var_order = list(csp.domains)
        var_order.sort(key=lambda var: len(csp.domains[var]))
    return list(mrv_dfs_solver(csp.constraints, csp.domains, {}, var_order))

def mrv_dfs_solve1(csp, var_order=None):
    """ depth-first CSP solver """
    global num_expanded
    num_expanded = 0
    if var_order == None:    # order variables by MRV
        var_order = list(csp.domains)
        var_order.sort(key=lambda var: len(csp.domains[var]))
    for sol in mrv_dfs_solver(csp.constraints, csp.domains, {}, var_order):
        return sol  # return first one
```

Run this solver on the sample problem.

Note: Again there are no costs calculated.

In [212…

```
def test_mrv_dfs_solver(csp_problem):
    solution = mrv_dfs_solve1(csp_problem)
    if solution == None:
        print('No solution')
    else:
        result_str = ''
        for name in solution.keys():
            result_str += '\n'+str(name)+': '+Day_Time().week_hour_number_to_day
        print(result_str[1:])

# call the Depth-First MRV Search solver
csp_problem = create_CSP_from_spec(sample_spec)
test_mrv_dfs_solver(csp_problem) # set display to True to see nodes expanded
```

```
task, t1 3
task, t2 4
constraint, t1 before t2
constraint, t1 same-day t2
domain, t2 mon
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by mon 3pm 10
Nodes expanded to reach solution: 5
t2: mon 12pm
t1: mon 9am
```

Assignment

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Question 1 (4 marks)

Consider the search spaces for the fuzzy scheduling CSP solvers – domain splitting with arc consistency and the DFS solver (without forward checking).

- Describe the search spaces in terms of start state, successor functions and goal state(s) (1 mark)
- What is the branching factor and maximum depth to find any solution for the two algorithms (ignoring costs)? (1 mark)
- What is the worst case time and space complexity of the two search algorithms? (1 mark)
- Give one example of a fuzzy scheduling problem that is *easier* for the domain splitting with arc consistency solver than it is for the DFS solver, and explain why (1 mark)

For the second and third part-questions, give the answer in a general form in terms of fuzzy scheduling CSP size parameters.

Answers for Question 1

1. Domain Splitting + Arc Consistency:

   Start state: Each variable has a complete optional range.

   Successor function: Choose a task and then divide the scope of this task into two, finally eliminating the impossible scenarios

   Goal state: When each task has only one determined time point left and all constraints are met

   DFS:

   Start state: All tasks have not been scheduled.

   Successor function: Choose a task and select a specific scope for it. If conflicts arise later, revert back.

   Goal state: All tasks are specifically arranged and meet the rules.

2. Domain Splitting:

   Branching factor: each split becomes 2

   Maximum depth: $O(n \log d)$ n = tasks' number d = average domain size

   DFS:

   Branching factor: values per variable

   Maximum depth: n

3. Domain Splitting + Arc Consistency: Time complexity: $O(2^n \cdot e \cdot d^3)$ Space complexity: $O(n \cdot d)$

   DFS: Time complexity: $O(d^n)$ Space complexity: $O(n)$

4. Example: Four tasks with chain constraints demonstrating AC propagation

   task, t1 2

   task, t2 2

   task, t3 2

   task, t4 2

   Chain of before constraints

   constraint, t1 before t2

   constraint, t2 before t3

   constraint, t3 before t4

   Hard constraint fixing the first task

   domain, t1, mon 9am, hard

   Reason: DFS needs to try many combinations, while Domain Splitting converges quickly.

Question 2 (5 marks)

Define the *cost* function for a fuzzy scheduling CSP (i.e. a node in the search space for domain splitting and arc consistency) as the total cost of the soft deadline constraints violated for all of the variables, assuming that each variable is assigned one of the best possible values from its domain, where a "best" value for a variable *v* is one that has the lowest cost to violate the soft deadline constraint (if any) for that variable *v*.

- Implement the cost function in the indicated cell and place a copy of the code below (3 marks)
- What is its computational complexity (give a general form in terms of fuzzy scheduling CSP size parameters)? (1 mark)
- Show that the cost function *f* never decreases along a path, and explain why this means the search algorithm is optimal (1 mark)

In [213…

```
# Code for Question 2
# Place a copy of your code here and run it in the relevant cell

# implement nodes as CSP problems with cost functions
class CSP_with_Cost(CSP):
    """ cost_functions maps a CSP var, here a task name, to a list of functions
```

```
    def __init__(self, domains, durations, constraints, cost_functions, soft_day
        self.domains = domains
        self.variables = self.domains.keys()
        super().__init__("title of csp", self.variables, constraints)
        self.durations = durations
        self.cost_functions = cost_functions
        self.soft_day_time = soft_day_time
        self.soft_costs = soft_costs
        self.cost = self.calculate_cost()

    # specific to fuzzy scheduling CSP problems
    def calculate_cost(self):
        """ this is really a function f = path cost + heuristic to be used by th
        cost = 0
        # TODO: write cost function
        for var in self.domains:
            if not self.domains[var]:
                continue
            cost_funcs = self.cost_functions.get(var, [])
            min_cost_for_var = float('inf')
            for value in self.domains[var]:
                value_cost = 0
                for cost_func in cost_funcs:
                    func_name = cost_func.__name__
                    if func_name == 'ends_by':
                        result = cost_func(
                            value,
                            self.soft_day_time[var],
                            self.durations[var],
                            self.soft_costs[var]
                        )
                        if result is not None:
                            value_cost += result
                    elif func_name == 'no_cost':
                        value_cost += 0
                min_cost_for_var = min(min_cost_for_var, value_cost)
            if min_cost_for_var != float('inf'):
                cost += min_cost_for_var
        return cost

    def __repr__(self):
        """ string representation of an arc"""
        return "CSP_with_Cost("+str(list(self.domains.keys()))+':'+str(self.cost
```

Answers for Question 2

time complexity: $O(n \times d \times c)$ Space complexity: $O(1)$

n = number of variables (tasks)

d = average domain size per variable (number of possible start times)

c = number of cost functions per variable

Domain splitting divides the domain of the parent node into two subsets, and after applying arc consistency, the domain of the child nodes may be further reduced min{cost(d) | d ∈ Domain_child(v)} ≥ min{cost(d) | d ∈ Domain_parent(v)} cost(child) = Σ

min_cost(v, child) ≥ Σ min_cost(v, parent) = cost(parent) f(child) ≥ f(parent) So cost function f never decreases

Because it is monotonous and the greedy search leads to results similar to the optimal results of A*

Question 3 (4 marks)

Conduct an empirical evaluation of the domain splitting CSP solver using the cost function defined as above compared to using no cost function (i.e. the zero cost function, as originally defined in the above cell). Use the *average number of nodes expanded* as a metric to compare the two algorithms.

- Write a function `generate_problem(n)` that takes an integer `n` and generates a problem specification with `n` tasks and a random set of hard constraints and soft deadline constraints in the correct format for the constraint solvers (2 marks)

Run the CSP solver (with and without the cost function) over a number of problems of size `n` for a range of values of `n`.

- Plot the performance of the two constraint solving algorithms on the above metric against `n` (1 mark)
- Quantify the performance gain (if any) achieved by the use of this cost function (1 mark)

In [214…

```python
import random
import numpy as np
import matplotlib.pyplot as plt
from copy import deepcopy


def shengcheng_wenti(n: int, zhongzi: int | None = None,
                     shichang_fanwei=(1, 4), ruan_chengben_fanwei=(10, 50),
                     youxian_p: float = 0.8, tongri_p: float = 0.4) -> str:
    rng = random.Random(zhongzi)
    dt = Day_Time()
    renwu = [f"t{i}" for i in range(1, n + 1)]
    shichang = {t: rng.randint(*shichang_fanwei) for t in renwu}

    hanglie = [f"task, {t} {shichang[t]}" for t in renwu]

    shunxu = renwu[:]
    rng.shuffle(shunxu)
    for i in range(n - 1):
        if rng.random() < youxian_p:
            hanglie.append(f"constraint, {shunxu[i]} before {shunxu[i+1]}")
            if rng.random() < tongri_p:
                hanglie.append(f"constraint, {shunxu[i]} same-day {shunxu[i+1]}"

    for t in renwu:
        ri, shijian = rng.choice(dt.day_names), rng.choice(dt.time_names)
        chengben = rng.randint(*ruan_chengben_fanwei)
        hanglie.append(f"domain, {t} ends-by {ri} {shijian} {chengben}")
```

```
    return "\n".join(hanglie)


class Daijiage_CSP_AC_Sousuo_Jishu(Search_with_AC_from_Cost_CSP):
    def __init__(self, csp):
        super().__init__(csp)
        self.zhankaishu = 0

    def neighbors(self, jiedian):
        self.zhankaishu += 1
        return super().neighbors(jiedian)


def shanchu_chengben(csp: CSP_with_Cost) -> CSP_with_Cost:
    goujianqi = CSP_builder()
    wu_chengben = goujianqi.get_cost_function('no-cost')[0]
    return CSP_with_Cost(
        {v: set(vals) for v, vals in csp.domains.items()},
        durations=deepcopy(csp.durations),
        constraints=list(csp.constraints),
        cost_functions={k: [wu_chengben] for k in csp.cost_functions},
        soft_day_time=deepcopy(csp.soft_day_time),
        soft_costs={k: 0 for k in csp.soft_costs}
    )


def _yunxing_yici(n: int, zhongzi: int, shiyong_chengben: bool) -> tuple[int, bo
    csp = create_CSP_from_spec(shengcheng_wenti(n, zhongzi=zhongzi))
    if not shiyong_chengben:
        csp = shanchu_chengben(csp)
    wenti = Daijiage_CSP_AC_Sousuo_Jishu(csp)
    lujing = GreedySearcher(wenti).search()
    return wenti.zhankaishu, lujing is not None


def yunxing_shiyan(ns: list[int], shiyanci: int = 10, zhongzi: int = 2025):
    rng = random.Random(zhongzi)
    tongji = {"dai": {n: [] for n in ns}, "wu": {n: [] for n in ns}}

    for n in ns:
        for _ in range(shiyanci):
            s = rng.randrange(1, 10**9)
            tongji["dai"][n].append(_yunxing_yici(n, s, True)[0])
            tongji["wu"][n].append(_yunxing_yici(n, s, False)[0])

    pingjun_dai = [np.mean(tongji["dai"][n]) for n in ns]
    pingjun_wu = [np.mean(tongji["wu"][n]) for n in ns]
    biaozhuncha_dai = [np.std(tongji["dai"][n], ddof=1) for n in ns]
    biaozhuncha_wu = [np.std(tongji["wu"][n], ddof=1) for n in ns]

    print(f"\nNodes expanded (mean ± std, {shiyanci} trials):")
    for i, n in enumerate(ns):
        zengyi = (pingjun_wu[i] - pingjun_dai[i]) / pingjun_wu[i] * 100 if pingj
        print(f"n={n}: with cost {pingjun_dai[i]:.1f}±{biaozhuncha_dai[i]:.1f} |
              f"no cost {pingjun_wu[i]:.1f}±{biaozhuncha_wu[i]:.1f} | gain {zeng

    plt.figure(figsize=(6.4, 4.8))
    plt.errorbar(ns, pingjun_dai, yerr=biaozhuncha_dai, marker='o', label='with
    plt.errorbar(ns, pingjun_wu, yerr=biaozhuncha_wu, marker='s', linestyle='--'
    plt.xlabel('n')
```

```
    plt.ylabel('nodes expanded')
    plt.legend()
    plt.grid(alpha=0.3)
    plt.tight_layout()
    plt.show()

    return {"ns": ns, "dai_pingjun": pingjun_dai, "dai_biaozhuncha": biaozhuncha
            "wu_pingjun": pingjun_wu, "wu_biaozhuncha": biaozhuncha_wu}


Con_solver.max_display_level = 0
Search_with_AC_from_Cost_CSP.max_display_level = 0
GreedySearcher.max_display_level = 0

_ = yunxing_shiyan(ns=[4, 6, 8], shiyanci=5, zhongzi=1234)
```

```
task, t1 4
task, t2 3
task, t3 3
task, t4 2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t3 before t1
domain, t1 ends-by wed 11am 36
domain, t2 ends-by wed 10am 10
domain, t3 ends-by wed 2pm 49
domain, t4 ends-by mon 1pm 19
task, t1 4
task, t2 3
task, t3 3
task, t4 2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t3 before t1
domain, t1 ends-by wed 11am 36
domain, t2 ends-by wed 10am 10
domain, t3 ends-by wed 2pm 49
domain, t4 ends-by mon 1pm 19
task, t1 3
task, t2 2
task, t3 1
task, t4 2
constraint, t3 before t4
constraint, t4 before t2
constraint, t2 before t1
domain, t1 ends-by fri 3pm 17
domain, t2 ends-by tue 3pm 41
domain, t3 ends-by tue 9am 22
domain, t4 ends-by wed 1pm 31
task, t1 3
task, t2 2
task, t3 1
task, t4 2
constraint, t3 before t4
constraint, t4 before t2
constraint, t2 before t1
domain, t1 ends-by fri 3pm 17
domain, t2 ends-by tue 3pm 41
domain, t3 ends-by tue 9am 22
domain, t4 ends-by wed 1pm 31
task, t1 2
task, t2 4
task, t3 3
task, t4 3
constraint, t2 before t1
constraint, t2 same-day t1
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t4
domain, t1 ends-by fri 9am 30
domain, t2 ends-by thu 12pm 37
domain, t3 ends-by tue 3pm 22
domain, t4 ends-by fri 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 4
```

```
task, t3 3
task, t4 3
constraint, t2 before t1
constraint, t2 same-day t1
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t4
domain, t1 ends-by fri 9am 30
domain, t2 ends-by thu 12pm 37
domain, t3 ends-by tue 3pm 22
domain, t4 ends-by fri 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 2
task, t3 4
task, t4 2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t1
domain, t1 ends-by fri 2pm 21
domain, t2 ends-by fri 11am 44
domain, t3 ends-by tue 11am 32
domain, t4 ends-by tue 1pm 15
task, t1 4
task, t2 2
task, t3 4
task, t4 2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t1
domain, t1 ends-by fri 2pm 21
domain, t2 ends-by fri 11am 44
domain, t3 ends-by tue 11am 32
domain, t4 ends-by tue 1pm 15
task, t1 3
task, t2 1
task, t3 4
task, t4 2
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t4 before t2
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by thu 4pm 41
domain, t3 ends-by wed 4pm 15
domain, t4 ends-by fri 12pm 19
task, t1 3
task, t2 1
task, t3 4
task, t4 2
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t4 before t2
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by thu 4pm 41
domain, t3 ends-by wed 4pm 15
domain, t4 ends-by fri 12pm 19
task, t1 3
task, t2 2
task, t3 1
task, t4 1
```

```
task, t5 1
task, t6 3
constraint, t5 before t4
constraint, t5 same-day t4
constraint, t4 before t2
constraint, t2 before t3
constraint, t2 same-day t3
constraint, t3 before t6
constraint, t6 before t1
constraint, t6 same-day t1
domain, t1 ends-by fri 4pm 29
domain, t2 ends-by fri 10am 32
domain, t3 ends-by mon 1pm 26
domain, t4 ends-by mon 10am 17
domain, t5 ends-by wed 4pm 24
domain, t6 ends-by wed 9am 42
task, t1 3
task, t2 2
task, t3 1
task, t4 1
task, t5 1
task, t6 3
constraint, t5 before t4
constraint, t5 same-day t4
constraint, t4 before t2
constraint, t2 before t3
constraint, t2 same-day t3
constraint, t3 before t6
constraint, t6 before t1
constraint, t6 same-day t1
domain, t1 ends-by fri 4pm 29
domain, t2 ends-by fri 10am 32
domain, t3 ends-by mon 1pm 26
domain, t4 ends-by mon 10am 17
domain, t5 ends-by wed 4pm 24
domain, t6 ends-by wed 9am 42
task, t1 4
task, t2 1
task, t3 1
task, t4 1
task, t5 2
task, t6 1
constraint, t2 before t4
constraint, t4 before t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t3 before t5
domain, t1 ends-by thu 1pm 40
domain, t2 ends-by fri 1pm 28
domain, t3 ends-by fri 11am 42
domain, t4 ends-by fri 2pm 15
domain, t5 ends-by fri 10am 19
domain, t6 ends-by thu 4pm 50
task, t1 4
task, t2 1
task, t3 1
task, t4 1
task, t5 2
task, t6 1
constraint, t2 before t4
```

