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 [37]:  import sys
          sys.path.append('aipython') # change to your directory
          sys.path # check that aipython is now on the path
```

```
Out[37]:  ['C:\\Program Files\\WindowsApps\\PythonSoftwareFoundation.Python.3.12_3.12.280
          0.0_x64__qbz5n2kfra8p0\\python312.zip',
           'C:\\Program Files\\WindowsApps\\PythonSoftwareFoundation.Python.3.12_3.12.280
          0.0_x64__qbz5n2kfra8p0\\DLLs',
           'C:\\Program Files\\WindowsApps\\PythonSoftwareFoundation.Python.3.12_3.12.280
          0.0_x64__qbz5n2kfra8p0\\Lib',
           'C:\\Program Files\\WindowsApps\\PythonSoftwareFoundation.Python.3.12_3.12.280
          0.0_x64__qbz5n2kfra8p0',
           '',
           'C:\\Users\\jelly\\AppData\\Local\\Packages\\PythonSoftwareFoundation.Python.
          3.12_qbz5n2kfra8p0\\LocalCache\\local-packages\\Python312\\site-packages',
           'C:\\Users\\jelly\\AppData\\Local\\Packages\\PythonSoftwareFoundation.Python.
          3.12_qbz5n2kfra8p0\\LocalCache\\local-packages\\Python312\\site-packages\\win3
          2',
           'C:\\Users\\jelly\\AppData\\Local\\Packages\\PythonSoftwareFoundation.Python.
          3.12_qbz5n2kfra8p0\\LocalCache\\local-packages\\Python312\\site-packages\\win32
          \\lib',
           'C:\\Users\\jelly\\AppData\\Local\\Packages\\PythonSoftwareFoundation.Python.
          3.12_qbz5n2kfra8p0\\LocalCache\\local-packages\\Python312\\site-packages\\Pytho
          nwin',
           'C:\\Program Files\\WindowsApps\\PythonSoftwareFoundation.Python.3.12_3.12.280
          0.0_x64__qbz5n2kfra8p0\\Lib\\site-packages',
           '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 [38]:  # -*- 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 [39]:
```python
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
```

```python
                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):
        cost = 0

        for var in self.domains:
            domain_values = self.domains[var]

            min_cost_for_var = float('inf')

            for domain_val in domain_values:
                cost_func = self.cost_functions[var][0]

                var_cost = cost_func(domain_val, self.soft_day_time[var], self.d

                if var_cost is not None and var_cost < min_cost_for_var:
                    min_cost_for_var = var_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
```

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 [40]:
```python
from cspConsistency import Con_solver, select, partition_domain
from searchProblem import Arc, Search_problem
```

```python
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 [41]:
```python
# domain specific CSP builder for week schedule
class CSP_builder():
```

```python
    # 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
```

```python
        # 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
```

```python
        # 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 [42]:
```
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 [43]:
```
# 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 [44]:
```python
# 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: 10
```

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 [45]:
```python
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 [46]:
```
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 [47]:
```python
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
```

```python
                    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.

```python
In [48]: 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

Write the answers here.

Describe the search spaces in terms of start state, successor functions and goal state(s) (1 mark)

Domain Splitting with Arc Consistency

- Initial state: The initial CSP with variable domains pruned by a first pass of arc consistency.
- Successor function: Select a variable with more than one value in its domain, partition its domain to create two new sub-problems (states), and apply arc consistency to each.
- Goal state: A CSP where every variable's domain contains exactly one value.

DFS Solver

- Initial state: An empty assignment.
- Successor function: Assign a value to the next unassigned variable that does not conflict with previously assigned variables.
- Goal state: A complete assignment of values to all variables that satisfies all constraints.

What is the branching factor and maximum depth to find any solution for the two algorithms (ignoring costs)? (1 mark)

n: number of variables. d: maximum domain size.

Domain Splitting with Arc Consistency: branching = 2, depth = $n * \log_2(d)$

DFS: branching = d, depth = n

What is the worst case time and space complexity of the two search algorithms? (1 mark)

n: number of variables. d: maximum domain size.

DFS: Time = $O(d^n)$, Space = $O(n)$

Domain Splitting with Arc Consistency: Time = $O(d^n)$, Space = $O(n * d)$

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)

A problem where tasks have long durations and a same day constraint would be easier for the domain splitting with arc consisteny. For example there are multiple tasks with a deadline due within the same day. The arc consisteny would quickly prune impossible start times, such as the other days, wheras the DFS would attempt invalid combinations before backtracking.

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 [49]:  # Code for Question 2
          # Place a copy of your code here and run it in the relevant cell

          # def calculate_cost(self):
          #         cost = 0

          #         for var in self.domains:
          #             domain_values = self.domains[var]

          #             min_cost_for_var = float('inf')

          #             for domain_val in domain_values:
          #                 cost_func = self.cost_functions[var][0]

          #                 var_cost = cost_func(domain_val, self.soft_day_time[var], self
          
          #                 if var_cost is not None and var_cost < min_cost_for_var:
          #                     min_cost_for_var = var_cost

          #             if min_cost_for_var != float('inf'):
          #                 cost += min_cost_for_var

          #         return cost
```

Answers for Question 2

Write the other answers here.

What is its computational complexity (give a general form in terms of fuzzy scheduling CSP size parameters)? (1 mark)

O (n * d)

Show that the cost function *f* never decreases along a path, and explain why this means the search algorithm is optimal (1 mark)

The *f* never decreases along a path because as we move along the path, the domain splitting means that the domains only get smaller into children, not adding better ones, so values are only removed not added. Since the cost for each variable is calculated from minimum soft constraint over its domain, removing values cannot decrease the minimun cost cost for that variable but only stay the same or increase. Thus the *f* will never decrease along a path.

This property of not decreasing makes it monotonic, and since *f* represents the lower bound of a cost that will never decrease and always underestimates or equals the true cost, the exploration of solutions can be considered optimal

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)

Quantify the performance gain (if any) achieved by the use of this cost function (1 mark)

There is a 0% performance gain, they both perform the same

```
In [50]:  import random

          def generate_problem(n):
              days = ['mon', 'tue', 'wed', 'thu', 'fri']
              times = ['9am', '10am', '11am', '12pm', '1pm', '2pm', '3pm', '4pm']
              costs = [5, 10, 15, 20]

              lines = []
              tasks = [f"t{i+1}" for i in range(n)]

              for t in tasks:
                  dur = random.randint(1, min(7, 8))
                  lines.append(f"task, {t} {dur}")

              if n >= 2:
                  num_bin = random.randint(0, min(2, n - 1))
                  for _ in range(num_bin):
                      t1, t2 = random.sample(tasks, 2)
                      rel = random.choice(['before', 'same-day'])
                      lines.append(f"constraint, {t1} {rel} {t2}")

              for t in tasks:
                  day = random.choice(days)
                  lines.append(f"domain, {t} {day}")

              for t in tasks:
                  day = random.choice(days)
                  time = random.choice(times)
                  cost = random.choice(costs)
                  lines.append(f"domain, {t} ends-by {day} {time} {cost}")
```

```python
        return "\n".join(lines)
```

In [51]:
```python
import numpy as np
import matplotlib.pyplot as plt

def run_empirical_evaluation(max_n=6, trials_per_n=10):
    avg_with = {}
    avg_without = {}

    original_cost_func = CSP_with_Cost.calculate_cost

    def zero_cost(self):
        return 0

    for n in range(2, max_n + 1):
        total_with = 0
        total_without = 0
        count_with = 0
        count_without = 0

        for _ in range(trials_per_n):
            spec = generate_problem(n)

            try:
                CSP_with_Cost.calculate_cost = original_cost_func
                csp = create_CSP_from_spec(spec)
                if csp is None:
                    continue
                problem = Search_with_AC_from_Cost_CSP(csp)
                solver = GreedySearcher(problem)
                solver.search()
                if hasattr(solver, 'num_expanded'):
                    total_with += solver.num_expanded
                    count_with += 1
            except Exception:
                pass

            try:
                CSP_with_Cost.calculate_cost = zero_cost
                csp = create_CSP_from_spec(spec)
                if csp is None:
                    continue
                problem = Search_with_AC_from_Cost_CSP(csp)
                solver = GreedySearcher(problem)
                solver.search()
                if hasattr(solver, 'num_expanded'):
                    total_without += solver.num_expanded
                    count_without += 1
            except Exception:
                pass

        avg_with[n] = total_with / count_with if count_with > 0 else 0
        avg_without[n] = total_without / count_without if count_without > 0 else
        print(f"n={n}: with={avg_with[n]:.1f}, without={avg_without[n]:.1f} (tri

    CSP_with_Cost.calculate_cost = original_cost_func

    ns = list(avg_with.keys())
    plt.figure(figsize=(8, 5))
```

```python
    plt.plot(ns, [avg_with[n] for n in ns], 'o-', label='With Cost Heuristic')
    plt.plot(ns, [avg_without[n] for n in ns], 's--', label='Without Cost (Zero)
    plt.xlabel('Number of Tasks (n)')
    plt.ylabel('Average Nodes Expanded')
    plt.title('Domain Splitting Solver: Cost Heuristic Impact')
    plt.legend()
    plt.grid(True)
    plt.xticks(ns)
    plt.show()

    gains = []
    for n in ns:
        if avg_without[n] > 0:
            reduction = (avg_without[n] - avg_with[n]) / avg_without[n] * 100
            gains.append(reduction)
    avg_gain = np.mean(gains) if gains else 0
    print(f"Average reduction in nodes expanded: {avg_gain:.1f}%")

    return avg_with, avg_without
```

In [52]:
```python
results_with, results_without = run_empirical_evaluation(max_n=10, trials_per_n=
```

```
task, t1 7
task, t2 3
constraint, t1 same-day t2
domain, t1 mon
domain, t2 wed
domain, t1 ends-by fri 4pm 10
domain, t2 ends-by mon 2pm 15
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 3
constraint, t1 same-day t2
domain, t1 mon
domain, t2 wed
domain, t1 ends-by fri 4pm 10
domain, t2 ends-by mon 2pm 15
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 7
domain, t1 tue
domain, t2 thu
domain, t1 ends-by fri 11am 20
domain, t2 ends-by fri 3pm 10
Splitting t1 into {8} and {9}
task, t1 6
task, t2 7
domain, t1 tue
domain, t2 thu
domain, t1 ends-by fri 11am 20
domain, t2 ends-by fri 3pm 10
Splitting t1 into {8} and {9}
task, t1 3
task, t2 7
domain, t1 thu
domain, t2 fri
domain, t1 ends-by wed 4pm 15
domain, t2 ends-by thu 11am 5
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
task, t1 3
task, t2 7
domain, t1 thu
domain, t2 fri
domain, t1 ends-by wed 4pm 15
domain, t2 ends-by thu 11am 5
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
task, t1 7
task, t2 6
domain, t1 fri
domain, t2 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by thu 10am 10
Splitting t2 into {0} and {1}
task, t1 7
task, t2 6
domain, t1 fri
domain, t2 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by thu 10am 10
Splitting t2 into {0} and {1}
```

```
task, t1 6
task, t2 7
constraint, t1 before t2
domain, t1 thu
domain, t2 fri
domain, t1 ends-by tue 9am 10
domain, t2 ends-by wed 1pm 20
Splitting t1 into {24} and {25}
task, t1 6
task, t2 7
constraint, t1 before t2
domain, t1 thu
domain, t2 fri
domain, t1 ends-by tue 9am 10
domain, t2 ends-by wed 1pm 20
Splitting t1 into {24} and {25}
task, t1 4
task, t2 2
constraint, t1 before t2
domain, t1 tue
domain, t2 thu
domain, t1 ends-by wed 9am 15
domain, t2 ends-by tue 1pm 20
Splitting t1 into {8, 9} and {10, 11}
Splitting t1 into {8} and {9}
Splitting t2 into {24, 25, 26} and {27, 28, 29}
Splitting t2 into {24} and {25, 26}
task, t1 4
task, t2 2
constraint, t1 before t2
domain, t1 tue
domain, t2 thu
domain, t1 ends-by wed 9am 15
domain, t2 ends-by tue 1pm 20
Splitting t1 into {8, 9} and {10, 11}
Splitting t1 into {8} and {9}
Splitting t2 into {24, 25, 26} and {27, 28, 29}
Splitting t2 into {24} and {25, 26}
task, t1 2
task, t2 4
domain, t1 fri
domain, t2 tue
domain, t1 ends-by tue 3pm 5
domain, t2 ends-by fri 4pm 10
Splitting t1 into {32, 33, 34} and {35, 36, 37}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
task, t1 2
task, t2 4
domain, t1 fri
domain, t2 tue
domain, t1 ends-by tue 3pm 5
domain, t2 ends-by fri 4pm 10
Splitting t1 into {32, 33, 34} and {35, 36, 37}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
task, t1 7
task, t2 4
```

```
domain, t1 wed
domain, t2 tue
domain, t1 ends-by wed 4pm 20
domain, t2 ends-by thu 2pm 20
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
task, t1 7
task, t2 4
domain, t1 wed
domain, t2 tue
domain, t1 ends-by wed 4pm 20
domain, t2 ends-by thu 2pm 20
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
task, t1 7
task, t2 5
constraint, t1 same-day t2
domain, t1 wed
domain, t2 wed
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by mon 1pm 15
Splitting t2 into {16} and {17, 18}
task, t1 7
task, t2 5
constraint, t1 same-day t2
domain, t1 wed
domain, t2 wed
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by mon 1pm 15
Splitting t2 into {16} and {17, 18}
task, t1 4
task, t2 3
domain, t1 mon
domain, t2 mon
domain, t1 ends-by mon 9am 10
domain, t2 ends-by tue 12pm 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {0, 1} and {2, 3, 4}
Splitting t2 into {0} and {1}
task, t1 4
task, t2 3
domain, t1 mon
domain, t2 mon
domain, t1 ends-by mon 9am 10
domain, t2 ends-by tue 12pm 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {0, 1} and {2, 3, 4}
Splitting t2 into {0} and {1}
n=2: with=3.0, without=3.0 (trials: 10/10)
task, t1 3
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t3 before t1
domain, t1 fri
domain, t2 mon
domain, t3 thu
domain, t1 ends-by mon 3pm 10
```

```
domain, t2 ends-by tue 9am 15
domain, t3 ends-by fri 4pm 10
Splitting t1 into {32, 33} and {34, 35, 36}
Splitting t1 into {32} and {33}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
task, t1 3
task, t2 1
task, t3 1
constraint, t2 before t1
constraint, t3 before t1
domain, t1 fri
domain, t2 mon
domain, t3 thu
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by tue 9am 15
domain, t3 ends-by fri 4pm 10
Splitting t1 into {32, 33} and {34, 35, 36}
Splitting t1 into {32} and {33}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
task, t1 5
task, t2 6
task, t3 6
domain, t1 mon
domain, t2 thu
domain, t3 wed
domain, t1 ends-by thu 3pm 20
domain, t2 ends-by fri 3pm 15
domain, t3 ends-by fri 3pm 15
Splitting t1 into {0} and {1, 2}
Splitting t2 into {24} and {25}
Splitting t3 into {16} and {17}
task, t1 5
task, t2 6
task, t3 6
domain, t1 mon
domain, t2 thu
domain, t3 wed
domain, t1 ends-by thu 3pm 20
domain, t2 ends-by fri 3pm 15
domain, t3 ends-by fri 3pm 15
Splitting t1 into {0} and {1, 2}
Splitting t2 into {24} and {25}
Splitting t3 into {16} and {17}
task, t1 4
task, t2 5
task, t3 6
constraint, t2 before t3
domain, t1 thu
domain, t2 fri
domain, t3 thu
domain, t1 ends-by fri 11am 15
domain, t2 ends-by tue 9am 5
domain, t3 ends-by fri 3pm 10
Splitting t1 into {24, 25} and {26, 27}
```

```
... t1 in {24, 25} has no solution
... t1 in {26, 27} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 5
task, t3 6
constraint, t2 before t3
domain, t1 thu
domain, t2 fri
domain, t3 thu
domain, t1 ends-by fri 11am 15
domain, t2 ends-by tue 9am 5
domain, t3 ends-by fri 3pm 10
Splitting t1 into {24, 25} and {26, 27}
... t1 in {24, 25} has no solution
... t1 in {26, 27} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 1
task, t3 1
domain, t1 thu
domain, t2 thu
domain, t3 fri
domain, t1 ends-by thu 9am 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 1pm 5
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t3 into {32} and {33, 34}
task, t1 3
task, t2 1
task, t3 1
domain, t1 thu
domain, t2 thu
domain, t3 fri
domain, t1 ends-by thu 9am 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 1pm 5
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t3 into {32} and {33, 34}
task, t1 3
task, t2 3
task, t3 1
constraint, t2 before t1
constraint, t1 same-day t3
domain, t1 wed
domain, t2 thu
domain, t3 thu
domain, t1 ends-by thu 4pm 15
domain, t2 ends-by thu 12pm 5
domain, t3 ends-by tue 2pm 15
No (more) solutions. Total of 1 paths expanded.
task, t1 3
```

```
task, t2 3
task, t3 1
constraint, t2 before t1
constraint, t1 same-day t3
domain, t1 wed
domain, t2 thu
domain, t3 thu
domain, t1 ends-by thu 4pm 15
domain, t2 ends-by thu 12pm 5
domain, t3 ends-by tue 2pm 15
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 7
task, t3 5
domain, t1 fri
domain, t2 fri
domain, t3 tue
domain, t1 ends-by tue 10am 15
domain, t2 ends-by thu 1pm 5
domain, t3 ends-by tue 4pm 20
Splitting t3 into {8} and {9, 10}
task, t1 7
task, t2 7
task, t3 5
domain, t1 fri
domain, t2 fri
domain, t3 tue
domain, t1 ends-by tue 10am 15
domain, t2 ends-by thu 1pm 5
domain, t3 ends-by tue 4pm 20
Splitting t3 into {8} and {9, 10}
task, t1 1
task, t2 4
task, t3 7
constraint, t3 same-day t1
constraint, t2 same-day t1
domain, t1 fri
domain, t2 fri
domain, t3 wed
domain, t1 ends-by tue 9am 10
domain, t2 ends-by tue 1pm 5
domain, t3 ends-by fri 11am 20
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 4
task, t3 7
constraint, t3 same-day t1
constraint, t2 same-day t1
domain, t1 fri
domain, t2 fri
domain, t3 wed
domain, t1 ends-by tue 9am 10
domain, t2 ends-by tue 1pm 5
domain, t3 ends-by fri 11am 20
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 6
task, t3 3
constraint, t1 same-day t2
constraint, t2 before t3
```

```
domain, t1 fri
domain, t2 thu
domain, t3 tue
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by fri 10am 5
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 6
task, t3 3
constraint, t1 same-day t2
constraint, t2 before t3
domain, t1 fri
domain, t2 thu
domain, t3 tue
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by fri 10am 5
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 7
task, t3 2
constraint, t2 before t1
constraint, t2 same-day t3
domain, t1 mon
domain, t2 mon
domain, t3 tue
domain, t1 ends-by fri 10am 15
domain, t2 ends-by tue 9am 15
domain, t3 ends-by tue 2pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 7
task, t3 2
constraint, t2 before t1
constraint, t2 same-day t3
domain, t1 mon
domain, t2 mon
domain, t3 tue
domain, t1 ends-by fri 10am 15
domain, t2 ends-by tue 9am 15
domain, t3 ends-by tue 2pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 3
task, t3 5
domain, t1 fri
domain, t2 mon
domain, t3 tue
domain, t1 ends-by tue 1pm 15
domain, t2 ends-by thu 4pm 5
domain, t3 ends-by mon 2pm 10
Splitting t1 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {0, 1} and {2, 3, 4}
Splitting t2 into {0} and {1}
Splitting t3 into {8} and {9, 10}
task, t1 1
task, t2 3
task, t3 5
```

```
domain, t1 fri
domain, t2 mon
domain, t3 tue
domain, t1 ends-by tue 1pm 15
domain, t2 ends-by thu 4pm 5
domain, t3 ends-by mon 2pm 10
Splitting t1 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {0, 1} and {2, 3, 4}
Splitting t2 into {0} and {1}
Splitting t3 into {8} and {9, 10}
n=3: with=3.1, without=3.1 (trials: 10/10)
task, t1 5
task, t2 5
task, t3 6
task, t4 3
constraint, t3 before t4
domain, t1 tue
domain, t2 fri
domain, t3 fri
domain, t4 thu
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by thu 2pm 5
domain, t3 ends-by wed 4pm 20
domain, t4 ends-by fri 9am 20
Splitting t1 into {8} and {9, 10}
... t1 in {8} has no solution
... t1 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 5
task, t3 6
task, t4 3
constraint, t3 before t4
domain, t1 tue
domain, t2 fri
domain, t3 fri
domain, t4 thu
domain, t1 ends-by wed 12pm 10
domain, t2 ends-by thu 2pm 5
domain, t3 ends-by wed 4pm 20
domain, t4 ends-by fri 9am 20
Splitting t1 into {8} and {9, 10}
... t1 in {8} has no solution
... t1 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 5
task, t3 5
task, t4 4
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 mon
domain, t1 ends-by mon 3pm 5
domain, t2 ends-by wed 2pm 10
domain, t3 ends-by thu 10am 5
domain, t4 ends-by mon 2pm 10
Splitting t1 into {8, 9} and {10, 11}
Splitting t1 into {8} and {9}
```

```
Splitting t2 into {32} and {33, 34}
Splitting t3 into {16} and {17, 18}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
task, t1 4
task, t2 5
task, t3 5
task, t4 4
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 mon
domain, t1 ends-by mon 3pm 5
domain, t2 ends-by wed 2pm 10
domain, t3 ends-by thu 10am 5
domain, t4 ends-by mon 2pm 10
Splitting t1 into {8, 9} and {10, 11}
Splitting t1 into {8} and {9}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {16} and {17, 18}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
task, t1 7
task, t2 6
task, t3 7
task, t4 4
constraint, t4 same-day t2
domain, t1 wed
domain, t2 thu
domain, t3 wed
domain, t4 fri
domain, t1 ends-by wed 12pm 15
domain, t2 ends-by fri 12pm 5
domain, t3 ends-by tue 10am 10
domain, t4 ends-by tue 2pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 6
task, t3 7
task, t4 4
constraint, t4 same-day t2
domain, t1 wed
domain, t2 thu
domain, t3 wed
domain, t4 fri
domain, t1 ends-by wed 12pm 15
domain, t2 ends-by fri 12pm 5
domain, t3 ends-by tue 10am 10
domain, t4 ends-by tue 2pm 10
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 1
task, t3 4
task, t4 1
domain, t1 mon
domain, t2 wed
domain, t3 thu
domain, t4 tue
domain, t1 ends-by wed 12pm 20
domain, t2 ends-by mon 3pm 5
```

```
domain, t3 ends-by fri 11am 20
domain, t4 ends-by wed 9am 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t4 into {8} and {9, 10}
task, t1 4
task, t2 1
task, t3 4
task, t4 1
domain, t1 mon
domain, t2 wed
domain, t3 thu
domain, t4 tue
domain, t1 ends-by wed 12pm 20
domain, t2 ends-by mon 3pm 5
domain, t3 ends-by fri 11am 20
domain, t4 ends-by wed 9am 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t4 into {8} and {9, 10}
task, t1 4
task, t2 7
task, t3 7
task, t4 2
constraint, t4 same-day t1
constraint, t1 same-day t3
domain, t1 mon
domain, t2 wed
domain, t3 tue
domain, t4 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by fri 4pm 20
domain, t3 ends-by wed 3pm 20
domain, t4 ends-by fri 4pm 15
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 7
task, t3 7
task, t4 2
constraint, t4 same-day t1
constraint, t1 same-day t3
domain, t1 mon
domain, t2 wed
domain, t3 tue
domain, t4 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by fri 4pm 20
domain, t3 ends-by wed 3pm 20
domain, t4 ends-by fri 4pm 15
No (more) solutions. Total of 1 paths expanded.
```

```
task, t1 6
task, t2 7
task, t3 2
task, t4 3
constraint, t2 same-day t4
constraint, t1 same-day t3
domain, t1 tue
domain, t2 thu
domain, t3 tue
domain, t4 fri
domain, t1 ends-by fri 11am 20
domain, t2 ends-by thu 1pm 15
domain, t3 ends-by mon 4pm 5
domain, t4 ends-by wed 11am 20
Splitting t1 into {8} and {9}
... t1 in {8} has no solution
... t1 in {9} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 7
task, t3 2
task, t4 3
constraint, t2 same-day t4
constraint, t1 same-day t3
domain, t1 tue
domain, t2 thu
domain, t3 tue
domain, t4 fri
domain, t1 ends-by fri 11am 20
domain, t2 ends-by thu 1pm 15
domain, t3 ends-by mon 4pm 5
domain, t4 ends-by wed 11am 20
Splitting t1 into {8} and {9}
... t1 in {8} has no solution
... t1 in {9} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 2
task, t3 2
task, t4 7
constraint, t4 before t3
domain, t1 mon
domain, t2 mon
domain, t3 wed
domain, t4 wed
domain, t1 ends-by thu 11am 5
domain, t2 ends-by thu 9am 20
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by tue 12pm 20
Splitting t1 into {0, 1, 2} and {3, 4, 5, 6}
... t1 in {0, 1, 2} has no solution
... t1 in {3, 4, 5, 6} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 2
task, t3 2
task, t4 7
constraint, t4 before t3
domain, t1 mon
domain, t2 mon
```

