CS 342302 Operating Systems

Fall Semester 2021

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Weekly Review 9

(Scope: Ch. 8)

* + Section 3.1: **graph.py**, **typescript1**
  + Section 3.2: **banker.py**, **typescript2** (showing output of TestUtility(), TestConstructor(), TestSafety(), and TestRequest())
  + Section 3.3: **detect.py**, **typescript3**

## 1. Definitions and Short Answers

1. Given two processes

|  |  |
| --- | --- |
| process1:    lock(mutex1)    lock(mutex2)    work()    unlock(mutex2)    unlock(mutex1) | process2:    lock(mutex2)    lock(mutex1)    work()    unlock(mutex1)    unlock(mutex2) |

* 1. Do they always deadlock?

A: No, they don’t always deadlock. If you first lock mutex 1 and then you lock mutex 2, a deadlock won’t occur.

* 1. Do they sometimes deadlock? If so, describe one such condition

A: Yes, they sometimes deadlock. Deadlock is possible if process 1. acquires mutex1 while process 2 acquires mutex 2.

1. If two processes are not blocked but busy trying and keep failing to make progress, is it a deadlock?

A: No, it is not a deadlock. It is a Livelock. Processes are not blocked but fail to make any progress.

1. What are the **four necessary conditions** of a deadlock?

A: 1) Mutual exclusion: Only one process at a time can use a resource.

2) Hold and wait: A process holding at least one resource is waiting to acquire additional resources held by other processes.

3) No preemption of resource (Not the same as process or thread preemption): A resource can be released only voluntarily by the process holding it, after that process has completed its task.

4) Circular wait: There exists a set {P0, P1, … PN} of waiting processes such that Pi is waiting for a resource held by Pi+1, for 0<=i<=n, and Pn is waiting for a resource that is held by P0.

1. If **mutual exclusion** is a necessary condition for a deadlock, then does it mean that
   1. If you use a mutex then you **always** have the possibility of getting a deadlock?

A:

* 1. If you use a **counting semaphore** of n > 1 then you won't get into a deadlock?

A: Assuming the counting semaphore is high enough and all requesting processes or threads are never blocked, then deadlocks can be avoided.

1. If hold-and-wait is a necessary condition for a deadlock, then does it mean that
   1. If you acquire multiple resources, then you always have the possibility of getting into a deadlock?

A:

* 1. If you acquire multiple resources but at most one at a time, then you won't get into a deadlock?

A:

1. If no-preemption is a necessary condition for a deadlock, then does it mean that
   1. All preemptive process (or thread) schedulers can get into deadlocks?

A: No, in a preemptive scheduler context switching and timer interrupts (i.e., preemption) then the no-preemption condition for a deadlock would be broken and thus there wouldn’t be a deadlock.

* 1. If a process P1 holds a mutex but is now blocked while waiting to acquire another resource, **preemption** in this case means to temporarily allow another process P1 to acquire that mutex, finish, and give the mutex back to P1?

A: Yes, this is the meaning of preemption of a resource. If preemption does not occur, then process P1 would be constantly blocked and waiting to acquire said resource.

1. If circular-wait is a necessary condition for a deadlock, then does it mean that
   1. Whenever you have a process P1 that is waiting to acquire an instance of a resource type R1 that is currently assigned to process P2 and P2 is waiting to acquire an instance of a resource type R2 that is currently assigned to process P1, then you have a deadlock?

A: Yes, assuming the other 3 conditions hold, this scenario constitutes of a circular wait and thus we have a deadlock.

1. A resource-allocation graph (RAG) can be used to model a system for deadlock analysis.
   1. Is a RAG a bipartite graph? If so, what are the two sets of vertices and what do they represent?

A: Yes, it is a bipartite graph. The first vertex set P = {P1, P2 … PN} represents the processes and the second vertex set R = {R1, R2 … RN} represents the resources. In a RAG each edge is connected between different sets, thus it is bipartite.

* 1. Is a RAG a directed or undirected graph?

A: a RAG is a directed graph because edges can only be traversed in one direction. Either in resource request or resource assignment direction.

