Requirement: What should do?

- Based on learned knowledge to select data structure and design algorithms for merge sort algorithms.
- Conditions: Using parallel algorithms

Roles:

- Customer: Teacher and some students
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Work Process Model:

- Model Type: Waterfall (Step-driven)
  - Spec Summary
  - Idea Tutorial
  - Design algorithms
  - Implement code
  - Validation
  - Report documents

Activiti (0): Spec Summary

- Outcome:
  - Problem Abstraction
  - Define Input and Output of problem
  - Define Conditions of problem

Problem Abstraction

- Problem:
  - Give a array include ***n*** non-negative integer numbers ***a***.
  - Requirement: design a function that help sort ***a***
- Input:
  - array ***a***, python-type: list
- Output - Return:
  - array ***a*** after sort, python-type: list
- Conditions:
  - 1 <= n <= 2e5
  - using **parallel program (multiprocessor)** to optimize rate for code

Activiti (1): Idea Tutorial

- Outcome:
    - some comment about problem and task

Tutorial

- A computer that have many processor to implement a program
- To implement a job, we may divide data to several independence parts
- Implement computation on each part a parallel way and combine outcome of them

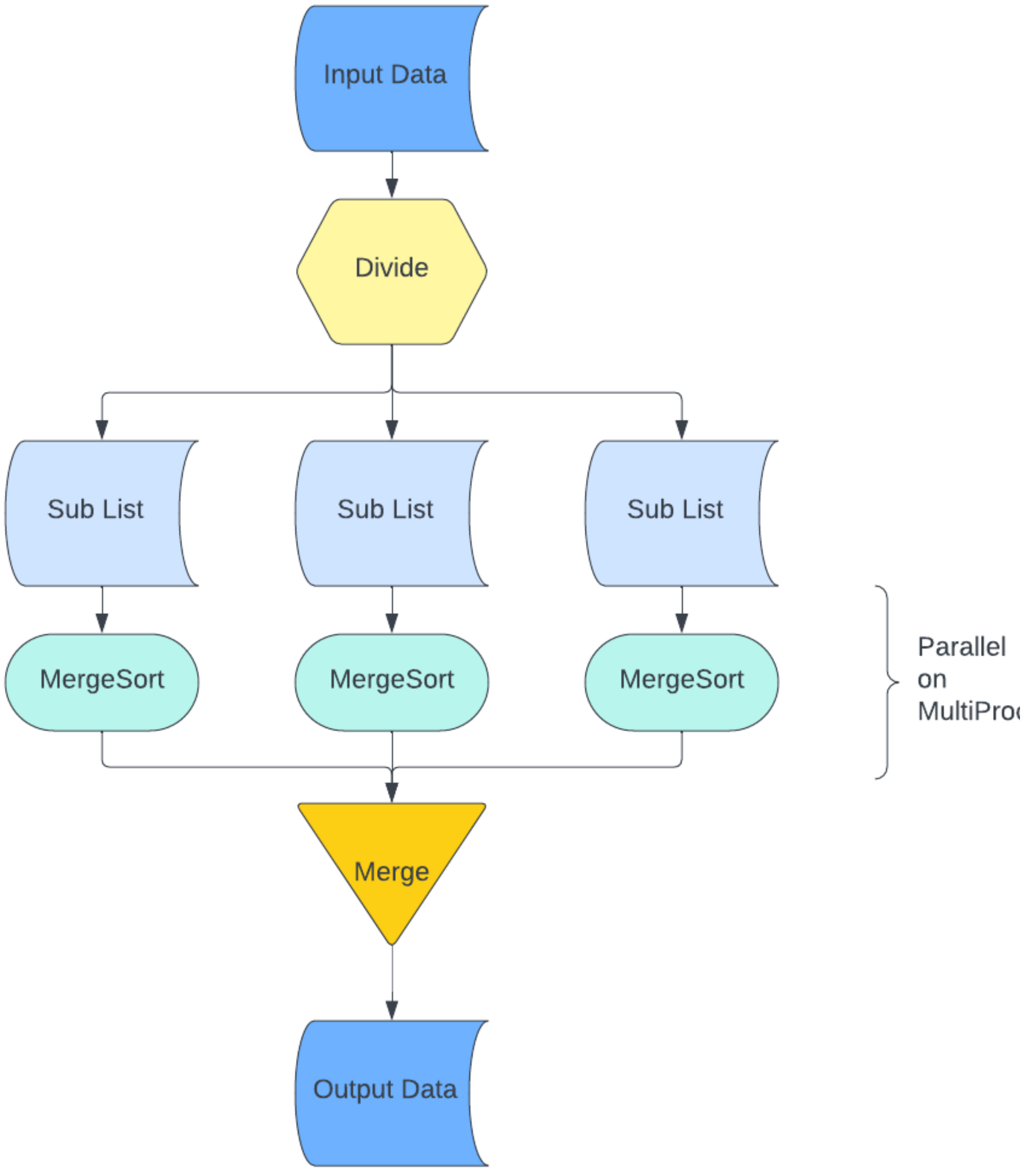
Step to Step

- Divide a into k lists
- Implement merge_sort on each list
- Then, merge k lists

Activiti (2): Design

- Outcome:
    - Diagram

Diagram



Activiti (3): Implement

Import Libraries

```
import os
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from multiprocessing import Pool
```

Constant

```
NUMBER_PROCESSOR = os.cpu_count()
NUMBER_PROCESSOR
```

```
2
```

Utils

```
# api merge
def __init__():
  pass

def merge(listoflist: list) -> list:
  '''
  - This is a function that will merge k lists
  - inputs:
    - listoflist: list of k lists, type: list, shape: (k, +)
  - return:
    - a list of k lists after merge, type: list, shape (+)
  '''
  cursors = [[i, 0] for i in range(len(listoflist))]
  tmpData = []

  while len(cursors) > 0:
    valueMin = listoflist[cursors[0][ 0]][ cursors[0][ 1]]
    curHome = 0
    for i in range(len(cursors)):
      cur = cursors[i]
      if listoflist[cur[0]][ cur[1]] < valueMin:
        valueMin = listoflist[cur[0]][ cur[1]]
        curHome = i