```
domain, t3 wed
domain, t4 wed
domain, t1 ends-by thu 11am 5
domain, t2 ends-by thu 9am 20
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by tue 12pm 20
Splitting t1 into {0, 1, 2} and {3, 4, 5, 6}
... t1 in {0, 1, 2} has no solution
... t1 in {3, 4, 5, 6} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 2
task, t3 4
task, t4 6
domain, t1 thu
domain, t2 fri
domain, t3 tue
domain, t4 tue
domain, t1 ends-by tue 11am 15
domain, t2 ends-by fri 2pm 5
domain, t3 ends-by tue 4pm 20
domain, t4 ends-by thu 10am 10
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
Splitting t2 into {32, 33, 34} and {35, 36, 37}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {8} and {9}
task, t1 3
task, t2 2
task, t3 4
task, t4 6
domain, t1 thu
domain, t2 fri
domain, t3 tue
domain, t4 tue
domain, t1 ends-by tue 11am 15
domain, t2 ends-by fri 2pm 5
domain, t3 ends-by tue 4pm 20
domain, t4 ends-by thu 10am 10
Splitting t1 into {24, 25} and {26, 27, 28}
Splitting t1 into {24} and {25}
Splitting t2 into {32, 33, 34} and {35, 36, 37}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {8} and {9}
task, t1 3
task, t2 7
task, t3 4
task, t4 3
constraint, t2 before t1
constraint, t2 before t1
domain, t1 thu
domain, t2 fri
domain, t3 fri
domain, t4 fri
domain, t1 ends-by fri 10am 20
domain, t2 ends-by tue 2pm 15
```

```
domain, t3 ends-by mon 10am 5
domain, t4 ends-by wed 11am 10
Splitting t3 into {32, 33} and {34, 35}
... t3 in {32, 33} has no solution
... t3 in {34, 35} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 7
task, t3 4
task, t4 3
constraint, t2 before t1
constraint, t2 before t1
domain, t1 thu
domain, t2 fri
domain, t3 fri
domain, t4 fri
domain, t1 ends-by fri 10am 20
domain, t2 ends-by tue 2pm 15
domain, t3 ends-by mon 10am 5
domain, t4 ends-by wed 11am 10
Splitting t3 into {32, 33} and {34, 35}
... t3 in {32, 33} has no solution
... t3 in {34, 35} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 3
task, t3 5
task, t4 1
constraint, t2 before t3
constraint, t4 before t3
domain, t1 fri
domain, t2 mon
domain, t3 tue
domain, t4 fri
domain, t1 ends-by thu 2pm 15
domain, t2 ends-by tue 2pm 15
domain, t3 ends-by tue 2pm 15
domain, t4 ends-by mon 2pm 10
Splitting t1 into {32, 33} and {34, 35, 36}
... t1 in {32, 33} has no solution
... t1 in {34, 35, 36} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 3
task, t3 5
task, t4 1
constraint, t2 before t3
constraint, t4 before t3
domain, t1 fri
domain, t2 mon
domain, t3 tue
domain, t4 fri
domain, t1 ends-by thu 2pm 15
domain, t2 ends-by tue 2pm 15
domain, t3 ends-by tue 2pm 15
domain, t4 ends-by mon 2pm 10
Splitting t1 into {32, 33} and {34, 35, 36}
... t1 in {32, 33} has no solution
... t1 in {34, 35, 36} has no solution
No (more) solutions. Total of 1 paths expanded.
```

```
n=4: with=3.1, without=3.1 (trials: 10/10)
task, t1 7
task, t2 5
task, t3 4
task, t4 4
task, t5 1
domain, t1 wed
domain, t2 mon
domain, t3 tue
domain, t4 tue
domain, t5 thu
domain, t1 ends-by fri 11am 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by wed 4pm 20
domain, t4 ends-by thu 11am 5
domain, t5 ends-by tue 1pm 20
Splitting t2 into {0} and {1, 2}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {8, 9} and {10, 11}
Splitting t4 into {8} and {9}
Splitting t5 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t5 into {24} and {25, 26}
task, t1 7
task, t2 5
task, t3 4
task, t4 4
task, t5 1
domain, t1 wed
domain, t2 mon
domain, t3 tue
domain, t4 tue
domain, t5 thu
domain, t1 ends-by fri 11am 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by wed 4pm 20
domain, t4 ends-by thu 11am 5
domain, t5 ends-by tue 1pm 20
Splitting t2 into {0} and {1, 2}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {8, 9} and {10, 11}
Splitting t4 into {8} and {9}
Splitting t5 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t5 into {24} and {25, 26}
task, t1 3
task, t2 1
task, t3 4
task, t4 2
task, t5 1
constraint, t1 before t4
domain, t1 mon
domain, t2 mon
domain, t3 mon
domain, t4 tue
domain, t5 fri
domain, t1 ends-by wed 2pm 20
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by wed 9am 20
domain, t4 ends-by mon 10am 10
```

```
domain, t5 ends-by fri 11am 5
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {0, 1} and {2, 3}
Splitting t3 into {0} and {1}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t5 into {32} and {33, 34}
task, t1 3
task, t2 1
task, t3 4
task, t4 2
task, t5 1
constraint, t1 before t4
domain, t1 mon
domain, t2 mon
domain, t3 mon
domain, t4 tue
domain, t5 fri
domain, t1 ends-by wed 2pm 20
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by wed 9am 20
domain, t4 ends-by mon 10am 10
domain, t5 ends-by fri 11am 5
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {0, 1} and {2, 3}
Splitting t3 into {0} and {1}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t5 into {32} and {33, 34}
task, t1 6
task, t2 3
task, t3 5
task, t4 3
task, t5 3
constraint, t2 before t3
domain, t1 fri
domain, t2 fri
domain, t3 wed
domain, t4 mon
domain, t5 tue
domain, t1 ends-by thu 4pm 15
domain, t2 ends-by thu 10am 20
domain, t3 ends-by mon 4pm 5
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by thu 4pm 20
Splitting t1 into {32} and {33}
... t1 in {32} has no solution
... t1 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 3
task, t3 5
```

```
task, t4 3
task, t5 3
constraint, t2 before t3
domain, t1 fri
domain, t2 fri
domain, t3 wed
domain, t4 mon
domain, t5 tue
domain, t1 ends-by thu 4pm 15
domain, t2 ends-by thu 10am 20
domain, t3 ends-by mon 4pm 5
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by thu 4pm 20
Splitting t1 into {32} and {33}
... t1 in {32} has no solution
... t1 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 2
task, t3 6
task, t4 1
task, t5 5
constraint, t5 same-day t2
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 tue
domain, t5 thu
domain, t1 ends-by fri 11am 5
domain, t2 ends-by wed 10am 5
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by fri 9am 5
domain, t5 ends-by mon 4pm 5
Splitting t1 into {0} and {1, 2}
... t1 in {0} has no solution
... t1 in {1, 2} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 2
task, t3 6
task, t4 1
task, t5 5
constraint, t5 same-day t2
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 tue
domain, t5 thu
domain, t1 ends-by fri 11am 5
domain, t2 ends-by wed 10am 5
domain, t3 ends-by wed 2pm 10
domain, t4 ends-by fri 9am 5
domain, t5 ends-by mon 4pm 5
Splitting t1 into {0} and {1, 2}
... t1 in {0} has no solution
... t1 in {1, 2} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 2
task, t3 3
```

```
task, t4 7
task, t5 2
domain, t1 tue
domain, t2 wed
domain, t3 wed
domain, t4 wed
domain, t5 fri
domain, t1 ends-by mon 1pm 5
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by mon 1pm 15
domain, t4 ends-by thu 4pm 10
domain, t5 ends-by tue 9am 15
Splitting t1 into {8} and {9}
Splitting t2 into {16, 17, 18} and {19, 20, 21}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {16, 17} and {18, 19, 20}
Splitting t3 into {16} and {17}
Splitting t5 into {32, 33, 34} and {35, 36, 37}
Splitting t5 into {32} and {33, 34}
task, t1 6
task, t2 2
task, t3 3
task, t4 7
task, t5 2
domain, t1 tue
domain, t2 wed
domain, t3 wed
domain, t4 wed
domain, t5 fri
domain, t1 ends-by mon 1pm 5
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by mon 1pm 15
domain, t4 ends-by thu 4pm 10
domain, t5 ends-by tue 9am 15
Splitting t1 into {8} and {9}
Splitting t2 into {16, 17, 18} and {19, 20, 21}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {16, 17} and {18, 19, 20}
Splitting t3 into {16} and {17}
Splitting t5 into {32, 33, 34} and {35, 36, 37}
Splitting t5 into {32} and {33, 34}
task, t1 5
task, t2 5
task, t3 5
task, t4 5
task, t5 2
domain, t1 tue
domain, t2 mon
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by fri 9am 15
domain, t5 ends-by wed 11am 5
Splitting t1 into {8} and {9, 10}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {24} and {25, 26}
```

```
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
task, t1 5
task, t2 5
task, t3 5
task, t4 5
task, t5 2
domain, t1 tue
domain, t2 mon
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t1 ends-by mon 3pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by fri 9am 15
domain, t5 ends-by wed 11am 5
Splitting t1 into {8} and {9, 10}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {24} and {25, 26}
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
task, t1 5
task, t2 5
task, t3 1
task, t4 1
task, t5 1
constraint, t4 same-day t3
constraint, t1 before t5
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 thu
domain, t5 tue
domain, t1 ends-by mon 11am 20
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by fri 2pm 10
domain, t4 ends-by tue 4pm 20
domain, t5 ends-by tue 2pm 20
Splitting t1 into {0} and {1, 2}
... t1 in {0} has no solution
... t1 in {1, 2} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 5
task, t3 1
task, t4 1
task, t5 1
constraint, t4 same-day t3
constraint, t1 before t5
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 thu
domain, t5 tue
domain, t1 ends-by mon 11am 20
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by fri 2pm 10
domain, t4 ends-by tue 4pm 20
```

```
domain, t5 ends-by tue 2pm 20
Splitting t1 into {0} and {1, 2}
... t1 in {0} has no solution
... t1 in {1, 2} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 4
task, t3 3
task, t4 2
task, t5 5
constraint, t2 before t1
domain, t1 wed
domain, t2 tue
domain, t3 wed
domain, t4 tue
domain, t5 thu
domain, t1 ends-by tue 10am 5
domain, t2 ends-by tue 10am 15
domain, t3 ends-by tue 1pm 5
domain, t4 ends-by wed 1pm 5
domain, t5 ends-by wed 11am 15
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {16, 17} and {18, 19, 20}
Splitting t3 into {16} and {17}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {24} and {25, 26}
task, t1 1
task, t2 4
task, t3 3
task, t4 2
task, t5 5
constraint, t2 before t1
domain, t1 wed
domain, t2 tue
domain, t3 wed
domain, t4 tue
domain, t5 thu
domain, t1 ends-by tue 10am 5
domain, t2 ends-by tue 10am 15
domain, t3 ends-by tue 1pm 5
domain, t4 ends-by wed 1pm 5
domain, t5 ends-by wed 11am 15
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {16, 17} and {18, 19, 20}
Splitting t3 into {16} and {17}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {24} and {25, 26}
task, t1 4
task, t2 7
task, t3 1
task, t4 6
task, t5 4
```

```
domain, t1 wed
domain, t2 thu
domain, t3 mon
domain, t4 wed
domain, t5 thu
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by fri 4pm 5
domain, t3 ends-by tue 11am 15
domain, t4 ends-by tue 1pm 5
domain, t5 ends-by mon 11am 20
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t3 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {16} and {17}
Splitting t5 into {24, 25} and {26, 27}
Splitting t5 into {24} and {25}
task, t1 4
task, t2 7
task, t3 1
task, t4 6
task, t5 4
domain, t1 wed
domain, t2 thu
domain, t3 mon
domain, t4 wed
domain, t5 thu
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by fri 4pm 5
domain, t3 ends-by tue 11am 15
domain, t4 ends-by tue 1pm 5
domain, t5 ends-by mon 11am 20
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t3 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {16} and {17}
Splitting t5 into {24, 25} and {26, 27}
Splitting t5 into {24} and {25}
task, t1 3
task, t2 4
task, t3 3
task, t4 4
task, t5 6
domain, t1 mon
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 tue
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by fri 11am 5
domain, t3 ends-by wed 12pm 10
domain, t4 ends-by tue 11am 15
domain, t5 ends-by mon 1pm 10
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
```

```
Splitting t4 into {32, 33} and {34, 35}
Splitting t4 into {32} and {33}
Splitting t5 into {8} and {9}
task, t1 3
task, t2 4
task, t3 3
task, t4 4
task, t5 6
domain, t1 mon
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 tue
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by fri 11am 5
domain, t3 ends-by wed 12pm 10
domain, t4 ends-by tue 11am 15
domain, t5 ends-by mon 1pm 10
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
Splitting t4 into {32, 33} and {34, 35}
Splitting t4 into {32} and {33}
Splitting t5 into {8} and {9}
n=5: with=6.5, without=6.5 (trials: 10/10)
task, t1 6
task, t2 2
task, t3 2
task, t4 6
task, t5 6
task, t6 4
constraint, t5 before t1
constraint, t3 before t5
domain, t1 thu
domain, t2 wed
domain, t3 mon
domain, t4 fri
domain, t5 mon
domain, t6 mon
domain, t1 ends-by mon 11am 15
domain, t2 ends-by thu 10am 20
domain, t3 ends-by thu 9am 20
domain, t4 ends-by tue 1pm 5
domain, t5 ends-by thu 4pm 5
domain, t6 ends-by tue 1pm 20
Splitting t2 into {16, 17, 18} and {19, 20, 21}
... t2 in {16, 17, 18} has no solution
... t2 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 2
task, t3 2
task, t4 6
task, t5 6
task, t6 4
constraint, t5 before t1
constraint, t3 before t5
```

```
domain, t1 thu
domain, t2 wed
domain, t3 mon
domain, t4 fri
domain, t5 mon
domain, t6 mon
domain, t1 ends-by mon 11am 15
domain, t2 ends-by thu 10am 20
domain, t3 ends-by thu 9am 20
domain, t4 ends-by tue 1pm 5
domain, t5 ends-by thu 4pm 5
domain, t6 ends-by tue 1pm 20
Splitting t2 into {16, 17, 18} and {19, 20, 21}
... t2 in {16, 17, 18} has no solution
... t2 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 3
task, t3 3
task, t4 4
task, t5 1
task, t6 3
domain, t1 wed
domain, t2 fri
domain, t3 fri
domain, t4 wed
domain, t5 wed
domain, t6 thu
domain, t1 ends-by fri 12pm 10
domain, t2 ends-by tue 3pm 20
domain, t3 ends-by mon 10am 15
domain, t4 ends-by fri 4pm 10
domain, t5 ends-by thu 2pm 10
domain, t6 ends-by tue 10am 15
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t2 into {32, 33} and {34, 35, 36}
Splitting t2 into {32} and {33}
Splitting t3 into {32, 33} and {34, 35, 36}
Splitting t3 into {32} and {33}
Splitting t4 into {16, 17} and {18, 19}
Splitting t4 into {16} and {17}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {24, 25} and {26, 27, 28}
Splitting t6 into {24} and {25}
task, t1 4
task, t2 3
task, t3 3
task, t4 4
task, t5 1
task, t6 3
domain, t1 wed
domain, t2 fri
domain, t3 fri
domain, t4 wed
domain, t5 wed
domain, t6 thu
domain, t1 ends-by fri 12pm 10
domain, t2 ends-by tue 3pm 20
```

```
domain, t3 ends-by mon 10am 15
domain, t4 ends-by fri 4pm 10
domain, t5 ends-by thu 2pm 10
domain, t6 ends-by tue 10am 15
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t2 into {32, 33} and {34, 35, 36}
Splitting t2 into {32} and {33}
Splitting t3 into {32, 33} and {34, 35, 36}
Splitting t3 into {32} and {33}
Splitting t4 into {16, 17} and {18, 19}
Splitting t4 into {16} and {17}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {24, 25} and {26, 27, 28}
Splitting t6 into {24} and {25}
task, t1 6
task, t2 1
task, t3 7
task, t4 4
task, t5 2
task, t6 1
constraint, t1 same-day t4
domain, t1 tue
domain, t2 thu
domain, t3 fri
domain, t4 tue
domain, t5 thu
domain, t6 mon
domain, t1 ends-by mon 9am 15
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by mon 4pm 10
domain, t4 ends-by thu 12pm 5
domain, t5 ends-by fri 10am 5
domain, t6 ends-by thu 2pm 5
Splitting t1 into {8} and {9}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t4 into {8, 9} and {10, 11}
Splitting t4 into {8} and {9}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t6 into {0} and {1, 2}
task, t1 6
task, t2 1
task, t3 7
task, t4 4
task, t5 2
task, t6 1
constraint, t1 same-day t4
domain, t1 tue
domain, t2 thu
domain, t3 fri
domain, t4 tue
domain, t5 thu
domain, t6 mon
domain, t1 ends-by mon 9am 15
domain, t2 ends-by tue 3pm 10
domain, t3 ends-by mon 4pm 10
```

```
domain, t4 ends-by thu 12pm 5
domain, t5 ends-by fri 10am 5
domain, t6 ends-by thu 2pm 5
Splitting t1 into {8} and {9}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t4 into {8, 9} and {10, 11}
Splitting t4 into {8} and {9}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t6 into {0} and {1, 2}
task, t1 2
task, t2 5
task, t3 1
task, t4 6
task, t5 2
task, t6 7
constraint, t2 before t6
domain, t1 wed
domain, t2 fri
domain, t3 wed
domain, t4 wed
domain, t5 fri
domain, t6 mon
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by mon 9am 10
domain, t3 ends-by fri 4pm 15
domain, t4 ends-by tue 11am 10
domain, t5 ends-by fri 4pm 10
domain, t6 ends-by mon 10am 10
Splitting t1 into {16, 17, 18} and {19, 20, 21}
... t1 in {16, 17, 18} has no solution
... t1 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 5
task, t3 1
task, t4 6
task, t5 2
task, t6 7
constraint, t2 before t6
domain, t1 wed
domain, t2 fri
domain, t3 wed
domain, t4 wed
domain, t5 fri
domain, t6 mon
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by mon 9am 10
domain, t3 ends-by fri 4pm 15
domain, t4 ends-by tue 11am 10
domain, t5 ends-by fri 4pm 10
domain, t6 ends-by mon 10am 10
Splitting t1 into {16, 17, 18} and {19, 20, 21}
... t1 in {16, 17, 18} has no solution
... t1 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 3
```

```
task, t3 1
task, t4 3
task, t5 2
task, t6 6
constraint, t5 before t2
domain, t1 wed
domain, t2 mon
domain, t3 fri
domain, t4 mon
domain, t5 fri
domain, t6 thu
domain, t1 ends-by fri 11am 15
domain, t2 ends-by fri 4pm 15
domain, t3 ends-by wed 12pm 15
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by fri 3pm 10
domain, t6 ends-by tue 10am 5
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
... t3 in {32, 33, 34} has no solution
... t3 in {35, 36, 37, 38} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 3
task, t3 1
task, t4 3
task, t5 2
task, t6 6
constraint, t5 before t2
domain, t1 wed
domain, t2 mon
domain, t3 fri
domain, t4 mon
domain, t5 fri
domain, t6 thu
domain, t1 ends-by fri 11am 15
domain, t2 ends-by fri 4pm 15
domain, t3 ends-by wed 12pm 15
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by fri 3pm 10
domain, t6 ends-by tue 10am 5
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
... t3 in {32, 33, 34} has no solution
... t3 in {35, 36, 37, 38} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 6
task, t3 1
task, t4 2
task, t5 7
task, t6 3
domain, t1 fri
domain, t2 wed
domain, t3 fri
domain, t4 tue
domain, t5 fri
domain, t6 tue
domain, t1 ends-by mon 3pm 20
domain, t2 ends-by thu 2pm 10
domain, t3 ends-by thu 11am 5
domain, t4 ends-by tue 3pm 5
```

```
domain, t5 ends-by wed 9am 5
domain, t6 ends-by thu 1pm 20
Splitting t1 into {32, 33} and {34, 35}
Splitting t1 into {32} and {33}
Splitting t2 into {16} and {17}
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t3 into {32} and {33, 34}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t6 into {8, 9} and {10, 11, 12}
Splitting t6 into {8} and {9}
task, t1 4
task, t2 6
task, t3 1
task, t4 2
task, t5 7
task, t6 3
domain, t1 fri
domain, t2 wed
domain, t3 fri
domain, t4 tue
domain, t5 fri
domain, t6 tue
domain, t1 ends-by mon 3pm 20
domain, t2 ends-by thu 2pm 10
domain, t3 ends-by thu 11am 5
domain, t4 ends-by tue 3pm 5
domain, t5 ends-by wed 9am 5
domain, t6 ends-by thu 1pm 20
Splitting t1 into {32, 33} and {34, 35}
Splitting t1 into {32} and {33}
Splitting t2 into {16} and {17}
Splitting t3 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t3 into {32} and {33, 34}
Splitting t4 into {8, 9, 10} and {11, 12, 13}
Splitting t4 into {8} and {9, 10}
Splitting t6 into {8, 9} and {10, 11, 12}
Splitting t6 into {8} and {9}
task, t1 5
task, t2 3
task, t3 5
task, t4 4
task, t5 2
task, t6 4
constraint, t2 before t3
constraint, t1 before t6
domain, t1 wed
domain, t2 tue
domain, t3 mon
domain, t4 mon
domain, t5 fri
domain, t6 mon
domain, t1 ends-by wed 3pm 5
domain, t2 ends-by thu 2pm 20
domain, t3 ends-by fri 9am 20
domain, t4 ends-by tue 9am 20
domain, t5 ends-by wed 1pm 20
domain, t6 ends-by tue 10am 15
Splitting t4 into {0, 1} and {2, 3}
... t4 in {0, 1} has no solution
```

```
... t4 in {2, 3} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 3
task, t3 5
task, t4 4
task, t5 2
task, t6 4
constraint, t2 before t3
constraint, t1 before t6
domain, t1 wed
domain, t2 tue
domain, t3 mon
domain, t4 mon
domain, t5 fri
domain, t6 mon
domain, t1 ends-by wed 3pm 5
domain, t2 ends-by thu 2pm 20
domain, t3 ends-by fri 9am 20
domain, t4 ends-by tue 9am 20
domain, t5 ends-by wed 1pm 20
domain, t6 ends-by tue 10am 15
Splitting t4 into {0, 1} and {2, 3}
... t4 in {0, 1} has no solution
... t4 in {2, 3} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 2
task, t3 3
task, t4 5
task, t5 3
task, t6 1
domain, t1 tue
domain, t2 mon
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t1 ends-by fri 10am 5
domain, t2 ends-by thu 2pm 20
domain, t3 ends-by wed 10am 5
domain, t4 ends-by mon 4pm 5
domain, t5 ends-by thu 12pm 5
domain, t6 ends-by tue 11am 15
Splitting t2 into {0, 1, 2} and {3, 4, 5}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t6 into {16} and {17, 18}
task, t1 7
task, t2 2
task, t3 3
task, t4 5
task, t5 3
task, t6 1
domain, t1 tue
```

```
domain, t2 mon
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t1 ends-by fri 10am 5
domain, t2 ends-by thu 2pm 20
domain, t3 ends-by wed 10am 5
domain, t4 ends-by mon 4pm 5
domain, t5 ends-by thu 12pm 5
domain, t6 ends-by tue 11am 15
Splitting t2 into {0, 1, 2} and {3, 4, 5}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t6 into {16} and {17, 18}
task, t1 6
task, t2 3
task, t3 7
task, t4 3
task, t5 4
task, t6 1
constraint, t3 same-day t6
domain, t1 tue
domain, t2 fri
domain, t3 mon
domain, t4 fri
domain, t5 fri
domain, t6 mon
domain, t1 ends-by fri 11am 5
domain, t2 ends-by thu 3pm 15
domain, t3 ends-by tue 10am 15
domain, t4 ends-by wed 12pm 20
domain, t5 ends-by fri 2pm 5
domain, t6 ends-by wed 2pm 15
Splitting t1 into {8} and {9}
Splitting t2 into {32, 33} and {34, 35, 36}
Splitting t2 into {32} and {33}
Splitting t4 into {32, 33} and {34, 35, 36}
Splitting t4 into {32} and {33}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t6 into {0} and {1, 2}
task, t1 6
task, t2 3
task, t3 7
task, t4 3
task, t5 4
task, t6 1
constraint, t3 same-day t6
domain, t1 tue
domain, t2 fri
domain, t3 mon
domain, t4 fri
domain, t5 fri
```

```
domain, t6 mon
domain, t1 ends-by fri 11am 5
domain, t2 ends-by thu 3pm 15
domain, t3 ends-by tue 10am 15
domain, t4 ends-by wed 12pm 20
domain, t5 ends-by fri 2pm 5
domain, t6 ends-by wed 2pm 15
Splitting t1 into {8} and {9}
Splitting t2 into {32, 33} and {34, 35, 36}
Splitting t2 into {32} and {33}
Splitting t4 into {32, 33} and {34, 35, 36}
Splitting t4 into {32} and {33}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t6 into {0} and {1, 2}
task, t1 5
task, t2 1
task, t3 2
task, t4 6
task, t5 2
task, t6 6
domain, t1 wed
domain, t2 thu
domain, t3 mon
domain, t4 thu
domain, t5 thu
domain, t6 tue
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by tue 9am 5
domain, t3 ends-by wed 9am 20
domain, t4 ends-by thu 1pm 5
domain, t5 ends-by mon 3pm 10
domain, t6 ends-by mon 12pm 10
Splitting t1 into {16} and {17, 18}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {0, 1, 2} and {3, 4, 5}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {24} and {25}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {8} and {9}
task, t1 5
task, t2 1
task, t3 2
task, t4 6
task, t5 2
task, t6 6
domain, t1 wed
domain, t2 thu
domain, t3 mon
domain, t4 thu
domain, t5 thu
domain, t6 tue
domain, t1 ends-by fri 1pm 20
domain, t2 ends-by tue 9am 5
domain, t3 ends-by wed 9am 20
domain, t4 ends-by thu 1pm 5
domain, t5 ends-by mon 3pm 10
```