* 1. How is a resource request represented in the RAG?

A: As an edge from process Pi to resource Rj. Pi -> Rj.

* 1. How is a resource assignment represented in the RAG?

A: As an edge from resource Rj to process Rj. Rj -> Pi.

1. Give a RAG that contains a **cycle but does not have deadlock**.

A: We first assume that all resources are considered equivalent. In the following RAG, there are several instances of a resource R2 and R1 held by processes P2 and P4. However, P2 and P4 are not waiting for anyone and thus the hold and wait condition is broken and a deadlock does not exist between P1 and P3.

A picture containing clock

Description automatically generated

1. In some RAG, having a cycle means a deadlock exists. Why would this be the case?

A: In some RAG where a cycle exists, a deadlock exists if and only if every process is waiting for a resource held by another process which itself holds a resource needed by another process.

1. What is the meaning of deadlock **prevention**? What is its general approach?

A: Deadlock prevention means to ensure the necessary conditions for deadlock cannot hold. The general approach is to provide deadlock prevention methods that constrain how requests for resources can be made.

1. What is difficult about **denying mutual exclusion** as a way of achieving deadlock prevention?

A: The difficulty of denying mutual exclusion lies in the nature of the resources shared by the processes. Some processes require resources such as printers and tape drives need to be mutually excluded between processes. For example, at most one process can be printing a certain time.

1. What are two ways of eliminating **hold-and-wait**?

A: 1. Allocate all requested resources before process starts – Impractical for most applications – too “static”

2. Process must hold no resource before request -> If can’t get all resources -> Need to release all currently held resources.

1. What are disadvantages with the two ways of eliminating hold and wait above?

A: Low resource utilization and possible starvation.

1. What are difficulties with deadlock prevention by **allowing resource preemption**?

A: OS needs to track and re-acquire resources that the process has acquired but got taken away (May be more than one resource) -> Lots of book-keeping required, for example must track directories, file sizes, file pointers.

With resource preemption you may have to restart for the process to be executed smoothly. In addition, you can only move the process into the ready queue once all its resources can be acquired.

1. What is a way of breaking **circular wait** as the 4th way of deadlock prevention?

A: To break a circular wait, a total ordering of all resource types must be imposed. E.g., F (tape drive) = 1, F (disk drive) = 5, F(printer) = 12. A process must request tape and disk drive before printer. However, this is hard to enforce practically however it is still the most feasible one among the 4 deadlock prevention methods.`

1. For **deadlock avoidance** to work, what does each process have to declare?

A: In deadlock avoidance, each process must declare the maximum number of resources of each type that it may need.

1. Does deadlock avoidance ensure that the system …
   1. never gets a deadlock?

A: NO.

* 1. never enters an unsafe state?

A: YES.

* 1. always stays in a safe state?

A: NO.

1. What is a **claim** in a deadlock avoidance algorithm?

A: A claim is a “a priori” or previous knowledge of the resource needs.

1. In the **resource allocation graph** (RAG) scheme of deadlock avoidance,
   1. Why does the RAG use only a claim edge but does NOT use an edge weight to indicate the max **number of instances** of a resource that the process may claim?

A: Because this knowledge must be known a priori to enforce deadlock avoidance.

* 1. What is the difference between a **claim edge** and a **request edge** in the resource allocation graph scheme of deadlock avoidance?

A: A claim edge is converted to a request edge when a process requests a resource. A claim edge on the other hand, implies that a process might request a resource and resources are claimed a priori in the system.

* 1. When a request is granted, what happens to the **request edge**?

It converts into an assignment edge where and the arrow direction is reversed.

* 1. When the resource is released, what happens to the **assignment edge**?

It converts into a claim edge (dashed) and the direction is reversed.

* 1. What does a cycle mean? Under what condition is a request granted?

A: A cycle implies an unsafe state. A request is granted only if no cycle is created.

1. To use the Banker's algorithm for deadlock avoidance,
   1. Banker's algorithm uses the Safety Algorithm to find a safety sequence. If such a sequence is found, is it a **necessary** condition or a **sufficient** condition that the system is in a safe state?