```
constraint, t4 before t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t3 before t5
domain, t1 ends-by thu 1pm 40
domain, t2 ends-by fri 1pm 28
domain, t3 ends-by fri 11am 42
domain, t4 ends-by fri 2pm 15
domain, t5 ends-by fri 10am 19
domain, t6 ends-by thu 4pm 50
task, t1 3
task, t2 4
task, t3 2
task, t4 3
task, t5 2
task, t6 1
constraint, t1 before t5
constraint, t4 before t3
constraint, t3 before t2
constraint, t2 before t6
domain, t1 ends-by tue 10am 48
domain, t2 ends-by fri 4pm 14
domain, t3 ends-by wed 9am 38
domain, t4 ends-by wed 11am 33
domain, t5 ends-by thu 2pm 33
domain, t6 ends-by fri 11am 19
task, t1 3
task, t2 4
task, t3 2
task, t4 3
task, t5 2
task, t6 1
constraint, t1 before t5
constraint, t4 before t3
constraint, t3 before t2
constraint, t2 before t6
domain, t1 ends-by tue 10am 48
domain, t2 ends-by fri 4pm 14
domain, t3 ends-by wed 9am 38
domain, t4 ends-by wed 11am 33
domain, t5 ends-by thu 2pm 33
domain, t6 ends-by fri 11am 19
task, t1 4
task, t2 4
task, t3 1
task, t4 4
task, t5 1
task, t6 3
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t3
constraint, t2 before t1
constraint, t2 same-day t1
domain, t1 ends-by mon 3pm 34
domain, t2 ends-by tue 11am 15
domain, t3 ends-by wed 2pm 22
domain, t4 ends-by thu 1pm 36
domain, t5 ends-by fri 4pm 26
domain, t6 ends-by mon 12pm 29
No (more) solutions. Total of 1 paths expanded.
```

```
task, t1 4
task, t2 4
task, t3 1
task, t4 4
task, t5 1
task, t6 3
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t3
constraint, t2 before t1
constraint, t2 same-day t1
domain, t1 ends-by mon 3pm 34
domain, t2 ends-by tue 11am 15
domain, t3 ends-by wed 2pm 22
domain, t4 ends-by thu 1pm 36
domain, t5 ends-by fri 4pm 26
domain, t6 ends-by mon 12pm 29
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 3
task, t3 1
task, t4 4
task, t5 1
task, t6 2
constraint, t4 before t6
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 4pm 29
domain, t3 ends-by fri 1pm 48
domain, t4 ends-by thu 4pm 31
domain, t5 ends-by fri 11am 13
domain, t6 ends-by mon 10am 24
task, t1 3
task, t2 3
task, t3 1
task, t4 4
task, t5 1
task, t6 2
constraint, t4 before t6
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 4pm 29
domain, t3 ends-by fri 1pm 48
domain, t4 ends-by thu 4pm 31
domain, t5 ends-by fri 11am 13
domain, t6 ends-by mon 10am 24
task, t1 1
task, t2 4
task, t3 3
task, t4 2
task, t5 4
task, t6 4
task, t7 2
task, t8 1
constraint, t1 before t4
constraint, t7 before t3
constraint, t3 before t2
constraint, t2 before t5
constraint, t5 before t8
domain, t1 ends-by mon 9am 30
domain, t2 ends-by mon 11am 12
domain, t3 ends-by fri 10am 29
```

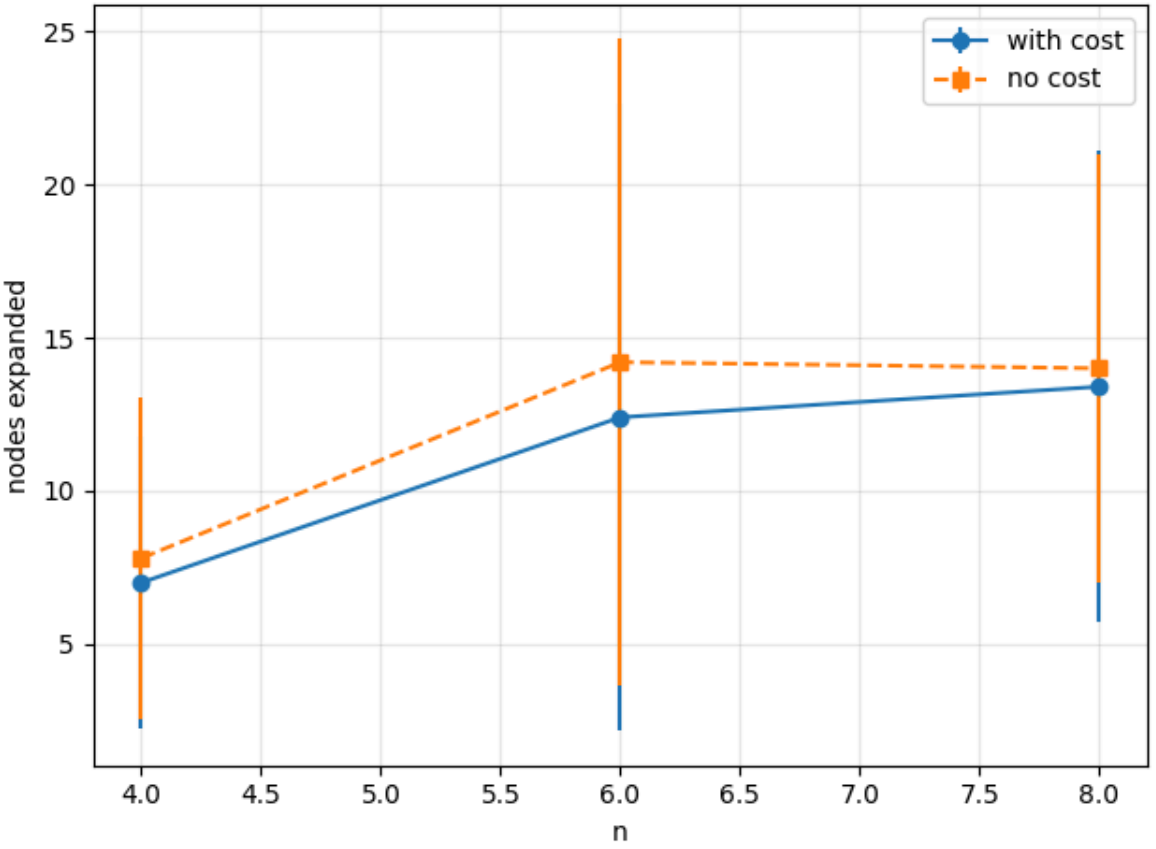
```
domain, t4 ends-by mon 10am 35
domain, t5 ends-by wed 2pm 30
domain, t6 ends-by wed 2pm 50
domain, t7 ends-by fri 1pm 47
domain, t8 ends-by fri 1pm 10
task, t1 1
task, t2 4
task, t3 3
task, t4 2
task, t5 4
task, t6 4
task, t7 2
task, t8 1
constraint, t1 before t4
constraint, t7 before t3
constraint, t3 before t2
constraint, t2 before t5
constraint, t5 before t8
domain, t1 ends-by mon 9am 30
domain, t2 ends-by mon 11am 12
domain, t3 ends-by fri 10am 29
domain, t4 ends-by mon 10am 35
domain, t5 ends-by wed 2pm 30
domain, t6 ends-by wed 2pm 50
domain, t7 ends-by fri 1pm 47
domain, t8 ends-by fri 1pm 10
task, t1 4
task, t2 4
task, t3 4
task, t4 3
task, t5 1
task, t6 2
task, t7 4
task, t8 3
constraint, t3 before t5
constraint, t7 before t1
constraint, t1 before t6
constraint, t6 before t2
constraint, t2 before t8
constraint, t2 same-day t8
constraint, t8 before t4
domain, t1 ends-by mon 1pm 35
domain, t2 ends-by wed 3pm 50
domain, t3 ends-by wed 9am 10
domain, t4 ends-by thu 11am 43
domain, t5 ends-by thu 12pm 27
domain, t6 ends-by mon 11am 38
domain, t7 ends-by fri 10am 50
domain, t8 ends-by thu 11am 38
task, t1 4
task, t2 4
task, t3 4
task, t4 3
task, t5 1
task, t6 2
task, t7 4
task, t8 3
constraint, t3 before t5
constraint, t7 before t1
constraint, t1 before t6
```

```
constraint, t6 before t2
constraint, t2 before t8
constraint, t2 same-day t8
constraint, t8 before t4
domain, t1 ends-by mon 1pm 35
domain, t2 ends-by wed 3pm 50
domain, t3 ends-by wed 9am 10
domain, t4 ends-by thu 11am 43
domain, t5 ends-by thu 12pm 27
domain, t6 ends-by mon 11am 38
domain, t7 ends-by fri 10am 50
domain, t8 ends-by thu 11am 38
task, t1 4
task, t2 3
task, t3 2
task, t4 1
task, t5 1
task, t6 3
task, t7 3
task, t8 1
constraint, t6 before t8
constraint, t8 before t7
constraint, t8 same-day t7
constraint, t7 before t2
constraint, t7 same-day t2
constraint, t2 before t3
constraint, t3 before t4
constraint, t4 before t5
constraint, t4 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
domain, t1 ends-by thu 1pm 40
domain, t2 ends-by wed 10am 42
domain, t3 ends-by thu 10am 28
domain, t4 ends-by fri 10am 34
domain, t5 ends-by wed 12pm 23
domain, t6 ends-by fri 2pm 24
domain, t7 ends-by thu 1pm 47
domain, t8 ends-by fri 9am 34
task, t1 4
task, t2 3
task, t3 2
task, t4 1
task, t5 1
task, t6 3
task, t7 3
task, t8 1
constraint, t6 before t8
constraint, t8 before t7
constraint, t8 same-day t7
constraint, t7 before t2
constraint, t7 same-day t2
constraint, t2 before t3
constraint, t3 before t4
constraint, t4 before t5
constraint, t4 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
domain, t1 ends-by thu 1pm 40
domain, t2 ends-by wed 10am 42
```

```
domain, t3 ends-by thu 10am 28
domain, t4 ends-by fri 10am 34
domain, t5 ends-by wed 12pm 23
domain, t6 ends-by fri 2pm 24
domain, t7 ends-by thu 1pm 47
domain, t8 ends-by fri 9am 34
task, t1 3
task, t2 2
task, t3 1
task, t4 1
task, t5 3
task, t6 1
task, t7 3
task, t8 2
constraint, t7 before t2
constraint, t7 same-day t2
constraint, t2 before t6
constraint, t6 before t3
constraint, t3 before t5
constraint, t3 same-day t5
constraint, t5 before t1
constraint, t1 before t4
domain, t1 ends-by wed 10am 39
domain, t2 ends-by wed 12pm 25
domain, t3 ends-by fri 2pm 29
domain, t4 ends-by thu 9am 18
domain, t5 ends-by thu 12pm 47
domain, t6 ends-by mon 12pm 32
domain, t7 ends-by wed 10am 42
domain, t8 ends-by thu 2pm 40
task, t1 3
task, t2 2
task, t3 1
task, t4 1
task, t5 3
task, t6 1
task, t7 3
task, t8 2
constraint, t7 before t2
constraint, t7 same-day t2
constraint, t2 before t6
constraint, t6 before t3
constraint, t3 before t5
constraint, t3 same-day t5
constraint, t5 before t1
constraint, t1 before t4
domain, t1 ends-by wed 10am 39
domain, t2 ends-by wed 12pm 25
domain, t3 ends-by fri 2pm 29
domain, t4 ends-by thu 9am 18
domain, t5 ends-by thu 12pm 47
domain, t6 ends-by mon 12pm 32
domain, t7 ends-by wed 10am 42
domain, t8 ends-by thu 2pm 40
task, t1 1
task, t2 1
task, t3 2
task, t4 4
task, t5 4
task, t6 2
```

```
task, t7 1
task, t8 3
constraint, t8 before t4
constraint, t4 before t6
constraint, t4 same-day t6
constraint, t6 before t7
constraint, t7 before t3
constraint, t3 before t5
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t2 before t1
domain, t1 ends-by mon 9am 44
domain, t2 ends-by fri 12pm 32
domain, t3 ends-by thu 4pm 19
domain, t4 ends-by tue 11am 24
domain, t5 ends-by fri 1pm 38
domain, t6 ends-by thu 11am 45
domain, t7 ends-by fri 1pm 23
domain, t8 ends-by thu 10am 46
task, t1 1
task, t2 1
task, t3 2
task, t4 4
task, t5 4
task, t6 2
task, t7 1
task, t8 3
constraint, t8 before t4
constraint, t4 before t6
constraint, t4 same-day t6
constraint, t6 before t7
constraint, t7 before t3
constraint, t3 before t5
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t2 before t1
domain, t1 ends-by mon 9am 44
domain, t2 ends-by fri 12pm 32
domain, t3 ends-by thu 4pm 19
domain, t4 ends-by tue 11am 24
domain, t5 ends-by fri 1pm 38
domain, t6 ends-by thu 11am 45
domain, t7 ends-by fri 1pm 23
domain, t8 ends-by thu 10am 46

Nodes expanded (mean ± std, 5 trials):
n=4: with cost 7.0±4.7 | no cost 7.8±5.3 | gain 10.3%
n=6: with cost 12.4±10.2 | no cost 14.2±10.5 | gain 12.7%
n=8: with cost 13.4±7.7 | no cost 14.0±7.0 | gain 4.3%
```



Question 4 (5 marks)

Compare the Depth-First Search (DFS) solver to the Depth-First Search solver using forward checking with Minimum Remaining Values heuristic (DFS-MRV). For this question, ignore the costs associated with the CSP problems.

- What is the worst case time and space complexity of each algorithm (give a general form in terms of fuzzy scheduling problem sizes)? (1 mark)
- What are the properties of the search algorithms (completeness, optimality)? (1 mark)
- Give an example of a problem that is *easier* for the DFS-MRV solver than it is for the DFS solver, and explain why (1 mark)
- Empirically compare the quality of the first solution found by DFS and DFS-MRV compared to the optimal solution (1 mark)
- Empirically compare DFS-MRV with DFS in terms of the number of nodes expanded (1 mark)

For the empirical evaluations, run the two algorithms on a variety of problems of size `n` for varying `n`. Note that the domain splitting CSP solver with costs should always find an optimal solution.

In [215…

```
def jisuan_jiejue_chengben(jiejue, csp):
    if jiejue is None: return float('inf')
    zongshu = 0
    for var, val in jiejue.items():
        for f in csp.cost_functions.get(var, []):
            if f.__name__ == 'ends_by':
```

