1)

a) Unrestricted Algorithm

```
def unrestricted(self, seq1, seq2):
        self.score = 0
        self.matrix[(-1,-1)] = 0
        if(self.MaxCharactersToAlign > len(seq1)):
            self.min_length1 = len(seq1)
        else:
            self.min_length1 = self.MaxCharactersToAlign
        if(self.MaxCharactersToAlign > len(seq2)):
            self.min_length2 = len(seq2)
        else:
            self.min_length2 = self.MaxCharactersToAlign
        for i in range(-1,self.min_length1):
            for j in range(-1, self.min_length2):
                if(i==-1 and j==-1):
                    continue
                if(i == -1 and j >-1) :
                    self.matrix[-1,j] = self.matrix[-1,j-1] + INDEL
                    self.back_pointers[-1,j] = (-1,j-1,'left')
                    continue
                if(i > -1 and j == -1):
                    self.matrix[i,-1] = self.matrix[i-1, -1] + INDEL
                    self.back_pointers[i,-1] = (i-1, -1, 'top')
                    continue
                if(seq1[i] == seq2[j]):
                    diagonal = self.matrix[i-1,j-1] + MATCH
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                else:
                    diagonal = self.matrix[i-1,j-1] + SUB
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                if(direction == 'left'):
                    self.matrix[i,j] = self.matrix[i,j-1] + INDEL
                    self.back_pointers[i,j] = (i,j-1,'left')
                    continue
                if(direction == 'top'):
                    self.matrix[i,j] = self.matrix[i-1,j] + INDEL
                    self.back_pointers[i,j] = (i-1,j, 'top')
                    continue
                if(direction == 'diagonal'):
                    self.matrix[i,j] = diagonal
                    self.back_pointers[i,j] = (i-1,j-1,'diagonal')
```

```
                    continue
        self.score = self.matrix[self.min_length1-1,self.min_length2-1]
```

The above code is one of the function executed for unrestricted algorithm. Unrestricted function takes up majority of the runtime and space. The function has a loop inside a loop and it iterates over the length of the seq1 and length of seq2 (with the maximum of the align length given by the user). The matrix dictionary has a length of the number of iterations done by the for loops. Therefore the time complexity and space complexity of this algorithm is O(mn), where m is the size of seq1 and n is the size of seq2 with the maximum of align length.

b) banded algorithm

```
self.score = 0
        self.matrix[(-1,-1)] = 0
        if(self.MaxCharactersToAlign > len(seq1)):
            self.min_length1 = len(seq1)
        else:
            self.min_length1 = self.MaxCharactersToAlign
        if(self.MaxCharactersToAlign > len(seq2)):
            self.min_length2 = len(seq2)
        else:
            self.min_length2 = self.MaxCharactersToAlign
        for i in range(-1,self.min_length1):
            if(-1 >= i - MAXINDELS):
                j_start = -1
            else:
                j_start = i - MAXINDELS
            if(self.min_length2 <= i + MAXINDELS):
                j_end = self.min_length2
            else:
                j_end = i + MAXINDELS + 1
            for j in range(j_start, j_end):
                if(i==-1 and j==-1):
                    continue
                if(i == -1 and j >-1) :
                    self.matrix[-1,j] = self.matrix[-1,j-1] + INDEL
                    self.back_pointers[-1,j] = (-1,j-1,'left')
                    continue
                if(i > -1 and j == -1):
```