A: It is a sufficient condition for system to be in a safe state.

* 1. What are variables *m* and *n*?

A: Numbers resources and processes respectively.

* 1. What do *Available*[*j*] and *Work*[*j*] represent?

A: Number of instances of a resource type R that exist and number of instances of a resource type not yet allocated.

* 1. What does the variable int *Max*[*n*][*m*] represent? Where does this matrix get its values from?

A: A matrix or 2-d array that contains a promise of each process P and the number of each resource type these processes might need. Recall that each process P must declare the number of resources types it may need (the claim).

* 1. What does the variable int *Allocation*[*n*][*m*] represent?

A: It represents the current number of allocated resources per process.

* 1. What is the meaning of variable int *Need*[*n*][*m*] and how does it get its values from?

A: Is declares as follows: Need[i,j] = Max[i,j] – Allocation[i,j].

Represents the instances each process might need. Note that if allocation is full for every process the need is 0.

* 1. In Step 3, Process Pi is chosen because its worst-case requests can be fulfilled, so why is *Allocation*[*i*][*j*] added back into *Work*[*j*] instead of being subtracted from *Work*[*j*]?

A: Because the allocated resources for that process Pi is given back to the pool Work[i][j] once the resource Pi has Finish[i] = true

1. In the Resource-Request Algorithm, which decides whether a request *Requesti* (by process Pi, of different resource types),
   1. If *Requesti*[:] ≤ *Needi*[:], does it mean that the request can be fulfilled? In other words, is it a **necessary** condition or a **sufficient** for granting the request?

A: It is a necessary condition.

* 1. If the previous condition is a necessary condition, then what additional condition is needed in order to grant the request?

A: The resources must be available after some other processes run.

* 1. If the request cannot be granted, what happens?

A: The process must wait, and the old resource allocation state is restored.

1. A **wait-for** graph is used for deadlock detection of single-instance resource types.
   1. What is the wait-for graph that corresponds to the RAG below?  
      Chart

      Description automatically generated
   2. if the wait-for graph contains a cycle, does it mean there is a deadlock or just possibility of a deadlock?

A: There is a deadlock.

* 1. If the processes are in a deadlock, does it mean there is a cycle or possibility of a cycle?
  2. A: There is a cycle.
  3. What is the complexity of cycle detection?

A: O(n^2)

1. For deadlock detection of multi-instance resource types, an algorithm essentially the same as the Safety Algorithm is used to detect cycles.
   1. How can you tell if the processes are deadlocked after running the algorithm?

A: The corresponding processes Pi are in a deadlock state if their corresponding value in the array Finish[i] == 0

* 1. How do you find all the processes that have the circular dependency in the deadlock?

A: All the processes Pi for which Finish[i] == 0 have a circular dependency.

1. In practice, is the deadlock detection algorithm invoked on every request? Why or why not?

A: No, in practice the deadlock detection algorithm is invoked every few minutes because a system may have hundreds if not thousands of resources. It might be very expensive to make such calls.

1. What can an OS do after it detects a deadlock?
   1. Does it abort a process? If so, what are possible considerations?

A: It might abort a process or all of them.

* 1. What does **roll back** mean? Can every process be rolled back? What needs to happen first before a roll back?

A: It means to return to some safe state and restart process for that state. Not every process can be rolled back (e.g., printing). A snapshot of the safe state needs to exist, otherwise process must restart.

* 1. Even if a system can recover from a deadlock, what problem may still happen to some unlucky process?

A: Starvation may happen.