```
                r = f(val, csp.soft_day_time[var], csp.durations[var], csp.soft_
                if r is not None: zongshu += r
    return zongshu


def dfs_qiujieqi_daitongji(yueshu, yuyu, shangxiawen, bianliang_shunxu, tongji):
    daipinggu = {c for c in yueshu if c.can_evaluate(shangxiawen)}
    if not all(c.holds(shangxiawen) for c in daipinggu): return
    if not bianliang_shunxu:
        yield shangxiawen; return
    var, shengyu = bianliang_shunxu[0], bianliang_shunxu[1:]
    for val in yuyu[var]:
        tongji['nodes_expanded'] += 1
        yield from dfs_qiujieqi_daitongji(yueshu, yuyu, shangxiawen | {var: val}


def dfs_qiujie1_daitongji(csp, bianliang_shunxu=None):
    tongji = {'nodes_expanded': 0}
    bs = list(csp.domains) if bianliang_shunxu is None else bianliang_shunxu
    for jie in dfs_qiujieqi_daitongji(csp.constraints, csp.domains, {}, bs, tong
        return jie, tongji['nodes_expanded']
    return None, tongji['nodes_expanded']


def mrv_dfs_qiujieqi_daitongji(yueshu, yuyu, shangxiawen, bianliang_shunxu, tong
    daipinggu = {c for c in yueshu if can_evaluate(c, shangxiawen)}
    if not all(c.holds(shangxiawen) for c in daipinggu): return
    if not bianliang_shunxu:
        yield shangxiawen; return

    var, shengyu = bianliang_shunxu[0], bianliang_shunxu[1:]
    for val in list(yuyu[var]):
        tongji['nodes_expanded'] += 1
        xin_shangxiawen = shangxiawen | {var: val}
        if shengyu:
            kuaizhao = [(v, set(yuyu[v])) for v in shengyu]
            daichuli = [c for c in yueshu if c not in daipinggu]
            for sybl in shengyu:
                yuyu[sybl] = {
                    sybl_zhi for sybl_zhi in yuyu[sybl]
                    if all(c.holds(xin_shangxiawen | {sybl: sybl_zhi})
                           for c in daichuli if can_evaluate(c, xin_shangxiawen
                }
            shengyu.sort(key=lambda v: len(yuyu[v]))
        if not shengyu or all(yuyu[sybl] for sybl in shengyu):
            yield from mrv_dfs_qiujieqi_daitongji(yueshu, yuyu, xin_shangxiawen,
        if shengyu:
            for v, dom in kuaizhao: yuyu[v] = dom


def mrv_dfs_qiujie1_daitongji(csp, bianliang_shunxu=None):
    tongji = {'nodes_expanded': 0}
    bs = sorted(list(csp.domains), key=lambda v: len(csp.domains[v])) if bianlia
    for jie in mrv_dfs_qiujieqi_daitongji(csp.constraints, csp.domains, {}, bs,
        return jie, tongji['nodes_expanded']
    return None, tongji['nodes_expanded']


def shengcheng_jiandan_wenti(n, zhongzi=None):
    rng = random.Random(zhongzi)
```

```
    rizi = ['mon','tue','wed']
    shijian = ['9am','10am','11am','12pm','1pm','2pm','3pm','4pm']
    renwu = [f"t{i+1}" for i in range(n)]
    shichang  = {t: rng.randint(1, 2) for t in renwu}
    hanglie = [f"task, {t} {shichang[t]}" for t in renwu]
    for _ in range(min(2, n-1)):
        a, b = rng.sample(renwu, 2); hanglie.append(f"constraint, {a} before {b}
    for t in renwu:
        hanglie.append(f"domain, {t} ends-by {rng.choice(rizi)} {rng.choice(shij
    return "\n".join(hanglie)


def yunxing_bijiao(n, shiyanci=5, zhongzi=2025):
    rng = random.Random(zhongzi)
    dfs_chaju, mrv_chaju, dfs_jiedian, mrv_jiedian = [], [], [], []
    chenggong = 0
    while chenggong < shiyanci:
        s = rng.randrange(1, 10**9)
        guige = shengcheng_jiandan_wenti(n, zhongzi=s)

        csp_zuiyou = create_CSP_from_spec(guige)
        zuiyou_lujing = GreedySearcher(Search_with_AC_from_Cost_CSP(csp_zuiyou))
        if zuiyou_lujing is None: continue
        zuiyou_chengben = zuiyou_lujing.end().cost

        csp_dfs = create_CSP_from_spec(guige)
        dfs_jie, dfs_n = dfs_qiujie1_daitongji(csp_dfs)
        if dfs_jie is None: continue
        dfs_chengben = jisuan_jiejue_chengben(dfs_jie, csp_dfs)

        csp_mrv = create_CSP_from_spec(guige)
        mrv_jie, mrv_n = mrv_dfs_qiujie1_daitongji(csp_mrv)
        if mrv_jie is None: continue
        mrv_chengben = jisuan_jiejue_chengben(mrv_jie, csp_mrv)

        dfs_chaju.append((dfs_chengben - zuiyou_chengben) / max(1, zuiyou_chengb
        mrv_chaju.append((mrv_chengben - zuiyou_chengben) / max(1, zuiyou_chengb
        dfs_jiedian.append(dfs_n); mrv_jiedian.append(mrv_n)
        chenggong += 1

    return {
        'dfs_gap': float(np.mean(dfs_chaju)),
        'mrv_gap': float(np.mean(mrv_chaju)),
        'dfs_nodes': float(np.mean(dfs_jiedian)),
        'mrv_nodes': float(np.mean(mrv_jiedian)),
        'success': chenggong
    }

Con_solver.max_display_level = 0
Search_with_AC_from_Cost_CSP.max_display_level = 0
GreedySearcher.max_display_level = 0

chicun = [3, 4, 5, 6]
jieguo = {n: yunxing_bijiao(n, shiyanci=5, zhongzi=2025+n) for n in chicun}

for n in chicun:
    r = jieguo[n]
    print(f"n={n} succ={r['success']} | DFS gap={r['dfs_gap']:.3f} nodes={r['dfs

ns = chicun
```

```
dg = [jieguo[n]['dfs_gap']  for n in ns]
mg = [jieguo[n]['mrv_gap']  for n in ns]
dn = [jieguo[n]['dfs_nodes'] for n in ns]
mn = [jieguo[n]['mrv_nodes'] for n in ns]

tu, (ax1, ax2) = plt.subplots(1, 2, figsize=(10, 4))
ax1.plot(ns, dg, 'o-', label='DFS'); ax1.plot(ns, mg, 's--', label='MRV')
ax1.set_xlabel('n'); ax1.set_ylabel('gap'); ax1.legend(); ax1.grid(alpha=0.3)
ax2.plot(ns, dn, 'o-', label='DFS'); ax2.plot(ns, mn, 's--', label='MRV')
ax2.set_xlabel('n'); ax2.set_ylabel('nodes'); ax2.legend(); ax2.grid(alpha=0.3)
plt.tight_layout(); plt.show()
```

```
task, t1 2
task, t2 2
task, t3 1
constraint, t3 before t1
constraint, t1 before t3
domain, t1 ends-by wed 11am 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by wed 2pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 2
task, t3 2
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by wed 4pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 4pm 10
task, t1 2
task, t2 2
task, t3 2
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by wed 4pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 4pm 10
task, t1 2
task, t2 2
task, t3 2
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by wed 4pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 4pm 10
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t3 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t3 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t3 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
task, t1 1
task, t2 2
task, t3 2
```

```
constraint, t3 before t1
constraint, t3 before t2
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
task, t1 1
task, t2 2
task, t3 2
constraint, t3 before t1
constraint, t3 before t2
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
task, t1 1
task, t2 2
task, t3 2
constraint, t3 before t1
constraint, t3 before t2
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 2
constraint, t2 before t3
constraint, t3 before t2
domain, t1 ends-by wed 3pm 10
domain, t2 ends-by wed 11am 10
domain, t3 ends-by wed 3pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 1
task, t3 2
constraint, t2 before t1
constraint, t1 before t2
domain, t1 ends-by wed 4pm 10
domain, t2 ends-by wed 4pm 10
domain, t3 ends-by tue 12pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t2 before t3
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by tue 1pm 10
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t2 before t3
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by tue 1pm 10
task, t1 1
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t2 before t3
```

```
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by tue 1pm 10
task, t1 2
task, t2 1
task, t3 1
constraint, t3 before t1
constraint, t1 before t2
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 1pm 10
task, t1 2
task, t2 1
task, t3 1
constraint, t3 before t1
constraint, t1 before t2
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 1pm 10
task, t1 2
task, t2 1
task, t3 1
constraint, t3 before t1
constraint, t1 before t2
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 1pm 10
task, t1 2
task, t2 2
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t2 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by mon 12pm 10
task, t1 2
task, t2 2
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t2 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by mon 12pm 10
task, t1 2
task, t2 2
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t2 before t1
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by mon 12pm 10
task, t1 1
task, t2 1
task, t3 1
```

```
task, t4 2
constraint, t2 before t3
constraint, t3 before t4
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by wed 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
constraint, t2 before t3
constraint, t3 before t4
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by wed 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
constraint, t2 before t3
constraint, t3 before t4
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by wed 4pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 1
constraint, t2 before t3
constraint, t2 before t4
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by wed 3pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by wed 12pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 1
constraint, t2 before t3
constraint, t2 before t4
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by wed 3pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by wed 12pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 1
constraint, t2 before t3
constraint, t2 before t4
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by wed 3pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by wed 12pm 10
task, t1 2
task, t2 1
task, t3 1
```

```
task, t4 1
constraint, t2 before t4
constraint, t2 before t3
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 4pm 10
domain, t4 ends-by tue 12pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
constraint, t2 before t4
constraint, t2 before t3
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 4pm 10
domain, t4 ends-by tue 12pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
constraint, t2 before t4
constraint, t2 before t3
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by wed 4pm 10
domain, t4 ends-by tue 12pm 10
task, t1 1
task, t2 2
task, t3 2
task, t4 1
constraint, t4 before t2
constraint, t2 before t4
domain, t1 ends-by tue 4pm 10
domain, t2 ends-by wed 2pm 10
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by mon 4pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 2
task, t3 1
task, t4 1
constraint, t3 before t4
constraint, t3 before t2
domain, t1 ends-by tue 3pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 1pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 1
constraint, t3 before t4
constraint, t3 before t2
domain, t1 ends-by tue 3pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 1pm 10
task, t1 2
task, t2 2
```

```
task, t3 1
task, t4 1
constraint, t3 before t4
constraint, t3 before t2
domain, t1 ends-by tue 3pm 10
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 1pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 2
task, t5 1
constraint, t2 before t5
constraint, t1 before t4
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by mon 3pm 10
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by wed 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 2
task, t5 1
constraint, t2 before t5
constraint, t1 before t4
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by mon 3pm 10
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by wed 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 2
task, t5 1
constraint, t2 before t5
constraint, t1 before t4
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by mon 3pm 10
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by wed 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
task, t5 2
constraint, t1 before t4
constraint, t3 before t2
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 4pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
```

```
task, t5 2
constraint, t1 before t4
constraint, t3 before t2
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 4pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
task, t5 2
constraint, t1 before t4
constraint, t3 before t2
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 4pm 10
task, t1 1
task, t2 2
task, t3 1
task, t4 1
task, t5 2
constraint, t3 before t4
constraint, t2 before t3
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by mon 12pm 10
task, t1 1
task, t2 2
task, t3 1
task, t4 1
task, t5 2
constraint, t3 before t4
constraint, t2 before t3
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by mon 12pm 10
task, t1 1
task, t2 2
task, t3 1
task, t4 1
task, t5 2
constraint, t3 before t4
constraint, t2 before t3
domain, t1 ends-by mon 4pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by mon 12pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 1
```

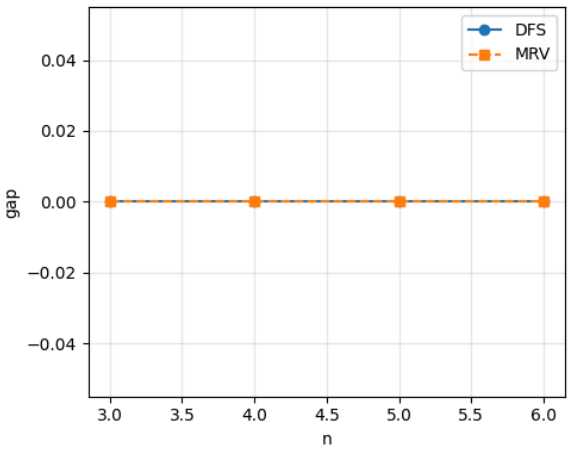
```
task, t5 2
constraint, t2 before t4
constraint, t1 before t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by wed 4pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 1
task, t5 2
constraint, t2 before t4
constraint, t1 before t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by wed 4pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 1
task, t5 2
constraint, t2 before t4
constraint, t1 before t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by wed 4pm 10
domain, t3 ends-by tue 4pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
task, t5 1
constraint, t1 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 4pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
task, t5 1
constraint, t1 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 4pm 10
task, t1 2
task, t2 1
task, t3 1
task, t4 1
```

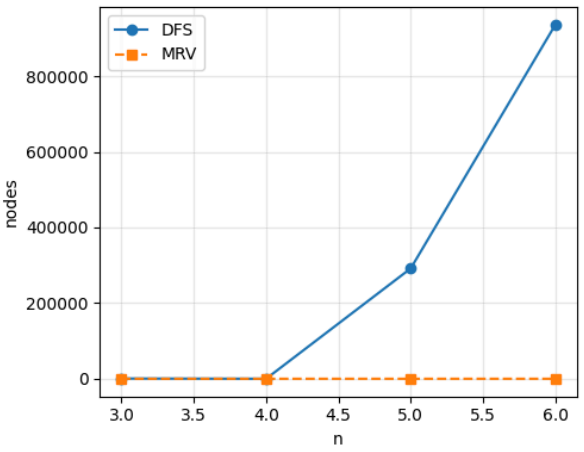
```
task, t5 1
constraint, t1 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 2
task, t6 1
constraint, t1 before t3
constraint, t5 before t2
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by wed 11am 10
domain, t6 ends-by tue 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 2
task, t6 1
constraint, t1 before t3
constraint, t5 before t2
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by wed 11am 10
domain, t6 ends-by tue 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 2
task, t6 1
constraint, t1 before t3
constraint, t5 before t2
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by tue 11am 10
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by wed 11am 10
domain, t6 ends-by tue 4pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 2
task, t6 2
constraint, t3 before t4
constraint, t2 before t4
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by mon 4pm 10
```

```
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by wed 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 2
task, t6 2
constraint, t3 before t4
constraint, t2 before t4
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by wed 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 2
task, t6 2
constraint, t3 before t4
constraint, t2 before t4
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by mon 4pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 11am 10
domain, t5 ends-by wed 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t5
constraint, t3 before t1
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by wed 1pm 10
domain, t5 ends-by wed 12pm 10
domain, t6 ends-by wed 4pm 10
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t5
constraint, t3 before t1
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by wed 1pm 10
domain, t5 ends-by wed 12pm 10
domain, t6 ends-by wed 4pm 10
```

```
task, t1 2
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t5
constraint, t3 before t1
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by wed 1pm 10
domain, t5 ends-by wed 12pm 10
domain, t6 ends-by wed 4pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t2 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by wed 2pm 10
domain, t5 ends-by tue 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t2 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by wed 2pm 10
domain, t5 ends-by tue 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 1
task, t2 1
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t2 before t4
constraint, t5 before t1
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by wed 2pm 10
domain, t5 ends-by tue 3pm 10
domain, t6 ends-by wed 12pm 10
task, t1 2
task, t2 1
task, t3 2
task, t4 1
```

```
task, t5 1
task, t6 2
constraint, t3 before t5
constraint, t5 before t1
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 4pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by wed 4pm 10
domain, t6 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 2
task, t4 1
task, t5 1
task, t6 2
constraint, t3 before t5
constraint, t5 before t1
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 4pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by wed 4pm 10
domain, t6 ends-by mon 2pm 10
task, t1 2
task, t2 1
task, t3 2
task, t4 1
task, t5 1
task, t6 2
constraint, t3 before t5
constraint, t5 before t1
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 4pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by wed 4pm 10
domain, t6 ends-by mon 2pm 10
n=3 succ=5 | DFS gap=0.000 nodes=666.4 | MRV gap=0.000 nodes=4.0
n=4 succ=5 | DFS gap=0.000 nodes=26.0 | MRV gap=0.000 nodes=5.4
n=5 succ=5 | DFS gap=0.000 nodes=291817.4 | MRV gap=0.000 nodes=5.4
n=6 succ=5 | DFS gap=0.000 nodes=936214.8 | MRV gap=0.000 nodes=8.2
```





Answers for Question 4

DFS:

time complexity: $O(d^n)$ Space complexity: $O(n)$

DFS-MRV:

time complexity: $O(d^n)$ Space complexity: $O(n \cdot d)$

completeness: If a solution exists, it can ultimately be found. optimality: Both of these just need to have a solution; an optimal solution is not required

task, t1 2 task, t2 2 task, t3 2 task, t4 2

domain, t1 starts-in mon 9am-mon 9am

constraint, t1 before t2 constraint, t2 before t3 constraint, t3 before t4

MRV first selects the domain with the smallest t1, immediately triggering forward deletion of t2, t3, and t4, greatly reducing subsequent branches, while DFS would generate a large number of invalid attempts

Question 5 (4 marks)

The DFS solver chooses variables in random order, and systematically explores all values for those variables in no particular order.

Incorporate costs into the DFS constraint solver as heuristics to guide the search. Similar to the cost function for the domain splitting solver, for a given variable *v*, the cost of assigning the value *val* to *v* is the cost of violating the soft deadline constraint (if any) associated with *v* for the value *val*. The *minimum cost* for *v* is the lowest cost from amongst the values in the domain of *v*. The DFS solver should choose a variable *v* with lowest minimum cost, and explore its values in order of cost from lowest to highest.

- Implement this behaviour by modifying the code in `dfs_solver` and place a copy of the code below (2 marks)
- Empirically compare the performance of DFS with and without these heuristics (2 marks)

For the empirical evaluations, again run the two algorithms on a variety of problems of size `n` for varying `n`.

In [216…

