Search and Task Allocation

Game Theory

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1 Introduction

This study is a continuation of a previous study where we implemented a system of randomly moving reactive agents R that solve tasks T randomly distributed over a square search area A [1]. While we have previously solved this search and task allocation (STA) problem with *reactive*, passive agents; we will in this study solve the same problem using *strategic* agents.

Now, whenever a new task is discovered an auction takes place among the agents within communication range. The discoverer of the task functions as the acutioneer, and the agents within communication distance as bidders. The potentially helping bidders use the distance to the task as their bid in the auction. The acutioneer will recruit help based on their bids in order to have enough agengs, including itself, to solve the task.

2 Extending PyGame Framework

From before we already have a framework implemented in PyGame[2], that is able to simulate the STA problem with reactive agents. The framework consists of three main classes, `Agent`, `Task` and `Simulation`. The `Task` class' relevant members are the task capacity T_c and an `update()` method that kills the task if enough agents, compared to T_c, are tasked to it. The `Agent` class' most important functionality is the `update()` method that functions differently depding on the *state* of the agent. An agent can be *searching*, *tasked* or *called*. As such, it is a very passive sprite. All other mechanics within the simulation is controlled by the `Simulation` class. Therefore, it is easiest from an implementation standpoint to extend the `Simulation` class to make the agents strategic, because it is here that the states of the `Agent` class instances are changed.

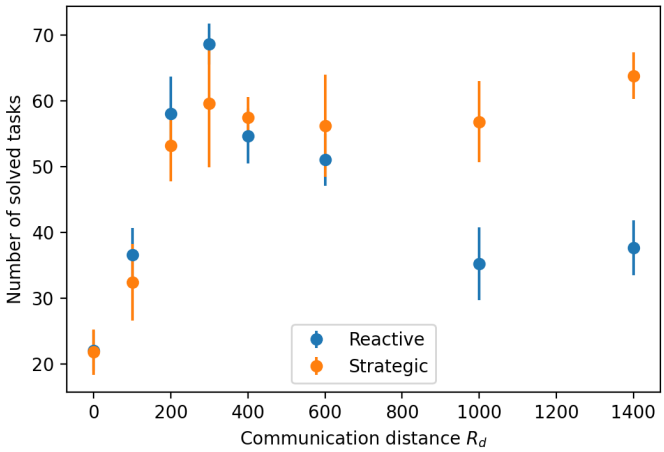


Figure 1: Comparison of strategic and reactive agents. Each point represents the mean and standard deviation for number of solved tasks after $T = 1000$ times steps for five simulations. We notice a reduction in performance as the communication distance R_d increases for the reactive agents.

To accomplish this, we move the lines of code that checks if a task is disovered, i.e. an agent is within task radius T_r of the tasks, to a separate method within the `Simulation` class. Then we can create a subclass `AuctionSimulation` that only needs to reimplement this method, `check_for_tasks()`. The entire implementation is included in Appendix B.

3 Results

We perform five strategic agent simulations over $T = 1000$ time steps for different communication distances $R_d \in \{0, 100, 200, 300, 400, 600, 1000, 1400\}$. Figures showing cumulative number of tasks solved for these simulations are provided in Appendix A.

A comparison of the strategic and reactive agents is shown in Figure 1. We uncover no significant difference in performance between the two types of agents for a low communication distance $R_d \leq 600$. Above this level, the strategic agents perform significantly better.

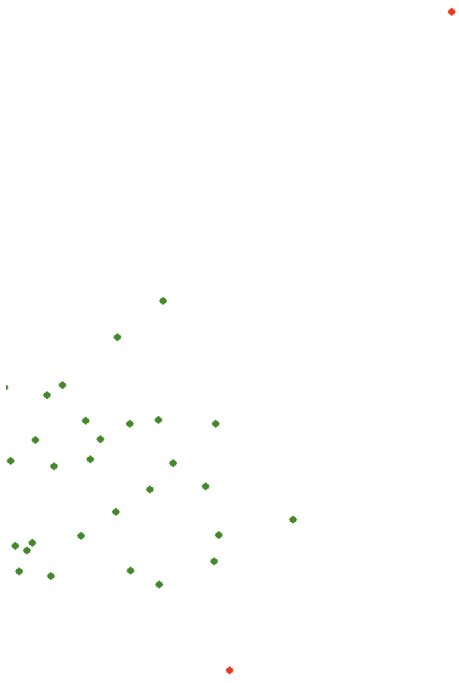


Figure 2: Clustering of reactive agents that commonly occurs for high communication distances - this is for $R_d = 1400$.