## 

## 2. Problem Set

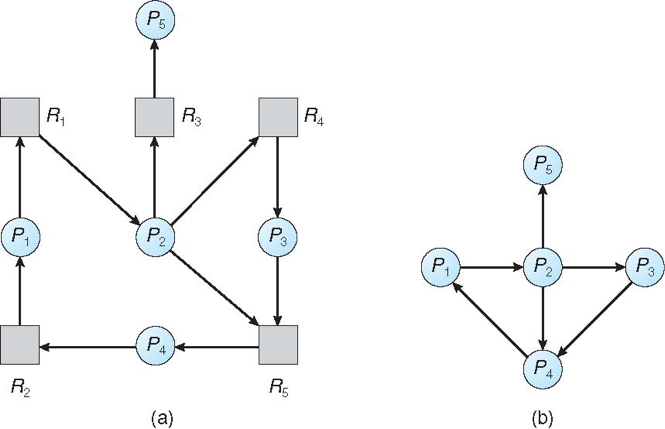
1. Fix the transaction() function to prevent deadlocks.  
   **void** transaction(Account from, Account to, **double** amount) {  
    mutex lock1, lock2;  
    lock1 = get\_lock(from);  
    lock2 = get\_lock(to);  
    acquire(lock1);  
    acquire(lock2);  
    withdraw(from, amount);  
    deposit(to, amount);  
    release(lock2);  
    release(lock1);  
   }
2. Consider a system consisting of four resources of the same type that are shared by three processes, each of which needs at most two resources. Show that the system is deadlock free.

## 3. Programming Exercise

In this programming exercise, you are to implement a number of deadlock detection and avoidance algorithms.

### 3.1 Cycle Detection in Graphs

Cycle detection can be used to detect deadlocks. Cycles are found in graphs. A (system) resource-allocation graph (RAG) is a directed graph for capturing the dependencies of processes on resources. An example of a RAG is shown in the following figure (a):



For a special case of a RAG where there is exactly one instance of resource per type, it can be transformed into a wait-for graph (WFG), which can use a conventional directed graph to capture just the processes but not resources. It is shown in figure (b) above.

A conventional graph *G*(*V*, *E*) can be represented in adjacency-list format, which has space complexity closer to *O*(*V*+*E*) for sparse graphs. In Python, a (directed) graph can be represented more conveniently using a dictionary, where a dictionary keeps track of key-value pairs often in the form of a hash table. For example, consider the graph from Fig. (b) above. It can be represented in Python as

G = {'P1': ['P2'], 'P2': ['P4', 'P5', 'P3'], 'P3': ['P4'], 'P4': ['P1'], 'P5': []}

To find the list of neighbors of a vertex v, simply do G[v]. For example, G['P2'] gives the value ['P4', 'P5', 'P3']. However, it is more convenient to wrap the adjacency list inside a class so that more attributes can be associated with the graph. One way to do this is

**class** Graph:  
 **def** \_\_init\_\_(self, G):

self.G = G

self.vertices = list(G.keys())

**def** Adj(self, v):

# return the adjacency list

**return** iter(self.G[v])

**def** V(self):

**return** iter(self.vertices)

In case you did not know, iter() is a built-in function in Python that returns an iterator object that lets you pull out one element at a time. Several iterators may simultaneously exist on the same list, for example.

Cycle detection can be done by depth-first search (DFS), among many other algorithms. A generic version of DFS based on the CLRS textbook (Cormen, Leiserson, Rivest, and Stein) is given below (assuming you have the Graph data structure above). You may download the

[graph-template.py](https://drive.google.com/file/d/1qU-gpJUmSRU93MLU9duWhLScT_1XBOmt/view) file and rename it graph.py. It contains the Graph class and the following DFS code.

WHITE = 'white'  
GRAY = 'gray'  
BLACK = 'black'  
  
**def** DFS(G):

G.color = {} # color, which is WHITE, GRAY, or BLACK

G.pred = {} # the predecessor

# you may add your own field for tracking cycles

**for** u **in** G.V():

G.color[u] = WHITE

G.pred[u] = None

**for** u **in** G.V():

**if** G.color[u] == WHITE:

DFSVisit(G, u)

**def** DFSVisit(G, u):

G.color[u] = GRAY

**for** v **in** G.Adj(u):

**if** G.color[v] == WHITE:

G.pred[v] = u

DFSVisit(G, v)

# add your own code for cycle detection here!!

G.color[u] = BLACK

DFS can be used for cycle detection, but it does not do it automatically. You will need to know the right place to make the modification to detect a cycle. The two graphs in the above figures (a) and (b) have been input to the test case of the .py file.