```
def jisuan_zhi_chengben(var, val, csp):
    if var not in csp.cost_functions: return 0
    zongshu = 0
    for f in csp.cost_functions[var]:
        if f.__name__ == 'ends_by':
            r = f(val, csp.soft_day_time[var], csp.durations[var], csp.soft_cost
            if r is not None: zongshu += r
    return zongshu

def huoqu_zuixiao_chengben(var, yuyu, csp):
    return float('inf') if not yuyu else min(jisuan_zhi_chengben(var, v, csp) fo

def chengben_yindao_dfs_qiujieqi(yueshu, yuyu, shangxiawen, bianliang_shunxu, cs
```

```
    daipinggu = {c for c in yueshu if c.can_evaluate(shangxiawen)}
    if not all(c.holds(shangxiawen) for c in daipinggu): return
    if not bianliang_shunxu:
        yield shangxiawen; return
    shengyu_yueshu = [c for c in yueshu if c not in daipinggu]
    var = min(bianliang_shunxu, key=lambda v: huoqu_zuixiao_chengben(v, yuyu[v],
    shengyu = [v for v in bianliang_shunxu if v != var]
    for val in sorted(yuyu[var], key=lambda v: jisuan_zhi_chengben(var, v, csp))
        tongji['nodes_expanded'] += 1
        yield from chengben_yindao_dfs_qiujieqi(shengyu_yueshu, yuyu, shangxiawe

def chengben_yindao_dfs_qiujie1(csp):
    tongji = {'nodes_expanded': 0}
    bs = list(csp.domains)
    for jie in chengben_yindao_dfs_qiujieqi(csp.constraints, csp.domains, {}, bs
        return jie, tongji['nodes_expanded']
    return None, tongji['nodes_expanded']

def yunxing_q5_bijiao(n, shiyanci=10, zhongzi=2025):
    rng = random.Random(zhongzi)
    chaju_yuanshi, jiedian_yuanshi, chaju_yindao, jiedian_yindao = [], [], [], [
    chenggong = 0
    while chenggong < shiyanci:
        guige = shengcheng_wenti(n, zhongzi=rng.randrange(1, 10**9))  # 修正: see
        csp_zuiyou = create_CSP_from_spec(guige)
        zuiyou_lujing = GreedySearcher(Search_with_AC_from_Cost_CSP(csp_zuiyou))
        if zuiyou_lujing is None: continue
        zuiyou_chengben = zuiyou_lujing.end().cost

        csp_y = create_CSP_from_spec(guige)
        jie_y, n_y = dfs_qiujie1_daitongji(csp_y)
        if jie_y is None: continue
        chengben_y = jisuan_jiejue_chengben(jie_y, csp_y)

        csp_d = create_CSP_from_spec(guige)
        jie_d, n_d = chengben_yindao_dfs_qiujie1(csp_d)
        if jie_d is None: continue
        chengben_d = jisuan_jiejue_chengben(jie_d, csp_d)

        chaju_yuanshi.append((chengben_y - zuiyou_chengben) / max(1, zuiyou_chen
        chaju_yindao.append((chengben_d - zuiyou_chengben) / max(1, zuiyou_cheng
        jiedian_yuanshi.append(n_y); jiedian_yindao.append(n_d)
        chenggong += 1

    return {
        'original_gap': float(np.mean(chaju_yuanshi)),
        'guided_gap'  : float(np.mean(chaju_yindao)),
        'original_nodes': float(np.mean(jiedian_yuanshi)),
        'guided_nodes'  : float(np.mean(jiedian_yindao)),
        'success': chenggong
    }

def yunxing_q5_shiyan(ceshi_chicun=[4, 6, 8], shiyanci=10, zhongzi=2025):
    Con_solver.max_display_level = 0
    Search_with_AC_from_Cost_CSP.max_display_level = 0
    GreedySearcher.max_display_level = 0

    jieguo = {n: yunxing_q5_bijiao(n, shiyanci=shiyanci, zhongzi=zhongzi+n) for
    for n in ceshi_chicun:
        r = jieguo[n]
```

```
        print(f"n={n} succ={r['success']} | orig gap={r['original_gap']:.3f} nod

    ns = ceshi_chicun
    og = [jieguo[n]['original_gap']   for n in ns]
    gg = [jieguo[n]['guided_gap']     for n in ns]
    on = [jieguo[n]['original_nodes'] for n in ns]
    gn = [jieguo[n]['guided_nodes']   for n in ns]

    tu, (ax1, ax2) = plt.subplots(1, 2, figsize=(10, 4))
    ax1.plot(ns, og, 'o-', label='orig');   ax1.plot(ns, gg, 's--', label='guide
    ax1.set_xlabel('n'); ax1.set_ylabel('gap'); ax1.legend(); ax1.grid(alpha=0.3
    ax2.plot(ns, on, 'o-', label='orig');   ax2.plot(ns, gn, 's--', label='guide
    ax2.set_xlabel('n'); ax2.set_ylabel('nodes'); ax2.legend(); ax2.grid(alpha=0
    plt.tight_layout(); plt.show()
    return jieguo

q5_jieguo = yunxing_q5_shiyan(ceshi_chicun=[3, 4, 5, 6], shiyanci=10, zhongzi=12
```

```
task, t1 4
task, t2 3
task, t3 2
constraint, t3 before t2
domain, t1 ends-by thu 1pm 21
domain, t2 ends-by wed 12pm 32
domain, t3 ends-by fri 12pm 14
task, t1 4
task, t2 3
task, t3 2
constraint, t3 before t2
domain, t1 ends-by thu 1pm 21
domain, t2 ends-by wed 12pm 32
domain, t3 ends-by fri 12pm 14
task, t1 4
task, t2 3
task, t3 2
constraint, t3 before t2
domain, t1 ends-by thu 1pm 21
domain, t2 ends-by wed 12pm 32
domain, t3 ends-by fri 12pm 14
task, t1 3
task, t2 2
task, t3 4
constraint, t2 before t3
constraint, t3 before t1
domain, t1 ends-by tue 11am 37
domain, t2 ends-by tue 12pm 31
domain, t3 ends-by tue 9am 39
task, t1 3
task, t2 2
task, t3 4
constraint, t2 before t3
constraint, t3 before t1
domain, t1 ends-by tue 11am 37
domain, t2 ends-by tue 12pm 31
domain, t3 ends-by tue 9am 39
task, t1 3
task, t2 2
task, t3 4
constraint, t2 before t3
constraint, t3 before t1
domain, t1 ends-by tue 11am 37
domain, t2 ends-by tue 12pm 31
domain, t3 ends-by tue 9am 39
task, t1 2
task, t2 1
task, t3 4
domain, t1 ends-by thu 4pm 35
domain, t2 ends-by wed 9am 46
domain, t3 ends-by wed 12pm 25
task, t1 2
task, t2 1
task, t3 4
domain, t1 ends-by thu 4pm 35
domain, t2 ends-by wed 9am 46
domain, t3 ends-by wed 12pm 25
task, t1 2
task, t2 1
task, t3 4
```

```
domain, t1 ends-by thu 4pm 35
domain, t2 ends-by wed 9am 46
domain, t3 ends-by wed 12pm 25
task, t1 3
task, t2 4
task, t3 1
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by tue 2pm 16
domain, t2 ends-by tue 9am 35
domain, t3 ends-by tue 1pm 18
task, t1 3
task, t2 4
task, t3 1
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by tue 2pm 16
domain, t2 ends-by tue 9am 35
domain, t3 ends-by tue 1pm 18
task, t1 3
task, t2 4
task, t3 1
constraint, t1 before t3
constraint, t3 before t2
domain, t1 ends-by tue 2pm 16
domain, t2 ends-by tue 9am 35
domain, t3 ends-by tue 1pm 18
task, t1 3
task, t2 4
task, t3 4
constraint, t3 before t2
domain, t1 ends-by tue 12pm 40
domain, t2 ends-by fri 2pm 30
domain, t3 ends-by wed 1pm 30
task, t1 3
task, t2 4
task, t3 4
constraint, t3 before t2
domain, t1 ends-by tue 12pm 40
domain, t2 ends-by fri 2pm 30
domain, t3 ends-by wed 1pm 30
task, t1 3
task, t2 4
task, t3 4
constraint, t3 before t2
domain, t1 ends-by tue 12pm 40
domain, t2 ends-by fri 2pm 30
domain, t3 ends-by wed 1pm 30
task, t1 1
task, t2 4
task, t3 4
constraint, t2 before t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by wed 3pm 42
domain, t2 ends-by wed 4pm 28
domain, t3 ends-by thu 2pm 45
task, t1 1
task, t2 4
task, t3 4
```

```
constraint, t2 before t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by wed 3pm 42
domain, t2 ends-by wed 4pm 28
domain, t3 ends-by thu 2pm 45
task, t1 1
task, t2 4
task, t3 4
constraint, t2 before t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by wed 3pm 42
domain, t2 ends-by wed 4pm 28
domain, t3 ends-by thu 2pm 45
task, t1 4
task, t2 4
task, t3 3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by mon 10am 22
domain, t2 ends-by mon 10am 47
domain, t3 ends-by thu 9am 46
task, t1 4
task, t2 4
task, t3 3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by mon 10am 22
domain, t2 ends-by mon 10am 47
domain, t3 ends-by thu 9am 46
task, t1 4
task, t2 4
task, t3 3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by mon 10am 22
domain, t2 ends-by mon 10am 47
domain, t3 ends-by thu 9am 46
task, t1 1
task, t2 3
task, t3 4
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by thu 9am 15
domain, t2 ends-by tue 3pm 19
domain, t3 ends-by thu 12pm 39
task, t1 1
task, t2 3
task, t3 4
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by thu 9am 15
domain, t2 ends-by tue 3pm 19
domain, t3 ends-by thu 12pm 39
```

```
task, t1 1
task, t2 3
task, t3 4
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t2
domain, t1 ends-by thu 9am 15
domain, t2 ends-by tue 3pm 19
domain, t3 ends-by thu 12pm 39
task, t1 3
task, t2 2
task, t3 2
constraint, t1 before t3
domain, t1 ends-by mon 9am 49
domain, t2 ends-by mon 12pm 19
domain, t3 ends-by fri 12pm 42
task, t1 3
task, t2 2
task, t3 2
constraint, t1 before t3
domain, t1 ends-by mon 9am 49
domain, t2 ends-by mon 12pm 19
domain, t3 ends-by fri 12pm 42
task, t1 3
task, t2 2
task, t3 2
constraint, t1 before t3
domain, t1 ends-by mon 9am 49
domain, t2 ends-by mon 12pm 19
domain, t3 ends-by fri 12pm 42
task, t1 3
task, t2 1
task, t3 3
constraint, t2 before t1
constraint, t2 same-day t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by thu 10am 40
domain, t2 ends-by thu 9am 14
domain, t3 ends-by fri 10am 22
task, t1 3
task, t2 1
task, t3 3
constraint, t2 before t1
constraint, t2 same-day t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by thu 10am 40
domain, t2 ends-by thu 9am 14
domain, t3 ends-by fri 10am 22
task, t1 3
task, t2 1
task, t3 3
constraint, t2 before t1
constraint, t2 same-day t1
constraint, t1 before t3
constraint, t1 same-day t3
domain, t1 ends-by thu 10am 40
domain, t2 ends-by thu 9am 14
domain, t3 ends-by fri 10am 22
```

```
task, t1 4
task, t2 3
task, t3 3
task, t4 1
constraint, t4 before t1
constraint, t4 same-day t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by wed 1pm 16
domain, t2 ends-by fri 4pm 17
domain, t3 ends-by thu 12pm 30
domain, t4 ends-by mon 2pm 34
task, t1 4
task, t2 3
task, t3 3
task, t4 1
constraint, t4 before t1
constraint, t4 same-day t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by wed 1pm 16
domain, t2 ends-by fri 4pm 17
domain, t3 ends-by thu 12pm 30
domain, t4 ends-by mon 2pm 34
task, t1 4
task, t2 3
task, t3 3
task, t4 1
constraint, t4 before t1
constraint, t4 same-day t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by wed 1pm 16
domain, t2 ends-by fri 4pm 17
domain, t3 ends-by thu 12pm 30
domain, t4 ends-by mon 2pm 34
task, t1 3
task, t2 4
task, t3 2
task, t4 2
constraint, t2 before t3
constraint, t2 same-day t3
constraint, t3 before t1
constraint, t3 same-day t1
domain, t1 ends-by thu 12pm 42
domain, t2 ends-by fri 1pm 44
domain, t3 ends-by tue 12pm 40
domain, t4 ends-by fri 11am 21
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 1
task, t3 2
task, t4 4
constraint, t2 before t1
constraint, t1 before t4
constraint, t1 same-day t4
constraint, t4 before t3
```

```
domain, t1 ends-by tue 2pm 47
domain, t2 ends-by wed 1pm 48
domain, t3 ends-by thu 11am 30
domain, t4 ends-by thu 2pm 38
task, t1 2
task, t2 1
task, t3 2
task, t4 4
constraint, t2 before t1
constraint, t1 before t4
constraint, t1 same-day t4
constraint, t4 before t3
domain, t1 ends-by tue 2pm 47
domain, t2 ends-by wed 1pm 48
domain, t3 ends-by thu 11am 30
domain, t4 ends-by thu 2pm 38
task, t1 2
task, t2 1
task, t3 2
task, t4 4
constraint, t2 before t1
constraint, t1 before t4
constraint, t1 same-day t4
constraint, t4 before t3
domain, t1 ends-by tue 2pm 47
domain, t2 ends-by wed 1pm 48
domain, t3 ends-by thu 11am 30
domain, t4 ends-by thu 2pm 38
task, t1 2
task, t2 2
task, t3 1
task, t4 2
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
constraint, t2 same-day t4
domain, t1 ends-by tue 3pm 17
domain, t2 ends-by mon 12pm 23
domain, t3 ends-by mon 9am 21
domain, t4 ends-by mon 3pm 47
task, t1 2
task, t2 2
task, t3 1
task, t4 2
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
constraint, t2 same-day t4
domain, t1 ends-by tue 3pm 17
domain, t2 ends-by mon 12pm 23
domain, t3 ends-by mon 9am 21
domain, t4 ends-by mon 3pm 47
task, t1 2
task, t2 2
task, t3 1
task, t4 2
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
constraint, t2 same-day t4
```

```
domain, t1 ends-by tue 3pm 17
domain, t2 ends-by mon 12pm 23
domain, t3 ends-by mon 9am 21
domain, t4 ends-by mon 3pm 47
task, t1 2
task, t2 3
task, t3 4
task, t4 4
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t2
domain, t1 ends-by fri 11am 25
domain, t2 ends-by wed 10am 39
domain, t3 ends-by fri 3pm 29
domain, t4 ends-by tue 1pm 34
task, t1 2
task, t2 3
task, t3 4
task, t4 4
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t2
domain, t1 ends-by fri 11am 25
domain, t2 ends-by wed 10am 39
domain, t3 ends-by fri 3pm 29
domain, t4 ends-by tue 1pm 34
task, t1 2
task, t2 3
task, t3 4
task, t4 4
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t2
domain, t1 ends-by fri 11am 25
domain, t2 ends-by wed 10am 39
domain, t3 ends-by fri 3pm 29
domain, t4 ends-by tue 1pm 34
task, t1 4
task, t2 2
task, t3 1
task, t4 3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by wed 10am 43
domain, t2 ends-by tue 4pm 46
domain, t3 ends-by fri 12pm 20
domain, t4 ends-by mon 2pm 20
task, t1 4
task, t2 2
task, t3 1
task, t4 3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by wed 10am 43
domain, t2 ends-by tue 4pm 46
domain, t3 ends-by fri 12pm 20
domain, t4 ends-by mon 2pm 20
task, t1 4
```

