LP1 Assignment AIR A3

Implement Goal Stack Planning

Date - 12th October, 2020.

Assignment Number - AIR A3

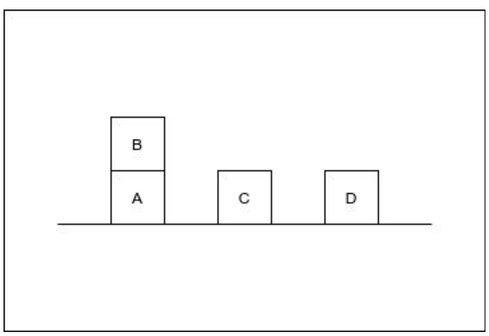
Title

Implement Goal Stack Planning

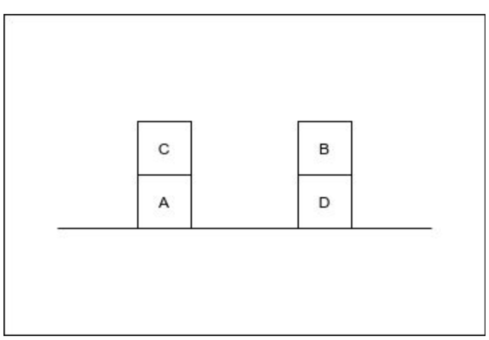
Problem Definition

Implement goal stack planning for the following configuration from the blocks world

Initial State



Final State



Learning Objectives

- To learn and implement goal stack planning

Learning Outcomes

I will be able to learn and implement Goal Stack Planning

Software Packages and Hardware Apparatus Used

- Operating System : 64-bit Ubuntu 18.04
- Programming Language : Python 3
- Jupyter Notebook Environment : Google Colaboratory

Mathematical Model

S = {s; e; X; Y; Fme; Ff; DD; NDD}

s = initial state

- ON(B,A) ∧ ONTABLE(A) ∧ ONTABLE(C) ∧ ONTABLE(D)

e = goal state

- ON(C,A) ∧ ON(B,D) ∧ ONTABLE(A) ∧ ONTABLE(D)

X = {X1}

- X1 = s

Y = {Y1}

- Y1 = e

Fme = {f0}

- f0 = function to perform Goal Stack Planning

Ff = {f1, f2, f3, f4, f5} where

- f1 = function to display final path
- f2 = function to replace unsatisfied goal with an action
- f3 = function to check if object is predicate
- f4 = function to check if object is action
- f5 = function to get status of the arm

DD = List of Predicates of Initial State

NDD = No non deterministic data

Concepts related Theory

Block World Problem

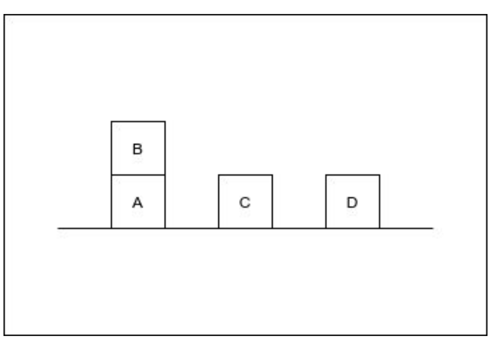
- There is a flat surface on which blocks can be placed
- There are a number of square blocks, all the same size
- They can be stacked one upon another
- There is a robot arm that can manipulate the blocks

Goal Stack Planning

- We work backwards from the goal, looking for an operator which has one or more of the goal literals as one of its effects and then trying to satisfy the preconditions of the operator.
- The preconditions of the operator become subgoals that must be satisfied. We keep doing this until we reach the initial state.
- Goal stack planning uses a stack to hold goals and actions to satisfy the goals, and a knowledge base to hold the current state, action schemas and domain axioms

Initial State

ON(B,A) ∧ ONTABLE(A) ∧ ONTABLE(C) ∧ ONTABLE(D) ∧ CLEAR(B) ∧ CLEAR(C) ∧ CLEAR(D)



Perception

Predicates

PREDICATE	MEANING
ON(A,B)	Block A is on B
ONTABLE(A)	A is on table
CLEAR(A)	Nothing is on top of A
HOLDING(A)	Arm is holding A
ARMEMPTY	Arm is holding nothing