```
domain, t6 ends-by mon 12pm 10
Splitting t1 into {16} and {17, 18}
Splitting t2 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {0, 1, 2} and {3, 4, 5}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {24} and {25}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {8} and {9}
n=6: with=6.7, without=6.7 (trials: 10/10)
task, t1 7
task, t2 6
task, t3 4
task, t4 4
task, t5 5
task, t6 1
task, t7 4
constraint, t2 same-day t6
constraint, t4 same-day t2
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 thu
domain, t5 tue
domain, t6 tue
domain, t7 mon
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by fri 1pm 15
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by fri 10am 15
domain, t5 ends-by tue 12pm 20
domain, t6 ends-by tue 11am 5
domain, t7 ends-by tue 3pm 15
Splitting t3 into {16, 17} and {18, 19}
... t3 in {16, 17} has no solution
... t3 in {18, 19} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 6
task, t3 4
task, t4 4
task, t5 5
task, t6 1
task, t7 4
constraint, t2 same-day t6
constraint, t4 same-day t2
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 thu
domain, t5 tue
domain, t6 tue
domain, t7 mon
domain, t1 ends-by wed 1pm 10
domain, t2 ends-by fri 1pm 15
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by fri 10am 15
domain, t5 ends-by tue 12pm 20
domain, t6 ends-by tue 11am 5
```

```
domain, t7 ends-by tue 3pm 15
Splitting t3 into {16, 17} and {18, 19}
... t3 in {16, 17} has no solution
... t3 in {18, 19} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 4
task, t3 7
task, t4 1
task, t5 7
task, t6 7
task, t7 2
constraint, t3 before t7
constraint, t7 same-day t2
domain, t1 thu
domain, t2 mon
domain, t3 wed
domain, t4 mon
domain, t5 mon
domain, t6 tue
domain, t7 wed
domain, t1 ends-by fri 3pm 10
domain, t2 ends-by fri 4pm 15
domain, t3 ends-by tue 4pm 15
domain, t4 ends-by mon 12pm 5
domain, t5 ends-by thu 10am 15
domain, t6 ends-by mon 12pm 5
domain, t7 ends-by thu 12pm 5
Splitting t1 into {24, 25, 26} and {27, 28, 29}
... t1 in {24, 25, 26} has no solution
... t1 in {27, 28, 29} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 4
task, t3 7
task, t4 1
task, t5 7
task, t6 7
task, t7 2
constraint, t3 before t7
constraint, t7 same-day t2
domain, t1 thu
domain, t2 mon
domain, t3 wed
domain, t4 mon
domain, t5 mon
domain, t6 tue
domain, t7 wed
domain, t1 ends-by fri 3pm 10
domain, t2 ends-by fri 4pm 15
domain, t3 ends-by tue 4pm 15
domain, t4 ends-by mon 12pm 5
domain, t5 ends-by thu 10am 15
domain, t6 ends-by mon 12pm 5
domain, t7 ends-by thu 12pm 5
Splitting t1 into {24, 25, 26} and {27, 28, 29}
... t1 in {24, 25, 26} has no solution
... t1 in {27, 28, 29} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
```

```
task, t2 3
task, t3 5
task, t4 3
task, t5 4
task, t6 3
task, t7 2
constraint, t4 same-day t5
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 thu
domain, t5 tue
domain, t6 wed
domain, t7 thu
domain, t1 ends-by thu 10am 10
domain, t2 ends-by thu 9am 15
domain, t3 ends-by wed 10am 10
domain, t4 ends-by fri 4pm 20
domain, t5 ends-by mon 2pm 15
domain, t6 ends-by wed 11am 5
domain, t7 ends-by mon 10am 20
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
... t1 in {8, 9, 10} has no solution
... t1 in {11, 12, 13, 14} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 3
task, t3 5
task, t4 3
task, t5 4
task, t6 3
task, t7 2
constraint, t4 same-day t5
domain, t1 tue
domain, t2 fri
domain, t3 wed
domain, t4 thu
domain, t5 tue
domain, t6 wed
domain, t7 thu
domain, t1 ends-by thu 10am 10
domain, t2 ends-by thu 9am 15
domain, t3 ends-by wed 10am 10
domain, t4 ends-by fri 4pm 20
domain, t5 ends-by mon 2pm 15
domain, t6 ends-by wed 11am 5
domain, t7 ends-by mon 10am 20
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
... t1 in {8, 9, 10} has no solution
... t1 in {11, 12, 13, 14} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 1
task, t3 4
task, t4 5
task, t5 1
task, t6 5
task, t7 6
domain, t1 fri
domain, t2 mon
```

```
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 tue
domain, t1 ends-by fri 4pm 20
domain, t2 ends-by mon 4pm 15
domain, t3 ends-by thu 2pm 15
domain, t4 ends-by tue 2pm 15
domain, t5 ends-by mon 4pm 10
domain, t6 ends-by tue 4pm 20
domain, t7 ends-by mon 1pm 10
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {32, 33} and {34, 35}
Splitting t3 into {32} and {33}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {8} and {9}
task, t1 7
task, t2 1
task, t3 4
task, t4 5
task, t5 1
task, t6 5
task, t7 6
domain, t1 fri
domain, t2 mon
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 tue
domain, t1 ends-by fri 4pm 20
domain, t2 ends-by mon 4pm 15
domain, t3 ends-by thu 2pm 15
domain, t4 ends-by tue 2pm 15
domain, t5 ends-by mon 4pm 10
domain, t6 ends-by tue 4pm 20
domain, t7 ends-by mon 1pm 10
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {32, 33} and {34, 35}
Splitting t3 into {32} and {33}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {8} and {9}
task, t1 5
task, t2 7
task, t3 4
task, t4 6
task, t5 7
task, t6 5
task, t7 7
constraint, t5 before t2
constraint, t5 before t7
```

```
domain, t1 wed
domain, t2 wed
domain, t3 thu
domain, t4 mon
domain, t5 mon
domain, t6 thu
domain, t7 tue
domain, t1 ends-by thu 11am 20
domain, t2 ends-by tue 12pm 15
domain, t3 ends-by wed 2pm 15
domain, t4 ends-by fri 11am 20
domain, t5 ends-by thu 4pm 10
domain, t6 ends-by fri 1pm 15
domain, t7 ends-by wed 9am 10
Splitting t1 into {16} and {17, 18}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {0} and {1}
Splitting t6 into {24} and {25, 26}
task, t1 5
task, t2 7
task, t3 4
task, t4 6
task, t5 7
task, t6 5
task, t7 7
constraint, t5 before t2
constraint, t5 before t7
domain, t1 wed
domain, t2 wed
domain, t3 thu
domain, t4 mon
domain, t5 mon
domain, t6 thu
domain, t7 tue
domain, t1 ends-by thu 11am 20
domain, t2 ends-by tue 12pm 15
domain, t3 ends-by wed 2pm 15
domain, t4 ends-by fri 11am 20
domain, t5 ends-by thu 4pm 10
domain, t6 ends-by fri 1pm 15
domain, t7 ends-by wed 9am 10
Splitting t1 into {16} and {17, 18}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {0} and {1}
Splitting t6 into {24} and {25, 26}
task, t1 1
task, t2 1
task, t3 2
task, t4 7
task, t5 2
task, t6 7
task, t7 3
domain, t1 wed
domain, t2 wed
domain, t3 fri
domain, t4 thu
domain, t5 thu
domain, t6 tue
```

```
domain, t7 mon
domain, t1 ends-by fri 1pm 10
domain, t2 ends-by thu 10am 10
domain, t3 ends-by mon 3pm 5
domain, t4 ends-by mon 12pm 15
domain, t5 ends-by fri 1pm 5
domain, t6 ends-by tue 1pm 10
domain, t7 ends-by fri 10am 20
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {32, 33, 34} and {35, 36, 37}
Splitting t3 into {32} and {33, 34}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t7 into {0, 1} and {2, 3, 4}
Splitting t7 into {0} and {1}
task, t1 1
task, t2 1
task, t3 2
task, t4 7
task, t5 2
task, t6 7
task, t7 3
domain, t1 wed
domain, t2 wed
domain, t3 fri
domain, t4 thu
domain, t5 thu
domain, t6 tue
domain, t7 mon
domain, t1 ends-by fri 1pm 10
domain, t2 ends-by thu 10am 10
domain, t3 ends-by mon 3pm 5
domain, t4 ends-by mon 12pm 15
domain, t5 ends-by fri 1pm 5
domain, t6 ends-by tue 1pm 10
domain, t7 ends-by fri 10am 20
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {32, 33, 34} and {35, 36, 37}
Splitting t3 into {32} and {33, 34}
Splitting t5 into {24, 25, 26} and {27, 28, 29}
Splitting t5 into {24} and {25, 26}
Splitting t7 into {0, 1} and {2, 3, 4}
Splitting t7 into {0} and {1}
task, t1 6
task, t2 1
task, t3 1
task, t4 2
task, t5 5
task, t6 6
task, t7 3
constraint, t2 before t3
constraint, t6 same-day t1
domain, t1 thu
domain, t2 fri
```

```
domain, t3 tue
domain, t4 wed
domain, t5 tue
domain, t6 wed
domain, t7 thu
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by tue 9am 10
domain, t5 ends-by fri 2pm 15
domain, t6 ends-by fri 12pm 20
domain, t7 ends-by mon 2pm 20
Splitting t4 into {16, 17, 18} and {19, 20, 21}
... t4 in {16, 17, 18} has no solution
... t4 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 1
task, t3 1
task, t4 2
task, t5 5
task, t6 6
task, t7 3
constraint, t2 before t3
constraint, t6 same-day t1
domain, t1 thu
domain, t2 fri
domain, t3 tue
domain, t4 wed
domain, t5 tue
domain, t6 wed
domain, t7 thu
domain, t1 ends-by wed 1pm 15
domain, t2 ends-by fri 3pm 10
domain, t3 ends-by wed 1pm 10
domain, t4 ends-by tue 9am 10
domain, t5 ends-by fri 2pm 15
domain, t6 ends-by fri 12pm 20
domain, t7 ends-by mon 2pm 20
Splitting t4 into {16, 17, 18} and {19, 20, 21}
... t4 in {16, 17, 18} has no solution
... t4 in {19, 20, 21} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 6
task, t3 7
task, t4 6
task, t5 6
task, t6 3
task, t7 2
constraint, t6 same-day t2
constraint, t7 same-day t4
domain, t1 thu
domain, t2 thu
domain, t3 thu
domain, t4 fri
domain, t5 thu
domain, t6 fri
domain, t7 wed
domain, t1 ends-by mon 10am 10
```

```
domain, t2 ends-by mon 2pm 5
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by fri 4pm 15
domain, t6 ends-by thu 2pm 10
domain, t7 ends-by mon 3pm 5
Splitting t1 into {24, 25, 26} and {27, 28, 29}
... t1 in {24, 25, 26} has no solution
... t1 in {27, 28, 29} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 6
task, t3 7
task, t4 6
task, t5 6
task, t6 3
task, t7 2
constraint, t6 same-day t2
constraint, t7 same-day t4
domain, t1 thu
domain, t2 thu
domain, t3 thu
domain, t4 fri
domain, t5 thu
domain, t6 fri
domain, t7 wed
domain, t1 ends-by mon 10am 10
domain, t2 ends-by mon 2pm 5
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by fri 4pm 15
domain, t6 ends-by thu 2pm 10
domain, t7 ends-by mon 3pm 5
Splitting t1 into {24, 25, 26} and {27, 28, 29}
... t1 in {24, 25, 26} has no solution
... t1 in {27, 28, 29} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 7
task, t3 2
task, t4 5
task, t5 2
task, t6 7
task, t7 1
domain, t1 wed
domain, t2 wed
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 tue
domain, t7 fri
domain, t1 ends-by fri 2pm 5
domain, t2 ends-by wed 9am 5
domain, t3 ends-by fri 1pm 10
domain, t4 ends-by wed 11am 20
domain, t5 ends-by thu 11am 15
domain, t6 ends-by tue 11am 5
domain, t7 ends-by tue 11am 10
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
```

```
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t7 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t7 into {32} and {33, 34}
task, t1 4
task, t2 7
task, t3 2
task, t4 5
task, t5 2
task, t6 7
task, t7 1
domain, t1 wed
domain, t2 wed
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 tue
domain, t7 fri
domain, t1 ends-by fri 2pm 5
domain, t2 ends-by wed 9am 5
domain, t3 ends-by fri 1pm 10
domain, t4 ends-by wed 11am 20
domain, t5 ends-by thu 11am 15
domain, t6 ends-by tue 11am 5
domain, t7 ends-by tue 11am 10
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t7 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t7 into {32} and {33, 34}
task, t1 7
task, t2 6
task, t3 7
task, t4 4
task, t5 7
task, t6 2
task, t7 5
constraint, t6 same-day t1
domain, t1 tue
domain, t2 fri
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 wed
domain, t7 thu
domain, t1 ends-by wed 2pm 10
domain, t2 ends-by wed 4pm 15
domain, t3 ends-by wed 9am 5
domain, t4 ends-by tue 12pm 20
domain, t5 ends-by wed 2pm 15
domain, t6 ends-by thu 4pm 10
domain, t7 ends-by wed 12pm 20
Splitting t2 into {32} and {33}
```

```
... t2 in {32} has no solution
... t2 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 6
task, t3 7
task, t4 4
task, t5 7
task, t6 2
task, t7 5
constraint, t6 same-day t1
domain, t1 tue
domain, t2 fri
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 wed
domain, t7 thu
domain, t1 ends-by wed 2pm 10
domain, t2 ends-by wed 4pm 15
domain, t3 ends-by wed 9am 5
domain, t4 ends-by tue 12pm 20
domain, t5 ends-by wed 2pm 15
domain, t6 ends-by thu 4pm 10
domain, t7 ends-by wed 12pm 20
Splitting t2 into {32} and {33}
... t2 in {32} has no solution
... t2 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
n=7: with=4.3, without=4.3 (trials: 10/10)
task, t1 2
task, t2 4
task, t3 2
task, t4 3
task, t5 4
task, t6 2
task, t7 5
task, t8 2
domain, t1 wed
domain, t2 tue
domain, t3 tue
domain, t4 thu
domain, t5 mon
domain, t6 mon
domain, t7 fri
domain, t8 thu
domain, t1 ends-by fri 9am 10
domain, t2 ends-by thu 10am 20
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by mon 3pm 10
domain, t5 ends-by fri 1pm 10
domain, t6 ends-by wed 12pm 20
domain, t7 ends-by thu 3pm 20
domain, t8 ends-by mon 4pm 15
Splitting t1 into {16, 17, 18} and {19, 20, 21}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
```

```
Splitting t4 into {24, 25} and {26, 27, 28}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1} and {2, 3}
Splitting t5 into {0} and {1}
Splitting t6 into {0, 1, 2} and {3, 4, 5}
Splitting t6 into {0} and {1, 2}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {24, 25, 26} and {27, 28, 29}
Splitting t8 into {24} and {25, 26}
task, t1 2
task, t2 4
task, t3 2
task, t4 3
task, t5 4
task, t6 2
task, t7 5
task, t8 2
domain, t1 wed
domain, t2 tue
domain, t3 tue
domain, t4 thu
domain, t5 mon
domain, t6 mon
domain, t7 fri
domain, t8 thu
domain, t1 ends-by fri 9am 10
domain, t2 ends-by thu 10am 20
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by mon 3pm 10
domain, t5 ends-by fri 1pm 10
domain, t6 ends-by wed 12pm 20
domain, t7 ends-by thu 3pm 20
domain, t8 ends-by mon 4pm 15
Splitting t1 into {16, 17, 18} and {19, 20, 21}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {24, 25} and {26, 27, 28}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1} and {2, 3}
Splitting t5 into {0} and {1}
Splitting t6 into {0, 1, 2} and {3, 4, 5}
Splitting t6 into {0} and {1, 2}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {24, 25, 26} and {27, 28, 29}
Splitting t8 into {24} and {25, 26}
task, t1 3
task, t2 7
task, t3 6
task, t4 4
task, t5 2
task, t6 6
task, t7 6
task, t8 4
domain, t1 mon
domain, t2 thu
domain, t3 mon
domain, t4 mon
```

```
domain, t5 mon
domain, t6 tue
domain, t7 mon
domain, t8 mon
domain, t1 ends-by thu 11am 15
domain, t2 ends-by wed 11am 10
domain, t3 ends-by thu 1pm 5
domain, t4 ends-by mon 12pm 10
domain, t5 ends-by tue 3pm 10
domain, t6 ends-by wed 9am 10
domain, t7 ends-by mon 3pm 5
domain, t8 ends-by mon 3pm 5
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t3 into {0} and {1}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
Splitting t6 into {8} and {9}
Splitting t7 into {0} and {1}
Splitting t8 into {0, 1} and {2, 3}
Splitting t8 into {0} and {1}
task, t1 3
task, t2 7
task, t3 6
task, t4 4
task, t5 2
task, t6 6
task, t7 6
task, t8 4
domain, t1 mon
domain, t2 thu
domain, t3 mon
domain, t4 mon
domain, t5 mon
domain, t6 tue
domain, t7 mon
domain, t8 mon
domain, t1 ends-by thu 11am 15
domain, t2 ends-by wed 11am 10
domain, t3 ends-by thu 1pm 5
domain, t4 ends-by mon 12pm 10
domain, t5 ends-by tue 3pm 10
domain, t6 ends-by wed 9am 10
domain, t7 ends-by mon 3pm 5
domain, t8 ends-by mon 3pm 5
Splitting t1 into {0, 1} and {2, 3, 4}
Splitting t1 into {0} and {1}
Splitting t3 into {0} and {1}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
Splitting t6 into {8} and {9}
Splitting t7 into {0} and {1}
Splitting t8 into {0, 1} and {2, 3}
Splitting t8 into {0} and {1}
task, t1 4
task, t2 6
```

```
task, t3 1
task, t4 4
task, t5 2
task, t6 7
task, t7 2
task, t8 4
domain, t1 wed
domain, t2 fri
domain, t3 thu
domain, t4 mon
domain, t5 wed
domain, t6 mon
domain, t7 wed
domain, t8 tue
domain, t1 ends-by fri 4pm 15
domain, t2 ends-by fri 9am 20
domain, t3 ends-by wed 11am 10
domain, t4 ends-by fri 9am 10
domain, t5 ends-by thu 12pm 5
domain, t6 ends-by mon 10am 10
domain, t7 ends-by thu 3pm 10
domain, t8 ends-by tue 1pm 15
Splitting t1 into {16, 17} and {18, 19}
Splitting t1 into {16} and {17}
Splitting t2 into {32} and {33}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t7 into {16, 17, 18} and {19, 20, 21}
Splitting t7 into {16} and {17, 18}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
task, t1 4
task, t2 6
task, t3 1
task, t4 4
task, t5 2
task, t6 7
task, t7 2
task, t8 4
domain, t1 wed
domain, t2 fri
domain, t3 thu
domain, t4 mon
domain, t5 wed
domain, t6 mon
domain, t7 wed
domain, t8 tue
domain, t1 ends-by fri 4pm 15
domain, t2 ends-by fri 9am 20
domain, t3 ends-by wed 11am 10
domain, t4 ends-by fri 9am 10
domain, t5 ends-by thu 12pm 5
domain, t6 ends-by mon 10am 10
domain, t7 ends-by thu 3pm 10
domain, t8 ends-by tue 1pm 15
Splitting t1 into {16, 17} and {18, 19}
```

```
Splitting t1 into {16} and {17}
Splitting t2 into {32} and {33}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
Splitting t4 into {0, 1} and {2, 3}
Splitting t4 into {0} and {1}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t7 into {16, 17, 18} and {19, 20, 21}
Splitting t7 into {16} and {17, 18}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
task, t1 5
task, t2 2
task, t3 6
task, t4 7
task, t5 4
task, t6 6
task, t7 5
task, t8 7
constraint, t7 before t2
domain, t1 tue
domain, t2 thu
domain, t3 tue
domain, t4 fri
domain, t5 tue
domain, t6 tue
domain, t7 fri
domain, t8 fri
domain, t1 ends-by tue 11am 15
domain, t2 ends-by wed 9am 10
domain, t3 ends-by fri 2pm 20
domain, t4 ends-by fri 3pm 15
domain, t5 ends-by wed 3pm 15
domain, t6 ends-by mon 4pm 15
domain, t7 ends-by mon 4pm 15
domain, t8 ends-by wed 10am 10
Splitting t1 into {8} and {9, 10}
... t1 in {8} has no solution
... t1 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 2
task, t3 6
task, t4 7
task, t5 4
task, t6 6
task, t7 5
task, t8 7
constraint, t7 before t2
domain, t1 tue
domain, t2 thu
domain, t3 tue
domain, t4 fri
domain, t5 tue
domain, t6 tue
domain, t7 fri
domain, t8 fri
domain, t1 ends-by tue 11am 15
domain, t2 ends-by wed 9am 10
```

```
domain, t3 ends-by fri 2pm 20
domain, t4 ends-by fri 3pm 15
domain, t5 ends-by wed 3pm 15
domain, t6 ends-by mon 4pm 15
domain, t7 ends-by mon 4pm 15
domain, t8 ends-by wed 10am 10
Splitting t1 into {8} and {9, 10}
... t1 in {8} has no solution
... t1 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 6
task, t3 3
task, t4 2
task, t5 1
task, t6 1
task, t7 2
task, t8 6
domain, t1 thu
domain, t2 thu
domain, t3 fri
domain, t4 wed
domain, t5 wed
domain, t6 thu
domain, t7 fri
domain, t8 mon
domain, t1 ends-by wed 3pm 15
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 10am 10
domain, t4 ends-by fri 11am 20
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by mon 4pm 10
domain, t7 ends-by tue 10am 15
domain, t8 ends-by thu 9am 20
Splitting t1 into {24, 25, 26} and {27, 28, 29}
Splitting t1 into {24} and {25, 26}
Splitting t2 into {24} and {25}
Splitting t3 into {32, 33} and {34, 35, 36}
Splitting t3 into {32} and {33}
Splitting t4 into {16, 17, 18} and {19, 20, 21}
Splitting t4 into {16} and {17, 18}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t6 into {24} and {25, 26}
Splitting t7 into {32, 33, 34} and {35, 36, 37}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {0} and {1}
task, t1 2
task, t2 6
task, t3 3
task, t4 2
task, t5 1
task, t6 1
task, t7 2
task, t8 6
domain, t1 thu
domain, t2 thu
domain, t3 fri
domain, t4 wed
```

```
domain, t5 wed
domain, t6 thu
domain, t7 fri
domain, t8 mon
domain, t1 ends-by wed 3pm 15
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 10am 10
domain, t4 ends-by fri 11am 20
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by mon 4pm 10
domain, t7 ends-by tue 10am 15
domain, t8 ends-by thu 9am 20
Splitting t1 into {24, 25, 26} and {27, 28, 29}
Splitting t1 into {24} and {25, 26}
Splitting t2 into {24} and {25}
Splitting t3 into {32, 33} and {34, 35, 36}
Splitting t3 into {32} and {33}
Splitting t4 into {16, 17, 18} and {19, 20, 21}
Splitting t4 into {16} and {17, 18}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t6 into {24} and {25, 26}
Splitting t7 into {32, 33, 34} and {35, 36, 37}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {0} and {1}
task, t1 7
task, t2 4
task, t3 1
task, t4 7
task, t5 3
task, t6 2
task, t7 1
task, t8 4
domain, t1 thu
domain, t2 thu
domain, t3 thu
domain, t4 tue
domain, t5 wed
domain, t6 tue
domain, t7 fri
domain, t8 fri
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by mon 4pm 15
domain, t3 ends-by wed 1pm 5
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by thu 9am 10
domain, t6 ends-by tue 1pm 15
domain, t7 ends-by thu 3pm 5
domain, t8 ends-by tue 10am 15
Splitting t2 into {24, 25} and {26, 27}
Splitting t2 into {24} and {25}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {8, 9, 10} and {11, 12, 13}
Splitting t6 into {8} and {9, 10}
Splitting t7 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t7 into {32} and {33, 34}
```