```
task, t2 2
task, t3 1
task, t4 3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by wed 10am 43
domain, t2 ends-by tue 4pm 46
domain, t3 ends-by fri 12pm 20
domain, t4 ends-by mon 2pm 20
task, t1 1
task, t2 3
task, t3 3
task, t4 1
constraint, t3 before t1
domain, t1 ends-by thu 10am 26
domain, t2 ends-by thu 1pm 38
domain, t3 ends-by mon 12pm 29
domain, t4 ends-by mon 3pm 46
task, t1 1
task, t2 3
task, t3 3
task, t4 1
constraint, t3 before t1
domain, t1 ends-by thu 10am 26
domain, t2 ends-by thu 1pm 38
domain, t3 ends-by mon 12pm 29
domain, t4 ends-by mon 3pm 46
task, t1 1
task, t2 3
task, t3 3
task, t4 1
constraint, t3 before t1
domain, t1 ends-by thu 10am 26
domain, t2 ends-by thu 1pm 38
domain, t3 ends-by mon 12pm 29
domain, t4 ends-by mon 3pm 46
task, t1 3
task, t2 1
task, t3 3
task, t4 4
constraint, t4 before t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by thu 10am 23
domain, t2 ends-by thu 2pm 37
domain, t3 ends-by tue 12pm 33
domain, t4 ends-by tue 1pm 44
task, t1 3
task, t2 1
task, t3 3
task, t4 4
constraint, t4 before t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by thu 10am 23
domain, t2 ends-by thu 2pm 37
domain, t3 ends-by tue 12pm 33
```

```
domain, t4 ends-by tue 1pm 44
task, t1 3
task, t2 1
task, t3 3
task, t4 4
constraint, t4 before t1
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
domain, t1 ends-by thu 10am 23
domain, t2 ends-by thu 2pm 37
domain, t3 ends-by tue 12pm 33
domain, t4 ends-by tue 1pm 44
task, t1 3
task, t2 1
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
domain, t1 ends-by tue 12pm 45
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by thu 9am 37
domain, t4 ends-by tue 11am 30
task, t1 3
task, t2 1
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
domain, t1 ends-by tue 12pm 45
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by thu 9am 37
domain, t4 ends-by tue 11am 30
task, t1 3
task, t2 1
task, t3 2
task, t4 1
constraint, t2 before t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
domain, t1 ends-by tue 12pm 45
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by thu 9am 37
domain, t4 ends-by tue 11am 30
task, t1 1
task, t2 4
task, t3 3
task, t4 2
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by tue 4pm 18
domain, t2 ends-by thu 4pm 28
domain, t3 ends-by thu 10am 14
```

```
domain, t4 ends-by mon 10am 10
task, t1 1
task, t2 4
task, t3 3
task, t4 2
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by tue 4pm 18
domain, t2 ends-by thu 4pm 28
domain, t3 ends-by thu 10am 14
domain, t4 ends-by mon 10am 10
task, t1 1
task, t2 4
task, t3 3
task, t4 2
constraint, t1 before t3
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t2 before t4
domain, t1 ends-by tue 4pm 18
domain, t2 ends-by thu 4pm 28
domain, t3 ends-by thu 10am 14
domain, t4 ends-by mon 10am 10
task, t1 3
task, t2 2
task, t3 1
task, t4 3
constraint, t2 before t1
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 11am 37
domain, t2 ends-by tue 11am 46
domain, t3 ends-by tue 1pm 50
domain, t4 ends-by thu 9am 23
task, t1 3
task, t2 2
task, t3 1
task, t4 3
constraint, t2 before t1
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 11am 37
domain, t2 ends-by tue 11am 46
domain, t3 ends-by tue 1pm 50
domain, t4 ends-by thu 9am 23
task, t1 3
task, t2 2
task, t3 1
task, t4 3
constraint, t2 before t1
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 11am 37
domain, t2 ends-by tue 11am 46
domain, t3 ends-by tue 1pm 50
domain, t4 ends-by thu 9am 23
task, t1 4
task, t2 3
```

```
task, t3 3
task, t4 4
task, t5 4
constraint, t1 before t5
constraint, t1 same-day t5
constraint, t5 before t4
constraint, t4 before t3
constraint, t4 same-day t3
constraint, t3 before t2
domain, t1 ends-by tue 10am 12
domain, t2 ends-by mon 12pm 18
domain, t3 ends-by thu 11am 24
domain, t4 ends-by fri 11am 23
domain, t5 ends-by fri 3pm 37
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 3
task, t3 1
task, t4 2
task, t5 3
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t1 before t4
domain, t1 ends-by tue 10am 13
domain, t2 ends-by mon 11am 37
domain, t3 ends-by tue 11am 25
domain, t4 ends-by fri 9am 14
domain, t5 ends-by thu 4pm 30
task, t1 3
task, t2 3
task, t3 1
task, t4 2
task, t5 3
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t1 before t4
domain, t1 ends-by tue 10am 13
domain, t2 ends-by mon 11am 37
domain, t3 ends-by tue 11am 25
domain, t4 ends-by fri 9am 14
domain, t5 ends-by thu 4pm 30
task, t1 3
task, t2 3
task, t3 1
task, t4 2
task, t5 3
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t1 before t4
domain, t1 ends-by tue 10am 13
domain, t2 ends-by mon 11am 37
domain, t3 ends-by tue 11am 25
domain, t4 ends-by fri 9am 14
domain, t5 ends-by thu 4pm 30
task, t1 2
task, t2 2
task, t3 4
task, t4 4
task, t5 4
constraint, t2 before t4
```

```
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t5
domain, t1 ends-by thu 10am 28
domain, t2 ends-by wed 10am 15
domain, t3 ends-by fri 2pm 17
domain, t4 ends-by tue 2pm 11
domain, t5 ends-by tue 9am 29
task, t1 2
task, t2 2
task, t3 4
task, t4 4
task, t5 4
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t5
domain, t1 ends-by thu 10am 28
domain, t2 ends-by wed 10am 15
domain, t3 ends-by fri 2pm 17
domain, t4 ends-by tue 2pm 11
domain, t5 ends-by tue 9am 29
task, t1 2
task, t2 2
task, t3 4
task, t4 4
task, t5 4
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t3 before t1
constraint, t3 same-day t1
constraint, t1 before t5
domain, t1 ends-by thu 10am 28
domain, t2 ends-by wed 10am 15
domain, t3 ends-by fri 2pm 17
domain, t4 ends-by tue 2pm 11
domain, t5 ends-by tue 9am 29
task, t1 1
task, t2 3
task, t3 4
task, t4 3
task, t5 1
constraint, t1 before t5
constraint, t1 same-day t5
constraint, t5 before t3
constraint, t3 before t4
domain, t1 ends-by wed 2pm 29
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 40
domain, t4 ends-by fri 2pm 16
domain, t5 ends-by tue 4pm 28
task, t1 1
task, t2 3
task, t3 4
task, t4 3
```

```
task, t5 1
constraint, t1 before t5
constraint, t1 same-day t5
constraint, t5 before t3
constraint, t3 before t4
domain, t1 ends-by wed 2pm 29
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 40
domain, t4 ends-by fri 2pm 16
domain, t5 ends-by tue 4pm 28
task, t1 1
task, t2 3
task, t3 4
task, t4 3
task, t5 1
constraint, t1 before t5
constraint, t1 same-day t5
constraint, t5 before t3
constraint, t3 before t4
domain, t1 ends-by wed 2pm 29
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 40
domain, t4 ends-by fri 2pm 16
domain, t5 ends-by tue 4pm 28
task, t1 4
task, t2 4
task, t3 3
task, t4 4
task, t5 4
constraint, t5 before t1
constraint, t1 before t4
constraint, t4 before t2
constraint, t4 same-day t2
constraint, t2 before t3
constraint, t2 same-day t3
domain, t1 ends-by mon 2pm 15
domain, t2 ends-by tue 11am 22
domain, t3 ends-by mon 3pm 30
domain, t4 ends-by mon 11am 22
domain, t5 ends-by tue 3pm 26
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 3
task, t3 4
task, t4 3
task, t5 4
constraint, t1 before t2
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 4pm 45
domain, t2 ends-by mon 9am 10
domain, t3 ends-by wed 1pm 37
domain, t4 ends-by mon 1pm 47
domain, t5 ends-by fri 3pm 10
task, t1 1
task, t2 3
task, t3 4
task, t4 3
task, t5 4
constraint, t1 before t2
```

```
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 4pm 45
domain, t2 ends-by mon 9am 10
domain, t3 ends-by wed 1pm 37
domain, t4 ends-by mon 1pm 47
domain, t5 ends-by fri 3pm 10
task, t1 1
task, t2 3
task, t3 4
task, t4 3
task, t5 4
constraint, t1 before t2
constraint, t3 before t4
constraint, t3 same-day t4
domain, t1 ends-by wed 4pm 45
domain, t2 ends-by mon 9am 10
domain, t3 ends-by wed 1pm 37
domain, t4 ends-by mon 1pm 47
domain, t5 ends-by fri 3pm 10
task, t1 1
task, t2 2
task, t3 3
task, t4 3
task, t5 4
constraint, t4 before t5
constraint, t5 before t3
constraint, t1 before t2
domain, t1 ends-by wed 10am 38
domain, t2 ends-by thu 9am 38
domain, t3 ends-by wed 9am 39
domain, t4 ends-by mon 10am 37
domain, t5 ends-by thu 11am 29
task, t1 1
task, t2 2
task, t3 3
task, t4 3
task, t5 4
constraint, t4 before t5
constraint, t5 before t3
constraint, t1 before t2
domain, t1 ends-by wed 10am 38
domain, t2 ends-by thu 9am 38
domain, t3 ends-by wed 9am 39
domain, t4 ends-by mon 10am 37
domain, t5 ends-by thu 11am 29
task, t1 1
task, t2 2
task, t3 3
task, t4 3
task, t5 4
constraint, t4 before t5
constraint, t5 before t3
constraint, t1 before t2
domain, t1 ends-by wed 10am 38
domain, t2 ends-by thu 9am 38
domain, t3 ends-by wed 9am 39
domain, t4 ends-by mon 10am 37
domain, t5 ends-by thu 11am 29
task, t1 1
```

```
task, t2 2
task, t3 4
task, t4 1
task, t5 1
constraint, t5 before t1
constraint, t2 before t4
constraint, t4 before t3
constraint, t4 same-day t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by fri 12pm 38
domain, t3 ends-by thu 11am 20
domain, t4 ends-by thu 1pm 12
domain, t5 ends-by tue 3pm 20
task, t1 1
task, t2 2
task, t3 4
task, t4 1
task, t5 1
constraint, t5 before t1
constraint, t2 before t4
constraint, t4 before t3
constraint, t4 same-day t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by fri 12pm 38
domain, t3 ends-by thu 11am 20
domain, t4 ends-by thu 1pm 12
domain, t5 ends-by tue 3pm 20
task, t1 1
task, t2 2
task, t3 4
task, t4 1
task, t5 1
constraint, t5 before t1
constraint, t2 before t4
constraint, t4 before t3
constraint, t4 same-day t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by fri 12pm 38
domain, t3 ends-by thu 11am 20
domain, t4 ends-by thu 1pm 12
domain, t5 ends-by tue 3pm 20
task, t1 4
task, t2 4
task, t3 2
task, t4 3
task, t5 1
constraint, t5 before t3
constraint, t3 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t1
constraint, t4 same-day t1
domain, t1 ends-by fri 1pm 44
domain, t2 ends-by wed 3pm 48
domain, t3 ends-by tue 2pm 22
domain, t4 ends-by fri 9am 48
domain, t5 ends-by wed 11am 15
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 1
```

```
task, t3 4
task, t4 2
task, t5 1
constraint, t3 before t5
constraint, t4 before t1
domain, t1 ends-by mon 4pm 35
domain, t2 ends-by tue 9am 12
domain, t3 ends-by tue 2pm 11
domain, t4 ends-by thu 3pm 20
domain, t5 ends-by mon 9am 37
task, t1 1
task, t2 1
task, t3 4
task, t4 2
task, t5 1
constraint, t3 before t5
constraint, t4 before t1
domain, t1 ends-by mon 4pm 35
domain, t2 ends-by tue 9am 12
domain, t3 ends-by tue 2pm 11
domain, t4 ends-by thu 3pm 20
domain, t5 ends-by mon 9am 37
task, t1 1
task, t2 1
task, t3 4
task, t4 2
task, t5 1
constraint, t3 before t5
constraint, t4 before t1
domain, t1 ends-by mon 4pm 35
domain, t2 ends-by tue 9am 12
domain, t3 ends-by tue 2pm 11
domain, t4 ends-by thu 3pm 20
domain, t5 ends-by mon 9am 37
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 4
constraint, t3 before t5
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
domain, t1 ends-by thu 12pm 30
domain, t2 ends-by thu 12pm 10
domain, t3 ends-by fri 3pm 43
domain, t4 ends-by mon 4pm 35
domain, t5 ends-by thu 3pm 41
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 4
constraint, t3 before t5
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
domain, t1 ends-by thu 12pm 30
domain, t2 ends-by thu 12pm 10
domain, t3 ends-by fri 3pm 43
```

```
domain, t4 ends-by mon 4pm 35
domain, t5 ends-by thu 3pm 41
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 4
constraint, t3 before t5
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
domain, t1 ends-by thu 12pm 30
domain, t2 ends-by thu 12pm 10
domain, t3 ends-by fri 3pm 43
domain, t4 ends-by mon 4pm 35
domain, t5 ends-by thu 3pm 41
task, t1 1
task, t2 1
task, t3 2
task, t4 1
task, t5 1
constraint, t1 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t4 same-day t3
constraint, t3 before t5
constraint, t3 same-day t5
domain, t1 ends-by mon 11am 14
domain, t2 ends-by fri 9am 47
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by fri 11am 50
domain, t5 ends-by fri 10am 11
task, t1 1
task, t2 1
task, t3 2
task, t4 1
task, t5 1
constraint, t1 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t4 same-day t3
constraint, t3 before t5
constraint, t3 same-day t5
domain, t1 ends-by mon 11am 14
domain, t2 ends-by fri 9am 47
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by fri 11am 50
domain, t5 ends-by fri 10am 11
task, t1 1
task, t2 1
task, t3 2
task, t4 1
task, t5 1
constraint, t1 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
constraint, t4 same-day t3
```

```
constraint, t3 before t5
constraint, t3 same-day t5
domain, t1 ends-by mon 11am 14
domain, t2 ends-by fri 9am 47
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by fri 11am 50
domain, t5 ends-by fri 10am 11
task, t1 3
task, t2 1
task, t3 4
task, t4 3
task, t5 2
constraint, t4 before t2
constraint, t2 before t1
domain, t1 ends-by tue 12pm 24
domain, t2 ends-by tue 4pm 21
domain, t3 ends-by fri 11am 35
domain, t4 ends-by mon 4pm 26
domain, t5 ends-by mon 3pm 19
task, t1 3
task, t2 1
task, t3 4
task, t4 3
task, t5 2
constraint, t4 before t2
constraint, t2 before t1
domain, t1 ends-by tue 12pm 24
domain, t2 ends-by tue 4pm 21
domain, t3 ends-by fri 11am 35
domain, t4 ends-by mon 4pm 26
domain, t5 ends-by mon 3pm 19
task, t1 3
task, t2 1
task, t3 4
task, t4 3
task, t5 2
constraint, t4 before t2
constraint, t2 before t1
domain, t1 ends-by tue 12pm 24
domain, t2 ends-by tue 4pm 21
domain, t3 ends-by fri 11am 35
domain, t4 ends-by mon 4pm 26
domain, t5 ends-by mon 3pm 19
task, t1 4
task, t2 1
task, t3 4
task, t4 2
task, t5 1
task, t6 3
constraint, t4 before t3
constraint, t4 same-day t3
constraint, t3 before t5
constraint, t3 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t6 before t2
domain, t1 ends-by thu 3pm 14
domain, t2 ends-by thu 9am 47
```