Deliverable: graph.py, typescript1 showing the cycle has been detected or printed, or the empty list if there is no cycle.

### 3.2 Banker’s Algorithm

The Banker’s Algorithm by Dijkstra is a deadlock avoidance algorithm during resource allocation. To implement this in Python, it is easier to package things in a class and call a set of utility functions. You can download the [banker-template.py](https://drive.google.com/file/d/1NNMEqsVOLFXaIPQ-aALCIjFIYjYpT-Ht/view) file and rename it banker.py. There are two parts: the constructor and utility functions, Safety core algorithm, and the request processing.

#### 3.2.1 Constructor and Utility Functions

The helper functions are

def sumColumn(M, col):   
# M is a row major matrix; col is the column index.

# returns the scalar sum of the values in the column.

tot = 0

for row in M:

tot += row[col]

return tot

def IncrVec(A, B):

# helper function for A += B as vector, assuming len(A) == len(B)

# your code here

def DecrVec(A, B):

# vector A -= B, assuming len(A) == len(B)

# your code here

def GtVec(A, B):

# vector A[i]>B[i]. true if one or more pairs true. (disjunctive)

# your code here

def LeVec(A, B):

# vector A[i] <= B[i]. true if ALL pairs are true. (conjunctive)

# your code here

The code for sumColumn() is given to you, but you need to write the other four utility functions. GtVec() and LeVec() are the “greater-than” and “less-than-or-equal-to” functions comparing two vectors (represented as lists), respectively. Unlike the built-in > and <= operators on lists and tuples, which perform *lexicographical comparison*, what is required here is the pairwise comparison. Note the subtle point that GtVec() is ***disjunctive*** (i.e., true if ANY A[i] is > B[i]) while LeVec() is ***conjunctive*** (i.e., ALL of A[i] must be <= B[i]).

class Banker:

def \_\_init\_\_(self, alloc, max, totalRsrc):

'''

constructor for Banker class.

alloc is a vector of number of instances of m resource types.

max is a matrix for max #instances the process may request.

totalRsrc is vector of total #instances of ea. type of rsrc.

'''

self.Allocation = alloc

self.TotalResources = totalRsrc

self.n = len(alloc) # number of processes

self.m = len(totalRsrc) # number of resources

# the following if-max allows the deadlock detection algorithm

# to be able to subclass without max (since it doesn't need it)

if max is not None:

self.Max = max

self.Need = []# your code here to initialize the Need matrix.

self.Available = [] # your code here to compute Available.

# hint: involves TotalResources and sumColumn() function,

# a boolean flag to indicate whether in Safety() you want to

# print the traced output. by default False but can be = True.

self.traceSafety = False

Modify the testbench to call just the TestUtility() and TestConstructor() functions (provided) and make sure your code behaves correctly before moving on to the next subsections. You should output that looks like this:

Testing Utility Functions:

A = [1, 2, 1], B = [1, 0, 2],

A += B is [2, 2, 3], expect [2, 2, 3]

A -= B is [1, 2, 1], expect [1, 2, 1]

A > B is True, expect True; A <= B is False, expect False

A = [1, 2, 3], B = [2, 2, 4],

A += B is [3, 4, 7], expect [3, 4, 7]

A -= B is [1, 2, 3], expect [1, 2, 3]

A > B is False, expect False; A <= B is True, expect True

A = [2, 3, 3], B = [2, 3, 3],

A += B is [4, 6, 6], expect [4, 6, 6]

A -= B is [2, 3, 3], expect [2, 3, 3]

A > B is False, expect False; A <= B is True, expect True

b.Available=[3, 3, 2], expect ([3, 3, 2],)b.Need=[[7, 4, 3], [1, 2, 2], [6, 0, 0], [0, 1, 1], [4, 3, 1]], expect [[7, 4, 3], [1, 2, 2], [6, 0, 0], [0, 1, 1], [4, 3, 1]]

#### 3.2.2 Safety Algorithm (week 9 (Chapter 8) slide 37)

The Safety algorithm finds a safe sequence of executing a set of processes such that the system never enters an unsafe state, or else it reports that such a safe sequence does not exist. It is implemented as a method in the Banker class.