4 Discussion

The reason for the drop in performance for a long communication distance when one is applying reactive agents is illustrated clearly in Figure 2. When an agent discovers a task, a very large percentage of the other agents are called to its location, if the commucation radius R_d reaches across a large part of the search area. This in turn will sometimes result in clustering of agents, which again leads to a longer time until the next task is discovered.

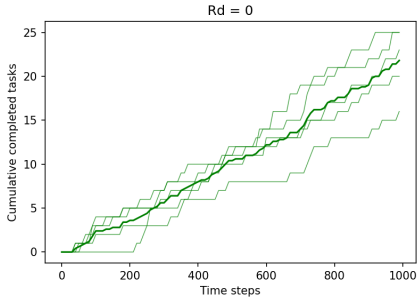
Several factors must be taken into account in the choice of agents. We assume here that strategic agents are about twice as costly as reactive agents. The first thing to consider is what is known about the search area. If one has knowledge of the size of the search area A, one can tune the communication distance R_d to be around half of the width of A, and reactive agents would perform just as well as strategic agents. If one does not have this knowledge,

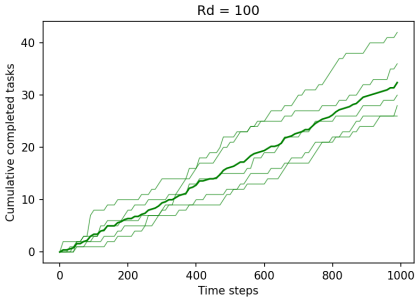
one would most likely be intersted in setting R_d as high as possible, to make sure that agents can communicate at all. Such a decision bears the risk of making the reactive agents preform at a suboptimal level. The difference in performance as shown in Figure 1 is 25 solved tasks for $R_d > 1000$ after $T = 1000$ time steps. Since the cummulative number of solved tasks as a function of time appear to be linear, one would expect this difference to increase over time. Therefore, the time it takes to complete the problem will affect the perfomance, favourably for strategic agents. After enough time, this difference would quickly make up the difference in cost of agents. In conclusion, if it is possible to adjust the communication distance R_d from prior knowledge of the search area A; use cheap, reactive agents. If the search area is unknown, opting for more dear strategic agents set with very high R_d is the prudent choice.

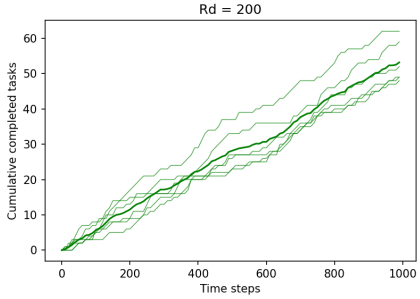
References

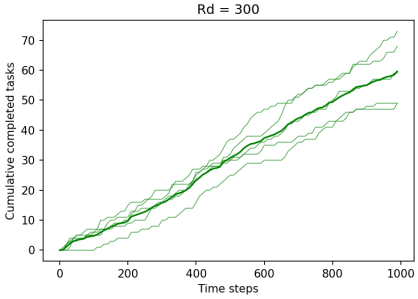
1. Winther-Larsen, S. G. *Multi-Agent Systems* `https://github.com/gregwinther/mas`. 2020.
2. Shinners, P. *et al. PyGame* `http://pygame.org/`. 2020.