First Order Logic

LOGICAL STATEMENT	MEANING
[∃ X : HOLDING(X)] -> ~ARMEMPTY	If arm is holding a block, then it is not empty
∀ X : ONTABLE(X) -> ~∃ Y : ON(X,Y)	If a block is on table, then it is not on another block
∀ X : [~∃ Y : ON(Y,X)] -> CLEAR(X)	Any block with no block on it is clear

Cognition

Goal Stack Planning Algorithm

1. Push the goal state on the stack.
2. Repeat until the stack is empty:
    1. If stack top is a compound goal
        1. push its unsatisfied subgoals on the stack.
    2. If stack top is a single unsatisfied goal
        1. replace it by an action that makes it satisfied
        2. push the action's precondition on the stack.
    3. If stack top is an action
        1. check for unsatisfied prerequisites

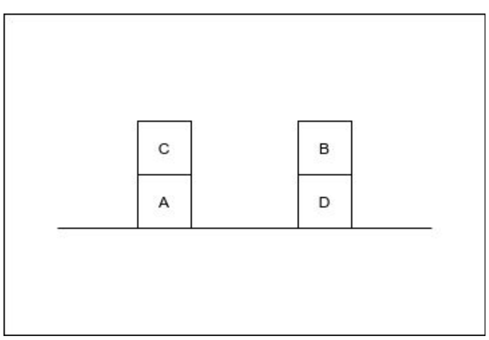
2. if all prerequisites are satisfied
    1. pop action from the stack
    2. execute it
    3. change the knowledge base by the action’s effects.
3. else
    1. push unsatisfied preconditions on the stack
4. If stack top is a satisfied goal
    1. pop it from the stack.

Action

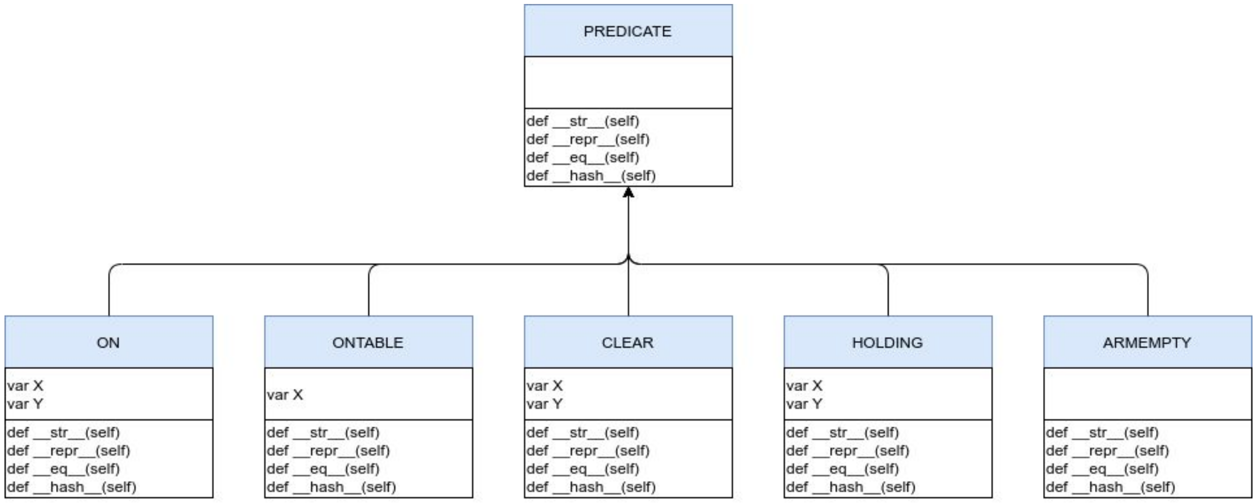
OPERATORS	**PRECONDITION**	**DELETE**	**ADD**
STACK(X,Y)	CLEAR(Y)∧ HOLDING(X)	CLEAR(Y) HOLDING(X)	ARMEMPTY ON(X,Y)
UNSTACK(X,Y)	ARMEMPTY∧ ON(X,Y)∧ CLEAR(X)	ARMEMPTY∧ ON(X,Y)	HOLDING(X) ∧CLEAR(Y)
PICKUP(X)	CLEAR(X)∧ ONTABLE(X)∧ ARMEMPTY	ONTABLE(X)∧ ARMEMPTY	HOLDING(X)
PUTDOWN(X)	HOLDING(X)	HOLDING(X)	ONTABLE(X)∧ ARMEMPTY