```
Splitting t8 into {32, 33} and {34, 35}
Splitting t8 into {32} and {33}
task, t1 7
task, t2 4
task, t3 1
task, t4 7
task, t5 3
task, t6 2
task, t7 1
task, t8 4
domain, t1 thu
domain, t2 thu
domain, t3 thu
domain, t4 tue
domain, t5 wed
domain, t6 tue
domain, t7 fri
domain, t8 fri
domain, t1 ends-by mon 12pm 15
domain, t2 ends-by mon 4pm 15
domain, t3 ends-by wed 1pm 5
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by thu 9am 10
domain, t6 ends-by tue 1pm 15
domain, t7 ends-by thu 3pm 5
domain, t8 ends-by tue 10am 15
Splitting t2 into {24, 25} and {26, 27}
Splitting t2 into {24} and {25}
Splitting t3 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t3 into {24} and {25, 26}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {8, 9, 10} and {11, 12, 13}
Splitting t6 into {8} and {9, 10}
Splitting t7 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {32, 33} and {34, 35}
Splitting t8 into {32} and {33}
task, t1 1
task, t2 6
task, t3 7
task, t4 5
task, t5 6
task, t6 1
task, t7 5
task, t8 7
constraint, t4 before t3
domain, t1 thu
domain, t2 wed
domain, t3 fri
domain, t4 thu
domain, t5 mon
domain, t6 thu
domain, t7 fri
domain, t8 fri
domain, t1 ends-by thu 2pm 10
domain, t2 ends-by thu 10am 20
domain, t3 ends-by wed 2pm 20
domain, t4 ends-by wed 2pm 10
domain, t5 ends-by thu 4pm 20
```

```
domain, t6 ends-by mon 9am 20
domain, t7 ends-by fri 4pm 5
domain, t8 ends-by tue 3pm 10
Splitting t1 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t1 into {24} and {25, 26}
Splitting t2 into {16} and {17}
Splitting t4 into {24} and {25, 26}
Splitting t5 into {0} and {1}
Splitting t6 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t6 into {24} and {25, 26}
Splitting t7 into {32} and {33, 34}
task, t1 1
task, t2 6
task, t3 7
task, t4 5
task, t5 6
task, t6 1
task, t7 5
task, t8 7
constraint, t4 before t3
domain, t1 thu
domain, t2 wed
domain, t3 fri
domain, t4 thu
domain, t5 mon
domain, t6 thu
domain, t7 fri
domain, t8 fri
domain, t1 ends-by thu 2pm 10
domain, t2 ends-by thu 10am 20
domain, t3 ends-by wed 2pm 20
domain, t4 ends-by wed 2pm 10
domain, t5 ends-by thu 4pm 20
domain, t6 ends-by mon 9am 20
domain, t7 ends-by fri 4pm 5
domain, t8 ends-by tue 3pm 10
Splitting t1 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t1 into {24} and {25, 26}
Splitting t2 into {16} and {17}
Splitting t4 into {24} and {25, 26}
Splitting t5 into {0} and {1}
Splitting t6 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t6 into {24} and {25, 26}
Splitting t7 into {32} and {33, 34}
task, t1 2
task, t2 5
task, t3 6
task, t4 3
task, t5 3
task, t6 4
task, t7 1
task, t8 5
domain, t1 wed
domain, t2 tue
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 wed
domain, t8 tue
```

```
domain, t1 ends-by mon 10am 15
domain, t2 ends-by fri 11am 15
domain, t3 ends-by fri 11am 5
domain, t4 ends-by thu 12pm 15
domain, t5 ends-by thu 1pm 10
domain, t6 ends-by mon 9am 20
domain, t7 ends-by wed 1pm 10
domain, t8 ends-by mon 2pm 10
Splitting t1 into {16, 17, 18} and {19, 20, 21}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8} and {9, 10}
Splitting t3 into {32} and {33}
Splitting t4 into {0, 1} and {2, 3, 4}
Splitting t4 into {0} and {1}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {16, 17} and {18, 19}
Splitting t6 into {16} and {17}
Splitting t7 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t7 into {16} and {17, 18}
Splitting t8 into {8} and {9, 10}
task, t1 2
task, t2 5
task, t3 6
task, t4 3
task, t5 3
task, t6 4
task, t7 1
task, t8 5
domain, t1 wed
domain, t2 tue
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 wed
domain, t8 tue
domain, t1 ends-by mon 10am 15
domain, t2 ends-by fri 11am 15
domain, t3 ends-by fri 11am 5
domain, t4 ends-by thu 12pm 15
domain, t5 ends-by thu 1pm 10
domain, t6 ends-by mon 9am 20
domain, t7 ends-by wed 1pm 10
domain, t8 ends-by mon 2pm 10
Splitting t1 into {16, 17, 18} and {19, 20, 21}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {8} and {9, 10}
Splitting t3 into {32} and {33}
Splitting t4 into {0, 1} and {2, 3, 4}
Splitting t4 into {0} and {1}
Splitting t5 into {16, 17} and {18, 19, 20}
Splitting t5 into {16} and {17}
Splitting t6 into {16, 17} and {18, 19}
Splitting t6 into {16} and {17}
Splitting t7 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t7 into {16} and {17, 18}
Splitting t8 into {8} and {9, 10}
task, t1 6
task, t2 4
```

```
task, t3 4
task, t4 1
task, t5 4
task, t6 3
task, t7 4
task, t8 5
constraint, t6 same-day t2
domain, t1 tue
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 fri
domain, t6 tue
domain, t7 tue
domain, t8 tue
domain, t1 ends-by fri 9am 20
domain, t2 ends-by fri 10am 15
domain, t3 ends-by thu 3pm 20
domain, t4 ends-by mon 11am 5
domain, t5 ends-by fri 11am 20
domain, t6 ends-by thu 9am 5
domain, t7 ends-by tue 2pm 15
domain, t8 ends-by fri 3pm 20
Splitting t1 into {8} and {9}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t4 into {32} and {33, 34}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {8, 9} and {10, 11, 12}
Splitting t6 into {8} and {9}
Splitting t7 into {8, 9} and {10, 11}
Splitting t7 into {8} and {9}
Splitting t8 into {8} and {9, 10}
task, t1 6
task, t2 4
task, t3 4
task, t4 1
task, t5 4
task, t6 3
task, t7 4
task, t8 5
constraint, t6 same-day t2
domain, t1 tue
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 fri
domain, t6 tue
domain, t7 tue
domain, t8 tue
domain, t1 ends-by fri 9am 20
domain, t2 ends-by fri 10am 15
domain, t3 ends-by thu 3pm 20
domain, t4 ends-by mon 11am 5
domain, t5 ends-by fri 11am 20
domain, t6 ends-by thu 9am 5
```

```
domain, t7 ends-by tue 2pm 15
domain, t8 ends-by fri 3pm 20
Splitting t1 into {8} and {9}
Splitting t2 into {8, 9} and {10, 11}
Splitting t2 into {8} and {9}
Splitting t3 into {8, 9} and {10, 11}
Splitting t3 into {8} and {9}
Splitting t4 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t4 into {32} and {33, 34}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {8, 9} and {10, 11, 12}
Splitting t6 into {8} and {9}
Splitting t7 into {8, 9} and {10, 11}
Splitting t7 into {8} and {9}
Splitting t8 into {8} and {9, 10}
task, t1 7
task, t2 7
task, t3 4
task, t4 5
task, t5 3
task, t6 7
task, t7 5
task, t8 5
constraint, t6 before t1
constraint, t5 same-day t4
domain, t1 fri
domain, t2 tue
domain, t3 mon
domain, t4 thu
domain, t5 wed
domain, t6 wed
domain, t7 mon
domain, t8 mon
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 9am 5
domain, t3 ends-by wed 4pm 15
domain, t4 ends-by tue 10am 10
domain, t5 ends-by fri 3pm 10
domain, t6 ends-by tue 1pm 10
domain, t7 ends-by tue 4pm 5
domain, t8 ends-by wed 11am 15
Splitting t3 into {0, 1} and {2, 3}
... t3 in {0, 1} has no solution
... t3 in {2, 3} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 7
task, t3 4
task, t4 5
task, t5 3
task, t6 7
task, t7 5
task, t8 5
constraint, t6 before t1
constraint, t5 same-day t4
domain, t1 fri
domain, t2 tue
domain, t3 mon
domain, t4 thu
```

```
domain, t5 wed
domain, t6 wed
domain, t7 mon
domain, t8 mon
domain, t1 ends-by wed 11am 10
domain, t2 ends-by tue 9am 5
domain, t3 ends-by wed 4pm 15
domain, t4 ends-by tue 10am 10
domain, t5 ends-by fri 3pm 10
domain, t6 ends-by tue 1pm 10
domain, t7 ends-by tue 4pm 5
domain, t8 ends-by wed 11am 15
Splitting t3 into {0, 1} and {2, 3}
... t3 in {0, 1} has no solution
... t3 in {2, 3} has no solution
No (more) solutions. Total of 1 paths expanded.
n=8: with=11.0, without=11.0 (trials: 10/10)
task, t1 3
task, t2 4
task, t3 3
task, t4 5
task, t5 3
task, t6 7
task, t7 3
task, t8 6
task, t9 3
constraint, t9 before t3
constraint, t8 same-day t6
domain, t1 thu
domain, t2 fri
domain, t3 thu
domain, t4 mon
domain, t5 wed
domain, t6 tue
domain, t7 wed
domain, t8 mon
domain, t9 wed
domain, t1 ends-by tue 2pm 5
domain, t2 ends-by tue 3pm 20
domain, t3 ends-by wed 10am 10
domain, t4 ends-by thu 11am 5
domain, t5 ends-by thu 3pm 20
domain, t6 ends-by wed 1pm 20
domain, t7 ends-by wed 11am 5
domain, t8 ends-by fri 2pm 5
domain, t9 ends-by mon 11am 20
Splitting t1 into {24, 25} and {26, 27, 28}
... t1 in {24, 25} has no solution
... t1 in {26, 27, 28} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 4
task, t3 3
task, t4 5
task, t5 3
task, t6 7
task, t7 3
task, t8 6
task, t9 3
constraint, t9 before t3
```

```
constraint, t8 same-day t6
domain, t1 thu
domain, t2 fri
domain, t3 thu
domain, t4 mon
domain, t5 wed
domain, t6 tue
domain, t7 wed
domain, t8 mon
domain, t9 wed
domain, t1 ends-by tue 2pm 5
domain, t2 ends-by tue 3pm 20
domain, t3 ends-by wed 10am 10
domain, t4 ends-by thu 11am 5
domain, t5 ends-by thu 3pm 20
domain, t6 ends-by wed 1pm 20
domain, t7 ends-by wed 11am 5
domain, t8 ends-by fri 2pm 5
domain, t9 ends-by mon 11am 20
Splitting t1 into {24, 25} and {26, 27, 28}
... t1 in {24, 25} has no solution
... t1 in {26, 27, 28} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 6
task, t2 1
task, t3 4
task, t4 4
task, t5 1
task, t6 3
task, t7 4
task, t8 2
task, t9 7
constraint, t1 before t2
domain, t1 mon
domain, t2 fri
domain, t3 thu
domain, t4 thu
domain, t5 wed
domain, t6 wed
domain, t7 wed
domain, t8 thu
domain, t9 fri
domain, t1 ends-by wed 2pm 5
domain, t2 ends-by fri 11am 5
domain, t3 ends-by thu 4pm 10
domain, t4 ends-by wed 9am 5
domain, t5 ends-by mon 10am 10
domain, t6 ends-by fri 11am 15
domain, t7 ends-by fri 2pm 15
domain, t8 ends-by fri 11am 20
domain, t9 ends-by fri 9am 10
Splitting t1 into {0} and {1}
Splitting t2 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {24, 25} and {26, 27}
Splitting t4 into {24} and {25}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
```

```
Splitting t6 into {16, 17} and {18, 19, 20}
Splitting t6 into {16} and {17}
Splitting t7 into {16, 17} and {18, 19}
Splitting t7 into {16} and {17}
Splitting t8 into {24, 25, 26} and {27, 28, 29}
Splitting t8 into {24} and {25, 26}
task, t1 6
task, t2 1
task, t3 4
task, t4 4
task, t5 1
task, t6 3
task, t7 4
task, t8 2
task, t9 7
constraint, t1 before t2
domain, t1 mon
domain, t2 fri
domain, t3 thu
domain, t4 thu
domain, t5 wed
domain, t6 wed
domain, t7 wed
domain, t8 thu
domain, t9 fri
domain, t1 ends-by wed 2pm 5
domain, t2 ends-by fri 11am 5
domain, t3 ends-by thu 4pm 10
domain, t4 ends-by wed 9am 5
domain, t5 ends-by mon 10am 10
domain, t6 ends-by fri 11am 15
domain, t7 ends-by fri 2pm 15
domain, t8 ends-by fri 11am 20
domain, t9 ends-by fri 9am 10
Splitting t1 into {0} and {1}
Splitting t2 into {32, 33, 34} and {35, 36, 37, 38}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {24, 25} and {26, 27}
Splitting t4 into {24} and {25}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {16, 17} and {18, 19, 20}
Splitting t6 into {16} and {17}
Splitting t7 into {16, 17} and {18, 19}
Splitting t7 into {16} and {17}
Splitting t8 into {24, 25, 26} and {27, 28, 29}
Splitting t8 into {24} and {25, 26}
task, t1 7
task, t2 6
task, t3 4
task, t4 1
task, t5 5
task, t6 5
task, t7 7
task, t8 4
task, t9 3
constraint, t4 before t5
constraint, t3 before t4
```

```
domain, t1 fri
domain, t2 fri
domain, t3 mon
domain, t4 fri
domain, t5 mon
domain, t6 wed
domain, t7 tue
domain, t8 mon
domain, t9 tue
domain, t1 ends-by thu 9am 15
domain, t2 ends-by mon 2pm 20
domain, t3 ends-by thu 3pm 15
domain, t4 ends-by fri 9am 15
domain, t5 ends-by wed 1pm 15
domain, t6 ends-by tue 12pm 10
domain, t7 ends-by tue 12pm 10
domain, t8 ends-by wed 10am 10
domain, t9 ends-by tue 9am 20
Splitting t2 into {32} and {33}
... t2 in {32} has no solution
... t2 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 6
task, t3 4
task, t4 1
task, t5 5
task, t6 5
task, t7 7
task, t8 4
task, t9 3
constraint, t4 before t5
constraint, t3 before t4
domain, t1 fri
domain, t2 fri
domain, t3 mon
domain, t4 fri
domain, t5 mon
domain, t6 wed
domain, t7 tue
domain, t8 mon
domain, t9 tue
domain, t1 ends-by thu 9am 15
domain, t2 ends-by mon 2pm 20
domain, t3 ends-by thu 3pm 15
domain, t4 ends-by fri 9am 15
domain, t5 ends-by wed 1pm 15
domain, t6 ends-by tue 12pm 10
domain, t7 ends-by tue 12pm 10
domain, t8 ends-by wed 10am 10
domain, t9 ends-by tue 9am 20
Splitting t2 into {32} and {33}
... t2 in {32} has no solution
... t2 in {33} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 6
task, t3 7
task, t4 7
task, t5 5
```

```
task, t6 4
task, t7 3
task, t8 7
task, t9 6
constraint, t9 same-day t2
constraint, t5 same-day t6
domain, t1 fri
domain, t2 mon
domain, t3 fri
domain, t4 fri
domain, t5 mon
domain, t6 mon
domain, t7 mon
domain, t8 wed
domain, t9 tue
domain, t1 ends-by fri 1pm 10
domain, t2 ends-by wed 3pm 10
domain, t3 ends-by tue 2pm 10
domain, t4 ends-by wed 3pm 5
domain, t5 ends-by tue 11am 15
domain, t6 ends-by fri 12pm 5
domain, t7 ends-by wed 3pm 15
domain, t8 ends-by mon 3pm 10
domain, t9 ends-by mon 10am 5
Splitting t1 into {32, 33} and {34, 35}
... t1 in {32, 33} has no solution
... t1 in {34, 35} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 6
task, t3 7
task, t4 7
task, t5 5
task, t6 4
task, t7 3
task, t8 7
task, t9 6
constraint, t9 same-day t2
constraint, t5 same-day t6
domain, t1 fri
domain, t2 mon
domain, t3 fri
domain, t4 fri
domain, t5 mon
domain, t6 mon
domain, t7 mon
domain, t8 wed
domain, t9 tue
domain, t1 ends-by fri 1pm 10
domain, t2 ends-by wed 3pm 10
domain, t3 ends-by tue 2pm 10
domain, t4 ends-by wed 3pm 5
domain, t5 ends-by tue 11am 15
domain, t6 ends-by fri 12pm 5
domain, t7 ends-by wed 3pm 15
domain, t8 ends-by mon 3pm 10
domain, t9 ends-by mon 10am 5
Splitting t1 into {32, 33} and {34, 35}
... t1 in {32, 33} has no solution
... t1 in {34, 35} has no solution
```

```
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 4
task, t3 3
task, t4 3
task, t5 5
task, t6 4
task, t7 3
task, t8 3
task, t9 2
constraint, t7 same-day t2
domain, t1 wed
domain, t2 wed
domain, t3 tue
domain, t4 mon
domain, t5 thu
domain, t6 fri
domain, t7 wed
domain, t8 fri
domain, t9 fri
domain, t1 ends-by thu 3pm 15
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 15
domain, t4 ends-by mon 4pm 15
domain, t5 ends-by thu 1pm 5
domain, t6 ends-by thu 4pm 10
domain, t7 ends-by wed 3pm 20
domain, t8 ends-by mon 12pm 20
domain, t9 ends-by thu 11am 15
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {16, 17} and {18, 19}
Splitting t2 into {16} and {17}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
Splitting t4 into {0, 1} and {2, 3, 4}
Splitting t4 into {0} and {1}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {32, 33} and {34, 35}
Splitting t6 into {32} and {33}
Splitting t7 into {16, 17} and {18, 19, 20}
Splitting t7 into {16} and {17}
Splitting t8 into {32, 33} and {34, 35, 36}
Splitting t8 into {32} and {33}
Splitting t9 into {32, 33, 34} and {35, 36, 37}
Splitting t9 into {32} and {33, 34}
task, t1 1
task, t2 4
task, t3 3
task, t4 3
task, t5 5
task, t6 4
task, t7 3
task, t8 3
task, t9 2
constraint, t7 same-day t2
domain, t1 wed
domain, t2 wed
domain, t3 tue
domain, t4 mon
```

```
domain, t5 thu
domain, t6 fri
domain, t7 wed
domain, t8 fri
domain, t9 fri
domain, t1 ends-by thu 3pm 15
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 15
domain, t4 ends-by mon 4pm 15
domain, t5 ends-by thu 1pm 5
domain, t6 ends-by thu 4pm 10
domain, t7 ends-by wed 3pm 20
domain, t8 ends-by mon 12pm 20
domain, t9 ends-by thu 11am 15
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t1 into {16} and {17, 18}
Splitting t2 into {16, 17} and {18, 19}
Splitting t2 into {16} and {17}
Splitting t3 into {8, 9} and {10, 11, 12}
Splitting t3 into {8} and {9}
Splitting t4 into {0, 1} and {2, 3, 4}
Splitting t4 into {0} and {1}
Splitting t5 into {24} and {25, 26}
Splitting t6 into {32, 33} and {34, 35}
Splitting t6 into {32} and {33}
Splitting t7 into {16, 17} and {18, 19, 20}
Splitting t7 into {16} and {17}
Splitting t8 into {32, 33} and {34, 35, 36}
Splitting t8 into {32} and {33}
Splitting t9 into {32, 33, 34} and {35, 36, 37}
Splitting t9 into {32} and {33, 34}
task, t1 1
task, t2 1
task, t3 7
task, t4 6
task, t5 4
task, t6 4
task, t7 7
task, t8 5
task, t9 2
domain, t1 tue
domain, t2 tue
domain, t3 thu
domain, t4 wed
domain, t5 fri
domain, t6 thu
domain, t7 tue
domain, t8 fri
domain, t9 thu
domain, t1 ends-by tue 2pm 15
domain, t2 ends-by mon 10am 15
domain, t3 ends-by fri 1pm 10
domain, t4 ends-by wed 3pm 5
domain, t5 ends-by tue 12pm 5
domain, t6 ends-by mon 11am 5
domain, t7 ends-by thu 1pm 15
domain, t8 ends-by tue 10am 10
domain, t9 ends-by fri 4pm 10
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t1 into {8} and {9, 10}
```

```
Splitting t2 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t2 into {8} and {9, 10}
Splitting t4 into {16} and {17}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {24, 25} and {26, 27}
Splitting t6 into {24} and {25}
Splitting t8 into {32} and {33, 34}
Splitting t9 into {24, 25, 26} and {27, 28, 29}
Splitting t9 into {24} and {25, 26}
task, t1 1
task, t2 1
task, t3 7
task, t4 6
task, t5 4
task, t6 4
task, t7 7
task, t8 5
task, t9 2
domain, t1 tue
domain, t2 tue
domain, t3 thu
domain, t4 wed
domain, t5 fri
domain, t6 thu
domain, t7 tue
domain, t8 fri
domain, t9 thu
domain, t1 ends-by tue 2pm 15
domain, t2 ends-by mon 10am 15
domain, t3 ends-by fri 1pm 10
domain, t4 ends-by wed 3pm 5
domain, t5 ends-by tue 12pm 5
domain, t6 ends-by mon 11am 5
domain, t7 ends-by thu 1pm 15
domain, t8 ends-by tue 10am 10
domain, t9 ends-by fri 4pm 10
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t1 into {8} and {9, 10}
Splitting t2 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t2 into {8} and {9, 10}
Splitting t4 into {16} and {17}
Splitting t5 into {32, 33} and {34, 35}
Splitting t5 into {32} and {33}
Splitting t6 into {24, 25} and {26, 27}
Splitting t6 into {24} and {25}
Splitting t8 into {32} and {33, 34}
Splitting t9 into {24, 25, 26} and {27, 28, 29}
Splitting t9 into {24} and {25, 26}
task, t1 5
task, t2 3
task, t3 3
task, t4 4
task, t5 3
task, t6 7
task, t7 5
task, t8 4
task, t9 4
constraint, t3 same-day t6
domain, t1 mon
```

```
domain, t2 wed
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 mon
domain, t7 fri
domain, t8 tue
domain, t9 mon
domain, t1 ends-by thu 4pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by wed 11am 20
domain, t5 ends-by mon 11am 10
domain, t6 ends-by thu 11am 15
domain, t7 ends-by wed 4pm 10
domain, t8 ends-by wed 3pm 15
domain, t9 ends-by tue 1pm 10
Splitting t1 into {0} and {1, 2}
Splitting t2 into {16, 17} and {18, 19, 20}
Splitting t2 into {16} and {17}
Splitting t3 into {0, 1} and {2, 3, 4}
Splitting t3 into {0} and {1}
Splitting t4 into {24, 25} and {26, 27}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1} and {2, 3, 4}
Splitting t5 into {0} and {1}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
Splitting t9 into {0, 1} and {2, 3}
Splitting t9 into {0} and {1}
task, t1 5
task, t2 3
task, t3 3
task, t4 4
task, t5 3
task, t6 7
task, t7 5
task, t8 4
task, t9 4
constraint, t3 same-day t6
domain, t1 mon
domain, t2 wed
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 mon
domain, t7 fri
domain, t8 tue
domain, t9 mon
domain, t1 ends-by thu 4pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by wed 11am 20
domain, t5 ends-by mon 11am 10
domain, t6 ends-by thu 11am 15
domain, t7 ends-by wed 4pm 10
domain, t8 ends-by wed 3pm 15
domain, t9 ends-by tue 1pm 10
Splitting t1 into {0} and {1, 2}
```

```
Splitting t2 into {16, 17} and {18, 19, 20}
Splitting t2 into {16} and {17}
Splitting t3 into {0, 1} and {2, 3, 4}
Splitting t3 into {0} and {1}
Splitting t4 into {24, 25} and {26, 27}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1} and {2, 3, 4}
Splitting t5 into {0} and {1}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
Splitting t9 into {0, 1} and {2, 3}
Splitting t9 into {0} and {1}
task, t1 2
task, t2 4
task, t3 6
task, t4 6
task, t5 2
task, t6 7
task, t7 6
task, t8 5
task, t9 4
constraint, t2 same-day t1
domain, t1 mon
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 fri
domain, t6 tue
domain, t7 mon
domain, t8 mon
domain, t9 thu
domain, t1 ends-by tue 3pm 5
domain, t2 ends-by fri 9am 5
domain, t3 ends-by tue 3pm 10
domain, t4 ends-by fri 12pm 10
domain, t5 ends-by thu 1pm 5
domain, t6 ends-by thu 11am 15
domain, t7 ends-by fri 10am 15
domain, t8 ends-by tue 3pm 5
domain, t9 ends-by mon 12pm 10
Splitting t3 into {8} and {9}
... t3 in {8} has no solution
... t3 in {9} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 4
task, t3 6
task, t4 6
task, t5 2
task, t6 7
task, t7 6
task, t8 5
task, t9 4
constraint, t2 same-day t1
domain, t1 mon
domain, t2 tue
domain, t3 tue
domain, t4 fri
domain, t5 fri
```

```
domain, t6 tue
domain, t7 mon
domain, t8 mon
domain, t9 thu
domain, t1 ends-by tue 3pm 5
domain, t2 ends-by fri 9am 5
domain, t3 ends-by tue 3pm 10
domain, t4 ends-by fri 12pm 10
domain, t5 ends-by thu 1pm 5
domain, t6 ends-by thu 11am 15
domain, t7 ends-by fri 10am 15
domain, t8 ends-by tue 3pm 5
domain, t9 ends-by mon 12pm 10
Splitting t3 into {8} and {9}
... t3 in {8} has no solution
... t3 in {9} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 5
task, t3 2
task, t4 3
task, t5 1
task, t6 4
task, t7 7
task, t8 4
task, t9 4
constraint, t4 before t7
constraint, t7 same-day t6
domain, t1 wed
domain, t2 fri
domain, t3 thu
domain, t4 fri
domain, t5 thu
domain, t6 tue
domain, t7 thu
domain, t8 mon
domain, t9 thu
domain, t1 ends-by fri 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 15
domain, t4 ends-by tue 9am 5
domain, t5 ends-by fri 9am 15
domain, t6 ends-by fri 12pm 10
domain, t7 ends-by fri 9am 5
domain, t8 ends-by fri 12pm 5
domain, t9 ends-by thu 2pm 5
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
... t1 in {16, 17, 18} has no solution
... t1 in {19, 20, 21, 22} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 5
task, t3 2
task, t4 3
task, t5 1
task, t6 4
task, t7 7
task, t8 4
task, t9 4
constraint, t4 before t7
```