    tmpData += [listoflist[cursors[curHome][ 0]][ cursors[curHome][
1]]]
    cursors[curHome][ 1] += 1
    if cursors[curHome][ 1] >= len(listoflist[cursors[curHome][ 0]]):
      cursors.pop(curHome)

  return tmpData

def mergeSort(a: list) -> list:
  '''
  - This is a function that implement merge sort algorithms
  - inputs:
    - a: list that need sort, type: list, shape: (+)
  - return:
    - list after sort, type: list, shape: (+)
  '''
  if len(a) < 2:
    return a
  mid = len(a) // 2
  x = mergeSort(a[:mid])
  y = mergeSort(a[mid:])
  return merge(listoflist=[x, y])

def generateInput(maxValue: int = 10**18, size: tuple = (2 * 10**5),
draw = False) -> list:
  """
  - This is a function to generate input data that is a list include
'size' integer numbers and have max value is 'maxValue'
  - inputs:
    - maxValue: type: int, default = 10**18
    - size: type: tuple, default = 2 * 10**5
  - return:
    - a list
  - note:
    - draw distribution of input data
  """
  input = np.random.randint(maxValue, size=size).tolist()
  if(draw == True):
    sns.displot(data = input)
  return input

def divideInput(input: list, numberParts: int = NUMBER_PROCESSOR,
isPermutation: bool = True) -> list:
  """
  - This is a function to divide input into k parts
  - inputs:
    - input: type: list, shape: (+)
    - numberParts: type: int, default = number of processor
    - isPermutation: yes or no permutate input-list, default = True
  - return:
    - a list of k parts, type: list, shape: (k, +)
  """
  tmp = np.random.permutation(input).tolist()
  sublists = np.array_split(tmp, numberParts, axis = 0)
  sublists = [sub.tolist() for sub in sublists]
  return sublists
```

Demo

```
input = generateInput(20, 15)
input
```

```
[11, 2, 13, 1, 15, 13, 11, 13, 13, 19, 19, 18, 17, 15, 18]
```

```
subinputs = divideInput(input)
subinputs
```

```
[[15, 13, 18, 13, 19, 1, 13, 11], [15, 11, 17, 2, 13, 19, 18]]
```

```
pool = Pool(NUMBER_PROCESSOR)
suboutputs = pool.map(mergeSort, subinputs)
suboutputs
```

```
[[1, 11, 13, 13, 13, 15, 18, 19], [2, 11, 13, 15, 17, 18, 19]]
```

```
pool.close()
pool.join()
```

```
output = merge(suboutputs)
output
```

```
[1, 2, 11, 11, 13, 13, 13, 13, 15, 15, 17, 18, 18, 19, 19]
```

```
output == sorted(input)
```

```
True
```

```
output == mergeSort(input)
```

```
True
```