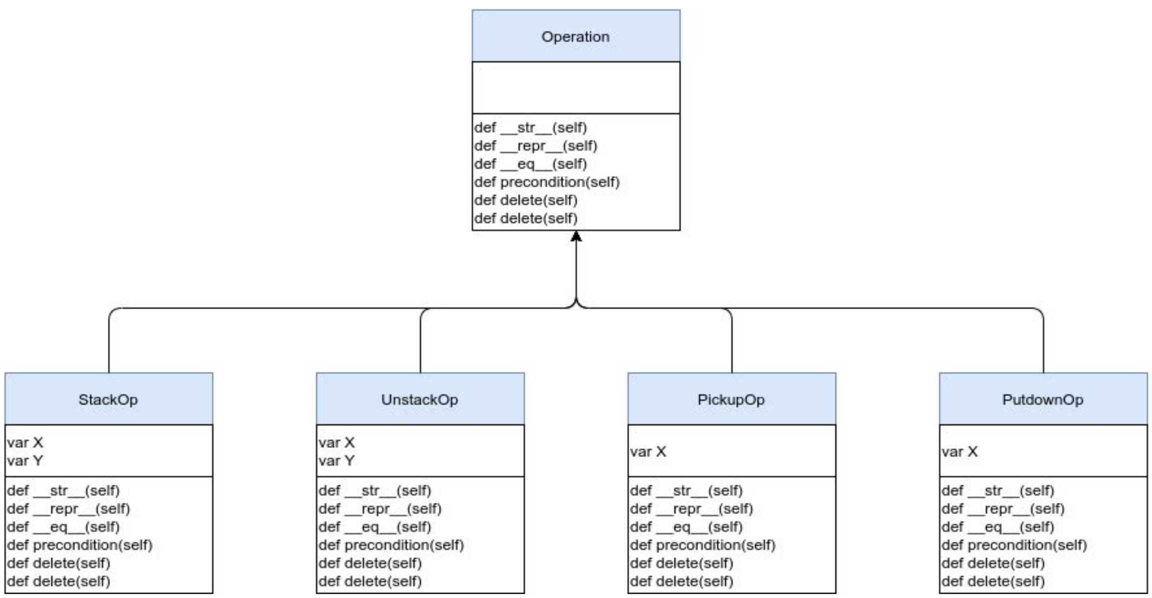
Goal State

ON(C,A) ∧ ON(B,D) ∧ ONTABLE(A) ∧ ONTABLE(D) ∧ CLEAR(C) ∧ CLEAR(B)