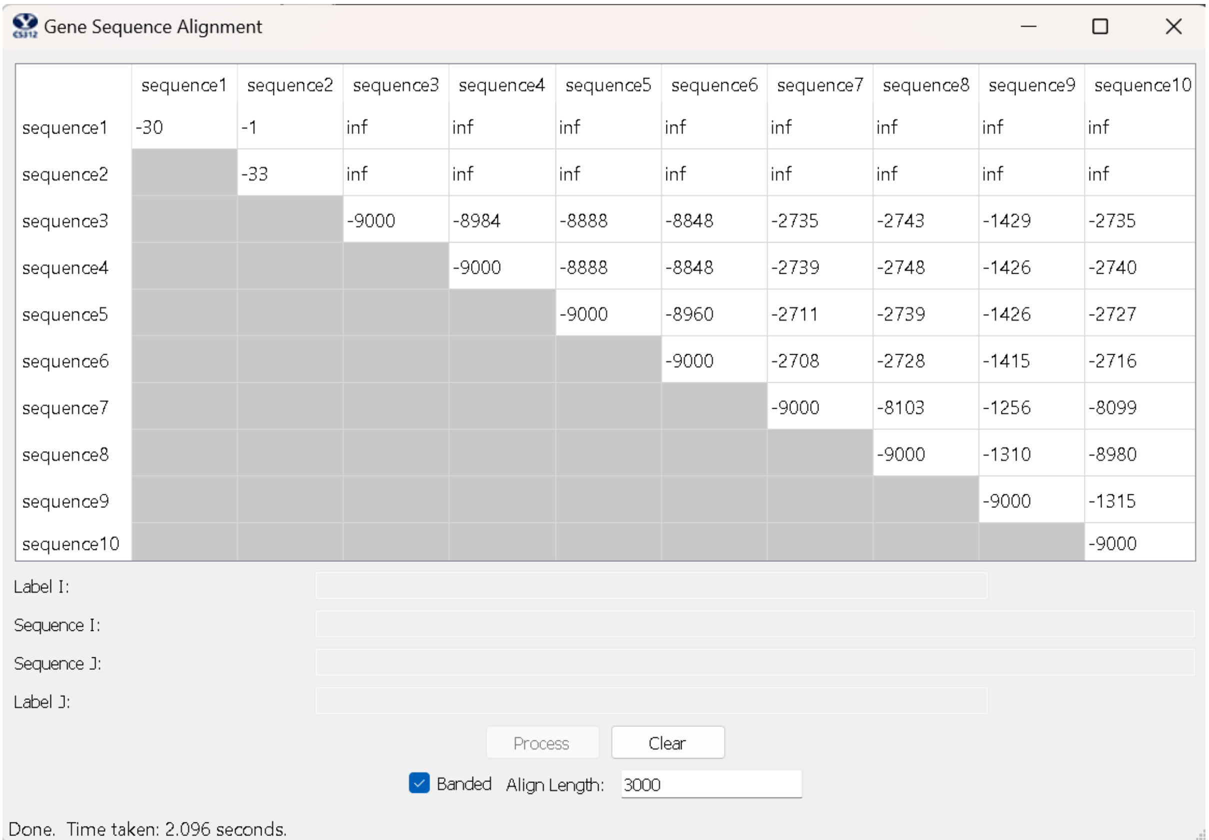
```
                    self.matrix[i,-1] = self.matrix[i-1, -1] + INDEL
                    self.back_pointers[i,-1] = (i-1, -1, 'top')
                    continue
                self.matrix.setdefault((i,j-1), float(inf))
                self.matrix.setdefault((i-1,j),float(inf))
                if(seq1[i] == seq2[j]):
                    diagonal = self.matrix[i-1,j-1] + MATCH
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                else:
                    diagonal = self.matrix[i-1,j-1] + SUB
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                if(direction == 'left'):
                    self.matrix[i,j] = self.matrix[i,j-1] + INDEL
                    self.back_pointers[i,j] = (i,j-1,'left')
                    continue
                if(direction == 'top'):
                    self.matrix[i,j] = self.matrix[i-1,j] + INDEL
                    self.back_pointers[i,j] = (i-1,j, 'top')
                    continue
                if(direction == 'diagonal'):
                    self.matrix[i,j] = diagonal
                    self.back_pointers[i,j] = (i-1,j-1,'diagonal')
                    continue
        self.matrix.setdefault((self.min_length1-1,self.min_length2-1),
float(inf))
        self.score = self.matrix[self.min_length1-1,self.min_length2-1]
```

banded_alignment function has the majority of time and space complexity of the algorithm when the user asks for banded alignment. The function has for loop but the number of iterations is the banded length times the length of the first sequence. The algorithm is very similar to the unrestricted with the only exception of the no of iteration in the inner loop which is banded length. The matrix dictionary has the length of the number of executions of the inner code. Therefore this algorithm has a time and space complexity of O(kn), where k is the banded length and n is the length of the seq1 and with maximum of align length.

2) In my alignment function I store the backpointers as a dictionary with the current cell as a tuple of I,j and with the value of 3-tuple of i,j of previous cell, and the direction the cell points to the current cell. For example, key = (2,2) and value = (1,1,'diagonal'). I use my alignment function to extract my alignments. I start with the last cell and go back and reach the final cell while checking if the tuple value is left or top. If I get left, I would add '-' to the first sequence and if I get top I would add '-' to the second sequence. This is how my extraction algorithm works.