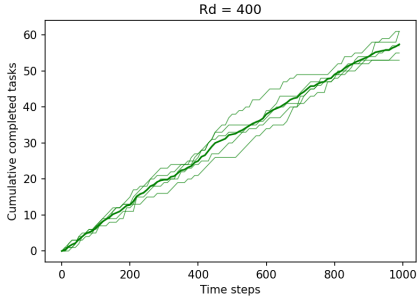
A Figures

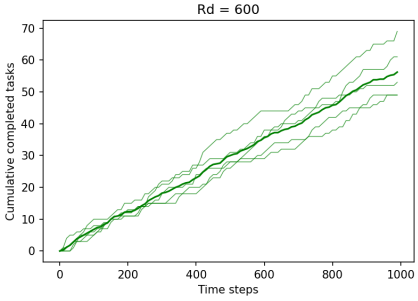

Rd = 0
Cumulative completed tasks
Time steps

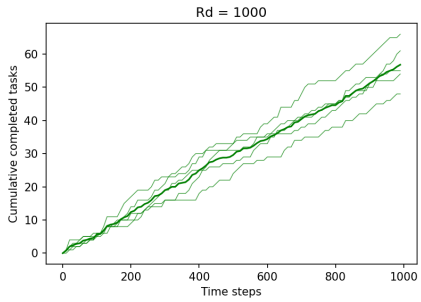

Rd = 100
Cumulative completed tasks
Time steps

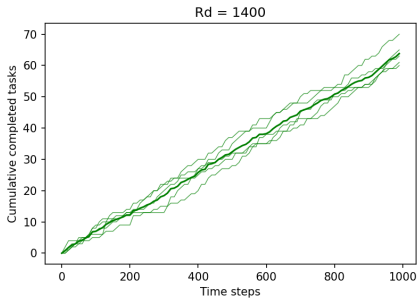

Rd = 200
Cumulative completed tasks
Time steps


Rd = 300
Cumulative completed tasks
Time steps


Rd = 400
Cumulative completed tasks
Time steps


Rd = 600
Cumulative completed tasks
Time steps





B Code listing

```
import pygame, sys
import numpy as np
import math
from collections import OrderedDict

BLACK = (0, 0, 0)
WHITE = (255, 255, 255)
GREY = (200, 200, 200)
PASTEL_RED = (245, 130, 120)
MINT = (160, 250, 160)
FOREST_GREEN = (30, 140, 30)
RED = (255, 0, 0)

BACKGROUND = WHITE

FRAME_RATE = 12


class Task(pygame.sprite.Sprite):
    def __init__(self, x, y, Tc=1, Tr=50):
        super().__init__()
        radius = 5  # Size of task
        self.image = pygame.Surface([radius * 2] * 2)
        self.image.fill(BACKGROUND)
        pygame.draw.circle(self.image, RED, (radius, radius), radius)

        self.pos = np.array([x, y])
        self.rect = self.image.get_rect()
        self.rect.centerx, self.rect.centery = x, y

        # Task capacity
        self.Tc = Tc
        self.tasked_agents = pygame.sprite.Group()
```

```
        # Task radius
        self.Tr = Tr

    def update(self):

        # Task completion
        if len(self.tasked_agents) >= self.Tc:
            self.kill()


class Agent(pygame.sprite.Sprite):
    def __init__(self, x, y, Rv=25, boundary=1000, Rd=250):
        super().__init__()
        radius = 5
        self.image = pygame.Surface([radius * 2] * 2)
        self.image.fill(BACKGROUND)
        pygame.draw.circle(
            self.image, FOREST_GREEN, (radius, radius), radius
        )

        self.pos = np.array([x, y], dtype=np.float64)
        self.rect = self.image.get_rect()
        self.rect.x, self.rect.y = x, y

        self.Rv = Rv  # / FRAME_RATE
        self.Rd = Rd

        self.vel = np.random.rand(2) * 2 - 1
        self.trend = (np.random.rand(2) * 2 - 1) / 2

        self.boundary = boundary

        self.tasked = False
        self.called = False
        self.call_dir = np.array([0, 0])

    def update(self):
        if self.tasked:
            # Stand still
            return

        if self.called:
            # print(self.call_dir)
            self.pos += self.call_dir
            self.rect.centerx, self.rect.centery = self.pos.copy().astype(
                "int"
            )
            return
```

```
            self.pos += self.normalize(self.vel + self.trend, self.Rv)
            self.rect.centerx, self.rect.centery = self.pos.copy().astype(
                "int"
            )

            # Boundary conditions
            if self.pos[0] > self.boundary or self.pos[0] < 0:
                self.vel[0] = -self.vel[0]
                self.trend[0] = -self.trend[0]
                if self.pos[0] > self.boundary:
                    self.pos[0] -= 20
                if self.pos[0] > self.boundary:
                    self.pos[0] += 20
            elif self.pos[1] > self.boundary or self.pos[1] < 0:
                self.vel[1] = -self.vel[1]
                self.trend[1] = -self.trend[1]
                if self.pos[1] > self.boundary:
                    self.pos[1] -= 20
                if self.pos[1] > self.boundary:
                    self.pos[1] += 20
            else:
                self.vel = np.random.rand(2) * 2 - 1

        def dist_to_sprite(self, other_sprite):
            return math.hypot(
                self.pos[0] - other_sprite.pos[0],
                self.pos[1] - other_sprite.pos[1],
            )

        def direction_to_sprite(self, other_sprite):
            direction = other_sprite.pos - self.pos
            return self.normalize(direction, self.Rv)

        def normalize(self, vector, renorm=1):
            vector /= np.linalg.norm(vector)
            return vector * renorm


    class Simulation:
        def __init__(self, width=1000):
            self.WIDTH = width  # Square

            self.tasks = pygame.sprite.Group()
            self.agents = pygame.sprite.Group()
            self.tasked_agents = pygame.sprite.Group()

            self.cycles = 1000

            self.n_T = 5
```

```
        self.Tc = 1
        self.Tr = 50
        self.n_R = 1
        self.Rd = 250

        self.replace_tasks = True
        self.communicate = False