Class Diagram





Source Code

```
#Base Classes

#PREDICATE - ON, ONTABLE, CLEAR, HOLDING, ARMEMPTY
class PREDICATE:
```

```
 #String
 def __str__(self):
   pass

 #Representation
 def __repr__(self):
   pass
  #Checking for Equality
 def __eq__(self, other) :
   pass

 #Making the object Hashable (Useful for set)
 def __hash__(self):
   pass


#OPERATIONS - Stack, Unstack, Pickup, Putdown
class Operation:

 #String
 def __str__(self):
   pass

 #Representation
 def __repr__(self):
   pass
  #Checking for Equality
 def __eq__(self, other) :
   pass

 #Return Precondition Predicates
 def precondition(self):
   pass

 #Return Delete Predicates
 def delete(self):
   pass
```

```
 #Return Add Predicates
 def add(self):
   pass

class ON(PREDICATE):

 def __init__(self, X, Y):
   self.X = X
   self.Y = Y

 def __str__(self):
   return "ON("+self.X+","+self.Y+")"

 def __repr__(self):
   return "ON("+self.X+","+self.Y+")"

 def __eq__(self, other) :
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def __hash__(self):
     return hash(str(self))

class ONTABLE(PREDICATE):

 def __init__(self, X):
   self.X = X

 def __str__(self):
   return "ONTABLE("+self.X+")"

 def __repr__(self):
   return "ONTABLE("+self.X+")"

 def __eq__(self, other) :
```

```
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def __hash__(self):
     return hash(str(self))


class CLEAR(PREDICATE):

 def __init__(self, X):
   self.X = X

 def __str__(self):
   return "CLEAR("+self.X+")"
   self.X = X

 def __repr__(self):
   return "CLEAR("+self.X+")"

 def __eq__(self, other) :
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def __hash__(self):
     return hash(str(self))


class HOLDING(PREDICATE):

 def __init__(self, X):
   self.X = X

 def __str__(self):
   return "HOLDING("+self.X+")"

 def __repr__(self):
   return "HOLDING("+self.X+")"
```

```
 def __eq__(self, other) :
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def __hash__(self):
     return hash(str(self))


class ARMEMPTY(PREDICATE):

 def __init__(self):
   pass

 def __str__(self):
   return "ARMEMPTY"

 def __repr__(self):
   return "ARMEMPTY"

 def __eq__(self, other) :
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def __hash__(self):
     return hash(str(self))



class StackOp(Operation):

 def __init__(self, X, Y):
   self.X = X
   self.Y = Y

 def __str__(self):
   return "STACK("+self.X+","+self.Y+")"
```

```
 def __repr__(self):
   return "STACK("+self.X+","+self.Y+")"

 def __eq__(self, other) :
   return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

 def precondition(self):
   clear_y = CLEAR(self.Y)
   holding_x = HOLDING(self.X)
   return [ clear_y , holding_x ]

 def delete(self):
   clear_y = CLEAR(self.Y)
   holding_x = HOLDING(self.X)
   return [ clear_y , holding_x ]

 def add(self):
   armempty = ARMEMPTY()
   on_xy = ON(self.X,self.Y)
   return [ armempty , on_xy ]


class UnstackOp(Operation):

 def __init__(self, X, Y):
   self.X = X
   self.Y = Y

 def __str__(self):
   return "UNSTACK("+self.X+","+self.Y+")"

 def __repr__(self):
   return "UNSTACK("+self.X+","+self.Y+")"

 def __eq__(self, other) :
```

```
    return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

  def precondition(self):
    armempty = ARMEMPTY()
    on_xy = ON(self.X,self.Y)
    clear_x = CLEAR(self.X)
    return [ armempty , on_xy , clear_x ]

  def delete(self):
    armempty = ARMEMPTY()
    on_xy = ON(self.X,self.Y)
    return [ armempty , on_xy ]

  def add(self):
    clear_y = CLEAR(self.Y)
    holding_x = HOLDING(self.X)
    return [ clear_y , holding_x ]


class PickupOp(Operation):

  def __init__(self, X):
    self.X = X

  def __str__(self):
    return "PICKUP("+self.X+")"

  def __repr__(self):
    return "PICKUP("+self.X+")"

  def __eq__(self, other) :
    return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

  def precondition(self):
    clear_x = CLEAR(self.X)
```

```
    ontable_x = ONTABLE(self.X)
    armempty = ARMEMPTY()
    return [ clear_x , ontable_x , armempty ]

  def delete(self):
    ontable_x = ONTABLE(self.X)
    armempty = ARMEMPTY()
    return [ armempty , ontable_x ]

  def add(self):
    holding_x = HOLDING(self.X)
    return [ holding_x ]


class PutdownOp(Operation):

  def __init__(self, X):
    self.X = X

  def __str__(self):
    return "PUTDOWN("+self.X+")"

  def __repr__(self):
    return "PUTDOWN("+self.X+")"

  def __eq__(self, other) :
    return self.__dict__ == other.__dict__ and self.__class__ ==
other.__class__

  def precondition(self):
    holding_x = HOLDING(self.X)
    return [ holding_x ]