Parallel PackPage

```
def parallelMergeSort(input: list, numberParts: int =
NUMBER_PROCESSOR, isPer = False) -> list:
  # divide input into parts
  subinputs = divideInput(input, numberParts = numberParts,
isPermutation = isPer)
  # parallel running
  pool = Pool() # create pool of processors
  suboutputs = pool.map(mergeSort, subinputs)
  # close and join pool
  pool.close()
  pool.join()
  # merge
  output = merge(suboutputs)
  return output
```

Activiti (4): Validation

controler for validation

```
from traitlets.traitlets import ForwardDeclaredInstance
NUMBER_TESTCASE = 10
MAX = 10**5
SIZE = (10**5)

import time
NUMBER_FOLD = 5

NUMBER_PARTS = 10
IS_PER = False

# compution time for fucntion
def computeTimeOfFunction(func, input, type, parts = NUMBER_PROCESSOR, isPer = False) -> float:
  runTime = time.perf_counter()
  if(type == False):
    func(input)
  else:
    func(input, parts, isPer)
  runTime = time.perf_counter() - runTime
  return round(runTime, 3)

normal, parallel = [], []
np.random.seed(42)
for testcase in range(NUMBER_TESTCASE):
  # generate input data
  inputRoot = generateInput(MAX, SIZE)
  # inputRoot = list(range(10**5))

  for fold in range(NUMBER_FOLD):
    # normal version
    input = inputRoot.copy()
    runTime = time.perf_counter()
    out1 = mergeSort(input)
    runTime = time.perf_counter() - runTime
    normal += [round(runTime, 3)]

    # parallel version
    input = inputRoot.copy()
    runTime = time.perf_counter()
    out2 = parallelMergeSort(input, NUMBER_PARTS, IS_PER)
    runTime = time.perf_counter() - runTime
    parallel += [round(runTime, 3)]

    # check wrong
    if(out1 != out2):
      print("WRONG ANSER!!!")

normal
```

```
[2.129,
 2.038,
 3.669,
 1.983,
 2.028,
 3.538,
 2.069,
 2.008,
 2.008,
 3.129,
 2.009,
 1.997,
 3.825,
 1.977,
 2.12,
 3.567,
 2.252,
 2.007,
 2.038,
 3.65,
 2.041,
 2.034,
 3.717,
 2.072,
 2.002,
 1.985,
 3.432,
 2.007,
 2.022,
 3.901,
 1.979,
 1.976,
 2.34,
 2.972,
 2.007,
 1.993,
 3.77,
 2.015,
 2.024,
 2.938,
 2.737,
 1.983,
 1.999,
 3.774,
 1.989,
 2.006,
 3.254,
 2.475,
 1.965,
 1.998]

parallel

[1.951,
 3.077,
 2.803,
 1.945,
 1.94,
 3.359,
 1.93,
 1.924,
 5.043,
 1.983,
 1.933,
 2.452,
 2.7,
 1.94,
 2.752,
 3.215,
 1.954,
 1.945,
 3.347,
 2.092,
 1.996,
 1.983,
 3.331,
 1.946,
 1.951,
 3.651,
 1.954,
 1.991,
 2.148,
 2.916,
 1.917,
 1.942,
 3.625,
 1.952,
 1.994,
 2.587,
 2.542,
 1.935,
 1.948,
 3.263,
 2.008,
 1.987,
 2.788,
 2.39,
 1.941,
 1.958,
 3.324,
 1.939,
 2.018,
 3.215]
```