```
domain, t3 ends-by wed 1pm 38
domain, t4 ends-by wed 12pm 12
domain, t5 ends-by mon 10am 38
domain, t6 ends-by tue 4pm 27
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 2
task, t3 1
task, t4 2
task, t5 3
task, t6 4
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t2 before t3
constraint, t6 before t1
constraint, t1 before t4
domain, t1 ends-by wed 10am 11
domain, t2 ends-by mon 9am 40
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by tue 2pm 22
domain, t5 ends-by mon 4pm 16
domain, t6 ends-by wed 2pm 10
task, t1 3
task, t2 2
task, t3 1
task, t4 2
task, t5 3
task, t6 4
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t2 before t3
constraint, t6 before t1
constraint, t1 before t4
domain, t1 ends-by wed 10am 11
domain, t2 ends-by mon 9am 40
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by tue 2pm 22
domain, t5 ends-by mon 4pm 16
domain, t6 ends-by wed 2pm 10
task, t1 3
task, t2 2
task, t3 1
task, t4 2
task, t5 3
task, t6 4
constraint, t5 before t2
constraint, t5 same-day t2
constraint, t2 before t3
constraint, t6 before t1
constraint, t1 before t4
domain, t1 ends-by wed 10am 11
domain, t2 ends-by mon 9am 40
domain, t3 ends-by wed 4pm 19
domain, t4 ends-by tue 2pm 22
domain, t5 ends-by mon 4pm 16
domain, t6 ends-by wed 2pm 10
task, t1 3
task, t2 4
task, t3 4
task, t4 2
```

```
task, t5 3
task, t6 1
constraint, t1 before t2
constraint, t5 before t6
constraint, t6 before t4
constraint, t6 same-day t4
domain, t1 ends-by mon 10am 29
domain, t2 ends-by thu 1pm 10
domain, t3 ends-by wed 1pm 12
domain, t4 ends-by fri 2pm 13
domain, t5 ends-by tue 1pm 45
domain, t6 ends-by wed 12pm 34
task, t1 3
task, t2 4
task, t3 4
task, t4 2
task, t5 3
task, t6 1
constraint, t1 before t2
constraint, t5 before t6
constraint, t6 before t4
constraint, t6 same-day t4
domain, t1 ends-by mon 10am 29
domain, t2 ends-by thu 1pm 10
domain, t3 ends-by wed 1pm 12
domain, t4 ends-by fri 2pm 13
domain, t5 ends-by tue 1pm 45
domain, t6 ends-by wed 12pm 34
task, t1 3
task, t2 4
task, t3 4
task, t4 2
task, t5 3
task, t6 1
constraint, t1 before t2
constraint, t5 before t6
constraint, t6 before t4
constraint, t6 same-day t4
domain, t1 ends-by mon 10am 29
domain, t2 ends-by thu 1pm 10
domain, t3 ends-by wed 1pm 12
domain, t4 ends-by fri 2pm 13
domain, t5 ends-by tue 1pm 45
domain, t6 ends-by wed 12pm 34
task, t1 4
task, t2 4
task, t3 3
task, t4 4
task, t5 4
task, t6 2
constraint, t5 before t4
constraint, t5 same-day t4
constraint, t4 before t3
constraint, t4 same-day t3
constraint, t3 before t2
domain, t1 ends-by fri 11am 38
domain, t2 ends-by fri 4pm 34
domain, t3 ends-by thu 9am 39
domain, t4 ends-by mon 3pm 47
domain, t5 ends-by wed 3pm 27
```

```
domain, t6 ends-by thu 10am 13
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 1
task, t3 1
task, t4 4
task, t5 1
task, t6 4
constraint, t2 before t4
constraint, t4 before t6
constraint, t6 before t5
constraint, t6 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
constraint, t1 before t3
domain, t1 ends-by wed 4pm 47
domain, t2 ends-by wed 12pm 24
domain, t3 ends-by thu 3pm 33
domain, t4 ends-by fri 3pm 50
domain, t5 ends-by wed 12pm 13
domain, t6 ends-by fri 12pm 36
task, t1 2
task, t2 1
task, t3 1
task, t4 4
task, t5 1
task, t6 4
constraint, t2 before t4
constraint, t4 before t6
constraint, t6 before t5
constraint, t6 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
constraint, t1 before t3
domain, t1 ends-by wed 4pm 47
domain, t2 ends-by wed 12pm 24
domain, t3 ends-by thu 3pm 33
domain, t4 ends-by fri 3pm 50
domain, t5 ends-by wed 12pm 13
domain, t6 ends-by fri 12pm 36
task, t1 2
task, t2 1
task, t3 1
task, t4 4
task, t5 1
task, t6 4
constraint, t2 before t4
constraint, t4 before t6
constraint, t6 before t5
constraint, t6 same-day t5
constraint, t5 before t1
constraint, t5 same-day t1
constraint, t1 before t3
domain, t1 ends-by wed 4pm 47
domain, t2 ends-by wed 12pm 24
domain, t3 ends-by thu 3pm 33
domain, t4 ends-by fri 3pm 50
domain, t5 ends-by wed 12pm 13
domain, t6 ends-by fri 12pm 36
task, t1 3
```

```
task, t2 3
task, t3 2
task, t4 3
task, t5 4
task, t6 4
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
domain, t1 ends-by mon 1pm 14
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by tue 11am 17
domain, t4 ends-by thu 11am 26
domain, t5 ends-by mon 1pm 24
domain, t6 ends-by tue 1pm 19
task, t1 3
task, t2 3
task, t3 2
task, t4 3
task, t5 4
task, t6 4
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
domain, t1 ends-by mon 1pm 14
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by tue 11am 17
domain, t4 ends-by thu 11am 26
domain, t5 ends-by mon 1pm 24
domain, t6 ends-by tue 1pm 19
task, t1 3
task, t2 3
task, t3 2
task, t4 3
task, t5 4
task, t6 4
constraint, t5 before t2
constraint, t2 before t4
constraint, t2 same-day t4
constraint, t4 before t3
domain, t1 ends-by mon 1pm 14
domain, t2 ends-by thu 12pm 42
domain, t3 ends-by tue 11am 17
domain, t4 ends-by thu 11am 26
domain, t5 ends-by mon 1pm 24
domain, t6 ends-by tue 1pm 19
task, t1 3
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t1 before t3
constraint, t3 before t2
constraint, t2 before t6
constraint, t2 same-day t6
constraint, t6 before t5
constraint, t5 before t4
domain, t1 ends-by mon 11am 38
```

```
domain, t2 ends-by fri 2pm 16
domain, t3 ends-by tue 11am 43
domain, t4 ends-by tue 1pm 37
domain, t5 ends-by tue 9am 11
domain, t6 ends-by tue 1pm 37
task, t1 3
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t1 before t3
constraint, t3 before t2
constraint, t2 before t6
constraint, t2 same-day t6
constraint, t6 before t5
constraint, t5 before t4
domain, t1 ends-by mon 11am 38
domain, t2 ends-by fri 2pm 16
domain, t3 ends-by tue 11am 43
domain, t4 ends-by tue 1pm 37
domain, t5 ends-by tue 9am 11
domain, t6 ends-by tue 1pm 37
task, t1 3
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t1 before t3
constraint, t3 before t2
constraint, t2 before t6
constraint, t2 same-day t6
constraint, t6 before t5
constraint, t5 before t4
domain, t1 ends-by mon 11am 38
domain, t2 ends-by fri 2pm 16
domain, t3 ends-by tue 11am 43
domain, t4 ends-by tue 1pm 37
domain, t5 ends-by tue 9am 11
domain, t6 ends-by tue 1pm 37
task, t1 1
task, t2 4
task, t3 2
task, t4 3
task, t5 1
task, t6 4
constraint, t4 before t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t3 before t2
domain, t1 ends-by wed 11am 38
domain, t2 ends-by wed 9am 35
domain, t3 ends-by mon 1pm 26
domain, t4 ends-by fri 4pm 45
domain, t5 ends-by thu 2pm 28
domain, t6 ends-by fri 4pm 11
task, t1 1
task, t2 4
task, t3 2
```

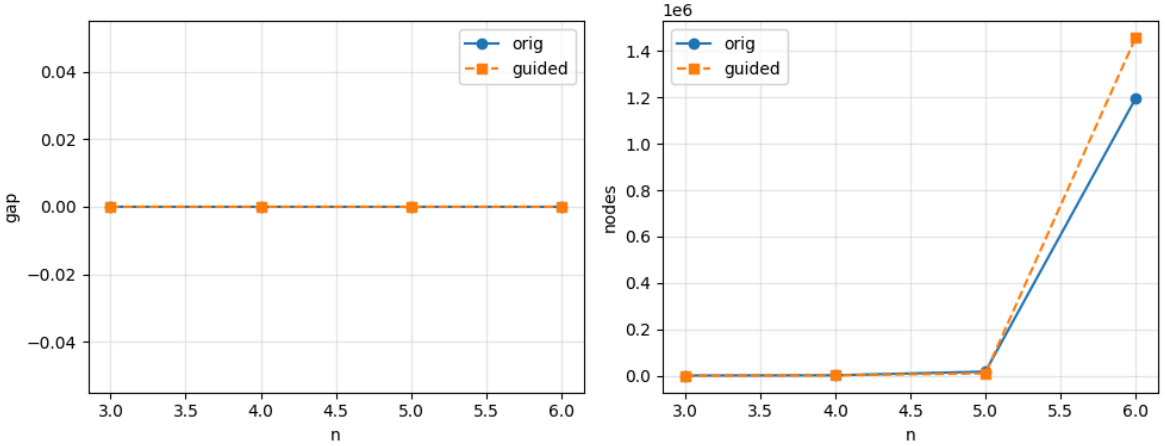
```
task, t4 3
task, t5 1
task, t6 4
constraint, t4 before t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t3 before t2
domain, t1 ends-by wed 11am 38
domain, t2 ends-by wed 9am 35
domain, t3 ends-by mon 1pm 26
domain, t4 ends-by fri 4pm 45
domain, t5 ends-by thu 2pm 28
domain, t6 ends-by fri 4pm 11
task, t1 1
task, t2 4
task, t3 2
task, t4 3
task, t5 1
task, t6 4
constraint, t4 before t1
constraint, t1 before t6
constraint, t1 same-day t6
constraint, t3 before t2
domain, t1 ends-by wed 11am 38
domain, t2 ends-by wed 9am 35
domain, t3 ends-by mon 1pm 26
domain, t4 ends-by fri 4pm 45
domain, t5 ends-by thu 2pm 28
domain, t6 ends-by fri 4pm 11
task, t1 4
task, t2 1
task, t3 2
task, t4 1
task, t5 1
task, t6 3
constraint, t5 before t4
constraint, t1 before t2
domain, t1 ends-by mon 1pm 11
domain, t2 ends-by wed 9am 41
domain, t3 ends-by thu 4pm 17
domain, t4 ends-by mon 11am 38
domain, t5 ends-by fri 4pm 10
domain, t6 ends-by mon 9am 49
task, t1 4
task, t2 1
task, t3 2
task, t4 1
task, t5 1
task, t6 3
constraint, t5 before t4
constraint, t1 before t2
domain, t1 ends-by mon 1pm 11
domain, t2 ends-by wed 9am 41
domain, t3 ends-by thu 4pm 17
domain, t4 ends-by mon 11am 38
domain, t5 ends-by fri 4pm 10
domain, t6 ends-by mon 9am 49
task, t1 4
task, t2 1
task, t3 2
```

```
task, t4 1
task, t5 1
task, t6 3
constraint, t5 before t4
constraint, t1 before t2
domain, t1 ends-by mon 1pm 11
domain, t2 ends-by wed 9am 41
domain, t3 ends-by thu 4pm 17
domain, t4 ends-by mon 11am 38
domain, t5 ends-by fri 4pm 10
domain, t6 ends-by mon 9am 49
task, t1 4
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t1
constraint, t1 before t6
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t2
domain, t1 ends-by thu 11am 36
domain, t2 ends-by tue 2pm 17
domain, t3 ends-by fri 2pm 16
domain, t4 ends-by fri 10am 42
domain, t5 ends-by tue 10am 43
domain, t6 ends-by fri 12pm 45
task, t1 4
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t1
constraint, t1 before t6
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t2
domain, t1 ends-by thu 11am 36
domain, t2 ends-by tue 2pm 17
domain, t3 ends-by fri 2pm 16
domain, t4 ends-by fri 10am 42
domain, t5 ends-by tue 10am 43
domain, t6 ends-by fri 12pm 45
task, t1 4
task, t2 2
task, t3 1
task, t4 2
task, t5 1
task, t6 1
constraint, t3 before t1
constraint, t1 before t6
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t2
domain, t1 ends-by thu 11am 36
domain, t2 ends-by tue 2pm 17
domain, t3 ends-by fri 2pm 16
domain, t4 ends-by fri 10am 42
```

```
domain, t5 ends-by tue 10am 43
domain, t6 ends-by fri 12pm 45
task, t1 3
task, t2 4
task, t3 4
task, t4 4
task, t5 2
task, t6 1
constraint, t3 before t2
constraint, t3 same-day t2
constraint, t1 before t4
constraint, t4 before t6
constraint, t4 same-day t6
domain, t1 ends-by fri 2pm 12
domain, t2 ends-by thu 9am 49
domain, t3 ends-by wed 1pm 33
domain, t4 ends-by mon 4pm 17
domain, t5 ends-by fri 12pm 41
domain, t6 ends-by mon 3pm 25
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 3
task, t3 2
task, t4 4
task, t5 4
task, t6 3
constraint, t4 before t3
constraint, t3 before t5
constraint, t3 same-day t5
constraint, t5 before t6
constraint, t5 same-day t6
constraint, t6 before t1
constraint, t6 same-day t1
constraint, t1 before t2
constraint, t1 same-day t2
domain, t1 ends-by fri 11am 16
domain, t2 ends-by fri 1pm 39
domain, t3 ends-by tue 12pm 36
domain, t4 ends-by mon 3pm 29
domain, t5 ends-by tue 12pm 28
domain, t6 ends-by wed 9am 16
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 4
task, t3 4
task, t4 2
task, t5 1
task, t6 3
constraint, t2 before t4
constraint, t4 before t6
constraint, t4 same-day t6
domain, t1 ends-by fri 3pm 27
domain, t2 ends-by wed 2pm 28
domain, t3 ends-by thu 10am 28
domain, t4 ends-by thu 2pm 22
domain, t5 ends-by tue 2pm 42
domain, t6 ends-by tue 4pm 45
task, t1 4
task, t2 4
task, t3 4
```

```
task, t4 2
task, t5 1
task, t6 3
constraint, t2 before t4
constraint, t4 before t6
constraint, t4 same-day t6
domain, t1 ends-by fri 3pm 27
domain, t2 ends-by wed 2pm 28
domain, t3 ends-by thu 10am 28
domain, t4 ends-by thu 2pm 22
domain, t5 ends-by tue 2pm 42
domain, t6 ends-by tue 4pm 45
task, t1 4
task, t2 4
task, t3 4
task, t4 2
task, t5 1
task, t6 3
constraint, t2 before t4
constraint, t4 before t6
constraint, t4 same-day t6
domain, t1 ends-by fri 3pm 27
domain, t2 ends-by wed 2pm 28
domain, t3 ends-by thu 10am 28
domain, t4 ends-by thu 2pm 22
domain, t5 ends-by tue 2pm 42
domain, t6 ends-by tue 4pm 45
task, t1 1
task, t2 2
task, t3 4
task, t4 2
task, t5 2
task, t6 4
constraint, t1 before t3
constraint, t1 same-day t3
constraint, t3 before t6
constraint, t3 same-day t6
constraint, t6 before t4
constraint, t6 same-day t4
constraint, t4 before t2
constraint, t2 before t5
domain, t1 ends-by thu 12pm 47
domain, t2 ends-by wed 2pm 43
domain, t3 ends-by mon 10am 37
domain, t4 ends-by tue 10am 39
domain, t5 ends-by mon 10am 30
domain, t6 ends-by mon 10am 21
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t5 before t3
constraint, t5 same-day t3
constraint, t3 before t2
constraint, t6 before t4
domain, t1 ends-by wed 1pm 46
domain, t2 ends-by thu 1pm 17
```