  def delete(self):
    holding_x = HOLDING(self.X)
    return [ holding_x ]
```

```
 def add(self):
   ontable_x = ONTABLE(self.X)
   armempty = ARMEMPTY()
   return [ armempty , ontable_x ]


initial_state = [

 ON('B','A'),
  ONTABLE('A'),
 ONTABLE('C'),
 ONTABLE('D'),

 CLEAR('B'),
 CLEAR('C'),
 CLEAR('D'),

 ARMEMPTY()

]

goal_state = [

 ON('B','D'),
 ON('C','A'),
  ONTABLE('A'),
 ONTABLE('D'),

 CLEAR('B'),
 CLEAR('C'),

 ARMEMPTY()
 ]

print("\nInitial State")
for predicate in initial_state:
 print(predicate)
```

```
print("\nGoal State")
for predicate in goal_state:
 print(predicate)

def isPredicate(obj):
 predicates = [ON, ONTABLE, CLEAR, HOLDING, ARMEMPTY]
 for predicate in predicates:
   if isinstance(obj,predicate):
     return True
 return False

def isOperation(obj):
 operations = [StackOp, UnstackOp, PickupOp, PutdownOp]
 for operation in operations:
   if isinstance(obj,operation):
     return True
 return False

#Function to replace unsatisfied goal with an action
def get_action(unsatisfied_goal, world_state):

 if isinstance(unsatisfied_goal,ON):
   #Stack block X on block Y
   X = unsatisfied_goal.X
   Y = unsatisfied_goal.Y
   return StackOp(X,Y)

 if isinstance(unsatisfied_goal,CLEAR):
     for predicate in world_state:
       #If Block is on another block, unstack
       if isinstance(predicate,ON) and predicate.Y==unsatisfied_goal.X:
         return UnstackOp(predicate.X, predicate.Y)
       #If Block is on table, pickup
       elif isinstance(predicate,ONTABLE) and
predicate.X==unsatisfied_goal.X:
         return PickupOp(predicate.X)
```

```
 if isinstance(unsatisfied_goal,ARMEMPTY):
     #If Arm is holding a block, put it on the table
     for predicate in world_state:
       if isinstance(predicate,HOLDING):
         return PutdownOp(predicate.X)
  elif isinstance(unsatisfied_goal,HOLDING):
   X = unsatisfied_goal.X
   #If block is on table, pick up
   if ONTABLE(X) in world_state:
     return PickupOp(X)
   #If block is on another block, unstack
   else:
     for predicate in world_state:
       if isinstance(predicate,ON) and predicate.X==X:
         return UnstackOp(X,predicate.Y)

def arm_status(world_state):
 #If Arm is holding a block, put it on the table
 for predicate in world_state:
   if isinstance(predicate, HOLDING):
     return predicate
 return ARMEMPTY()

#Store Steps
steps = []

#Program Stack
stack = []

#World State/Knowledge Base
world_state = initial_state.copy()

#Initially push the goal_state as compound goal onto the stack
stack.append(goal_state.copy())

#Repeat until the stack is empty
```

```
while len(stack)!=0:

 #Get the top of the stack
 stack_top = stack[-1]

 #Print Variables
 print('\nStack :: ',stack,' <- top')
 print('Arm Status :: ',arm_status(world_state))
 print('World State :: ',world_state)

 #If Stack Top is Compound Goal, push its unsatisfied goals onto stack
 if type(stack_top) is list:
   compound_goal = stack.pop()
   for goal in compound_goal:
     if goal not in world_state:
       stack.append(goal)

 #If Stack Top is an action
 elif isOperation(stack_top):

   #Peek the operation
   operation = stack[-1]

   all_preconditions_satisfied = True

   #Check if any precondition is unsatisfied and push it onto program
stack
   for predicate in operation.delete():
     if predicate not in world_state:
       all_preconditions_satisfied = False
       stack.append(predicate)

   #If all preconditions are satisfied, pop operation from stack and
execute it
   if all_preconditions_satisfied:

     stack.pop()
```

```
        steps.append(operation)

        for predicate in operation.delete():
          world_state.remove(predicate)
        for predicate in operation.add():
          world_state.append(predicate)

      else:

        pass


    #If Stack Top is a single satisfied goal
    elif stack_top in world_state:
      stack.pop()

    #If Stack Top is a single unsatisfied goal
    else:
      unsatisfied_goal = stack.pop()

      #Replace Unsatisfied Goal with an action that can complete it
      action = get_action(unsatisfied_goal, world_state)

      #Special Case - If action obtained is Holding, remove Armempty
Predicate
      if isinstance(action, HOLDING) and ARMEMPTY() in world_state:
        world_state.remove(ARMEMPTY())
      stack.append(action)

      #Push Precondition on the stack
      for predicate in action.precondition():
        if predicate not in world_state:
          stack.append(predicate)

  #Printing Variables
  print('\nStack :: ',stack,' <- top')
  print('Arm Status :: ',arm_status(world_state))
```