```
constraint, t7 same-day t6
domain, t1 wed
domain, t2 fri
domain, t3 thu
domain, t4 fri
domain, t5 thu
domain, t6 tue
domain, t7 thu
domain, t8 mon
domain, t9 thu
domain, t1 ends-by fri 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 15
domain, t4 ends-by tue 9am 5
domain, t5 ends-by fri 9am 15
domain, t6 ends-by fri 12pm 10
domain, t7 ends-by fri 9am 5
domain, t8 ends-by fri 12pm 5
domain, t9 ends-by thu 2pm 5
Splitting t1 into {16, 17, 18} and {19, 20, 21, 22}
... t1 in {16, 17, 18} has no solution
... t1 in {19, 20, 21, 22} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 4
task, t2 5
task, t3 2
task, t4 6
task, t5 4
task, t6 4
task, t7 3
task, t8 7
task, t9 6
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 mon
domain, t5 mon
domain, t6 thu
domain, t7 fri
domain, t8 fri
domain, t9 wed
domain, t1 ends-by wed 10am 15
domain, t2 ends-by tue 3pm 20
domain, t3 ends-by wed 2pm 5
domain, t4 ends-by tue 10am 5
domain, t5 ends-by wed 10am 5
domain, t6 ends-by fri 9am 20
domain, t7 ends-by wed 12pm 15
domain, t8 ends-by thu 10am 10
domain, t9 ends-by wed 11am 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0} and {1}
Splitting t5 into {0, 1} and {2, 3}
Splitting t5 into {0} and {1}
Splitting t6 into {24, 25} and {26, 27}
Splitting t6 into {24} and {25}
```

```
Splitting t7 into {32, 33} and {34, 35, 36}
Splitting t7 into {32} and {33}
Splitting t9 into {16} and {17}
task, t1 4
task, t2 5
task, t3 2
task, t4 6
task, t5 4
task, t6 4
task, t7 3
task, t8 7
task, t9 6
domain, t1 mon
domain, t2 fri
domain, t3 tue
domain, t4 mon
domain, t5 mon
domain, t6 thu
domain, t7 fri
domain, t8 fri
domain, t9 wed
domain, t1 ends-by wed 10am 15
domain, t2 ends-by tue 3pm 20
domain, t3 ends-by wed 2pm 5
domain, t4 ends-by tue 10am 5
domain, t5 ends-by wed 10am 5
domain, t6 ends-by fri 9am 20
domain, t7 ends-by wed 12pm 15
domain, t8 ends-by thu 10am 10
domain, t9 ends-by wed 11am 10
Splitting t1 into {0, 1} and {2, 3}
Splitting t1 into {0} and {1}
Splitting t2 into {32} and {33, 34}
Splitting t3 into {8, 9, 10} and {11, 12, 13}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0} and {1}
Splitting t5 into {0, 1} and {2, 3}
Splitting t5 into {0} and {1}
Splitting t6 into {24, 25} and {26, 27}
Splitting t6 into {24} and {25}
Splitting t7 into {32, 33} and {34, 35, 36}
Splitting t7 into {32} and {33}
Splitting t9 into {16} and {17}
n=9: with=8.1, without=8.1 (trials: 10/10)
task, t1 1
task, t2 6
task, t3 2
task, t4 3
task, t5 4
task, t6 5
task, t7 1
task, t8 7
task, t9 5
task, t10 7
constraint, t5 before t9
constraint, t10 same-day t4
domain, t1 mon
domain, t2 thu
domain, t3 mon
domain, t4 fri
```

```
domain, t5 mon
domain, t6 thu
domain, t7 wed
domain, t8 mon
domain, t9 wed
domain, t10 wed
domain, t1 ends-by thu 1pm 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by mon 4pm 20
domain, t5 ends-by wed 10am 10
domain, t6 ends-by mon 4pm 20
domain, t7 ends-by thu 12pm 15
domain, t8 ends-by mon 10am 15
domain, t9 ends-by wed 12pm 10
domain, t10 ends-by fri 3pm 15
Splitting t1 into {0, 1, 2} and {3, 4, 5, 6}
... t1 in {0, 1, 2} has no solution
... t1 in {3, 4, 5, 6} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 6
task, t3 2
task, t4 3
task, t5 4
task, t6 5
task, t7 1
task, t8 7
task, t9 5
task, t10 7
constraint, t5 before t9
constraint, t10 same-day t4
domain, t1 mon
domain, t2 thu
domain, t3 mon
domain, t4 fri
domain, t5 mon
domain, t6 thu
domain, t7 wed
domain, t8 mon
domain, t9 wed
domain, t10 wed
domain, t1 ends-by thu 1pm 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by mon 3pm 10
domain, t4 ends-by mon 4pm 20
domain, t5 ends-by wed 10am 10
domain, t6 ends-by mon 4pm 20
domain, t7 ends-by thu 12pm 15
domain, t8 ends-by mon 10am 15
domain, t9 ends-by wed 12pm 10
domain, t10 ends-by fri 3pm 15
Splitting t1 into {0, 1, 2} and {3, 4, 5, 6}
... t1 in {0, 1, 2} has no solution
... t1 in {3, 4, 5, 6} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 4
task, t3 2
task, t4 4
```

```
task, t5 2
task, t6 7
task, t7 6
task, t8 6
task, t9 2
task, t10 6
domain, t1 fri
domain, t2 mon
domain, t3 mon
domain, t4 wed
domain, t5 mon
domain, t6 fri
domain, t7 tue
domain, t8 wed
domain, t9 wed
domain, t10 mon
domain, t1 ends-by thu 2pm 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by wed 9am 15
domain, t4 ends-by wed 2pm 15
domain, t5 ends-by fri 3pm 15
domain, t6 ends-by mon 3pm 15
domain, t7 ends-by mon 2pm 20
domain, t8 ends-by mon 1pm 5
domain, t9 ends-by fri 12pm 5
domain, t10 ends-by fri 11am 10
Splitting t1 into {32, 33, 34} and {35, 36, 37}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {0, 1} and {2, 3}
Splitting t2 into {0} and {1}
Splitting t3 into {0, 1, 2} and {3, 4, 5}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {16, 17} and {18, 19}
Splitting t4 into {16} and {17}
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
Splitting t7 into {8} and {9}
Splitting t8 into {16} and {17}
Splitting t9 into {16, 17, 18} and {19, 20, 21}
Splitting t9 into {16} and {17, 18}
Splitting t10 into {0} and {1}
task, t1 2
task, t2 4
task, t3 2
task, t4 4
task, t5 2
task, t6 7
task, t7 6
task, t8 6
task, t9 2
task, t10 6
domain, t1 fri
domain, t2 mon
domain, t3 mon
domain, t4 wed
domain, t5 mon
domain, t6 fri
domain, t7 tue
domain, t8 wed
domain, t9 wed
```

```
domain, t10 mon
domain, t1 ends-by thu 2pm 20
domain, t2 ends-by tue 10am 20
domain, t3 ends-by wed 9am 15
domain, t4 ends-by wed 2pm 15
domain, t5 ends-by fri 3pm 15
domain, t6 ends-by mon 3pm 15
domain, t7 ends-by mon 2pm 20
domain, t8 ends-by mon 1pm 5
domain, t9 ends-by fri 12pm 5
domain, t10 ends-by fri 11am 10
Splitting t1 into {32, 33, 34} and {35, 36, 37}
Splitting t1 into {32} and {33, 34}
Splitting t2 into {0, 1} and {2, 3}
Splitting t2 into {0} and {1}
Splitting t3 into {0, 1, 2} and {3, 4, 5}
Splitting t3 into {0} and {1, 2}
Splitting t4 into {16, 17} and {18, 19}
Splitting t4 into {16} and {17}
Splitting t5 into {0, 1, 2} and {3, 4, 5}
Splitting t5 into {0} and {1, 2}
Splitting t7 into {8} and {9}
Splitting t8 into {16} and {17}
Splitting t9 into {16, 17, 18} and {19, 20, 21}
Splitting t9 into {16} and {17, 18}
Splitting t10 into {0} and {1}
task, t1 5
task, t2 2
task, t3 5
task, t4 1
task, t5 1
task, t6 6
task, t7 5
task, t8 6
task, t9 5
task, t10 1
domain, t1 wed
domain, t2 thu
domain, t3 tue
domain, t4 tue
domain, t5 wed
domain, t6 tue
domain, t7 thu
domain, t8 thu
domain, t9 tue
domain, t10 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by thu 1pm 10
domain, t4 ends-by fri 10am 10
domain, t5 ends-by mon 10am 15
domain, t6 ends-by fri 9am 20
domain, t7 ends-by mon 1pm 15
domain, t8 ends-by tue 10am 5
domain, t9 ends-by fri 12pm 5
domain, t10 ends-by fri 11am 20
Splitting t1 into {16} and {17, 18}
Splitting t2 into {24, 25, 26} and {27, 28, 29}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {8} and {9, 10}
```

```
Splitting t4 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {8} and {9}
Splitting t7 into {24} and {25, 26}
Splitting t8 into {24} and {25}
Splitting t9 into {8} and {9, 10}
Splitting t10 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t10 into {0} and {1, 2}
task, t1 5
task, t2 2
task, t3 5
task, t4 1
task, t5 1
task, t6 6
task, t7 5
task, t8 6
task, t9 5
task, t10 1
domain, t1 wed
domain, t2 thu
domain, t3 tue
domain, t4 tue
domain, t5 wed
domain, t6 tue
domain, t7 thu
domain, t8 thu
domain, t9 tue
domain, t10 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by thu 1pm 10
domain, t4 ends-by fri 10am 10
domain, t5 ends-by mon 10am 15
domain, t6 ends-by fri 9am 20
domain, t7 ends-by mon 1pm 15
domain, t8 ends-by tue 10am 5
domain, t9 ends-by fri 12pm 5
domain, t10 ends-by fri 11am 20
Splitting t1 into {16} and {17, 18}
Splitting t2 into {24, 25, 26} and {27, 28, 29}
Splitting t2 into {24} and {25, 26}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {8, 9, 10} and {11, 12, 13, 14}
Splitting t4 into {8} and {9, 10}
Splitting t5 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {8} and {9}
Splitting t7 into {24} and {25, 26}
Splitting t8 into {24} and {25}
Splitting t9 into {8} and {9, 10}
Splitting t10 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t10 into {0} and {1, 2}
task, t1 1
task, t2 3
task, t3 1
task, t4 6
task, t5 4
task, t6 7
```

```
task, t7 4
task, t8 7
task, t9 7
task, t10 2
constraint, t6 same-day t10
domain, t1 tue
domain, t2 tue
domain, t3 wed
domain, t4 fri
domain, t5 tue
domain, t6 wed
domain, t7 mon
domain, t8 tue
domain, t9 tue
domain, t10 thu
domain, t1 ends-by wed 1pm 20
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 10am 5
domain, t4 ends-by tue 11am 15
domain, t5 ends-by thu 1pm 20
domain, t6 ends-by thu 12pm 5
domain, t7 ends-by tue 4pm 5
domain, t8 ends-by tue 2pm 20
domain, t9 ends-by thu 12pm 15
domain, t10 ends-by mon 12pm 10
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
... t1 in {8, 9, 10} has no solution
... t1 in {11, 12, 13, 14} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 1
task, t2 3
task, t3 1
task, t4 6
task, t5 4
task, t6 7
task, t7 4
task, t8 7
task, t9 7
task, t10 2
constraint, t6 same-day t10
domain, t1 tue
domain, t2 tue
domain, t3 wed
domain, t4 fri
domain, t5 tue
domain, t6 wed
domain, t7 mon
domain, t8 tue
domain, t9 tue
domain, t10 thu
domain, t1 ends-by wed 1pm 20
domain, t2 ends-by tue 11am 10
domain, t3 ends-by tue 10am 5
domain, t4 ends-by tue 11am 15
domain, t5 ends-by thu 1pm 20
domain, t6 ends-by thu 12pm 5
domain, t7 ends-by tue 4pm 5
domain, t8 ends-by tue 2pm 20
domain, t9 ends-by thu 12pm 15
domain, t10 ends-by mon 12pm 10
```

```
Splitting t1 into {8, 9, 10} and {11, 12, 13, 14}
... t1 in {8, 9, 10} has no solution
... t1 in {11, 12, 13, 14} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 5
task, t2 1
task, t3 6
task, t4 3
task, t5 1
task, t6 2
task, t7 7
task, t8 4
task, t9 5
task, t10 1
constraint, t7 same-day t4
domain, t1 tue
domain, t2 wed
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 thu
domain, t7 thu
domain, t8 tue
domain, t9 mon
domain, t10 thu
domain, t1 ends-by fri 3pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 9am 10
domain, t4 ends-by thu 2pm 10
domain, t5 ends-by wed 10am 20
domain, t6 ends-by wed 10am 20
domain, t7 ends-by wed 4pm 5
domain, t8 ends-by fri 9am 15
domain, t9 ends-by wed 9am 10
domain, t10 ends-by fri 10am 10
Splitting t1 into {8} and {9, 10}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {0} and {1}
Splitting t4 into {24, 25} and {26, 27, 28}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t5 into {0} and {1, 2}
Splitting t6 into {24, 25, 26} and {27, 28, 29}
Splitting t6 into {24} and {25, 26}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
Splitting t9 into {0} and {1, 2}
Splitting t10 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t10 into {24} and {25, 26}
task, t1 5
task, t2 1
task, t3 6
task, t4 3
task, t5 1
task, t6 2
task, t7 7
task, t8 4
task, t9 5
task, t10 1
```

```
constraint, t7 same-day t4
domain, t1 tue
domain, t2 wed
domain, t3 mon
domain, t4 thu
domain, t5 mon
domain, t6 thu
domain, t7 thu
domain, t8 tue
domain, t9 mon
domain, t10 thu
domain, t1 ends-by fri 3pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 9am 10
domain, t4 ends-by thu 2pm 10
domain, t5 ends-by wed 10am 20
domain, t6 ends-by wed 10am 20
domain, t7 ends-by wed 4pm 5
domain, t8 ends-by fri 9am 15
domain, t9 ends-by wed 9am 10
domain, t10 ends-by fri 10am 10
Splitting t1 into {8} and {9, 10}
Splitting t2 into {16, 17, 18} and {19, 20, 21, 22}
Splitting t2 into {16} and {17, 18}
Splitting t3 into {0} and {1}
Splitting t4 into {24, 25} and {26, 27, 28}
Splitting t4 into {24} and {25}
Splitting t5 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t5 into {0} and {1, 2}
Splitting t6 into {24, 25, 26} and {27, 28, 29}
Splitting t6 into {24} and {25, 26}
Splitting t8 into {8, 9} and {10, 11}
Splitting t8 into {8} and {9}
Splitting t9 into {0} and {1, 2}
Splitting t10 into {24, 25, 26} and {27, 28, 29, 30}
Splitting t10 into {24} and {25, 26}
task, t1 3
task, t2 6
task, t3 5
task, t4 2
task, t5 4
task, t6 5
task, t7 6
task, t8 5
task, t9 5
task, t10 6
domain, t1 tue
domain, t2 fri
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 fri
domain, t8 wed
domain, t9 tue
domain, t10 mon
domain, t1 ends-by tue 10am 20
domain, t2 ends-by mon 2pm 5
domain, t3 ends-by mon 9am 5
domain, t4 ends-by wed 4pm 10
```

```
domain, t5 ends-by mon 10am 15
domain, t6 ends-by wed 12pm 5
domain, t7 ends-by wed 12pm 5
domain, t8 ends-by tue 9am 15
domain, t9 ends-by thu 10am 10
domain, t10 ends-by tue 1pm 5
Splitting t1 into {8, 9} and {10, 11, 12}
Splitting t1 into {8} and {9}
Splitting t2 into {32} and {33}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0, 1, 2} and {3, 4, 5}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17} and {18, 19}
Splitting t5 into {16} and {17}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {32} and {33}
Splitting t8 into {16} and {17, 18}
Splitting t9 into {8} and {9, 10}
Splitting t10 into {0} and {1}
task, t1 3
task, t2 6
task, t3 5
task, t4 2
task, t5 4
task, t6 5
task, t7 6
task, t8 5
task, t9 5
task, t10 6
domain, t1 tue
domain, t2 fri
domain, t3 tue
domain, t4 mon
domain, t5 wed
domain, t6 wed
domain, t7 fri
domain, t8 wed
domain, t9 tue
domain, t10 mon
domain, t1 ends-by tue 10am 20
domain, t2 ends-by mon 2pm 5
domain, t3 ends-by mon 9am 5
domain, t4 ends-by wed 4pm 10
domain, t5 ends-by mon 10am 15
domain, t6 ends-by wed 12pm 5
domain, t7 ends-by wed 12pm 5
domain, t8 ends-by tue 9am 15
domain, t9 ends-by thu 10am 10
domain, t10 ends-by tue 1pm 5
Splitting t1 into {8, 9} and {10, 11, 12}
Splitting t1 into {8} and {9}
Splitting t2 into {32} and {33}
Splitting t3 into {8} and {9, 10}
Splitting t4 into {0, 1, 2} and {3, 4, 5}
Splitting t4 into {0} and {1, 2}
Splitting t5 into {16, 17} and {18, 19}
Splitting t5 into {16} and {17}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {32} and {33}
Splitting t8 into {16} and {17, 18}
```

```
Splitting t9 into {8} and {9, 10}
Splitting t10 into {0} and {1}
task, t1 6
task, t2 1
task, t3 4
task, t4 2
task, t5 2
task, t6 5
task, t7 2
task, t8 5
task, t9 6
task, t10 5
constraint, t2 before t1
domain, t1 thu
domain, t2 mon
domain, t3 thu
domain, t4 wed
domain, t5 wed
domain, t6 wed
domain, t7 fri
domain, t8 wed
domain, t9 mon
domain, t10 wed
domain, t1 ends-by wed 12pm 5
domain, t2 ends-by fri 2pm 15
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by wed 9am 15
domain, t5 ends-by thu 10am 10
domain, t6 ends-by fri 9am 5
domain, t7 ends-by fri 12pm 20
domain, t8 ends-by tue 2pm 20
domain, t9 ends-by wed 2pm 15
domain, t10 ends-by fri 9am 5
Splitting t1 into {24} and {25}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {16, 17, 18} and {19, 20, 21}
Splitting t4 into {16} and {17, 18}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {32, 33, 34} and {35, 36, 37}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {16} and {17, 18}
Splitting t9 into {0} and {1}
Splitting t10 into {16} and {17, 18}
task, t1 6
task, t2 1
task, t3 4
task, t4 2
task, t5 2
task, t6 5
task, t7 2
task, t8 5
task, t9 6
task, t10 5
constraint, t2 before t1
domain, t1 thu
```

```
domain, t2 mon
domain, t3 thu
domain, t4 wed
domain, t5 wed
domain, t6 wed
domain, t7 fri
domain, t8 wed
domain, t9 mon
domain, t10 wed
domain, t1 ends-by wed 12pm 5
domain, t2 ends-by fri 2pm 15
domain, t3 ends-by thu 4pm 5
domain, t4 ends-by wed 9am 15
domain, t5 ends-by thu 10am 10
domain, t6 ends-by fri 9am 5
domain, t7 ends-by fri 12pm 20
domain, t8 ends-by tue 2pm 20
domain, t9 ends-by wed 2pm 15
domain, t10 ends-by fri 9am 5
Splitting t1 into {24} and {25}
Splitting t2 into {0, 1, 2} and {3, 4, 5, 6}
Splitting t2 into {0} and {1, 2}
Splitting t3 into {24, 25} and {26, 27}
Splitting t3 into {24} and {25}
Splitting t4 into {16, 17, 18} and {19, 20, 21}
Splitting t4 into {16} and {17, 18}
Splitting t5 into {16, 17, 18} and {19, 20, 21}
Splitting t5 into {16} and {17, 18}
Splitting t6 into {16} and {17, 18}
Splitting t7 into {32, 33, 34} and {35, 36, 37}
Splitting t7 into {32} and {33, 34}
Splitting t8 into {16} and {17, 18}
Splitting t9 into {0} and {1}
Splitting t10 into {16} and {17, 18}
task, t1 7
task, t2 3
task, t3 5
task, t4 3
task, t5 1
task, t6 3
task, t7 7
task, t8 4
task, t9 1
task, t10 3
constraint, t3 same-day t7
constraint, t5 before t2
domain, t1 fri
domain, t2 mon
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 thu
domain, t7 fri
domain, t8 mon
domain, t9 tue
domain, t10 fri
domain, t1 ends-by fri 12pm 5
domain, t2 ends-by thu 1pm 20
domain, t3 ends-by wed 3pm 5
domain, t4 ends-by mon 11am 20
```

domain, t5 ends-by thu 4pm 15
domain, t6 ends-by mon 3pm 10
domain, t7 ends-by tue 9am 20
domain, t8 ends-by mon 4pm 20
domain, t9 ends-by wed 12pm 20
domain, t10 ends-by tue 4pm 5
Splitting t3 into {32} and {33, 34}
... t3 in {32} has no solution
... t3 in {33, 34} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 7
task, t2 3
task, t3 5
task, t4 3
task, t5 1
task, t6 3
task, t7 7
task, t8 4
task, t9 1
task, t10 3
constraint, t3 same-day t7
constraint, t5 before t2
domain, t1 fri
domain, t2 mon
domain, t3 fri
domain, t4 mon
domain, t5 wed
domain, t6 thu
domain, t7 fri
domain, t8 mon
domain, t9 tue
domain, t10 fri
domain, t1 ends-by fri 12pm 5
domain, t2 ends-by thu 1pm 20
domain, t3 ends-by wed 3pm 5
domain, t4 ends-by mon 11am 20
domain, t5 ends-by thu 4pm 15
domain, t6 ends-by mon 3pm 10
domain, t7 ends-by tue 9am 20
domain, t8 ends-by mon 4pm 20
domain, t9 ends-by wed 12pm 20
domain, t10 ends-by tue 4pm 5
Splitting t3 into {32} and {33, 34}
... t3 in {32} has no solution
... t3 in {33, 34} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 5
task, t3 4
task, t4 1
task, t5 3
task, t6 2
task, t7 3
task, t8 1
task, t9 3
task, t10 7
constraint, t7 same-day t4
constraint, t4 same-day t1
domain, t1 thu
domain, t2 tue

```
domain, t3 wed
domain, t4 fri
domain, t5 thu
domain, t6 fri
domain, t7 thu
domain, t8 fri
domain, t9 wed
domain, t10 tue
domain, t1 ends-by mon 11am 15
domain, t2 ends-by wed 9am 5
domain, t3 ends-by tue 4pm 20
domain, t4 ends-by mon 4pm 20
domain, t5 ends-by thu 12pm 15
domain, t6 ends-by wed 11am 15
domain, t7 ends-by wed 9am 15
domain, t8 ends-by mon 12pm 15
domain, t9 ends-by fri 9am 5
domain, t10 ends-by wed 12pm 15
Splitting t2 into {8} and {9, 10}
... t2 in {8} has no solution
... t2 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 2
task, t2 5
task, t3 4
task, t4 1
task, t5 3
task, t6 2
task, t7 3
task, t8 1
task, t9 3
task, t10 7
constraint, t7 same-day t4
constraint, t4 same-day t1
domain, t1 thu
domain, t2 tue
domain, t3 wed
domain, t4 fri
domain, t5 thu
domain, t6 fri
domain, t7 thu
domain, t8 fri
domain, t9 wed
domain, t10 tue
domain, t1 ends-by mon 11am 15
domain, t2 ends-by wed 9am 5
domain, t3 ends-by tue 4pm 20
domain, t4 ends-by mon 4pm 20
domain, t5 ends-by thu 12pm 15
domain, t6 ends-by wed 11am 15
domain, t7 ends-by wed 9am 15
domain, t8 ends-by mon 12pm 15
domain, t9 ends-by fri 9am 5
domain, t10 ends-by wed 12pm 15
Splitting t2 into {8} and {9, 10}
... t2 in {8} has no solution
... t2 in {9, 10} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 7
```

```
task, t3 3
task, t4 4
task, t5 2
task, t6 1
task, t7 3
task, t8 1
task, t9 5
task, t10 3
constraint, t2 before t4
domain, t1 thu
domain, t2 thu
domain, t3 tue
domain, t4 wed
domain, t5 thu
domain, t6 tue
domain, t7 wed
domain, t8 thu
domain, t9 mon
domain, t10 fri
domain, t1 ends-by mon 9am 15
domain, t2 ends-by tue 3pm 5
domain, t3 ends-by tue 4pm 15
domain, t4 ends-by tue 12pm 5
domain, t5 ends-by fri 11am 20
domain, t6 ends-by fri 10am 5
domain, t7 ends-by tue 9am 15
domain, t8 ends-by wed 2pm 15
domain, t9 ends-by fri 1pm 5
domain, t10 ends-by fri 1pm 15
Splitting t1 into {24, 25} and {26, 27, 28}
... t1 in {24, 25} has no solution
... t1 in {26, 27, 28} has no solution
No (more) solutions. Total of 1 paths expanded.
task, t1 3
task, t2 7
task, t3 3
task, t4 4
task, t5 2
task, t6 1
task, t7 3
task, t8 1
task, t9 5
task, t10 3
constraint, t2 before t4
domain, t1 thu
domain, t2 thu
domain, t3 tue
domain, t4 wed
domain, t5 thu
domain, t6 tue
domain, t7 wed
domain, t8 thu
domain, t9 mon
domain, t10 fri
domain, t1 ends-by mon 9am 15
domain, t2 ends-by tue 3pm 5
domain, t3 ends-by tue 4pm 15
domain, t4 ends-by tue 12pm 5
domain, t5 ends-by fri 11am 20
domain, t6 ends-by fri 10am 5
```