3) Results:

	sequence1	sequence2	sequence3	sequence4	sequence5	sequence6	sequence7	sequence8	sequence9	sequence10
sequence1	-30	-1	4956	4956	4956	4956	4956	4956	4956	4956
sequence2		-33	4948	4948	4948	4948	4948	4948	4948	4948
sequence3			-3000	-2996	-2956	-2944	-1431	-1448	-1399	-1448
sequence4				-3000	-2960	-2948	-1431	-1448	-1399	-1448
sequence5					-3000	-2988	-1423	-1452	-1391	-1448
sequence6						-3000	-1426	-1452	-1394	-1448
sequence7							-3000	-2771	-2814	-2767
sequence8								-3000	-2731	-2996
sequence9									-3000	-2727
sequence10										-3000



Gene Sequence Alignment

	sequence1	sequence2	sequence3	sequence4	sequence5	sequence6	sequence7	sequence8	sequence9	sequence10
sequence1	-30	-1	inf	inf	inf	inf	inf	inf	inf	inf
sequence2		-33	inf	inf	inf	inf	inf	inf	inf	inf
sequence3			-9000	-8984	-8888	-8848	-2735	-2743	-1429	-2735
sequence4				-9000	-8888	-8848	-2739	-2748	-1426	-2740
sequence5					-9000	-8960	-2711	-2739	-1426	-2727
sequence6						-9000	-2708	-2728	-1415	-2716
sequence7							-9000	-8103	-1256	-8099
sequence8								-9000	-1310	-8980
sequence9									-9000	-1315
sequence10										-9000

Label I:
Sequence I:
Sequence J:
Label J:
Process Clear
Banded Align Length: 3000
Done. Time taken: 2.096 seconds.

4)

Unrestricted:

gattgcgagcgatttgcgtgcgtgcatcccgcttc-actg--at-ctcttgttagatcttttcataatctaaactttataaaaacatccactccctgta-

-aataa-gagtgattggcgtccgtacgtaccctttctactctcaaactcttgttagtttaaatc-taatctaaactttataaa--cggc-acttcctgtg

Banded:

gattgcgagcgatttgcgtgcgtgcatcccgcttc-actg--at-ctcttgttagatcttttcataatctaaactttataaaaacatccactccctgta-

-aataa-gagtgattggcgtccgtacgtaccctttctactctcaaactcttgttagtttaaatc-taatctaaactttataaa--cggc-acttcctgtg