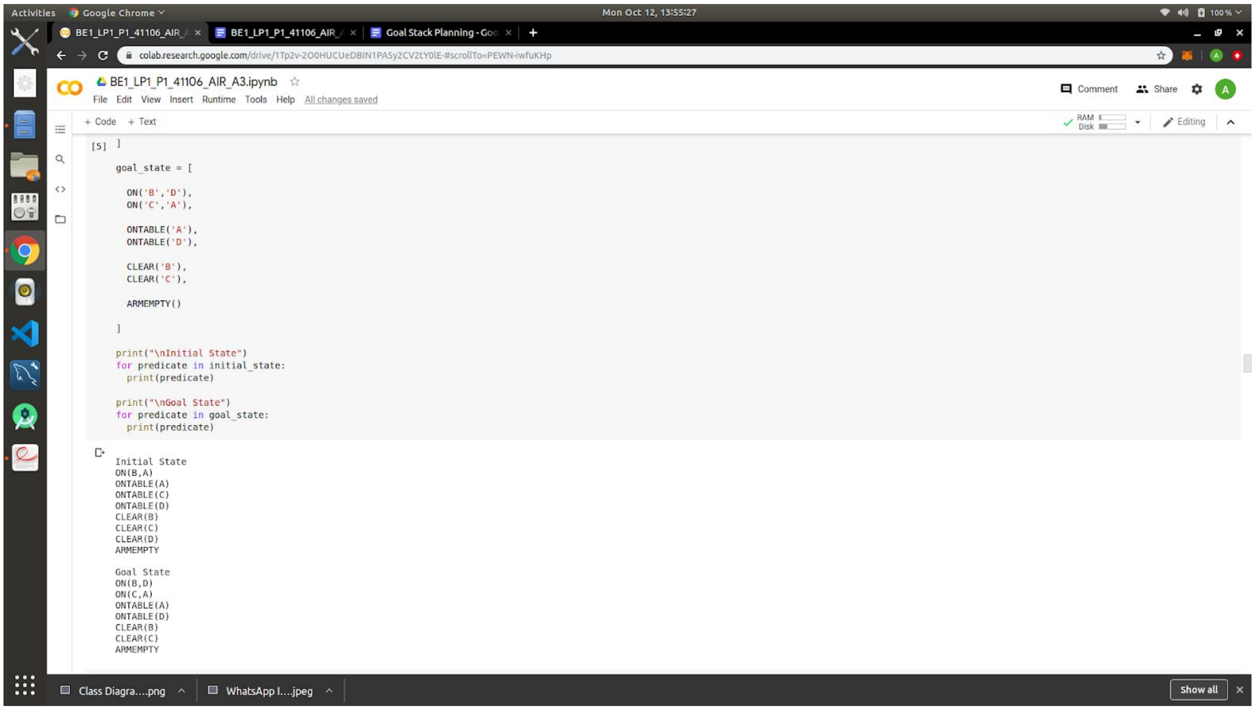
```python
print('World State :: ',world_state)

print('Goal State : ', goal_state)
print('World State : ', world_state)
print('Are the two states equal? : ',(set(goal_state)==set(world_state)))

print(steps)
```