```
domain, t3 ends-by tue 1pm 31
domain, t4 ends-by wed 2pm 21
domain, t5 ends-by tue 4pm 33
domain, t6 ends-by wed 9am 26
task, t1 4
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t5 before t3
constraint, t5 same-day t3
constraint, t3 before t2
constraint, t6 before t4
domain, t1 ends-by wed 1pm 46
domain, t2 ends-by thu 1pm 17
domain, t3 ends-by tue 1pm 31
domain, t4 ends-by wed 2pm 21
domain, t5 ends-by tue 4pm 33
domain, t6 ends-by wed 9am 26
task, t1 4
task, t2 3
task, t3 1
task, t4 1
task, t5 4
task, t6 4
constraint, t5 before t3
constraint, t5 same-day t3
constraint, t3 before t2
constraint, t6 before t4
domain, t1 ends-by wed 1pm 46
domain, t2 ends-by thu 1pm 17
domain, t3 ends-by tue 1pm 31
domain, t4 ends-by wed 2pm 21
domain, t5 ends-by tue 4pm 33
domain, t6 ends-by wed 9am 26
n=3 succ=10 | orig gap=0.000 nodes=697.1 | guided gap=0.000 nodes=578.6
n=4 succ=10 | orig gap=0.000 nodes=1911.0 | guided gap=0.000 nodes=1924.5
n=5 succ=10 | orig gap=0.000 nodes=17764.3 | guided gap=0.000 nodes=10108.8
n=6 succ=10 | orig gap=0.000 nodes=1195309.9 | guided gap=0.000 nodes=1456841.4
```



Question 6 (3 marks)

The CSP solver with domain splitting splits a CSP variable domain into *exactly two* partitions. Poole & Mackworth claim that in practice, this is as good as splitting into a

larger number of partitions. In this question, empirically evaluate this claim for fuzzy scheduling CSPs.

- Write a new `partition_domain` function that partitions a domain into a list of `k` partitions, where `k` is a parameter to the function (1 mark)
- Modify the CSP solver to use the list of `k` partitions and evaluate the performance of the solver using the above metric for a range of values of `k` (2 marks)

In [217…

```
import time

def huafen_yuyu_k_lu(yuyu, k):
    if not yuyu: return []
    if k <= 1: return [set(yuyu)]
    lst = list(yuyu); n = len(lst)
    if n <= k: return [{v} for v in lst]
    q, r = divmod(n, k)
    bufen = [set(lst[i*(q)+(i if i<r else r) : i*(q)+(i if i<r else r) + q + (1
    return [p for p in bufen if p]

class Daijiage_AC_k_lu_Sousuo(Search_problem):
    def __init__(self, csp, k=2):
        self.yueshuqiujieqi = Con_solver(csp)
        self.yuyu = self.yueshuqiujieqi.make_arc_consistent(csp.domains)
        self.yueshu = csp.constraints
        self.chengben_hanshu = csp.cost_functions
        self.shichang = csp.durations
        self.ruan_ri_shijian = csp.soft_day_time
        self.ruan_chengben = csp.soft_costs
        csp.domains = self.yuyu
        self.csp = csp
        self.k = k
        self.zhankaishu = 0

    def is_goal(self, jiedian):  # 修正：保持父类方法名
        return all(len(jiedian.domains[v]) == 1 for v in jiedian.domains)

    def start_node(self):  # 修正：保持父类方法名
        return CSP_with_Cost(self.yuyu, self.shichang, self.yueshu,
                             self.chengben_hanshu, self.ruan_ri_shijian, self.ru

    def neighbors(self, jiedian):  # 修正：保持父类方法名
        linjiedian = []
        var = select(x for x in jiedian.domains if len(jiedian.domains[x]) > 1)
        if not var: return linjiedian
        self.zhankaishu += 1
        bufen = huafen_yuyu_k_lu(jiedian.domains[var], self.k)
        daiban = self.yueshuqiujieqi.new_to_do(var, None)
        for part in bufen:
            xin_yuyu = jiedian.domains | {var: part}
            yueshu_yuyu = self.yueshuqiujieqi.make_arc_consistent(xin_yuyu, daib
            if all(len(yueshu_yuyu[v]) > 0 for v in yueshu_yuyu):
                linjiedian.append(Arc(jiedian, CSP_with_Cost(yueshu_yuyu, self.s
                                                             self.chengben_hanshu, self
        return linjiedian

    def heuristic(self, n):  # 修正：保持父类方法名
        return n.cost
```

```python
def yong_k_fenge_qiujie(guige, k=2, chaoshi=5):
    kaishi = time.time()
    csp = create_CSP_from_spec(guige)
    sousuo_wenti = Daijiage_AC_k_lu_Sousuo(csp, k=k)
    zuizhong_lujing = GreedySearcher(sousuo_wenti).search()
    yongshi = time.time() - kaishi
    if (zuizhong_lujing is None) or (yongshi > chaoshi): return None
    zhongdian = zuizhong_lujing.end()
    jie = {v: list(zhongdian.domains[v])[0] for v in zhongdian.domains}
    return {'solution': jie, 'cost': zhongdian.cost, 'nodes': sousuo_wenti.zhank
            'time': yongshi, 'success': True}

def shengcheng_ceshi_wenti(n, zhongzi=None):
    rng = random.Random(zhongzi)
    rizi = ['mon','tue','wed','thu','fri']
    shijianlie = ['9am','10am','11am','12pm','1pm','2pm','3pm','4pm']
    renwu = [f"t{i+1}" for i in range(n)]
    shichang  = {t: rng.randint(2, 3) for t in renwu}
    hanglie = [f"task, {t} {shichang[t]}" for t in renwu]
    for _ in range(min(n-1, rng.randint(2, max(2, n//2)))):
        a, b = rng.sample(renwu, 2)
        hanglie.append(f"constraint, {a} {rng.choice(['before','same-day'])} {b}
    for t in renwu:
        hanglie.append(f"domain, {t} ends-by {rng.choice(rizi[:3])} {rng.choice(
    return "\n".join(hanglie)

def shiyan_k_lu(k_zhi=[2,3,4,5], wenti_chicun=[4,5,6], mei_peizhi_shiyanci=5, zh
    rng = random.Random(zhongzi)
    shuju = {}
    for n in wenti_chicun:
        for k in k_zhi:
            jiedian, shijian, chengben = [], [], []
            while len(jiedian) < mei_peizhi_shiyanci:
                guige = shengcheng_ceshi_wenti(n, zhongzi=rng.randrange(1, 10**9
                r = yong_k_fenge_qiujie(guige, k=k, chaoshi=10)
                if r and r['success']:
                    jiedian.append(r['nodes']); shijian.append(r['time']); cheng
            shuju[(k,n)] = {'avg_nodes': float(np.mean(jiedian)),
                            'avg_time':  float(np.mean(shijian)),
                            'avg_cost':  float(np.mean(chengben))}
            print(f"n={n} k={k} | nodes={np.mean(jiedian):.1f} time={np.mean(shi
    return {'k_values': k_zhi, 'sizes': wenti_chicun, 'data': shuju}

Con_solver.max_display_level = 0
Search_with_AC_from_Cost_CSP.max_display_level = 0
GreedySearcher.max_display_level = 0

jieguo_q6 = shiyan_k_lu(k_zhi=[2,3,4,5,6],
                        wenti_chicun=[4,5,6],
                        mei_peizhi_shiyanci=4,
                        zhongzi=2025)

if jieguo_q6['data']:
    ks, ns, D = jieguo_q6['k_values'], jieguo_q6['sizes'], jieguo_q6['data']

    plt.figure(figsize=(5.5, 4.2))
    for n in ns:
        y = [D[(k,n)]['avg_nodes'] for k in ks]
        plt.plot(ks, y, 'o-', label=f'n={n}')
    plt.xlabel('k'); plt.ylabel('nodes'); plt.legend(); plt.grid(alpha=0.3); plt
```

```
    plt.figure(figsize=(5.5, 4.2))
    for n in ns:
        y = [D[(k,n)]['avg_time'] for k in ks]
        plt.plot(ks, y, 's--', label=f'n={n}')
    plt.xlabel('k'); plt.ylabel('time (s)'); plt.legend(); plt.grid(alpha=0.3);
```

```
task, t1 3
task, t2 3
task, t3 2
task, t4 2
constraint, t4 before t1
constraint, t3 before t4
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 12pm 15
domain, t4 ends-by wed 1pm 10
task, t1 3
task, t2 2
task, t3 2
task, t4 2
constraint, t3 same-day t4
constraint, t3 same-day t1
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by mon 2pm 15
domain, t3 ends-by wed 1pm 15
domain, t4 ends-by mon 11am 20
task, t1 3
task, t2 2
task, t3 3
task, t4 3
constraint, t3 before t2
constraint, t1 same-day t4
domain, t1 ends-by tue 11am 20
domain, t2 ends-by wed 12pm 15
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 11am 10
task, t1 2
task, t2 3
task, t3 3
task, t4 3
constraint, t3 before t4
constraint, t2 same-day t1
domain, t1 ends-by tue 11am 15
domain, t2 ends-by wed 2pm 20
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by tue 1pm 15
n=4 k=2 | nodes=16.0 time=0.003s cost=2.5
task, t1 2
task, t2 2
task, t3 2
task, t4 2
constraint, t4 same-day t3
constraint, t1 same-day t3
domain, t1 ends-by tue 11am 15
domain, t2 ends-by wed 2pm 15
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by wed 1pm 20
task, t1 2
task, t2 3
task, t3 3
task, t4 2
constraint, t4 before t3
constraint, t3 same-day t4
domain, t1 ends-by tue 1pm 15
domain, t2 ends-by wed 1pm 20
domain, t3 ends-by mon 12pm 10
```

```
domain, t4 ends-by wed 2pm 10
task, t1 3
task, t2 3
task, t3 2
task, t4 2
constraint, t4 before t1
constraint, t3 same-day t4
domain, t1 ends-by tue 12pm 15
domain, t2 ends-by mon 11am 15
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by mon 2pm 10
task, t1 3
task, t2 3
task, t3 2
task, t4 3
constraint, t1 before t3
constraint, t4 same-day t2
domain, t1 ends-by mon 11am 15
domain, t2 ends-by wed 2pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by wed 12pm 10
n=4 k=3 | nodes=10.2 time=0.003s cost=17.5
task, t1 2
task, t2 2
task, t3 2
task, t4 2
constraint, t4 before t2
constraint, t1 same-day t2
domain, t1 ends-by mon 11am 15
domain, t2 ends-by mon 12pm 15
domain, t3 ends-by wed 12pm 20
domain, t4 ends-by mon 1pm 20
task, t1 3
task, t2 2
task, t3 2
task, t4 2
constraint, t4 same-day t3
constraint, t3 same-day t2
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by wed 12pm 20
task, t1 3
task, t2 2
task, t3 3
task, t4 3
constraint, t2 before t4
constraint, t3 before t2
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by wed 2pm 15
domain, t3 ends-by tue 11am 20
domain, t4 ends-by mon 11am 10
task, t1 2
task, t2 2
task, t3 3
task, t4 3
constraint, t1 same-day t2
constraint, t2 same-day t3
domain, t1 ends-by wed 1pm 20
domain, t2 ends-by tue 2pm 10
```

```
domain, t3 ends-by wed 1pm 15
domain, t4 ends-by tue 1pm 10
n=4 k=4 | nodes=9.0 time=0.003s cost=66.2
task, t1 2
task, t2 2
task, t3 2
task, t4 3
constraint, t1 before t3
constraint, t3 before t1
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 3
task, t3 2
task, t4 2
constraint, t3 before t4
constraint, t4 same-day t3
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by tue 11am 15
task, t1 2
task, t2 3
task, t3 3
task, t4 3
constraint, t1 same-day t2
constraint, t2 before t1
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by wed 11am 10
domain, t3 ends-by wed 2pm 20
domain, t4 ends-by tue 2pm 20
task, t1 2
task, t2 3
task, t3 2
task, t4 2
constraint, t1 before t4
constraint, t1 before t3
domain, t1 ends-by mon 11am 10
domain, t2 ends-by mon 11am 20
domain, t3 ends-by mon 11am 10
domain, t4 ends-by wed 12pm 20
task, t1 2
task, t2 2
task, t3 3
task, t4 3
constraint, t1 same-day t3
constraint, t4 before t3
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by tue 11am 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by wed 2pm 15
n=4 k=5 | nodes=8.0 time=0.003s cost=10.0
task, t1 3
task, t2 2
task, t3 2
task, t4 3
constraint, t3 same-day t2
```

```
constraint, t4 before t1
domain, t1 ends-by tue 1pm 15
domain, t2 ends-by mon 2pm 15
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 11am 15
task, t1 2
task, t2 2
task, t3 3
task, t4 3
constraint, t2 before t4
constraint, t1 same-day t3
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by mon 11am 20
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 2pm 20
task, t1 3
task, t2 3
task, t3 2
task, t4 3
constraint, t3 before t4
constraint, t3 before t1
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by wed 12pm 10
domain, t3 ends-by wed 12pm 20
domain, t4 ends-by mon 11am 10
task, t1 2
task, t2 3
task, t3 2
task, t4 3
constraint, t4 same-day t2
constraint, t1 same-day t4
domain, t1 ends-by tue 11am 15
domain, t2 ends-by wed 12pm 10
domain, t3 ends-by tue 11am 15
domain, t4 ends-by wed 2pm 20
n=4 k=6 | nodes=6.5 time=0.002s cost=11.2
task, t1 3
task, t2 3
task, t3 2
task, t4 2
task, t5 3
constraint, t3 same-day t5
constraint, t5 before t1
domain, t1 ends-by wed 2pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by wed 12pm 20
domain, t5 ends-by tue 1pm 15
task, t1 2
task, t2 3
task, t3 2
task, t4 3
task, t5 2
constraint, t5 before t2
constraint, t3 same-day t5
domain, t1 ends-by wed 2pm 15
domain, t2 ends-by wed 11am 20
domain, t3 ends-by wed 12pm 10
domain, t4 ends-by tue 12pm 10
domain, t5 ends-by wed 11am 20
```

```
task, t1 2
task, t2 2
task, t3 2
task, t4 2
task, t5 2
constraint, t2 before t1
constraint, t4 same-day t2
domain, t1 ends-by wed 2pm 20
domain, t2 ends-by wed 12pm 15
domain, t3 ends-by tue 11am 15
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by wed 12pm 20
task, t1 3
task, t2 3
task, t3 2
task, t4 2
task, t5 2
constraint, t5 same-day t3
constraint, t3 same-day t1
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by tue 2pm 15
domain, t4 ends-by mon 11am 15
domain, t5 ends-by mon 12pm 15
n=5 k=2 | nodes=19.5 time=0.004s cost=0.0
task, t1 3
task, t2 2
task, t3 2
task, t4 2
task, t5 3
constraint, t1 same-day t5
constraint, t5 before t3
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 12pm 15
domain, t4 ends-by mon 11am 15
domain, t5 ends-by mon 2pm 10
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 3
constraint, t2 same-day t5
constraint, t5 same-day t2
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 11am 15
domain, t3 ends-by wed 1pm 15
domain, t4 ends-by wed 12pm 15
domain, t5 ends-by tue 1pm 20
task, t1 3
task, t2 2
task, t3 3
task, t4 2
task, t5 2
constraint, t3 same-day t5
constraint, t2 before t3
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 11am 15
domain, t3 ends-by tue 11am 20
domain, t4 ends-by wed 2pm 20
```

```
domain, t5 ends-by wed 2pm 10
task, t1 3
task, t2 2
task, t3 2
task, t4 3
task, t5 2
constraint, t4 before t2
constraint, t5 before t3
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 12pm 15
domain, t5 ends-by mon 11am 15
n=5 k=3 | nodes=14.0 time=0.004s cost=5.0
task, t1 3
task, t2 3
task, t3 3
task, t4 3
task, t5 3
constraint, t1 before t4
constraint, t2 same-day t3
domain, t1 ends-by wed 2pm 20
domain, t2 ends-by tue 11am 15
domain, t3 ends-by wed 11am 20
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by mon 2pm 15
task, t1 3
task, t2 3
task, t3 3
task, t4 2
task, t5 3
constraint, t3 same-day t4
constraint, t1 same-day t2
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by mon 1pm 15
domain, t5 ends-by mon 1pm 15
task, t1 3
task, t2 2
task, t3 2
task, t4 2
task, t5 3
constraint, t1 before t3
constraint, t1 before t2
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by mon 11am 15
domain, t3 ends-by tue 2pm 10
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 2pm 10
task, t1 3
task, t2 3
task, t3 3
task, t4 3
task, t5 2
constraint, t3 same-day t5
constraint, t2 same-day t4
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 1pm 15
domain, t3 ends-by wed 11am 20
```