def Safety(self):

if self.traceSafety: print('Need=%s, Available=%s' % (self.Need, self.Available))

# step 1

Sequence = [] # use this list to save the safe sequence

Finish = [False for i in range(self.n)]

Work = [] # your code to initialize Work vector

# step 2

for \_ in range(self.n):

for i in range(self.n):

if self.traceSafety: print('i=%d, ' % i, end="")

# follow the pseudocode on slide 37

# may need to print

#

# compare Need[i] with Work.

# - hint: you may use LeVec(A, B) for A <= B:

#

# step 3

# update Work, Finish, and add to sequence

# Hint: use IncrVec() for Work += Allocation

#

# step 4. return the sequence if there is one, else None

Run the TestSafety() function (provided) in the testbench. Note that we include a traceSafety flag, which will print the intermediate values as the code runs. You can expect to get output like the following:

i=0, (Need[0]=[7, 4, 3]) <= (Work=[3, 3, 2]) False, P0 must wait  
i=1, (Need[1]=[1, 2, 2]) <= (Work=[3, 3, 2]) True, append P1  
i=2, (Need[2]=[6, 0, 0]) <= (Work=[5, 3, 2]) False, P2 must wait  
i=3, (Need[3]=[0, 1, 1]) <= (Work=[5, 3, 2]) True, append P3  
i=4, (Need[4]=[4, 3, 1]) <= (Work=[7, 4, 3]) True, append P4  
i=0, (Need[0]=[7, 4, 3]) <= (Work=[7, 4, 5]) True, append P0  
i=1, Finish[1] True, skipping  
i=2, (Need[2]=[6, 0, 0]) <= (Work=[7, 5, 5]) True, append P2  
s is [1, 3, 4, 0, 2]

#### 3.2.3 Resource-Request Algorithm (week 9 (Chapter 8) slide 47)

The Resource-Request Algorithm is the outer code of the Banker’s algorithm that calls the Safety algorithm above to decide how to respond to the request by the process. Add the following method named Request() and a utility method named Release() to your Banker class:

**def** Request(self, i, rqst): # slide 47

'''

called w/the requesting process i and the resource vector

for how many instances of each resource to request.

the rqst is a vector of m length.

'''

# step 1

# hint: use GtVec of LeVec to compare request vector w/Need[i]

# raise an exception if overclaimed

#

# step 2

# in case of wait, simply return None

#

# step 3

# pretend to allocate requested resource:

# save snapshot of Available, Allocation, and Need

# update Available, Allocation, and Need

# call Safety()

# if a safe sequence exists, return it.

# otherwise, restore saved snapshot and return None

**def** Release(self, i):

'''

need this function to release the rsrc allocated to P\_i

after it has finished execution.

'''

# hint: update self.Available, self.Allocation, and self.Need.

# hint: you may want to call utility functions IncrVec

# hint: in which order? who goes first, last, or don't care?

Run the TestRequest() code using the return values of the TestSafety() as provided in the template code. You can expect to get the output like this for this part:

Found safe sequence [1, 3, 4, 0, 2]

P1 allocated [2, 0, 0], requesting [1, 0, 2],

P1 releasing, available=[5, 3, 2]

P3 allocated [2, 1, 1], requesting [0, 1, 1],

P3 releasing, available=[7, 4, 3]

P4 allocated [0, 0, 2], requesting [3, 3, 0],

P4 releasing, available=[7, 4, 5]

P0 allocated [0, 1, 0], requesting [0, 2, 0],

P0 releasing, available=[7, 5, 5]

P2 allocated [3, 0, 2], requesting [3, 0, 0],

P2 releasing, available=[10, 5, 7]

### 2.3 Deadlock Detection Algorithm (week 9 slides 53-54)

Write the deadlock detection algorithm. It is similar to the Banker’s algorithm, and code reuse including the utility functions and most of the constructor is possible, if you make minor adjustments. The differences are

* there is no Max and Need; instead, it has requests.   
  => we pass None to the superclass’s constructor, and it will skip capturing Max and computing Need.
* it detects deadlock from the current allocation and request matrix, rather than checking existence of a safe sequence.