Output Screenshots

Image 1 - Initial State and Goal State

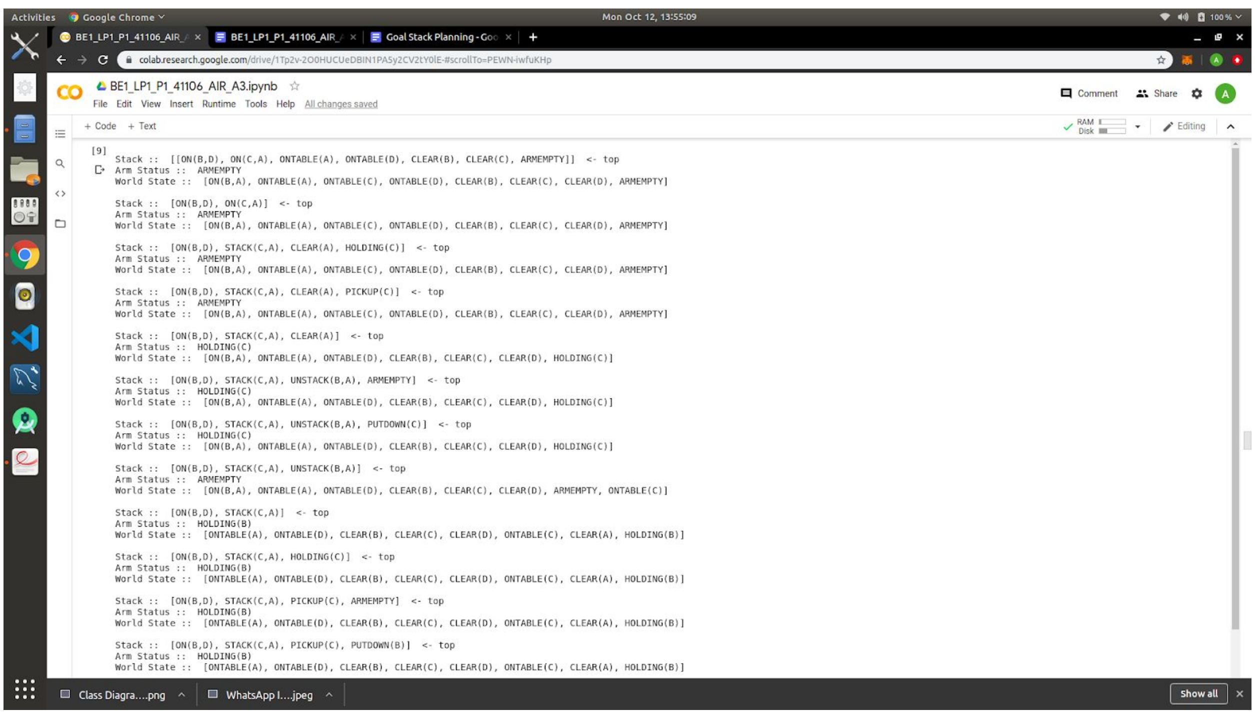
Image 2 - Goal Stack each Step

Image 3 - Final List of steps from Initial State to Goal State

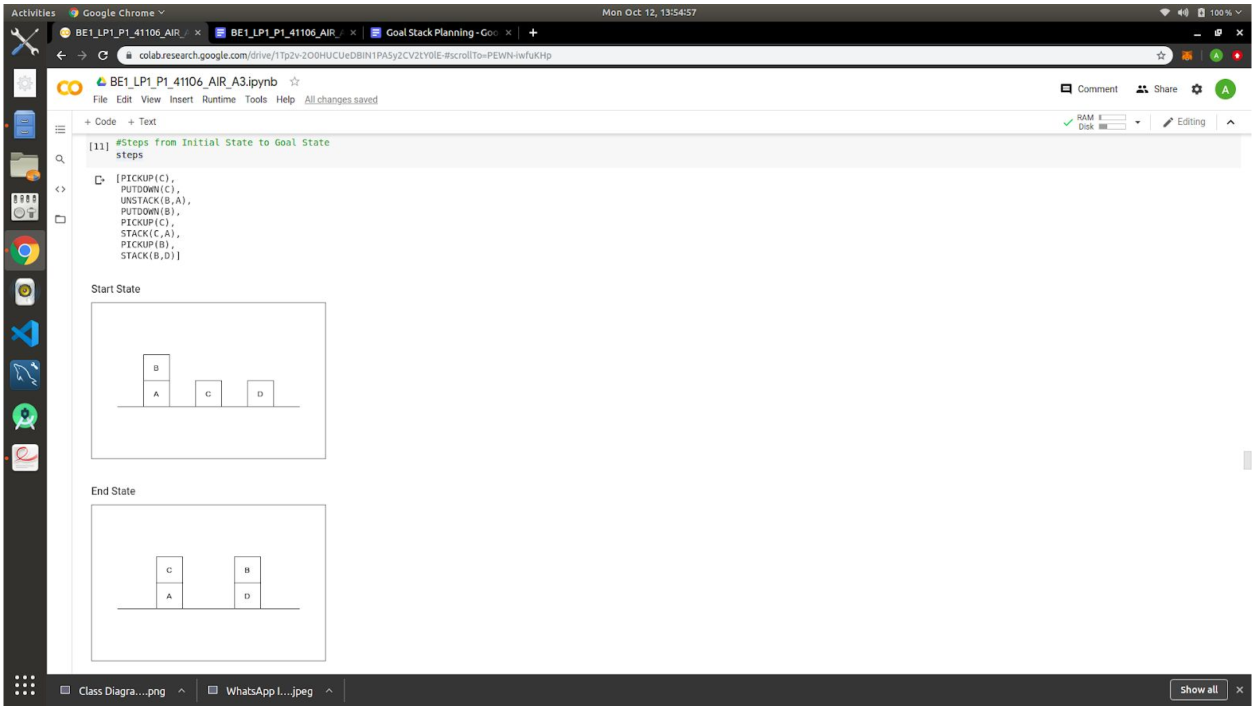


```
[5] ]

    goal_state = [

      ON('B','D'),
      ON('C','A'),

      ONTABLE('A'),
      ONTABLE('D'),

      CLEAR('B'),
      CLEAR('C'),

      ARMEMPTY()

    ]

    print("\nInitial State")
    for predicate in initial_state:
      print(predicate)

    print("\nGoal State")
    for predicate in goal_state:
      print(predicate)
```

```
Initial State
ON(B,A)
ONTABLE(A)
ONTABLE(C)
ONTABLE(D)
CLEAR(B)
CLEAR(C)
CLEAR(D)
ARMEMPTY

Goal State
ON(B,D)
ON(C,A)
ONTABLE(A)
ONTABLE(D)
CLEAR(B)
CLEAR(C)
ARMEMPTY
```



```
[9]
Stack ::  [[ON(B,D), ON(C,A), ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), ARMEMPTY]]  <- top
Arm Status ::  ARMEMPTY
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(C), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ARMEMPTY]

Stack ::  [ON(B,D), ON(C,A)]  <- top
Arm Status ::  ARMEMPTY
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(C), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ARMEMPTY]

Stack ::  [ON(B,D), STACK(C,A), CLEAR(A), HOLDING(C)]  <- top
Arm Status ::  ARMEMPTY
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(C), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ARMEMPTY]

Stack ::  [ON(B,D), STACK(C,A), CLEAR(A), PICKUP(C)]  <- top
Arm Status ::  ARMEMPTY