5) Source Code:

```python
class GeneSequencing:

    def __init__( self ):
        pass

    # Generates alignment using the back_pointers dictionary generated while
executing either banded or unrestricted.
    def alignment(self, seq1,seq2):
        self.alignment1 = []
        self.alignment2 = []
        current = self.back_pointers[self.min_length1-1, self.min_length2-1]
        i = self.min_length1-1
        j = self.min_length2 -1
        while(current[0] > -1 or current[1] > -1):
            if(current[2] == 'top'):
                self.alignment2.insert(0,'-')
                self.alignment1.insert(0,seq1[i])
            if(current[2] == 'left'):
                self.alignment1.insert(0, '-')
                self.alignment2.insert(0, seq2[j])
            if(current[2] == 'diagonal'):
                self.alignment1.insert(0,seq1[i])
                self.alignment2.insert(0,seq2[j])
            i = current[0]
            j = current[1]
            current = self.back_pointers[current[0], current[1]]
        self.alignment1.insert(0,seq1[i])
        self.alignment2.insert(0,seq2[j])
        if(current[2] == 'top'):
            self.alignment2.insert(0,'-')
        if(current[1] == 'left'):
            self.alignment1.insert(0,'-')
        return

    #Finds the min of the three values and return from which direction the cell
would go to current cell.
    # Used in banded or unrestricted
    def getMin(self, a, b, c):
        minimum = min(a,b,c)
        if(minimum == a):
            return 'left'
        if(minimum == b):
            return 'top'
        if(minimum == c):
            return 'diagonal'
```

```
    # Algorithm for implementing the unrestricted alignment.
    def unrestricted(self, seq1, seq2):
        self.score = 0
        self.matrix[(-1,-1)] = 0
        if(self.MaxCharactersToAlign > len(seq1)):
            self.min_length1 = len(seq1)
        else:
            self.min_length1 = self.MaxCharactersToAlign
        if(self.MaxCharactersToAlign > len(seq2)):
            self.min_length2 = len(seq2)
        else:
            self.min_length2 = self.MaxCharactersToAlign
        for i in range(-1,self.min_length1): #Time complexity of O(m) where m is
size of seq1
            for j in range(-1, self.min_length2): #Time complexity of O(n) where
n is size of seq2.
                if(i==-1 and j==-1):
                    continue
                if(i == -1 and j >-1) :
                    self.matrix[-1,j] = self.matrix[-1,j-1] + INDEL
                    self.back_pointers[-1,j] = (-1,j-1,'left')
                    continue
                if(i > -1 and j == -1):
                    self.matrix[i,-1] = self.matrix[i-1, -1] + INDEL
                    self.back_pointers[i,-1] = (i-1, -1, 'top')
                    continue
                if(seq1[i] == seq2[j]):
                    diagonal = self.matrix[i-1,j-1] + MATCH
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                else:
                    diagonal = self.matrix[i-1,j-1] + SUB
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                if(direction == 'left'):
                    self.matrix[i,j] = self.matrix[i,j-1] + INDEL
                    self.back_pointers[i,j] = (i,j-1,'left')
                    continue
                if(direction == 'top'):
                    self.matrix[i,j] = self.matrix[i-1,j] + INDEL
                    self.back_pointers[i,j] = (i-1,j, 'top')
                    continue
                if(direction == 'diagonal'):
                    self.matrix[i,j] = diagonal
```

```
                    self.back_pointers[i,j] = (i-1,j-1,'diagonal')
                    continue
        self.score = self.matrix[self.min_length1-1,self.min_length2-1]

    # Algorithm for implementing the banded alignment.
    def banded_alignment(self, seq1, seq2):
        self.score = 0
        self.matrix[(-1,-1)] = 0
        if(self.MaxCharactersToAlign > len(seq1)):
            self.min_length1 = len(seq1)
        else:
            self.min_length1 = self.MaxCharactersToAlign
        if(self.MaxCharactersToAlign > len(seq2)):
            self.min_length2 = len(seq2)
        else:
            self.min_length2 = self.MaxCharactersToAlign
        for i in range(-1,self.min_length1): #Time Complexity of O(n).
            if(-1 >= i - MAXINDELS):
                j_start = -1
            else:
                j_start = i - MAXINDELS
            if(self.min_length2 <= i + MAXINDELS):
                j_end = self.min_length2
            else:
                j_end = i + MAXINDELS + 1
            for j in range(j_start, j_end): #Time Complexity of O(K) which is 7
in this case.
                if(i==-1 and j==-1):
                    continue
                if(i == -1 and j >-1) :
                    self.matrix[-1,j] = self.matrix[-1,j-1] + INDEL
                    self.back_pointers[-1,j] = (-1,j-1,'left')
                    continue
                if(i > -1 and j == -1):
                    self.matrix[i,-1] = self.matrix[i-1, -1] + INDEL
                    self.back_pointers[i,-1] = (i-1, -1, 'top')
                    continue
                self.matrix.setdefault((i,j-1), float(inf))
                self.matrix.setdefault((i-1,j),float(inf))
                if(seq1[i] == seq2[j]):
                    diagonal = self.matrix[i-1,j-1] + MATCH
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                else:
                    diagonal = self.matrix[i-1,j-1] + SUB
```

```
                    direction = self.getMin(self.matrix[i,j-1]+INDEL,
self.matrix[i-1,j]+INDEL,diagonal)
                if(direction == 'left'):
                    self.matrix[i,j] = self.matrix[i,j-1] + INDEL
                    self.back_pointers[i,j] = (i,j-1,'left')
                    continue
                if(direction == 'top'):
                    self.matrix[i,j] = self.matrix[i-1,j] + INDEL
                    self.back_pointers[i,j] = (i-1,j, 'top')
                    continue
                if(direction == 'diagonal'):
                    self.matrix[i,j] = diagonal
                    self.back_pointers[i,j] = (i-1,j-1,'diagonal')
                    continue
        self.matrix.setdefault((self.min_length1-1,self.min_length2-1),
float(inf))
        self.score = self.matrix[self.min_length1-1,self.min_length2-1]

# This is the method called by the GUI.  _seq1_ and _seq2_ are two sequences to
be aligned, _banded_ is a boolean that tells
# you whether you should compute a banded alignment or full alignment, and
_align_length_ tells you
# how many base pairs to use in computing the alignment
    def align( self, seq1, seq2, banded, align_length):
        if(seq1 == 'polynomial' and seq2 == 'polynomial'):
            self.no_of_calls = 0
        self.no_of_calls += 1
        self.banded = banded
        self.MaxCharactersToAlign = align_length
        self.back_pointers = {}
        self.matrix = {}
        if(self.banded):
            self.banded_alignment(seq1, seq2)
        else:
            self.unrestricted(seq1, seq2)
        if(self.score == float(inf)):
            return {'align_cost':self.score, 'seqi_first100': 'No Alignment
Possible', 'seqj_first100':'No Alignment Possible'}
        self.alignment(seq1,seq2)

        # gets the first 100 characters of the alignment string.
        seqi100 = ''.join(self.alignment1[:100])
        seqj100 = ''.join(self.alignment2[:100])
```

```
        # Prints out the first 100 strings of each alignment as the gui was
cutting off the values.
        print(str(self.no_of_calls) +': ' + seqi100)
        print(str(self.no_of_calls) + ': ' + seqj100)
        print('')
        return {'align_cost':self.score, 'seqi_first100':seqi100,
'seqj_first100':seqj100}
```