```
domain, t7 ends-by tue 9am 15
domain, t8 ends-by wed 2pm 15
domain, t9 ends-by fri 1pm 5
domain, t10 ends-by fri 1pm 15
Splitting t1 into {24, 25} and {26, 27, 28}
... t1 in {24, 25} has no solution
... t1 in {26, 27, 28} has no solution
No (more) solutions. Total of 1 paths expanded.
n=10: with=8.2, without=8.2 (trials: 10/10)
```


Domain Splitting Solver: Cost Heuristic Impact
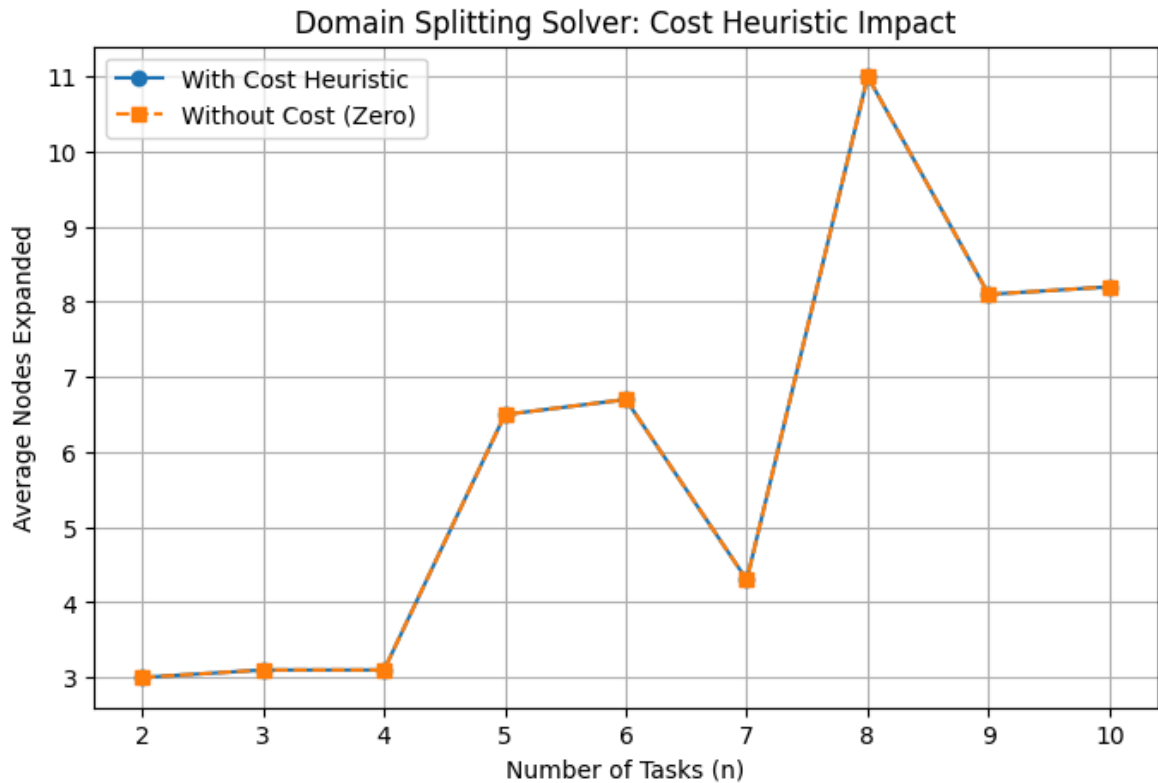
```
Average reduction in nodes expanded: 0.0%
```

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.

- 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)

n: number of tasks, d: maximum domain size

DFS: Time: $O(D^n)$, Space: $O(n)$

DFS-MRV: $O(D^n,)$, Space $O(n*d)$

What are the properties of the search algorithms (completeness, optimality)? (1 mark)

Both are complete for finite CSP, and guaranteed to find a solution if it exists.

Neither are optimal, as they stop on the first valid solution.

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)

An Example problem would be where we have a constrained task t1, which has a hard domain forcing to to be on monday and a binary constraint such as t1 same-day t2. DFS-MRV would deal with this better because it would select the most constrained variable t1, and through foward checking, it would prune invalid t2 paths, allowing it to not explore invalid branches. However DFS may assign t2 to tuesday and have to backtrack after discovering the same-day conflict.

Empirically compare the quality of the first solution found by DFS and DFS-MRV compared to the optimal solution (1 mark)

We can see initally that the DFS and DFS-MRV are similar in terms of quality of solution, but at some higher n values such as 6 that the DFS finds a lest costly solution compared to DFS-MRV. For example in n=6, the DFS is 1.54x more expenesive then the optimal solution while DFS-MRV is 3.27x more expensive.

Problem Size n=6: DFS Nodes Expanded: 165.4 DFS-MRV Nodes Expanded: 8.0 Node Reduction: 95.2% DFS Cost Ratio: 1.54x DFS-MRV Cost Ratio: 3.27x

Empirically compare DFS-MRV with DFS in terms of the number of nodes expanded (1 mark) For number of nodes expanded we can see that the DFS-MRV generally expands less nodes. For example at n=6, Dfs-MRV expanded 8 nodes, while DFS expanded 165.4 which is a 95.2% difference.The general trend shows DFS-MRV reduces significantly less ndoes compared to DFS

In [70]:
```python
import random
import matplotlib.pyplot as plt
import numpy as np


def generate_hard_problem(n):
    spec = ""
    tasks = [f"t{i}" for i in range(n)]
```

```python
    for i in range(n):
        duration = random.randint(4, 7)
        spec += f"task, t{i} {duration}\n"

    if n >= 2:
        num_constraints = random.randint(n // 2, n - 1)
        added_pairs = set()
        for _ in range(num_constraints):
            for _ in range(5):
                i = random.randint(0, n - 2)
                j = random.randint(i + 1, n - 1)
                if (i, j) not in added_pairs:
                    added_pairs.add((i, j))
                    constraint_type = random.choice(['before', 'same-day', 'same
                    spec += f"constraint, t{i} {constraint_type} t{j}\n"
                    break

    early_days = ['mon', 'tue']
    early_times = ['12pm', '1pm', '2pm']
    for i in range(n):
        day = random.choice(early_days)
        time = random.choice(early_times)
        cost = random.choice([10, 20, 30])
        spec += f"domain, t{i} ends-by {day} {time} {cost}\n"

        if i == 0:
            spec += f"domain, t{i} mon\n"

    return spec


def generate_random_problem(n):
    spec = ""

    for i in range(n):
        duration = random.choice([1, 2, 3])
        spec += f"task, t{i} {duration}\n"

    if n >= 2:
        num_constraints = min(random.randint(1, 3), n-1)
        for _ in range(num_constraints):
            i = random.randint(0, n-2)
            j = i + 1  # consecutive tasks only to avoid cycles
            constraint_type = random.choice(['before', 'same-day'])
            spec += f"constraint, t{i} {constraint_type} t{j}\n"

    for i in range(n):
        day = random.choice(['tue', 'wed', 'thu', 'fri'])
        time = random.choice(['12pm', '1pm', '2pm', '3pm', '4pm'])
        cost = random.choice([5, 10, 15, 20])
        spec += f"domain, t{i} ends-by {day} {time} {cost}\n"

    return spec


def calculate_solution_cost(solution, csp_problem):
    if solution is None:
        return None
```

```python
        total_cost = 0
        for var in solution:
            cost_func = csp_problem.cost_functions[var][0]
            val = solution[var]
            duration = csp_problem.durations[var]
            soft_day_time = csp_problem.soft_day_time[var]
            soft_cost = csp_problem.soft_costs[var]

            var_cost = cost_func(val, soft_day_time, duration, soft_cost)
            if var_cost is not None:
                total_cost += var_cost

        return total_cost


def compare_dfs_algorithms(problem_sizes, num_trials=5):
    results = {
        'sizes': problem_sizes,
        'dfs_nodes': [],
        'mrv_nodes': [],
        'dfs_cost': [],
        'mrv_cost': [],
        'optimal_cost': [],
        'dfs_cost_ratio': [],
        'mrv_cost_ratio': []
    }

    for n in problem_sizes:
        dfs_nodes_trials = []
        mrv_nodes_trials = []
        dfs_cost_trials = []
        mrv_cost_trials = []
        optimal_cost_trials = []

        successful_trials = 0
        trial = 0

        while successful_trials < num_trials and trial < num_trials * 5:
            trial += 1
            try:
                spec = generate_hard_problem(n)

                global num_expanded, display
                display = False
                csp_dfs = create_CSP_from_spec(spec)
                if csp_dfs is None or len(csp_dfs.domains) == 0:
                    continue

                if any(len(domain) == 0 for domain in csp_dfs.domains.values()):
                    continue

                num_expanded = 0
                dfs_solution = dfs_solve1(csp_dfs)
                if dfs_solution is None:
                    continue

                dfs_nodes = num_expanded
                dfs_nodes_trials.append(dfs_nodes)
                dfs_cost = calculate_solution_cost(dfs_solution, csp_dfs)
                if dfs_cost is not None:
```

```python
                    dfs_cost_trials.append(dfs_cost)

                    csp_mrv = create_CSP_from_spec(spec)
                    num_expanded = 0
                    mrv_solution = mrv_dfs_solve1(csp_mrv)
                    if mrv_solution is None:
                        continue

                    mrv_nodes = num_expanded
                    mrv_nodes_trials.append(mrv_nodes)
                    mrv_cost = calculate_solution_cost(mrv_solution, csp_mrv)
                    if mrv_cost is not None:
                        mrv_cost_trials.append(mrv_cost)

                    csp_optimal = create_CSP_from_spec(spec)
                    Search_with_AC_from_Cost_CSP.max_display_level = 0
                    solver = GreedySearcher(Search_with_AC_from_Cost_CSP(csp_optimal
                    final_path = solver.search()
                    if final_path is not None:
                        optimal_cost = final_path.end().cost
                        optimal_cost_trials.append(optimal_cost)

                    successful_trials += 1

            except Exception as e:
                continue

        if dfs_nodes_trials:
            results['dfs_nodes'].append(np.mean(dfs_nodes_trials))
        else:
            results['dfs_nodes'].append(0)

        if mrv_nodes_trials:
            results['mrv_nodes'].append(np.mean(mrv_nodes_trials))
        else:
            results['mrv_nodes'].append(0)

        if dfs_cost_trials and optimal_cost_trials:
            results['dfs_cost'].append(np.mean(dfs_cost_trials))
            results['optimal_cost'].append(np.mean(optimal_cost_trials))
            avg_optimal = np.mean(optimal_cost_trials)
            if avg_optimal > 0:
                results['dfs_cost_ratio'].append(np.mean(dfs_cost_trials) / avg_
            else:
                results['dfs_cost_ratio'].append(1.0)
        else:
            results['dfs_cost'].append(0)
            results['optimal_cost'].append(0)
            results['dfs_cost_ratio'].append(1.0)

        if mrv_cost_trials and optimal_cost_trials:
            results['mrv_cost'].append(np.mean(mrv_cost_trials))
            avg_optimal = np.mean(optimal_cost_trials)
            if avg_optimal > 0:
                results['mrv_cost_ratio'].append(np.mean(mrv_cost_trials) / avg_
            else:
                results['mrv_cost_ratio'].append(1.0)
        else:
            results['mrv_cost'].append(0)
            results['mrv_cost_ratio'].append(1.0)
```

```python
    return results


problem_sizes = [3, 4, 5, 6, 7]
results = compare_dfs_algorithms(problem_sizes, num_trials=5)

plt.figure(figsize=(12, 5))

plt.subplot(1, 2, 1)
plt.plot(results['sizes'], results['dfs_nodes'], 'o-', label='DFS', linewidth=2)
plt.plot(results['sizes'], results['mrv_nodes'], 's-', label='DFS-MRV', linewidt
plt.xlabel('Problem Size (n)')
plt.ylabel('Average Nodes Expanded')
plt.title('Nodes Expanded: DFS vs DFS-MRV')
plt.legend()
plt.grid(True)

plt.subplot(1, 2, 2)
plt.plot(results['sizes'], results['dfs_cost_ratio'], 'o-', label='DFS', linewid
plt.plot(results['sizes'], results['mrv_cost_ratio'], 's-', label='DFS-MRV', lin
plt.axhline(y=1.0, color='g', linestyle='--', label='Optimal', alpha=0.5)
plt.xlabel('Problem Size (n)')
plt.ylabel('Cost Ratio (Solution/Optimal)')
plt.title('Solution Quality vs Optimal')
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()

for i, n in enumerate(results['sizes']):
    print(f"\nProblem Size n={n}:")
    print(f"  DFS Nodes Expanded: {results['dfs_nodes'][i]:.1f}")
    print(f"  DFS-MRV Nodes Expanded: {results['mrv_nodes'][i]:.1f}")
    if results['mrv_nodes'][i] > 0:
        reduction = (1 - results['mrv_nodes'][i]/results['dfs_nodes'][i]) * 100
        print(f"  Node Reduction: {reduction:.1f}%")
    print(f"  DFS Cost Ratio: {results['dfs_cost_ratio'][i]:.2f}x")
    print(f"  DFS-MRV Cost Ratio: {results['mrv_cost_ratio'][i]:.2f}x")
```

```
task, t0 4
task, t1 7
task, t2 6
constraint, t1 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 4
task, t1 7
task, t2 6
constraint, t1 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 4
task, t1 7
task, t2 6
constraint, t1 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by mon 2pm 20
task, t0 6
task, t1 4
task, t2 7
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by mon 1pm 20
Nodes expanded to reach solution: 4
task, t0 6
task, t1 4
task, t2 7
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by mon 1pm 20
Nodes expanded to reach solution: 3
task, t0 6
task, t1 4
task, t2 7
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by mon 1pm 20
task, t0 6
task, t1 5
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by tue 12pm 20
```

```
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 30
Nodes expanded to reach solution: 3
task, t0 6
task, t1 5
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 30
Nodes expanded to reach solution: 3
task, t0 6
task, t1 5
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 5
constraint, t0 same-day t1
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 1pm 30
Nodes expanded to reach solution: 3
task, t0 4
task, t1 5
task, t2 5
constraint, t0 same-day t1
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 1pm 30
Nodes expanded to reach solution: 3
task, t0 4
task, t1 5
task, t2 5
constraint, t0 same-day t1
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 4
constraint, t0 same-day t2
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 1pm 20
Nodes expanded to reach solution: 3
task, t0 7
task, t1 6
task, t2 4
constraint, t0 same-day t2
```

```
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 1pm 20
Nodes expanded to reach solution: 3
task, t0 7
task, t1 6
task, t2 4
constraint, t0 same-day t2
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 1pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 6
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 2pm 30
domain, t3 ends-by tue 1pm 20
Nodes expanded to reach solution: 4
task, t0 6
task, t1 6
task, t2 6
task, t3 6
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 2pm 30
domain, t3 ends-by tue 1pm 20
Nodes expanded to reach solution: 4
task, t0 6
task, t1 6
task, t2 6
task, t3 6
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 2pm 30
domain, t3 ends-by tue 1pm 20
task, t0 6
task, t1 6
task, t2 4
task, t3 6
constraint, t0 before t1
constraint, t2 same-day t3
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by mon 12pm 10
Nodes expanded to reach solution: 6
```

```
task, t0 6
task, t1 6
task, t2 4
task, t3 6
constraint, t0 before t1
constraint, t2 same-day t3
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by mon 12pm 10
Nodes expanded to reach solution: 4
task, t0 6
task, t1 6
task, t2 4
task, t3 6
constraint, t0 before t1
constraint, t2 same-day t3
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by mon 12pm 10
task, t0 4
task, t1 7
task, t2 4
task, t3 4
constraint, t2 before t3
constraint, t0 before t1
domain, t0 ends-by tue 1pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by tue 2pm 10
Nodes expanded to reach solution: 9
task, t0 4
task, t1 7
task, t2 4
task, t3 4
constraint, t2 before t3
constraint, t0 before t1
domain, t0 ends-by tue 1pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by tue 2pm 10
Nodes expanded to reach solution: 4
task, t0 4
task, t1 7
task, t2 4
task, t3 4
constraint, t2 before t3
constraint, t0 before t1
domain, t0 ends-by tue 1pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by tue 2pm 10
task, t0 4
task, t1 5
```

```
task, t2 6
task, t3 7
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 30
Nodes expanded to reach solution: 4
task, t0 4
task, t1 5
task, t2 6
task, t3 7
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 30
Nodes expanded to reach solution: 4
task, t0 4
task, t1 5
task, t2 6
task, t3 7
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
task, t3 5
constraint, t1 before t2
constraint, t0 same-day t3
constraint, t0 same-day t1
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by mon 1pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 5
task, t2 7
task, t3 5
constraint, t1 before t2
constraint, t0 same-day t3
constraint, t0 same-day t1
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by mon 1pm 20
Nodes expanded to reach solution: 4
task, t0 5
```

```
task, t1 5
task, t2 7
task, t3 5
constraint, t1 before t2
constraint, t0 same-day t3
constraint, t0 same-day t1
domain, t0 ends-by tue 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by mon 1pm 20
task, t0 5
task, t1 7
task, t2 7
task, t3 5
task, t4 6
constraint, t2 same-day t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 7
task, t2 7
task, t3 5
task, t4 6
constraint, t2 same-day t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 7
task, t2 7
task, t3 5
task, t4 6
constraint, t2 same-day t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 20
task, t0 7
task, t1 5
task, t2 7
task, t3 6
task, t4 4
constraint, t0 same-day t1
constraint, t0 before t3
constraint, t2 same-day t3
```

```
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 12pm 10
Nodes expanded to reach solution: 18
task, t0 7
task, t1 5
task, t2 7
task, t3 6
task, t4 4
constraint, t0 same-day t1
constraint, t0 before t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 12pm 10
Nodes expanded to reach solution: 6
task, t0 7
task, t1 5
task, t2 7
task, t3 6
task, t4 4
constraint, t0 same-day t1
constraint, t0 before t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 12pm 10
task, t0 6
task, t1 5
task, t2 6
task, t3 4
task, t4 7
constraint, t3 before t4
constraint, t0 before t4
constraint, t1 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by mon 1pm 10
Nodes expanded to reach solution: 10
task, t0 6
task, t1 5
task, t2 6
task, t3 4
task, t4 7
constraint, t3 before t4
constraint, t0 before t4
constraint, t1 before t3
domain, t0 ends-by tue 2pm 20
```

```
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by mon 1pm 10
Nodes expanded to reach solution: 5
task, t0 6
task, t1 5
task, t2 6
task, t3 4
task, t4 7
constraint, t3 before t4
constraint, t0 before t4
constraint, t1 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by mon 1pm 10
task, t0 6
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t1 same-day t4
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 2pm 30
Nodes expanded to reach solution: 5
task, t0 6
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t1 same-day t4
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 2pm 30
Nodes expanded to reach solution: 5
task, t0 6
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t1 same-day t4
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 20
domain, t0 mon
```

```
domain, t1 ends-by tue 2pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 2pm 30
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 4
constraint, t3 before t4
constraint, t0 before t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 1pm 10
Nodes expanded to reach solution: 3928
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 4
constraint, t3 before t4
constraint, t0 before t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 1pm 10
Nodes expanded to reach solution: 10
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 4
constraint, t3 before t4
constraint, t0 before t3
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 5
task, t3 6
task, t4 4
task, t5 4
constraint, t4 same-day t5
constraint, t2 same-day t5
constraint, t3 same-day t4
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 20
```

```
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 6
task, t0 7
task, t1 4
task, t2 5
task, t3 6
task, t4 4
task, t5 4
constraint, t4 same-day t5
constraint, t2 same-day t5
constraint, t3 same-day t4
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 6
task, t0 7
task, t1 4
task, t2 5
task, t3 6
task, t4 4
task, t5 4
constraint, t4 same-day t5
constraint, t2 same-day t5
constraint, t3 same-day t4
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 2pm 10
domain, t5 ends-by tue 1pm 30
task, t0 6
task, t1 4
task, t2 7
task, t3 5
task, t4 5
task, t5 4
constraint, t0 same-day t4
constraint, t4 same-day t5
constraint, t3 before t5
constraint, t2 before t5
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 6
```

task, t5 4
constraint, t4 same-day t5
constraint, t0 same-day t3
constraint, t3 same-day t4
constraint, t0 same-day t5
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by mon 12pm 20
Nodes expanded to reach solution: 6
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 6
task, t5 4
constraint, t4 same-day t5
constraint, t0 same-day t3
constraint, t3 same-day t4
constraint, t0 same-day t5
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by mon 12pm 20
Nodes expanded to reach solution: 6
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 6
task, t5 4
constraint, t4 same-day t5
constraint, t0 same-day t3
constraint, t3 same-day t4
constraint, t0 same-day t5
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by mon 12pm 20
task, t0 4
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 7
constraint, t4 same-day t5
constraint, t2 same-day t4
constraint, t0 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20

```
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by tue 2pm 20
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 10
task, t0 4
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 7
constraint, t4 same-day t5
constraint, t2 same-day t4
constraint, t0 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by tue 2pm 20
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 6
task, t0 4
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 7
constraint, t4 same-day t5
constraint, t2 same-day t4
constraint, t0 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by tue 2pm 20
domain, t5 ends-by tue 1pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 7
task, t4 5
task, t5 6
constraint, t2 before t5
constraint, t4 before t5
constraint, t2 before t4
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 44
task, t0 6
task, t1 5
task, t2 4
task, t3 7
task, t4 5
```

```
task, t5 6
constraint, t2 before t5
constraint, t4 before t5
constraint, t2 before t4
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
Nodes expanded to reach solution: 11
task, t0 6
task, t1 5
task, t2 4
task, t3 7
task, t4 5
task, t5 6
constraint, t2 before t5
constraint, t4 before t5
constraint, t2 before t4
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
task, t0 5
task, t1 4
task, t2 5
task, t3 5
task, t4 6
task, t5 5
constraint, t4 same-day t5
constraint, t0 same-day t3
constraint, t3 before t5
constraint, t1 same-day t4
constraint, t2 before t3
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by mon 2pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 7
task, t4 6
task, t5 6
constraint, t1 same-day t4
constraint, t2 same-day t5
constraint, t4 before t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 20
```

```
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by tue 2pm 30
Nodes expanded to reach solution: 476
task, t0 6
task, t1 6
task, t2 5
task, t3 7
task, t4 6
task, t5 6
constraint, t1 same-day t4
constraint, t2 same-day t5
constraint, t4 before t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by tue 2pm 30
Nodes expanded to reach solution: 6
task, t0 6
task, t1 6
task, t2 5
task, t3 7
task, t4 6
task, t5 6
constraint, t1 same-day t4
constraint, t2 same-day t5
constraint, t4 before t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 30
domain, t5 ends-by tue 2pm 30
task, t0 5
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t2 same-day t3
constraint, t5 before t6
constraint, t0 same-day t2
constraint, t1 before t5
constraint, t4 same-day t5
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 2pm 10
domain, t6 ends-by mon 2pm 10
Nodes expanded to reach solution: 170
task, t0 5
task, t1 5
```

```
task, t2 4
task, t3 5
task, t4 6
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t2 same-day t3
constraint, t5 before t6
constraint, t0 same-day t2
constraint, t1 before t5
constraint, t4 same-day t5
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 2pm 10
domain, t6 ends-by mon 2pm 10
Nodes expanded to reach solution: 17
task, t0 5
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t2 same-day t3
constraint, t5 before t6
constraint, t0 same-day t2
constraint, t1 before t5
constraint, t4 same-day t5
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 2pm 10
domain, t6 ends-by mon 2pm 10
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 5
task, t5 7
task, t6 5
constraint, t4 same-day t6
constraint, t2 same-day t6
constraint, t5 before t6
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 2pm 20
Nodes expanded to reach solution: 54976
```

```
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 5
task, t5 7
task, t6 5
constraint, t4 same-day t6
constraint, t2 same-day t6
constraint, t5 before t6
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 2pm 20
Nodes expanded to reach solution: 7
task, t0 6
task, t1 7
task, t2 5
task, t3 5
task, t4 5
task, t5 7
task, t6 5
constraint, t4 same-day t6
constraint, t2 same-day t6
constraint, t5 before t6
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 2pm 20
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 4
task, t5 7
task, t6 7
constraint, t1 same-day t6
constraint, t0 same-day t6
constraint, t3 before t4
constraint, t1 same-day t2
constraint, t4 same-day t5
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 1pm 10
Nodes expanded to reach solution: 13
task, t0 6
```