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(C), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ARMEMPTY]

Stack ::  [ON(B,D), STACK(C,A), CLEAR(A)]  <- top
Arm Status ::  HOLDING(C)
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), HOLDING(C)]

Stack ::  [ON(B,D), STACK(C,A), UNSTACK(B,A), ARMEMPTY]  <- top
Arm Status ::  HOLDING(C)
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), HOLDING(C)]

Stack ::  [ON(B,D), STACK(C,A), UNSTACK(B,A), PUTDOWN(C)]  <- top
Arm Status ::  HOLDING(C)
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), HOLDING(C)]

Stack ::  [ON(B,D), STACK(C,A), UNSTACK(B,A)]  <- top
Arm Status ::  ARMEMPTY
World State ::  [ON(B,A), ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ARMEMPTY, ONTABLE(C)]

Stack ::  [ON(B,D), STACK(C,A)]  <- top
Arm Status ::  HOLDING(B)
World State ::  [ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ONTABLE(C), CLEAR(A), HOLDING(B)]

Stack ::  [ON(B,D), STACK(C,A), HOLDING(C)]  <- top
Arm Status ::  HOLDING(B)
World State ::  [ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ONTABLE(C), CLEAR(A), HOLDING(B)]

Stack ::  [ON(B,D), STACK(C,A), PICKUP(C), ARMEMPTY]  <- top
Arm Status ::  HOLDING(B)
World State ::  [ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ONTABLE(C), CLEAR(A), HOLDING(B)]

Stack ::  [ON(B,D), STACK(C,A), PICKUP(C), PUTDOWN(B)]  <- top
Arm Status ::  HOLDING(B)
World State ::  [ONTABLE(A), ONTABLE(D), CLEAR(B), CLEAR(C), CLEAR(D), ONTABLE(C), CLEAR(A), HOLDING(B)]
```



Conclusion

I have successfully designed and implemented Goal Stack Planning for Block World Problem