        self.write = False
        self.save_interval = 10

        self.total_tasks_solved = 0

    def check_for_tasks(self):
        for agent in self.agents:
            for task in self.tasks:
                distance = agent.dist_to_sprite(task)
                if abs(distance) < task.Tr and not agent.tasked:
                    print(f"Aha! A task at {task.pos}")
                    agent.tasked = True
                    task.tasked_agents.add(agent)
                    self.tasked_agents.add(agent)

        # Call out (and off)
        if self.communicate:
            for agent in self.tasked_agents:
                # Make sure to not call oneself.
                other_sprites = self.agents.copy()
                other_sprites.remove(agent)
                for agent2 in other_sprites:
                    distance = agent.dist_to_sprite(agent2)
                    if abs(distance) < agent2.Rd:
                        agent2.called = True
                        agent2.call_dir = agent2.direction_to_sprite(agent)

    def start(self):

        if self.write == True:
            f = open(
                f"sta_T{self.n_T}_Tc{self.Tc}_Tr{self.Tr}_R{self.n_R}.txt",
                "w",
            )

        pygame.init()

        area = pygame.display.set_mode([self.WIDTH, self.WIDTH])

        # Assigning initial Tasks
        # Random positions of initial tasks (n, dim)
```

```
T_pos = np.random.randint(0, self.WIDTH, size=(self.n_T, 2))

for x, y in T_pos:

    T = Task(x, y, Tc=self.Tc, Tr=self.Tr)
    self.tasks.add(T)

# Assigning initial Agents
R_pos = np.random.randint(0, self.WIDTH, size=(self.n_R, 2))

for x, y in R_pos:

    R = Agent(x, y, Rd=self.Rd)
    self.agents.add(R)

clock = pygame.time.Clock()

# Game loop
for i in range(self.cycles):
    for event in pygame.event.get():
        if event.type == pygame.QUIT:
            if self.write:
                f.close()
            sys.exit()

    if (self.write == True) and (i % self.save_interval == 0):
        f.write(f"{i:3} {self.total_tasks_solved:3}\n")

    self.tasks.update()
    self.agents.update()

    # Any tasks completed? Create new tasks.
    n_new_tasks = self.n_T - len(self.tasks)
    self.total_tasks_solved += n_new_tasks
    if n_new_tasks > 0:
        print("Solved!")
        R_pos = np.random.randint(
            0, self.WIDTH, size=(n_new_tasks, 2)
        )
        for x, y in R_pos:
            T = Task(x, y, Tc=self.Tc, Tr=50)
            self.tasks.add(T)
        for agent in self.agents:
            agent.tasked = False
            agent.called = False
        self.tasked_agents.empty()

    # Checking if a task is found
    self.check_for_tasks()
```

```
                area.fill(BACKGROUND)
                self.tasks.draw(area)
                self.agents.draw(area)
                pygame.display.flip()

                clock.tick(FRAME_RATE)

            if self.write:
                f.close()
            pygame.quit()


class AuctionSimulation(Simulation):
    def check_for_tasks(self):
        for agent in self.agents:
            for task in self.tasks:
                distance = agent.dist_to_sprite(task)
                if abs(distance) < task.Tr and not agent.tasked:
                    agent.tasked = True
                    task.tasked_agents.add(agent)
                    self.tasked_agents.add(agent)

        # Call out (and off)
        # Only the closes number of necessary agents
        if self.communicate:
            agent_bids = {}
            for agent in self.tasked_agents:
                # Make sure to not call oneself.
                other_sprites = self.agents.copy()
                other_sprites.remove(agent)
                for agent2 in other_sprites:
                    distance = agent.dist_to_sprite(agent2)
                    if abs(distance) < agent2.Rd:
                        agent_bids[distance] = agent2

                ordered_bidding_agents = OrderedDict(
                    sorted(agent_bids.items())
                )

                i = 0
                for bid in ordered_bidding_agents:
                    if i >= self.Tc - 1:
                        break
                    bidding_agent = ordered_bidding_agents[bid]
                    bidding_agent.called = True
                    bidding_agent.call_dir = (
                        bidding_agent.direction_to_sprite(agent)
                    )
```

```
i += 1
```