```
task, t1 5
task, t2 4
task, t3 5
task, t4 4
task, t5 7
task, t6 7
constraint, t1 same-day t6
constraint, t0 same-day t6
constraint, t3 before t4
constraint, t1 same-day t2
constraint, t4 same-day t5
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 1pm 10
Nodes expanded to reach solution: 8
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 4
task, t5 7
task, t6 7
constraint, t1 same-day t6
constraint, t0 same-day t6
constraint, t3 before t4
constraint, t1 same-day t2
constraint, t4 same-day t5
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 30
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 1pm 10
task, t0 6
task, t1 7
task, t2 5
task, t3 6
task, t4 6
task, t5 5
task, t6 4
constraint, t1 before t5
constraint, t3 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 12pm 20
```

```
Nodes expanded to reach solution: 14
task, t0 6
task, t1 7
task, t2 5
task, t3 6
task, t4 6
task, t5 5
task, t6 4
constraint, t1 before t5
constraint, t3 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 12pm 20
Nodes expanded to reach solution: 11
task, t0 6
task, t1 7
task, t2 5
task, t3 6
task, t4 6
task, t5 5
task, t6 4
constraint, t1 before t5
constraint, t3 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 12pm 20
task, t0 7
task, t1 4
task, t2 4
task, t3 5
task, t4 5
task, t5 6
task, t6 4
constraint, t0 before t3
constraint, t0 same-day t4
constraint, t3 same-day t5
constraint, t2 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by tue 2pm 30
Nodes expanded to reach solution: 12
task, t0 7
task, t1 4
```

```
task, t2 4
task, t3 5
task, t4 5
task, t5 6
task, t6 4
constraint, t0 before t3
constraint, t0 same-day t4
constraint, t3 same-day t5
constraint, t2 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by tue 2pm 30
Nodes expanded to reach solution: 9
task, t0 7
task, t1 4
task, t2 4
task, t3 5
task, t4 5
task, t5 6
task, t6 4
constraint, t0 before t3
constraint, t0 same-day t4
constraint, t3 same-day t5
constraint, t2 same-day t4
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by tue 2pm 30
```


Nodes Expanded: DFS vs DFS-MRV — Solution Quality vs Optimal
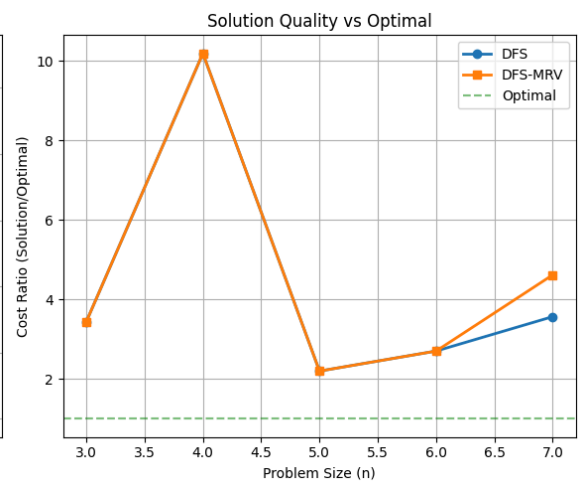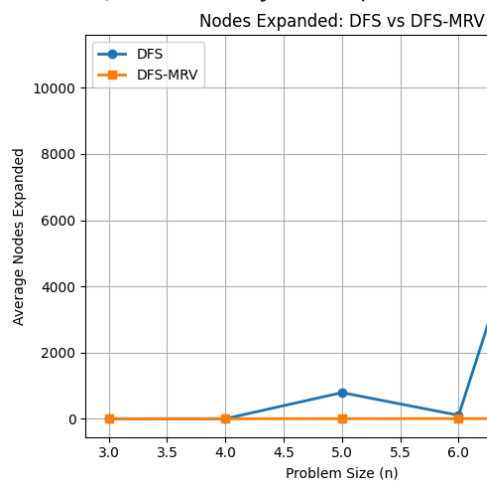
```
Problem Size n=3:
  DFS Nodes Expanded: 3.2
  DFS-MRV Nodes Expanded: 3.0
  Node Reduction: 6.2%
  DFS Cost Ratio: 3.44x
  DFS-MRV Cost Ratio: 3.44x

Problem Size n=4:
  DFS Nodes Expanded: 5.6
  DFS-MRV Nodes Expanded: 4.0
  Node Reduction: 28.6%
  DFS Cost Ratio: 10.19x
  DFS-MRV Cost Ratio: 10.19x

Problem Size n=5:
  DFS Nodes Expanded: 793.2
  DFS-MRV Nodes Expanded: 6.2
  Node Reduction: 99.2%
  DFS Cost Ratio: 2.20x
  DFS-MRV Cost Ratio: 2.20x

Problem Size n=6:
  DFS Nodes Expanded: 108.4
  DFS-MRV Nodes Expanded: 7.0
  Node Reduction: 93.5%
  DFS Cost Ratio: 2.70x
  DFS-MRV Cost Ratio: 2.70x

Problem Size n=7:
  DFS Nodes Expanded: 11037.0
  DFS-MRV Nodes Expanded: 10.4
  Node Reduction: 99.9%
  DFS Cost Ratio: 3.57x
  DFS-MRV Cost Ratio: 4.62x
```

Answers for Question 4

If you want to submit additional code, put this at the end of the notebook. Here just give the answers (including plots or tables).

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` .

Empirically compare the performance of DFS with and without these heuristics (2 marks)

We can see empirically that that the DFS with cost may have significantly more nodes explores in the magnitude of 1000s more. However in terms of optimal solution squality we can see that DFS cost manages to find a very optimal cost solution wheras DFS without cost is a signicantly less optimal solution.

In [60]:
```python
# Code for Question 5
# Modified dfs_solver with cost heuristics

num_expanded = 0
display = False

def dfs_solver(constraints, domains, context, var_order, durations=None, cost_fu
               soft_day_time=None, soft_costs=None):
    """ 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

        When cost parameters are provided, uses cost heuristics:
        - Choose variable with lowest minimum cost
        - Explore values in order of increasing cost
    """
    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]

            # Use cost heuristics if cost information is provided
            if cost_functions is not None and durations is not None:
                # Calculate minimum cost for each variable
                var_min_costs = []
                for var in var_order:
                    min_cost_for_var = float('inf')
                    for domain_val in domains[var]:
                        cost_func = cost_functions[var][0]
                        var_cost = cost_func(domain_val, soft_day_time[var],
                                             durations[var], soft_costs[var])
                        if var_cost is not None and var_cost < min_cost_for_var:
                            min_cost_for_var = var_cost
                    if min_cost_for_var == float('inf'):
                        min_cost_for_var = 0
                    var_min_costs.append((var, min_cost_for_var))

                # Choose variable with lowest minimum cost
                var_min_costs.sort(key=lambda x: x[1])
```

```python
                var = var_min_costs[0][0]

                # Sort values by cost
                val_costs = []
                for val in domains[var]:
                    cost_func = cost_functions[var][0]
                    val_cost = cost_func(val, soft_day_time[var],
                                        durations[var], soft_costs[var])
                    if val_cost is None:
                        val_cost = 0
                    val_costs.append((val, val_cost))

                val_costs.sort(key=lambda x: x[1])

                # Explore values in order of increasing cost
                new_var_order = [v for v in var_order if v != var]
                for val, cost in val_costs:
                    if display:
                        print("Setting", var, "to", val)
                    num_expanded += 1
                    yield from dfs_solver(rem_cons, domains, context|{var:val},
                                        durations, cost_functions, soft_day_tim
            else:
                # Original behavior
                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},

    def dfs_solve1_with_cost(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,
                            csp.durations, csp.cost_functions, csp.soft_day_time, c
            return sol  # return first one
```

```python
# Empirical Comparison
import random
import matplotlib.pyplot as plt
import numpy as np

def compare_dfs_with_without_cost(problem_sizes, num_trials=5):
    results = {
        'sizes': problem_sizes,
        'dfs_nodes': [],
        'dfs_cost_nodes': [],
        'dfs_solution_cost': [],
        'dfs_cost_solution_cost': [],
        'optimal_cost': []
    }

    for n in problem_sizes:

        dfs_nodes_trials = []
        dfs_cost_nodes_trials = []
```

```python
        dfs_sol_cost_trials = []
        dfs_cost_sol_cost_trials = []
        optimal_cost_trials = []

        successful_trials = 0
        trial = 0

        while successful_trials < num_trials and trial < num_trials * 5:
            trial += 1

            try:
                spec = generate_hard_problem(n)

                global num_expanded, display
                display = False
                csp_dfs = create_CSP_from_spec(spec)

                if csp_dfs is None or any(len(domain) == 0 for domain in csp_dfs
                    continue

                num_expanded = 0
                dfs_solution = dfs_solve1(csp_dfs)

                if dfs_solution is None:
                    continue

                dfs_nodes = num_expanded
                dfs_sol_cost = calculate_solution_cost(dfs_solution, csp_dfs)

                global num_expanded_cost, display_cost
                display_cost = False
                csp_dfs_cost = create_CSP_from_spec(spec)

                num_expanded_cost = 0
                dfs_cost_solution = dfs_solve1_with_cost(csp_dfs_cost)

                if dfs_cost_solution is None:
                    continue

                dfs_cost_nodes = num_expanded_cost
                dfs_cost_sol_cost = calculate_solution_cost(dfs_cost_solution, c

                csp_optimal = create_CSP_from_spec(spec)
                Search_with_AC_from_Cost_CSP.max_display_level = 0
                solver = GreedySearcher(Search_with_AC_from_Cost_CSP(csp_optimal
                final_path = solver.search()

                if final_path is None:
                    continue

                optimal_cost = final_path.end().cost

                dfs_nodes_trials.append(dfs_nodes)
                dfs_cost_nodes_trials.append(dfs_cost_nodes)
                dfs_sol_cost_trials.append(dfs_sol_cost)
                dfs_cost_sol_cost_trials.append(dfs_cost_sol_cost)
                optimal_cost_trials.append(optimal_cost)

                print(f"  Trial {successful_trials + 1}:")
                print(f"    DFS: {dfs_nodes} nodes, cost={dfs_sol_cost}")
```

```python
                print(f"    DFS+Cost: {dfs_cost_nodes} nodes, cost={dfs_cost_sol
                print(f"    Optimal: cost={optimal_cost}")

                successful_trials += 1

            except Exception as e:
                print(f"  Trial failed: {e}")
                continue

        if dfs_nodes_trials:
            results['dfs_nodes'].append(np.mean(dfs_nodes_trials))
            results['dfs_cost_nodes'].append(np.mean(dfs_cost_nodes_trials))
            results['dfs_solution_cost'].append(np.mean(dfs_sol_cost_trials))
            results['dfs_cost_solution_cost'].append(np.mean(dfs_cost_sol_cost_t
            results['optimal_cost'].append(np.mean(optimal_cost_trials))
        else:
            results['dfs_nodes'].append(0)
            results['dfs_cost_nodes'].append(0)
            results['dfs_solution_cost'].append(0)
            results['dfs_cost_solution_cost'].append(0)
            results['optimal_cost'].append(0)

    return results

problem_sizes = [3, 4, 5, 6, 7]
results = compare_dfs_with_without_cost(problem_sizes, num_trials=5)

fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

ax1.plot(results['sizes'], results['dfs_nodes'], 'o-', label='DFS (no cost)', li
ax1.plot(results['sizes'], results['dfs_cost_nodes'], 's-', label='DFS (with cos
ax1.set_xlabel('Problem Size (n)')
ax1.set_ylabel('Average Nodes Expanded')
ax1.set_title('Nodes Expanded: DFS with vs without Cost Heuristics')
ax1.legend()
ax1.grid(True)

ax2.plot(results['sizes'], results['dfs_solution_cost'], 'o-', label='DFS (no co
ax2.plot(results['sizes'], results['dfs_cost_solution_cost'], 's-', label='DFS (
ax2.plot(results['sizes'], results['optimal_cost'], '^--', label='Optimal', line
ax2.set_xlabel('Problem Size (n)')
ax2.set_ylabel('Average Solution Cost')
ax2.set_title('Solution Quality: DFS with vs without Cost Heuristics')
ax2.legend()
ax2.grid(True)

plt.tight_layout()
plt.show()

# Print summary
print("SUMMARY")

for i, n in enumerate(results['sizes']):
    print(f"\nProblem Size n={n}:")
    print(f"  DFS (no cost): {results['dfs_nodes'][i]:.1f} nodes, avg cost={res
    print(f"  DFS (with cost): {results['dfs_cost_nodes'][i]:.1f} nodes, avg cos
    print(f"  Optimal cost: {results['optimal_cost'][i]:.1f}")
```

```
task, t0 5
task, t1 7
task, t2 7
constraint, t0 same-day t1
constraint, t0 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
Nodes expanded to reach solution: 3
task, t0 5
task, t1 7
task, t2 7
constraint, t0 same-day t1
constraint, t0 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
Nodes expanded to reach solution: 3
task, t0 5
task, t1 7
task, t2 7
constraint, t0 same-day t1
constraint, t0 same-day t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
  Trial 1:
    DFS: 3 nodes, cost=150
    DFS+Cost: 0 nodes, cost=150
    Optimal: cost=150
task, t0 6
task, t1 6
task, t2 6
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 6
task, t1 6
task, t2 6
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 6
task, t1 6
task, t2 6
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 20
  Trial 2:
```

```
            DFS: 3 nodes, cost=60
            DFS+Cost: 0 nodes, cost=60
            Optimal: cost=60
task, t0 7
task, t1 7
task, t2 4
constraint, t1 before t2
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 1pm 30
task, t0 4
task, t1 5
task, t2 5
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by tue 1pm 30
Nodes expanded to reach solution: 6
task, t0 4
task, t1 5
task, t2 5
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by tue 1pm 30
Nodes expanded to reach solution: 6
task, t0 4
task, t1 5
task, t2 5
constraint, t1 before t2
constraint, t0 before t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by tue 1pm 30
  Trial 3:
     DFS: 6 nodes, cost=2190
     DFS+Cost: 0 nodes, cost=30
     Optimal: cost=30
task, t0 6
task, t1 6
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 6
task, t1 6
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by mon 12pm 10
domain, t0 mon
```

```
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 2pm 20
Nodes expanded to reach solution: 3
task, t0 6
task, t1 6
task, t2 5
constraint, t1 same-day t2
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 2pm 20
  Trial 4:
    DFS: 3 nodes, cost=30
    DFS+Cost: 0 nodes, cost=30
    Optimal: cost=30
task, t0 7
task, t1 4
task, t2 6
constraint, t0 same-day t2
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
Nodes expanded to reach solution: 3
task, t0 7
task, t1 4
task, t2 6
constraint, t0 same-day t2
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
Nodes expanded to reach solution: 3
task, t0 7
task, t1 4
task, t2 6
constraint, t0 same-day t2
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 2pm 10
  Trial 5:
    DFS: 3 nodes, cost=20
    DFS+Cost: 0 nodes, cost=20
    Optimal: cost=20
task, t0 6
task, t1 4
task, t2 7
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by tue 12pm 10
Nodes expanded to reach solution: 4
```

```
task, t0 6
task, t1 4
task, t2 7
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by tue 12pm 10
Nodes expanded to reach solution: 4
task, t0 6
task, t1 4
task, t2 7
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by tue 12pm 10
  Trial 1:
    DFS: 4 nodes, cost=150
    DFS+Cost: 0 nodes, cost=150
    Optimal: cost=150
task, t0 5
task, t1 6
task, t2 7
task, t3 7
constraint, t1 before t3
constraint, t2 before t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 10
Nodes expanded to reach solution: 5
task, t0 5
task, t1 6
task, t2 7
task, t3 7
constraint, t1 before t3
constraint, t2 before t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 10
Nodes expanded to reach solution: 5
task, t0 5
task, t1 6
task, t2 7
task, t3 7
constraint, t1 before t3
constraint, t2 before t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 30
```

```
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 10
  Trial 2:
    DFS: 5 nodes, cost=1040
    DFS+Cost: 0 nodes, cost=320
    Optimal: cost=320
task, t0 5
task, t1 6
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
Nodes expanded to reach solution: 8
task, t0 5
task, t1 6
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
Nodes expanded to reach solution: 8
task, t0 5
task, t1 6
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
  Trial 3:
    DFS: 8 nodes, cost=30
    DFS+Cost: 0 nodes, cost=30
    Optimal: cost=30
task, t0 5
task, t1 4
task, t2 6
task, t3 6
constraint, t0 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
Nodes expanded to reach solution: 4
task, t0 5
task, t1 4
task, t2 6
```

```
task, t3 6
constraint, t0 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
Nodes expanded to reach solution: 4
task, t0 5
task, t1 4
task, t2 6
task, t3 6
constraint, t0 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
  Trial 4:
    DFS: 4 nodes, cost=60
    DFS+Cost: 0 nodes, cost=60
    Optimal: cost=60
task, t0 5
task, t1 7
task, t2 4
task, t3 7
constraint, t1 same-day t2
constraint, t0 same-day t1
constraint, t0 before t3
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 7
task, t2 4
task, t3 7
constraint, t1 same-day t2
constraint, t0 same-day t1
constraint, t0 before t3
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 7
task, t2 4
task, t3 7
constraint, t1 same-day t2
constraint, t0 same-day t1
constraint, t0 before t3
domain, t0 ends-by tue 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
```

```
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
  Trial 5:
    DFS: 5 nodes, cost=2050
    DFS+Cost: 0 nodes, cost=610
    Optimal: cost=610
task, t0 7
task, t1 4
task, t2 5
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t0 same-day t2
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by tue 2pm 20
Nodes expanded to reach solution: 5
task, t0 7
task, t1 4
task, t2 5
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t0 same-day t2
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by tue 2pm 20
Nodes expanded to reach solution: 5
task, t0 7
task, t1 4
task, t2 5
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t0 same-day t2
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 20
domain, t4 ends-by tue 2pm 20
  Trial 1:
    DFS: 5 nodes, cost=40
    DFS+Cost: 0 nodes, cost=40
    Optimal: cost=40
task, t0 4
task, t1 6
task, t2 5
```

```
task, t3 6
task, t4 5
constraint, t3 before t4
constraint, t2 same-day t4
constraint, t0 same-day t2
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 10
task, t0 6
task, t1 6
task, t2 6
task, t3 7
task, t4 4
constraint, t1 before t2
constraint, t3 before t4
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
domain, t4 ends-by tue 12pm 10
Nodes expanded to reach solution: 11
task, t0 6
task, t1 6
task, t2 6
task, t3 7
task, t4 4
constraint, t1 before t2
constraint, t3 before t4
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
domain, t4 ends-by tue 12pm 10
Nodes expanded to reach solution: 11
task, t0 6
task, t1 6
task, t2 6
task, t3 7
task, t4 4
constraint, t1 before t2
constraint, t3 before t4
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by tue 1pm 30
domain, t4 ends-by tue 12pm 10
  Trial 2:
    DFS: 11 nodes, cost=2950
    DFS+Cost: 0 nodes, cost=790
    Optimal: cost=790
task, t0 5
task, t1 7
task, t2 4
```

```
task, t3 6
task, t4 7
constraint, t3 before t4
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by tue 2pm 20
Nodes expanded to reach solution: 1227
task, t0 5
task, t1 7
task, t2 4
task, t3 6
task, t4 7
constraint, t3 before t4
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by tue 2pm 20
Nodes expanded to reach solution: 7
task, t0 5
task, t1 7
task, t2 4
task, t3 6
task, t4 7
constraint, t3 before t4
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
domain, t4 ends-by tue 2pm 20
  Trial 3:
    DFS: 1227 nodes, cost=4420
    DFS+Cost: 0 nodes, cost=820
    Optimal: cost=820
task, t0 5
task, t1 7
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t4
constraint, t3 before t4
constraint, t1 before t4
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 20
domain, t2 ends-by mon 2pm 30
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 12pm 20
task, t0 4
task, t1 6
task, t2 4
task, t3 5
```

```
task, t4 5
constraint, t3 before t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 12pm 20
Nodes expanded to reach solution: 2450
task, t0 4
task, t1 6
task, t2 4
task, t3 5
task, t4 5
constraint, t3 before t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 12pm 20
Nodes expanded to reach solution: 490
task, t0 4
task, t1 6
task, t2 4
task, t3 5
task, t4 5
constraint, t3 before t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by tue 12pm 20
  Trial 4:
    DFS: 2450 nodes, cost=2950
    DFS+Cost: 0 nodes, cost=70
    Optimal: cost=70
task, t0 5
task, t1 4
task, t2 7
task, t3 5
task, t4 5
constraint, t3 same-day t4
constraint, t2 same-day t4
constraint, t0 same-day t4
constraint, t1 same-day t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 12pm 20
Nodes expanded to reach solution: 5
```

```
task, t0 5
task, t1 4
task, t2 7
task, t3 5
task, t4 5
constraint, t3 same-day t4
constraint, t2 same-day t4
constraint, t0 same-day t4
constraint, t1 same-day t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 12pm 20
Nodes expanded to reach solution: 5
task, t0 5
task, t1 4
task, t2 7
task, t3 5
task, t4 5
constraint, t3 same-day t4
constraint, t2 same-day t4
constraint, t0 same-day t4
constraint, t1 same-day t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 12pm 20
  Trial 5:
    DFS: 5 nodes, cost=60
    DFS+Cost: 0 nodes, cost=60
    Optimal: cost=60
task, t0 4
task, t1 4
task, t2 6
task, t3 5
task, t4 5
task, t5 6
constraint, t2 same-day t5
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t4 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 10
Nodes expanded to reach solution: 6
task, t0 4
task, t1 4
task, t2 6
task, t3 5
task, t4 5
task, t5 6
constraint, t2 same-day t5
```

constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t4 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 10
Nodes expanded to reach solution: 6
task, t0 4
task, t1 4
task, t2 6
task, t3 5
task, t4 5
task, t5 6
constraint, t2 same-day t5
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t4 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 1pm 10
  Trial 1:
    DFS: 6 nodes, cost=40
    DFS+Cost: 0 nodes, cost=40
    Optimal: cost=40
task, t0 5
task, t1 7
task, t2 6
task, t3 7
task, t4 5
task, t5 6
constraint, t3 before t4
constraint, t4 same-day t5
constraint, t0 same-day t2
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
Nodes expanded to reach solution: 11
task, t0 5
task, t1 7
task, t2 6
task, t3 7
task, t4 5
task, t5 6
constraint, t3 before t4
constraint, t4 same-day t5
constraint, t0 same-day t2
domain, t0 ends-by mon 12pm 30
domain, t0 mon

```
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
Nodes expanded to reach solution: 26
task, t0 5
task, t1 7
task, t2 6
task, t3 7
task, t4 5
task, t5 6
constraint, t3 before t4
constraint, t4 same-day t5
constraint, t0 same-day t2
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 10
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
  Trial 2:
    DFS: 11 nodes, cost=2540
    DFS+Cost: 0 nodes, cost=380
    Optimal: cost=380
task, t0 6
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 5
constraint, t0 same-day t2
constraint, t0 same-day t3
constraint, t3 same-day t4
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 12pm 10
Nodes expanded to reach solution: 6
task, t0 6
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 5
constraint, t0 same-day t2
constraint, t0 same-day t3
constraint, t3 same-day t4
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 12pm 10
Nodes expanded to reach solution: 6
```

```
task, t0 6
task, t1 4
task, t2 4
task, t3 4
task, t4 6
task, t5 5
constraint, t0 same-day t2
constraint, t0 same-day t3
constraint, t3 same-day t4
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 12pm 10
   Trial 3:
      DFS: 6 nodes, cost=60
      DFS+Cost: 0 nodes, cost=60
      Optimal: cost=60
task, t0 4
task, t1 7
task, t2 7
task, t3 7
task, t4 6
task, t5 7
constraint, t3 same-day t4
constraint, t1 before t4
constraint, t2 same-day t3
constraint, t3 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 1pm 20
Nodes expanded to reach solution: 26
task, t0 4
task, t1 7
task, t2 7
task, t3 7
task, t4 6
task, t5 7
constraint, t3 same-day t4
constraint, t1 before t4
constraint, t2 same-day t3
constraint, t3 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 1pm 20
Nodes expanded to reach solution: 46
task, t0 4
task, t1 7
task, t2 7
task, t3 7
```

```
task, t4 6
task, t5 7
constraint, t3 same-day t4
constraint, t1 before t4
constraint, t2 same-day t3
constraint, t3 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 20
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 1pm 20
  Trial 4:
    DFS: 26 nodes, cost=6720
    DFS+Cost: 0 nodes, cost=1680
    Optimal: cost=1680
task, t0 5
task, t1 5
task, t2 6
task, t3 4
task, t4 6
task, t5 6
constraint, t4 same-day t5
constraint, t1 same-day t2
constraint, t0 same-day t3
constraint, t0 same-day t4
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 1pm 20
Nodes expanded to reach solution: 6
task, t0 5
task, t1 5
task, t2 6
task, t3 4
task, t4 6
task, t5 6
constraint, t4 same-day t5
constraint, t1 same-day t2
constraint, t0 same-day t3
constraint, t0 same-day t4
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 1pm 20
Nodes expanded to reach solution: 6
task, t0 5
task, t1 5
task, t2 6
task, t3 4
task, t4 6
```

```
task, t5 6
constraint, t4 same-day t5
constraint, t1 same-day t2
constraint, t0 same-day t3
constraint, t0 same-day t4
constraint, t0 same-day t1
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 1pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by mon 1pm 20
  Trial 5:
    DFS: 6 nodes, cost=90
    DFS+Cost: 0 nodes, cost=90
    Optimal: cost=90
task, t0 7
task, t1 5
task, t2 7
task, t3 7
task, t4 6
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t4 same-day t6
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by tue 2pm 30
Nodes expanded to reach solution: 10
task, t0 7
task, t1 5
task, t2 7
task, t3 7
task, t4 6
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t4 same-day t6
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by tue 2pm 30
Nodes expanded to reach solution: 4105
task, t0 7
task, t1 5
task, t2 7
task, t3 7
task, t4 6
```