Activiti (5): Report

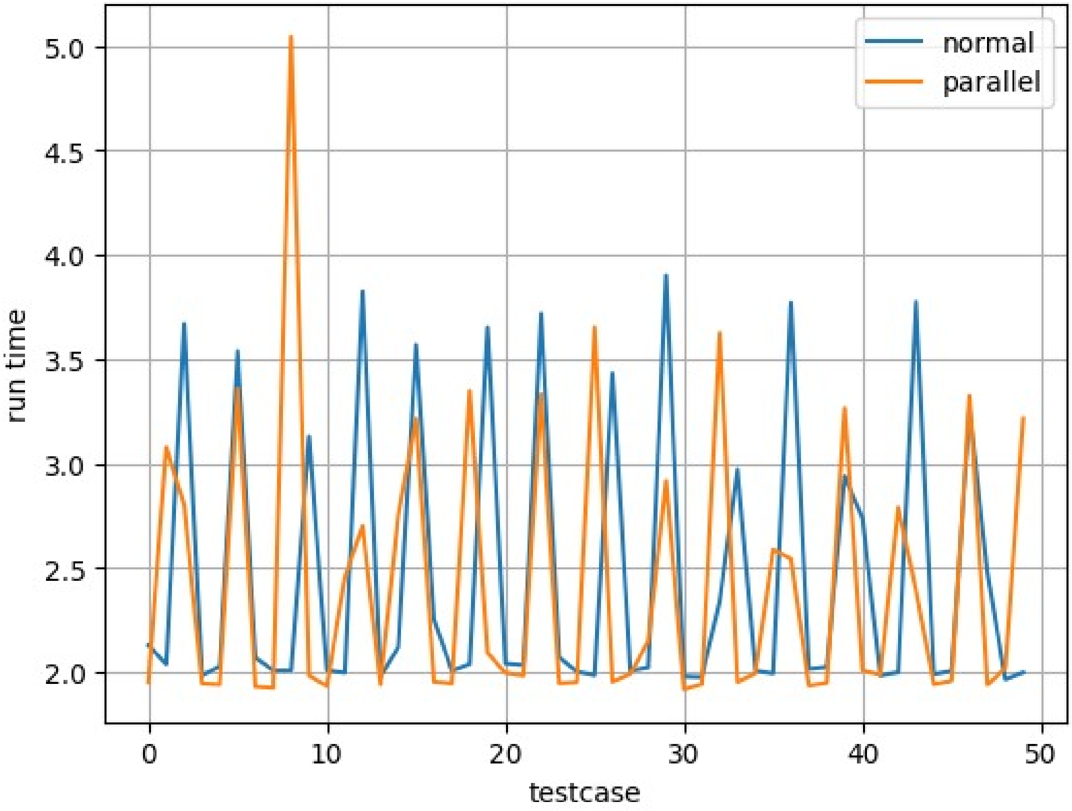
```
report = pd.DataFrame({'normal': normal, 'parallel': parallel})
report
```

```
    normal  parallel
0    2.129     1.951
1    2.038     3.077
2    3.669     2.803
3    1.983     1.945
4    2.028     1.940
5    3.538     3.359
6    2.069     1.930
7    2.008     1.924
8    2.008     5.043
9    3.129     1.983
10   2.009     1.933
11   1.997     2.452
12   3.825     2.700
13   1.977     1.940
14   2.120     2.752
15   3.567     3.215
16   2.252     1.954
17   2.007     1.945
18   2.038     3.347
19   3.650     2.092
20   2.041     1.996
21   2.034     1.983
22   3.717     3.331
23   2.072     1.946
24   2.002     1.951
25   1.985     3.651
26   3.432     1.954
27   2.007     1.991
28   2.022     2.148
29   3.901     2.916
30   1.979     1.917
31   1.976     1.942
32   2.340     3.625
33   2.972     1.952
34   2.007     1.994
35   1.993     2.587
```

```
36   3.770     2.542
37   2.015     1.935
38   2.024     1.948
39   2.938     3.263
40   2.737     2.008
41   1.983     1.987
42   1.999     2.788
43   3.774     2.390
44   1.989     1.941
45   2.006     1.958
46   3.254     3.324
47   2.475     1.939
48   1.965     2.018
49   1.998     3.215
```

```
plt.plot(report['normal'], label= 'normal')
plt.plot(report['parallel'], label= 'parallel')

plt.legend()
plt.xlabel('testcase')
plt.ylabel('run time')
plt.grid()
```



```
print('mean time of normal is: ', f"{np.mean(normal):.3f}")
print('mean time of parallel is: ', f"{np.mean(parallel):.3f}")
```

```
mean time of normal is:  2.469
mean time of parallel is:  2.429
```

Conclude:

- We can rely on the availability of multiple CPUs in a computer to design parallel algorithms.
- In Python, we can use the multiprocessing library and the Pool class.
- Generally, to perform a parallel algorithm, we need to divide the data into independent parts, perform calculations on each part simultaneously, and combine the results.
- In the above report, we see that the speed of the parallel algorithm is slightly faster than the serial algorithm.
- Depending on the hardware device, changing parameters such as NUMBER_PROCESSOR and the implementation method can yield impressive results on larger datasets with parallel algorithms.

```
print('thank you')
```

```
thank you
```