Download [detect-template.py](https://drive.google.com/file/d/10fH5M-nsZu8t6pgyYbdpTVrArAi6rmJg/view) and rename it detect.py. It looks like the following:

# Deadlock Detection, similar to Banker's

**from** banker **import** Banker, sumColumn, IncrVec, DecrVec, GtVec

**class** DeadlockDetector(Banker):

**def** \_\_init\_\_(self, alloc, totalRsrc):

Banker.\_\_init\_\_(self, alloc, None, totalRsrc)

**def** detect(self, Request): # see week 9 **slides 53-54**

'''detect deadlock with the request matrix'''

# 1(a) initialize Work = a copy of Available

# 1(b) Finish[i] = (Allocation[i] == [0, ...0])

# optionally, you can keep a Sequence list

**for** \_ **in** range(self.n):

**for** i **in** range(self.n):

# Step 2: similar to safety algorithm

# if there is an i such that (Finish[i] == False)

# and Request\_i <= Work, (hint: LeVec() could help)

# Step 3:

# Work += Allocation[i]

# Finish[i] = True

# continue Step 2

# Step 4: either done iterating or (no such i exists)

# Finish vector indicates deadlocked processes.

# if all True then no deadlock.

The testbench is included in the template file. There are two cases: one without deadlock and one with deadlock, both taken from the textbook. You can expect to see the following output:

Finish=[False, False, False, False, False]

i=0, (Request[0]=[0, 0, 0]) <= (Work=[0, 0, 0]) True, append P0

(+Allocation[0]=[0, 1, 0])=> Work=[0, 1, 0], Finish=[True, False, False, False, False]

i=1, (Request[1]=[2, 0, 2]) <= (Work=[0, 1, 0]) False, P1 must wait

i=2, (Request[2]=[0, 0, 0]) <= (Work=[0, 1, 0]) True, append P2

(+Allocation[2]=[3, 0, 3])=> Work=[3, 1, 3], Finish=[True, False, True, False, False]

i=3, (Request[3]=[1, 0, 0]) <= (Work=[3, 1, 3]) True, append P3

(+Allocation[3]=[2, 1, 1])=> Work=[5, 2, 4], Finish=[True, False, True, True, False]

i=4, (Request[4]=[0, 0, 2]) <= (Work=[5, 2, 4]) True, append P4

(+Allocation[4]=[0, 0, 2])=> Work=[5, 2, 6], Finish=[True, False, True, True, True]

i=0, Finish[0] is True, skipping

i=1, (Request[1]=[2, 0, 2]) <= (Work=[5, 2, 6]) True, append P1

(+Allocation[1]=[2, 0, 0])=> Work=[7, 2, 6], Finish=[True, True, True, True, True]

sequence = [0, 2, 3, 4, 1]

Finish=[False, False, False, False, False]

i=0, (Request[0]=[0, 0, 0]) <= (Work=[0, 0, 0]) True, append P0

(+Allocation[0]=[0, 1, 0])=> Work=[0, 1, 0], Finish=[True, False, False, False, False]

i=1, (Request[1]=[2, 0, 2]) <= (Work=[0, 1, 0]) False, P1 must wait

i=2, (Request[2]=[0, 0, 1]) <= (Work=[0, 1, 0]) False, P2 must wait

i=3, (Request[3]=[1, 0, 0]) <= (Work=[0, 1, 0]) False, P3 must wait

i=4, (Request[4]=[0, 0, 2]) <= (Work=[0, 1, 0]) False, P4 must wait

i=0, Finish[0] is True, skipping

i=1, (Request[1]=[2, 0, 2]) <= (Work=[0, 1, 0]) False, P1 must wait

i=2, (Request[2]=[0, 0, 1]) <= (Work=[0, 1, 0]) False, P2 must wait

i=3, (Request[3]=[1, 0, 0]) <= (Work=[0, 1, 0]) False, P3 must wait

i=4, (Request[4]=[0, 0, 2]) <= (Work=[0, 1, 0]) False, P4 must wait

deadlock