```
task, t5 5
task, t6 5
constraint, t3 before t5
constraint, t4 same-day t6
constraint, t1 same-day t4
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 1pm 20
domain, t6 ends-by tue 2pm 30
  Trial 1:
    DFS: 10 nodes, cost=1590
    DFS+Cost: 0 nodes, cost=150
    Optimal: cost=150
task, t0 4
task, t1 5
task, t2 6
task, t3 7
task, t4 6
task, t5 5
task, t6 5
constraint, t0 same-day t4
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by tue 12pm 20
domain, t6 ends-by tue 12pm 10
Nodes expanded to reach solution: 7
task, t0 4
task, t1 5
task, t2 6
task, t3 7
task, t4 6
task, t5 5
task, t6 5
constraint, t0 same-day t4
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by tue 12pm 20
domain, t6 ends-by tue 12pm 10
Nodes expanded to reach solution: 7
task, t0 4
task, t1 5
task, t2 6
task, t3 7
task, t4 6
```

```
task, t5 5
task, t6 5
constraint, t0 same-day t4
constraint, t0 same-day t1
constraint, t2 same-day t3
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 30
domain, t3 ends-by mon 2pm 20
domain, t4 ends-by mon 1pm 10
domain, t5 ends-by tue 12pm 20
domain, t6 ends-by tue 12pm 10
  Trial 2:
    DFS: 7 nodes, cost=150
    DFS+Cost: 0 nodes, cost=150
    Optimal: cost=150
task, t0 6
task, t1 6
task, t2 7
task, t3 6
task, t4 4
task, t5 5
task, t6 7
constraint, t3 same-day t5
constraint, t2 before t5
constraint, t2 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 12pm 30
domain, t6 ends-by mon 12pm 10
Nodes expanded to reach solution: 12
task, t0 6
task, t1 6
task, t2 7
task, t3 6
task, t4 4
task, t5 5
task, t6 7
constraint, t3 same-day t5
constraint, t2 before t5
constraint, t2 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 12pm 30
domain, t6 ends-by mon 12pm 10
Nodes expanded to reach solution: 12
task, t0 6
task, t1 6
task, t2 7
task, t3 6
task, t4 4
```

```
task, t5 5
task, t6 7
constraint, t3 same-day t5
constraint, t2 before t5
constraint, t2 before t3
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 20
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by tue 2pm 30
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by tue 12pm 30
domain, t6 ends-by mon 12pm 10
  Trial 3:
    DFS: 12 nodes, cost=4510
    DFS+Cost: 0 nodes, cost=190
    Optimal: cost=190
task, t0 6
task, t1 7
task, t2 5
task, t3 7
task, t4 5
task, t5 7
task, t6 4
constraint, t0 same-day t2
constraint, t2 same-day t3
constraint, t5 before t6
constraint, t3 same-day t4
constraint, t2 same-day t6
constraint, t0 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 12pm 10
domain, t5 ends-by mon 1pm 30
domain, t6 ends-by mon 12pm 10
task, t0 7
task, t1 6
task, t2 7
task, t3 6
task, t4 6
task, t5 7
task, t6 5
constraint, t3 before t4
constraint, t0 same-day t3
constraint, t2 before t3
constraint, t5 same-day t6
constraint, t2 same-day t5
constraint, t3 before t5
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by mon 12pm 10
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 12pm 30
domain, t6 ends-by mon 2pm 10
task, t0 7
```

```
task, t1 4
task, t2 6
task, t3 5
task, t4 7
task, t5 4
task, t6 6
constraint, t0 same-day t1
constraint, t0 before t6
constraint, t3 before t5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 2pm 20
Nodes expanded to reach solution: 15
task, t0 7
task, t1 4
task, t2 6
task, t3 5
task, t4 7
task, t5 4
task, t6 6
constraint, t0 same-day t1
constraint, t0 before t6
constraint, t3 before t5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 2pm 20
Nodes expanded to reach solution: 17
task, t0 7
task, t1 4
task, t2 6
task, t3 5
task, t4 7
task, t5 4
task, t6 6
constraint, t0 same-day t1
constraint, t0 before t6
constraint, t3 before t5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 2pm 10
domain, t5 ends-by tue 1pm 30
domain, t6 ends-by mon 2pm 20
  Trial 4:
    DFS: 15 nodes, cost=3550
```

```
        DFS+Cost: 0 nodes, cost=670
        Optimal: cost=670
task, t0 7
task, t1 7
task, t2 7
task, t3 7
task, t4 5
task, t5 6
task, t6 7
constraint, t2 same-day t5
constraint, t0 before t4
constraint, t1 before t2
constraint, t0 same-day t5
constraint, t2 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by mon 1pm 20
domain, t4 ends-by tue 2pm 20
domain, t5 ends-by tue 1pm 10
domain, t6 ends-by tue 12pm 30
task, t0 4
task, t1 6
task, t2 4
task, t3 7
task, t4 7
task, t5 6
task, t6 7
constraint, t1 same-day t4
constraint, t5 same-day t6
constraint, t4 same-day t5
constraint, t2 same-day t3
constraint, t2 same-day t6
constraint, t0 before t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 12pm 20
domain, t6 ends-by tue 12pm 10
Nodes expanded to reach solution: 950
task, t0 4
task, t1 6
task, t2 4
task, t3 7
task, t4 7
task, t5 6
task, t6 7
constraint, t1 same-day t4
constraint, t5 same-day t6
constraint, t4 same-day t5
constraint, t2 same-day t3
constraint, t2 same-day t6
constraint, t0 before t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
```
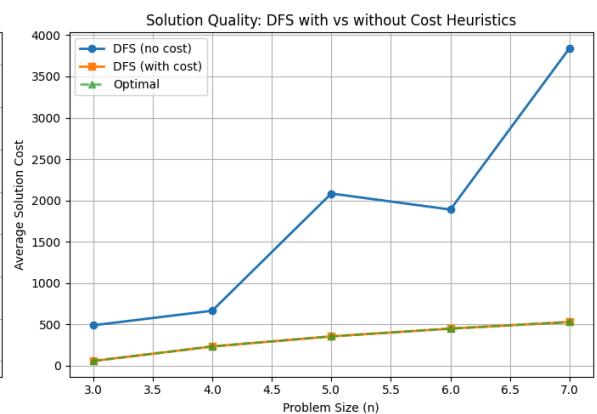
```
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 12pm 20
domain, t6 ends-by tue 12pm 10
Nodes expanded to reach solution: 2374
task, t0 4
task, t1 6
task, t2 4
task, t3 7
task, t4 7
task, t5 6
task, t6 7
constraint, t1 same-day t4
constraint, t5 same-day t6
constraint, t4 same-day t5
constraint, t2 same-day t3
constraint, t2 same-day t6
constraint, t0 before t4
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 1pm 20
domain, t5 ends-by mon 12pm 20
domain, t6 ends-by tue 12pm 10
  Trial 5:
    DFS: 950 nodes, cost=9410
    DFS+Cost: 0 nodes, cost=1490
    Optimal: cost=1490
```
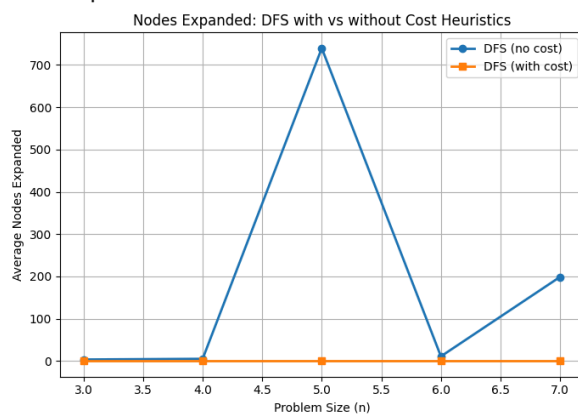

Nodes Expanded: DFS with vs without Cost Heuristics

Solution Quality: DFS with vs without Cost Heuristics

SUMMARY

```
Problem Size n=3:
  DFS (no cost):  3.6 nodes, avg cost=490.0
  DFS (with cost): 0.0 nodes, avg cost=58.0
  Optimal cost: 58.0

Problem Size n=4:
  DFS (no cost):  5.2 nodes, avg cost=666.0
  DFS (with cost): 0.0 nodes, avg cost=234.0
  Optimal cost: 234.0

Problem Size n=5:
  DFS (no cost):  739.6 nodes, avg cost=2084.0
  DFS (with cost): 0.0 nodes, avg cost=356.0
  Optimal cost: 356.0

Problem Size n=6:
  DFS (no cost):  11.0 nodes, avg cost=1890.0
  DFS (with cost): 0.0 nodes, avg cost=450.0
  Optimal cost: 450.0

Problem Size n=7:
  DFS (no cost):  198.8 nodes, avg cost=3842.0
  DFS (with cost): 0.0 nodes, avg cost=530.0
  Optimal cost: 530.0
```

Answers for Question 5

Write the other answers here.

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)

- 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)

We can see the performance that the k=2 partitions is just as good as all other partioning methods, as the average nodes expanded is less then the other k paritions. Thus supporting the claim for fuzzy scheduling CSps

```
In [66]: def partition_domain_k(dom, k):

             dom_list = sorted(dom)
             n = len(dom_list)
```

```
        if k >= n:
            return [set([val]) for val in dom_list]

        partitions = []
        base_size = n // k
        remainder = n % k

        start_idx = 0
        for i in range(k):
            size = base_size + (1 if i < remainder else 0)
            end_idx = start_idx + size
            partitions.append(set(dom_list[start_idx:end_idx]))
            start_idx = end_idx

        return partitions
```

In [67]:
```
#modified csp class to have k paritioning

class Search_with_AC_from_Cost_CSP_K(Search_problem):
    """ A search problem with domain splitting and arc consistency """

    def __init__(self, csp, k=2):
        self.cons = Con_solver(csp)
        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
        self.csp = csp
        self.k = k   # Number of partitions

    def is_goal(self, node):
        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_c

    def neighbors(self, node):
        neighs = []
        var = select(x for x in node.domains if len(node.domains[x]) > 1)

        if var:
            # Use k-way partitioning
            partitions = partition_domain_k(node.domains[var], self.k)
            self.display(2, f"Splitting {var} into {len(partitions)} partitions"

            to_do = self.cons.new_to_do(var, None)

            for dom in partitions:
                newdoms = node.domains | {var: dom}
                cons_doms = self.cons.make_arc_consistent(newdoms, to_do)

                if all(len(cons_doms[v]) > 0 for v in cons_doms):
                    csp_node = CSP_with_Cost(cons_doms, self.durations,
                                             self.constraints, self.cost_function
                                             self.soft_day_time, self.soft_costs)
```

```
                    neighs.append(Arc(node, csp_node))
                else:
                    self.display(2, f"...{var} in {dom} has no solution")

        return neighs

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

```
# Empirical evaluation function
def evaluate_k_partitions(problem_sizes, k_values, num_trials=5):

    results = {
        'k_values': k_values,
        'avg_nodes': {k: [] for k in k_values},
        'avg_time': {k: [] for k in k_values}
    }

    for n in problem_sizes:

        test_problems = []
        for trial in range(num_trials):
            spec = generate_hard_problem(n)
            csp = create_CSP_from_spec(spec)
            if csp is not None and all(len(d) > 0 for d in csp.domains.values())
                test_problems.append(spec)

        if len(test_problems) < num_trials:
            print(f"Warning: Only generated {len(test_problems)} valid problems"

        for k in k_values:
            nodes_expanded = []

            for spec in test_problems:
                try:
                    csp = create_CSP_from_spec(spec)

                    Search_with_AC_from_Cost_CSP_K.max_display_level = 0
                    problem = Search_with_AC_from_Cost_CSP_K(csp, k=k)
                    searcher = GreedySearcher(problem)

                    initial_count = searcher.num_expanded if hasattr(searcher, '
                    solution = searcher.search()
                    final_count = searcher.num_expanded if hasattr(searcher, 'nu

                    if solution is not None:
                        nodes = len(searcher.frontier) if hasattr(searcher, 'fro
                        nodes_expanded.append(nodes)

                except Exception as e:
                    continue

            if nodes_expanded:
                avg = np.mean(nodes_expanded)
                results['avg_nodes'][k].append(avg)

            else:
                results['avg_nodes'][k].append(0)
```

```python
        return results


import matplotlib.pyplot as plt
import numpy as np

problem_sizes = [3, 4, 5, 6, 7]
k_values = [2, 3, 4, 5, 8]


results = evaluate_k_partitions(problem_sizes, k_values, num_trials=5)

plt.figure(figsize=(12, 6))

for k in k_values:
    if results['avg_nodes'][k]:
        plt.plot(problem_sizes[:len(results['avg_nodes'][k])],
                 results['avg_nodes'][k],
                 marker='o',
                 label=f'k={k}',
                 linewidth=2)

plt.xlabel('Problem Size (n)', fontsize=12)
plt.ylabel('Average Nodes Expanded', fontsize=12)
plt.title('Domain Splitting Performance: k-way Partitioning', fontsize=14)
plt.legend()
plt.grid(True, alpha=0.3)
plt.tight_layout()
plt.show()

print("summary")

for i, n in enumerate(problem_sizes):
    print(f"\nProblem Size n={n}:")
    for k in k_values:
        if i < len(results['avg_nodes'][k]):
            nodes = results['avg_nodes'][k][i]
            print(f"  k={k}: {nodes:.1f} nodes")
```

```
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
```

```
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
```

```
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
```

```
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 7
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 2pm 20
task, t0 5
task, t1 6
task, t2 7
constraint, t1 same-day t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 20
task, t0 4
task, t1 6
task, t2 5
constraint, t1 before t2
domain, t0 ends-by mon 1pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 5
constraint, t0 same-day t2
domain, t0 ends-by mon 2pm 10
```

```
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 30
task, t0 5
task, t1 4
task, t2 4
constraint, t1 same-day t2
constraint, t0 before t2
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 4
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
```

```
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 4
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
```

```
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 4
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
```

```
task, t0 4
task, t1 5
task, t2 7
task, t3 4
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 4
```

```
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 4
constraint, t2 same-day t3
constraint, t1 same-day t2
constraint, t0 same-day t1
domain, t0 ends-by tue 1pm 10
```

```
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 2pm 20
task, t0 6
task, t1 6
task, t2 6
task, t3 7
constraint, t2 same-day t3
constraint, t1 same-day t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by tue 1pm 30
task, t0 7
task, t1 6
task, t2 6
task, t3 5
constraint, t2 same-day t3
constraint, t0 same-day t3
domain, t0 ends-by tue 12pm 30
domain, t0 mon
domain, t1 ends-by mon 2pm 20
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 12pm 30
task, t0 4
task, t1 5
task, t2 5
task, t3 5
constraint, t0 same-day t3
constraint, t2 same-day t3
domain, t0 ends-by mon 12pm 20
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 1pm 20
domain, t3 ends-by mon 2pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
constraint, t0 before t3
constraint, t1 before t2
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 10
domain, t2 ends-by tue 12pm 10
domain, t3 ends-by mon 1pm 30
task, t0 5
task, t1 5
task, t2 6
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
```

```
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 5
task, t1 5
task, t2 6
```

```
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
```

```
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 5
task, t1 5
task, t2 6
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
```

domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 5
task, t1 5
task, t2 6
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 sends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5

```
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 5
task, t1 5
task, t2 6
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
```

```
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 5
task, t1 5
task, t2 6
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t2 same-day t3
constraint, t1 same-day t2
domain, t0 ends-by tue 1pm 20
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 20
task, t0 6
task, t1 6
task, t2 5
task, t3 5
task, t4 7
constraint, t0 same-day t2
constraint, t0 before t1
domain, t0 ends-by mon 12pm 10
domain, t0 mon
```

```
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 2pm 20
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by mon 12pm 10
task, t0 4
task, t1 4
task, t2 6
task, t3 7
task, t4 5
constraint, t1 same-day t4
constraint, t0 before t2
constraint, t3 before t4
constraint, t0 same-day t3
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 30
domain, t2 ends-by tue 1pm 10
domain, t3 ends-by mon 1pm 10
domain, t4 ends-by mon 1pm 10
task, t0 5
task, t1 6
task, t2 4
task, t3 5
task, t4 4
constraint, t3 same-day t4
constraint, t0 same-day t4
constraint, t2 before t3
domain, t0 ends-by mon 1pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by tue 1pm 20
domain, t3 ends-by tue 12pm 30
domain, t4 ends-by mon 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 5
task, t2 5
task, t3 4
task, t4 6
constraint, t2 same-day t4
constraint, t1 before t3
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 20
domain, t2 ends-by tue 2pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 2pm 20
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
```

```
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
task, t0 6
task, t1 4
task, t2 5
task, t3 5
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 7
task, t3 4
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
```

```
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 6
task, t1 4
task, t2 5
task, t3 5
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
```

```
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 7
task, t3 4
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
No (more) solutions. Total of 1 paths expanded.
```

```
task, t0 6
task, t1 4
task, t2 5
task, t3 5
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 7
task, t3 4
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
```

```
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 6
task, t1 4
task, t2 5
task, t3 5
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
```

```
task, t0 7
task, t1 4
task, t2 7
task, t3 4
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 6
task, t1 4
task, t2 5
task, t3 5
```

```
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 7
task, t3 4
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
```

```
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 4
task, t1 5
task, t2 7
task, t3 6
task, t4 4
task, t5 6
constraint, t4 before t5
constraint, t2 before t4
constraint, t1 same-day t3
constraint, t1 before t2
constraint, t2 same-day t3
domain, t0 ends-by mon 2pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 20
domain, t5 ends-by tue 2pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 6
task, t1 4
task, t2 5
task, t3 5
task, t4 4
task, t5 6
constraint, t3 same-day t4
constraint, t1 same-day t4
constraint, t2 same-day t3
domain, t0 ends-by tue 2pm 10
domain, t0 mon
domain, t1 ends-by tue 12pm 10
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 10
task, t0 7
task, t1 7
task, t2 4
task, t3 5
task, t4 5
task, t5 5
constraint, t0 same-day t2
constraint, t3 same-day t5
constraint, t2 same-day t5
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by tue 2pm 20
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by tue 1pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by tue 1pm 10
task, t0 7
task, t1 4
task, t2 7
task, t3 4
```

```
task, t4 4
task, t5 6
constraint, t4 same-day t5
constraint, t2 before t4
constraint, t0 same-day t5
constraint, t1 same-day t3
constraint, t2 same-day t5
domain, t0 ends-by mon 2pm 30
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by mon 12pm 30
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by tue 1pm 20
domain, t5 ends-by mon 12pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 5
task, t2 7
task, t3 4
task, t4 7
task, t5 5
constraint, t2 before t3
constraint, t0 before t1
constraint, t3 same-day t4
constraint, t0 same-day t2
constraint, t0 same-day t5
domain, t0 ends-by tue 12pm 10
domain, t0 mon
domain, t1 ends-by mon 2pm 10
domain, t2 ends-by mon 1pm 10
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
```

```
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
```

```
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
```

```
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
```

```
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
```

constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20

```
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
```

```
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
```
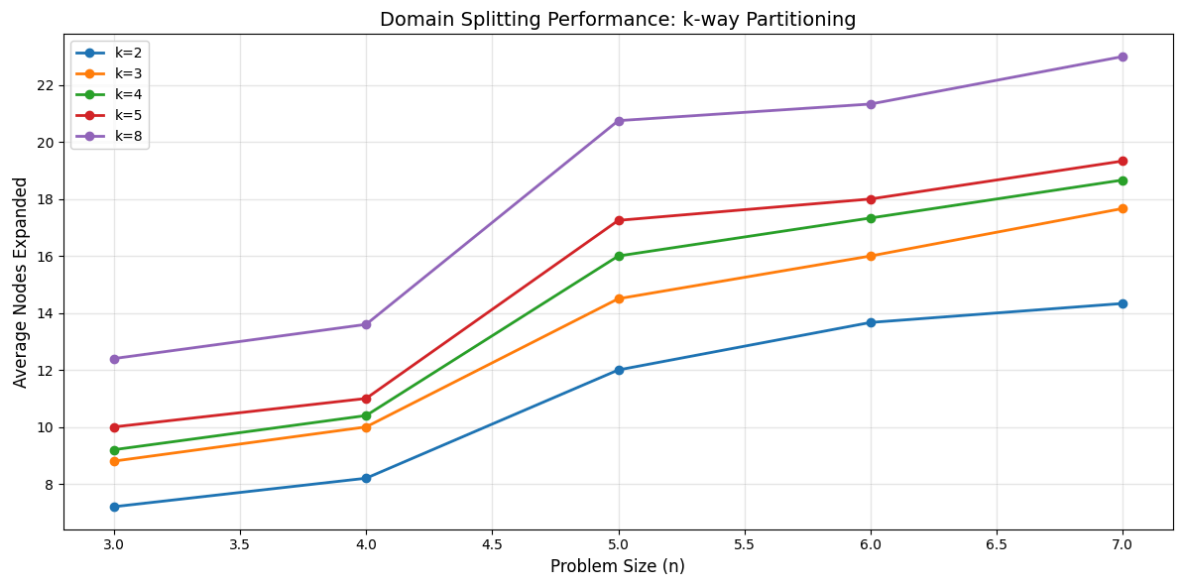
```
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
task, t0 7
task, t1 4
task, t2 6
task, t3 7
task, t4 4
task, t5 4
task, t6 5
constraint, t1 same-day t5
constraint, t1 same-day t4
constraint, t3 same-day t6
constraint, t4 same-day t6
constraint, t0 same-day t5
domain, t0 ends-by mon 2pm 20
domain, t0 mon
```

```
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by tue 12pm 20
domain, t3 ends-by mon 12pm 20
domain, t4 ends-by mon 1pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 2pm 30
task, t0 6
task, t1 5
task, t2 4
task, t3 5
task, t4 6
task, t5 6
task, t6 4
constraint, t1 same-day t2
constraint, t1 before t6
constraint, t0 same-day t4
constraint, t4 same-day t6
domain, t0 ends-by tue 2pm 20
domain, t0 mon
domain, t1 ends-by tue 12pm 30
domain, t2 ends-by mon 2pm 10
domain, t3 ends-by mon 2pm 10
domain, t4 ends-by mon 12pm 20
domain, t5 ends-by tue 2pm 20
domain, t6 ends-by tue 1pm 20
No (more) solutions. Total of 1 paths expanded.
task, t0 5
task, t1 4
task, t2 7
task, t3 7
task, t4 5
task, t5 4
task, t6 4
constraint, t2 same-day t3
constraint, t1 same-day t5
constraint, t1 same-day t2
constraint, t1 same-day t6
constraint, t4 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 1pm 30
domain, t2 ends-by tue 12pm 30
domain, t3 ends-by tue 1pm 20
domain, t4 ends-by tue 2pm 30
domain, t5 ends-by tue 2pm 10
domain, t6 ends-by tue 1pm 20
task, t0 6
task, t1 5
task, t2 5
task, t3 4
task, t4 4
task, t5 4
task, t6 4
constraint, t5 same-day t6
constraint, t1 same-day t4
constraint, t0 same-day t6
constraint, t4 same-day t5
constraint, t0 before t1
domain, t0 ends-by mon 12pm 30
domain, t0 mon
```

```
domain, t1 ends-by tue 1pm 30
domain, t2 ends-by mon 12pm 20
domain, t3 ends-by mon 12pm 10
domain, t4 ends-by mon 2pm 30
domain, t5 ends-by mon 1pm 20
domain, t6 ends-by mon 1pm 10
No (more) solutions. Total of 1 paths expanded.
task, t0 7
task, t1 6
task, t2 7
task, t3 5
task, t4 6
task, t5 4
task, t6 5
constraint, t4 before t5
constraint, t3 same-day t6
constraint, t0 same-day t6
domain, t0 ends-by mon 12pm 10
domain, t0 mon
domain, t1 ends-by mon 12pm 10
domain, t2 ends-by tue 1pm 30
domain, t3 ends-by tue 12pm 10
domain, t4 ends-by tue 1pm 10
domain, t5 ends-by mon 2pm 20
domain, t6 ends-by mon 1pm 30
```


Domain Splitting Performance: k-way Partitioning

summary

Problem Size n=3:
  k=2: 7.2 nodes
  k=3: 8.8 nodes
  k=4: 9.2 nodes
  k=5: 10.0 nodes
  k=8: 12.4 nodes

Problem Size n=4:
  k=2: 8.2 nodes
  k=3: 10.0 nodes
  k=4: 10.4 nodes
  k=5: 11.0 nodes
  k=8: 13.6 nodes

Problem Size n=5:
  k=2: 12.0 nodes
  k=3: 14.5 nodes
  k=4: 16.0 nodes
  k=5: 17.2 nodes
  k=8: 20.8 nodes

Problem Size n=6:
  k=2: 13.7 nodes
  k=3: 16.0 nodes
  k=4: 17.3 nodes
  k=5: 18.0 nodes
  k=8: 21.3 nodes

Problem Size n=7:
  k=2: 14.3 nodes
  k=3: 17.7 nodes
  k=4: 18.7 nodes
  k=5: 19.3 nodes
  k=8: 23.0 nodes

In [55]:
```python
# Code for Question 6
# Place a copy of your code here and run it in the relevant cell
```

Answers for Question 6

Write the other answers here.