```
domain, t4 ends-by tue 1pm 15
domain, t5 ends-by wed 11am 20
n=5 k=4 | nodes=13.8 time=0.004s cost=26.2
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 3
constraint, t5 before t1
constraint, t1 same-day t3
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by wed 1pm 15
domain, t3 ends-by wed 2pm 15
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by wed 1pm 15
task, t1 2
task, t2 2
task, t3 3
task, t4 3
task, t5 3
constraint, t4 before t3
constraint, t3 before t2
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 11am 20
domain, t3 ends-by tue 11am 15
domain, t4 ends-by wed 1pm 10
domain, t5 ends-by mon 1pm 15
task, t1 3
task, t2 2
task, t3 2
task, t4 2
task, t5 3
constraint, t4 before t5
constraint, t1 before t5
domain, t1 ends-by mon 11am 10
domain, t2 ends-by wed 1pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by tue 11am 20
task, t1 3
task, t2 3
task, t3 3
task, t4 3
task, t5 3
constraint, t5 before t3
constraint, t2 before t3
domain, t1 ends-by wed 11am 15
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 11am 10
domain, t5 ends-by mon 1pm 20
n=5 k=5 | nodes=9.8 time=0.003s cost=15.0
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 3
constraint, t5 before t3
constraint, t3 before t4
domain, t1 ends-by tue 1pm 10
```

```
domain, t2 ends-by wed 1pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by tue 2pm 15
domain, t5 ends-by tue 11am 15
task, t1 3
task, t2 3
task, t3 2
task, t4 3
task, t5 2
constraint, t1 before t5
constraint, t2 before t1
domain, t1 ends-by tue 11am 20
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by wed 11am 15
domain, t5 ends-by mon 1pm 15
task, t1 2
task, t2 3
task, t3 2
task, t4 3
task, t5 3
constraint, t5 same-day t3
constraint, t1 same-day t2
domain, t1 ends-by wed 12pm 15
domain, t2 ends-by wed 1pm 20
domain, t3 ends-by wed 2pm 15
domain, t4 ends-by wed 2pm 20
domain, t5 ends-by wed 1pm 20
task, t1 2
task, t2 3
task, t3 3
task, t4 3
task, t5 2
constraint, t2 same-day t4
constraint, t4 same-day t1
domain, t1 ends-by mon 11am 15
domain, t2 ends-by tue 12pm 15
domain, t3 ends-by mon 11am 20
domain, t4 ends-by tue 12pm 15
domain, t5 ends-by wed 1pm 15
n=5 k=6 | nodes=8.0 time=0.004s cost=87.5
task, t1 3
task, t2 2
task, t3 3
task, t4 3
task, t5 2
task, t6 2
constraint, t1 before t2
constraint, t6 same-day t2
constraint, t4 same-day t3
domain, t1 ends-by mon 2pm 15
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by wed 11am 20
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by mon 11am 10
domain, t6 ends-by tue 1pm 15
task, t1 2
task, t2 3
task, t3 2
task, t4 3
```

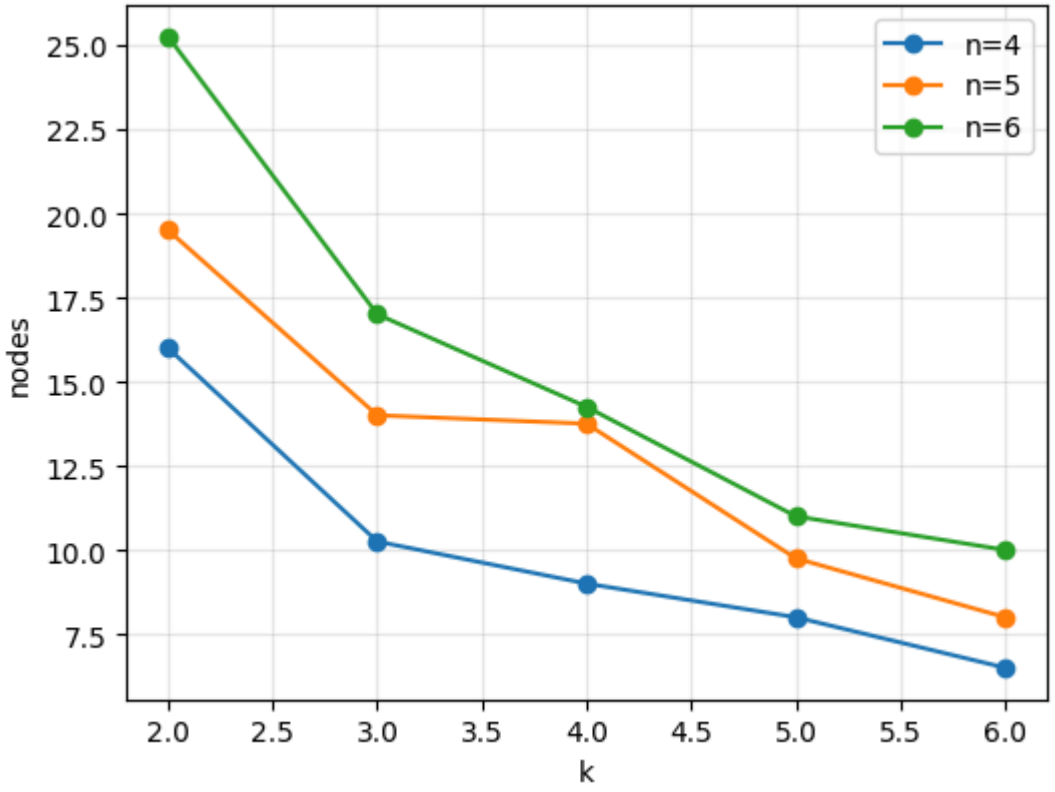
```
task, t5 2
task, t6 3
constraint, t5 same-day t4
constraint, t3 same-day t6
domain, t1 ends-by tue 2pm 15
domain, t2 ends-by tue 2pm 15
domain, t3 ends-by wed 1pm 20
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by wed 11am 20
domain, t6 ends-by mon 2pm 20
task, t1 2
task, t2 3
task, t3 3
task, t4 2
task, t5 3
task, t6 3
constraint, t5 same-day t1
constraint, t1 before t5
constraint, t5 same-day t3
domain, t1 ends-by mon 1pm 15
domain, t2 ends-by mon 11am 20
domain, t3 ends-by mon 11am 20
domain, t4 ends-by tue 12pm 10
domain, t5 ends-by wed 11am 10
domain, t6 ends-by mon 12pm 20
task, t1 2
task, t2 2
task, t3 3
task, t4 3
task, t5 3
task, t6 2
constraint, t1 same-day t3
constraint, t2 before t3
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by wed 12pm 20
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by wed 1pm 20
domain, t5 ends-by tue 11am 20
domain, t6 ends-by tue 12pm 10
n=6 k=2 | nodes=25.2 time=0.006s cost=10.0
task, t1 3
task, t2 2
task, t3 2
task, t4 3
task, t5 2
task, t6 3
constraint, t3 same-day t6
constraint, t6 before t1
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by wed 2pm 20
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by wed 1pm 15
domain, t6 ends-by tue 1pm 10
task, t1 3
task, t2 3
task, t3 3
task, t4 2
task, t5 3
task, t6 2
```

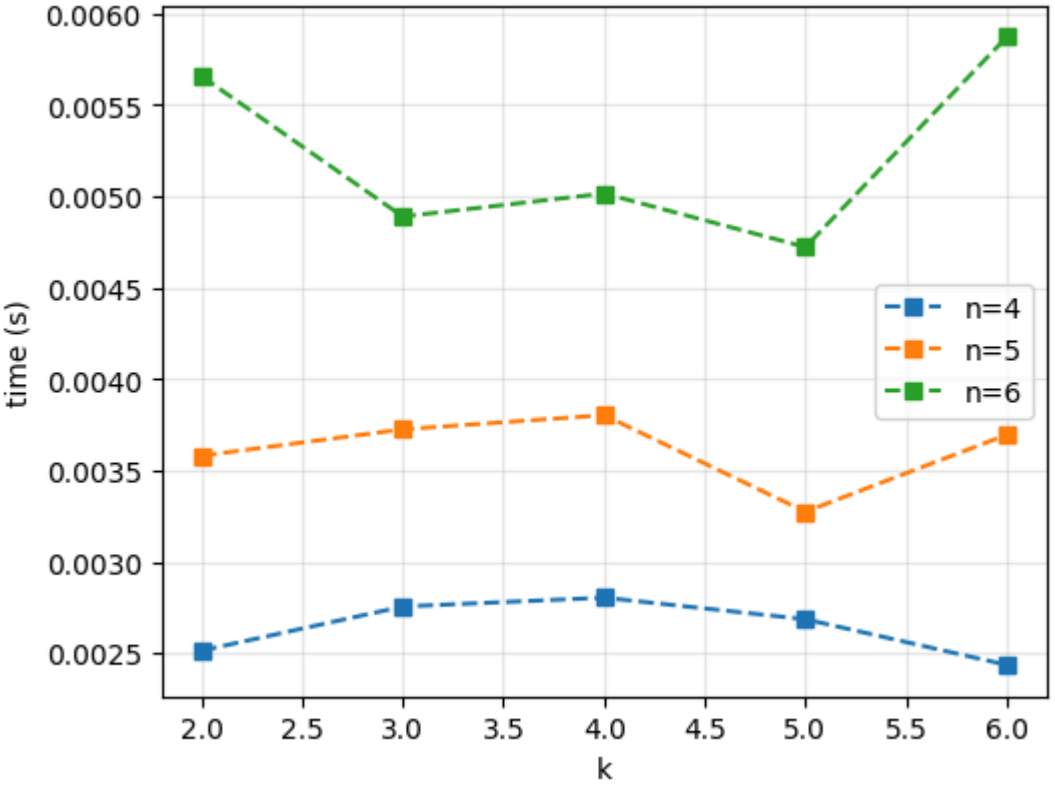
```
constraint, t3 same-day t4
constraint, t4 same-day t1
domain, t1 ends-by mon 11am 20
domain, t2 ends-by tue 1pm 15
domain, t3 ends-by mon 12pm 15
domain, t4 ends-by tue 2pm 20
domain, t5 ends-by mon 1pm 15
domain, t6 ends-by mon 2pm 15
task, t1 3
task, t2 3
task, t3 3
task, t4 3
task, t5 3
task, t6 2
constraint, t4 same-day t6
constraint, t6 before t3
constraint, t5 before t3
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by mon 11am 20
domain, t3 ends-by wed 12pm 10
domain, t4 ends-by wed 12pm 10
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by mon 2pm 20
task, t1 2
task, t2 3
task, t3 2
task, t4 2
task, t5 2
task, t6 3
constraint, t3 same-day t4
constraint, t3 before t5
domain, t1 ends-by wed 2pm 10
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by wed 11am 15
domain, t5 ends-by mon 2pm 10
domain, t6 ends-by wed 1pm 10
n=6 k=3 | nodes=17.0 time=0.005s cost=15.0
task, t1 3
task, t2 2
task, t3 3
task, t4 3
task, t5 2
task, t6 3
constraint, t2 same-day t3
constraint, t4 before t6
domain, t1 ends-by wed 12pm 20
domain, t2 ends-by tue 2pm 15
domain, t3 ends-by wed 1pm 20
domain, t4 ends-by wed 11am 20
domain, t5 ends-by wed 2pm 20
domain, t6 ends-by wed 11am 15
task, t1 3
task, t2 2
task, t3 3
task, t4 2
task, t5 2
task, t6 3
constraint, t6 before t2
constraint, t3 before t1
```

```
constraint, t6 same-day t4
domain, t1 ends-by tue 11am 10
domain, t2 ends-by wed 2pm 20
domain, t3 ends-by tue 11am 10
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by tue 11am 15
domain, t6 ends-by mon 2pm 15
task, t1 3
task, t2 2
task, t3 3
task, t4 3
task, t5 2
task, t6 2
constraint, t6 before t3
constraint, t4 same-day t6
constraint, t6 before t4
domain, t1 ends-by mon 1pm 15
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by wed 2pm 15
domain, t4 ends-by wed 11am 10
domain, t5 ends-by mon 12pm 15
domain, t6 ends-by mon 1pm 20
task, t1 2
task, t2 2
task, t3 2
task, t4 3
task, t5 2
task, t6 2
constraint, t1 same-day t6
constraint, t1 same-day t5
constraint, t6 same-day t5
domain, t1 ends-by mon 11am 10
domain, t2 ends-by mon 2pm 15
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by tue 11am 15
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by wed 1pm 15
n=6 k=4 | nodes=14.2 time=0.005s cost=0.0
task, t1 3
task, t2 2
task, t3 2
task, t4 3
task, t5 2
task, t6 3
constraint, t2 before t3
constraint, t3 before t1
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by wed 11am 15
domain, t3 ends-by wed 11am 15
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by mon 2pm 10
domain, t6 ends-by tue 2pm 10
task, t1 2
task, t2 2
task, t3 2
task, t4 2
task, t5 3
task, t6 2
constraint, t6 same-day t2
constraint, t5 same-day t3
```

```
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by mon 11am 15
domain, t6 ends-by mon 1pm 10
task, t1 3
task, t2 3
task, t3 3
task, t4 2
task, t5 3
task, t6 2
constraint, t3 same-day t2
constraint, t2 same-day t6
constraint, t5 before t2
domain, t1 ends-by tue 11am 10
domain, t2 ends-by wed 11am 20
domain, t3 ends-by mon 2pm 15
domain, t4 ends-by wed 1pm 20
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by tue 2pm 20
task, t1 3
task, t2 3
task, t3 3
task, t4 3
task, t5 3
task, t6 2
constraint, t6 same-day t2
constraint, t6 same-day t1
constraint, t2 same-day t3
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 11am 15
domain, t3 ends-by tue 2pm 10
domain, t4 ends-by mon 12pm 15
domain, t5 ends-by mon 11am 15
domain, t6 ends-by tue 11am 15
n=6 k=5 | nodes=11.0 time=0.005s cost=11.2
task, t1 2
task, t2 3
task, t3 2
task, t4 3
task, t5 2
task, t6 2
constraint, t2 same-day t1
constraint, t6 same-day t3
constraint, t2 before t6
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by mon 2pm 20
domain, t3 ends-by wed 11am 10
domain, t4 ends-by wed 12pm 20
domain, t5 ends-by wed 11am 10
domain, t6 ends-by mon 11am 15
task, t1 3
task, t2 2
task, t3 2
task, t4 2
task, t5 2
task, t6 2
constraint, t5 same-day t4
constraint, t4 same-day t5
```

```
constraint, t5 same-day t1
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 12pm 15
domain, t4 ends-by mon 12pm 15
domain, t5 ends-by tue 11am 15
domain, t6 ends-by tue 2pm 20
task, t1 3
task, t2 3
task, t3 2
task, t4 3
task, t5 3
task, t6 2
constraint, t5 same-day t6
constraint, t2 same-day t5
constraint, t2 same-day t1
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by mon 2pm 20
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by tue 1pm 15
domain, t5 ends-by wed 11am 20
domain, t6 ends-by wed 11am 15
task, t1 2
task, t2 3
task, t3 3
task, t4 2
task, t5 2
task, t6 3
constraint, t1 same-day t6
constraint, t2 before t4
domain, t1 ends-by wed 11am 10
domain, t2 ends-by wed 2pm 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by mon 11am 10
domain, t6 ends-by mon 2pm 15
n=6 k=6 | nodes=10.0 time=0.006s cost=11.2
```


nodes
k
n=4
n=5
n=6
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0


time (s)
k
n=4
n=5
n=6
0.0060
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
0.0025
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0