

Lezione 14

Bioinformatica

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Lecture 14: Longest Common Subsequence

Longest common subsequence (LCS) problem

BLAST (Basic Local Alignment Search Tool)

FASTA (FAST Alignment)



Sommario

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Dynamic Programming Approach

LCS : Longest Common Subsequence

Let $X, Y \in \text{Seq}$ be the sequences to compare, and X_i, Y_j be the subsequences of their first i, j characters, respectively.

The integer function

$$\text{LCS} : \text{Seq} \times \text{Seq} \rightarrow \text{Nat}$$

gives the integer length of longest common subsequence of any two (sub)sequences, as follows:



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gives the integer length of longest common subsequence of any two (sub)sequences, as follows:

$$\text{LCS}(X_i, Y_j) = \begin{cases} 0 & \text{if } i = 0 \text{ or } j = 0 \\ \text{LCS}(X_{i-1}, Y_{j-1}) + 1 & \text{if } x_i = y_j \\ \max(\text{LCS}(X_i, Y_{j-1}), \text{LCS}(X_{i-1}, Y_j)) & \text{if } x_i \neq y_j \end{cases}$$

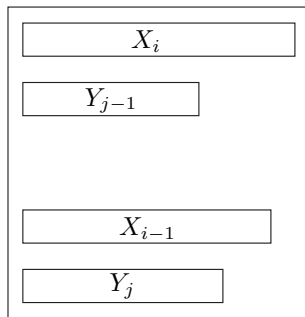
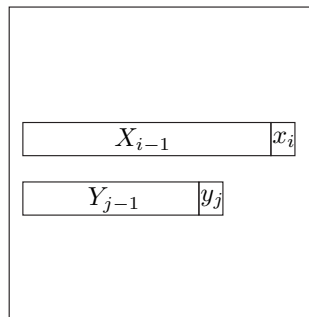


Longest common subsequence

LCS function defined

$$x_i = y_j$$

$$LCS(X_i, Y_j) = LCS(X_{i-1}, Y_{j-1}) + 1$$



$$x_i \neq y_j$$

$$LCS(X_i, Y_j) = \max(LCS(X_i, Y_{j-1}), LCS(X_{i-1}, Y_j))$$



Recursive implementation

just write down in Python the recursive equations above

```
1 def cls(X,Y):
2     i,j = len(X),len(Y)
3     if i == 0 or j == 0: return 0
4     elif X[i-1] == Y[j-1]: return cls(X[:i-1],Y[:j-1])+1
5     else: return max(cls(X[:i],Y[:j-1]),cls(X[:i-1],Y[:j]))
```

```
1 print cls("BASKETBALL", "BASEBALL") == 8
```

OK!

```
1 print cls("ABRACADABRA", "SUPERCALIFRAGILISTICSPIRALIDOSO")
```

VERY long execution time ... WHY ?



... because of recursion nonlinearity

the execution time is exponential with the sequence lengths

a recursion is said **linear** if the definition right-hand side contains at most **one recursive function call**

► **nonlinear recursion**: $\binom{n}{k} = \binom{n-1}{k} + \binom{n-1}{k-1}$ complexity: $O(2^n)$

```
1 def binomial(n,k):  
2     if k == 0 or n == k: return 1  
3     else: return binomial(n-1,k) + binomial(n-1,k-1)
```



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```
1 def binomial(n,k):
2     if k == 0 or n == k: return 1
3     else: return binomial(n-1,k) + binomial(n-1,k-1)
```

► **linear recursion:** $\binom{n}{k} = \binom{n-1}{k-1} \times \frac{n}{k}$ complexity: $O(n)$

```
1 def binomial(n,k):
2     if k == 0 or n == k: return 1
3     else: return binomial(n-1,k-1) * n / k
```



Memoization technique

In computing, “memoization” is an optimization technique used primarily to speed up computer programs by having function calls avoid repeating the calculation of results for previously-processed input

- ▶ This technique of saving values that have already been calculated is frequently used



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- ▶ Memoization is a means of lowering a function’s time cost in exchange for space cost; that is, memoized functions become optimized for speed in exchange for a higher use of computer memory space.



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- ▶ This technique of saving values that have already been calculated is frequently used
- ▶ Memoization is a means of lowering a function’s time cost in exchange for space cost; that is, memoized functions become optimized for speed in exchange for a higher use of computer memory space.
- ▶ An efficient LCS procedure requires: saving the solutions to one level of subproblem in a table so that the solutions are available to the next level of subproblems.



Length of the Longest Common Subsequence

computing the function $LCS : Seq \times Seq \rightarrow Nat$ with memoization

```
1 def LCS(X, Y):
2   m,n = len(X),len(Y)
3   # An (m+1) times (n+1) matrix
4   C = [[0] * (n+1) for i in range(m+1)]
5   for i in range(1, m+1):
6     for j in range(1, n+1):
7       if X[i-1] == Y[j-1]:
8         C[i][j] = C[i-1][j-1] + 1
9       else:
10        C[i][j] = max(C[i][j-1], C[i-1][j])
11   return C
```



Usage example — LCSfunction

```
1 >>> X = "AATCC"  
2 >>> Y = "ACACG"  
3 >>> m = len(X)  
4 >>> n = len(Y)  
5 >>> C = LCS(X, Y)
```



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3 >>> m = len(X)
4 >>> n = len(Y)
5 >>> C = LCS(X, Y)
```

```
1 >>> print C
2 [[0, 0, 0, 0, 0, 0],
3  [0, 1, 1, 1, 1, 1],
4  [0, 1, 1, 2, 2, 2],
5  [0, 1, 1, 2, 2, 2],
6  [0, 1, 2, 2, 3, 3],
7  [0, 1, 2, 2, 3, 3]]
```



Usage example — LCSfunction

```
1 >>> X = "ATGGCCTGGAC"  
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4 >>> n = len(Y)  
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```

```
1 >>> print C
2 [[0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
3  [0, 1, 1, 1, 1, 1, 1, 1, 1, 1],
4  [0, 1, 2, 2, 2, 2, 2, 2, 2, 2],
5  [0, 1, 2, 2, 2, 3, 3, 3, 3, 3],
6  [0, 1, 2, 2, 2, 3, 4, 4, 4, 4],
7  [0, 1, 2, 3, 3, 3, 4, 4, 5, 5],
8  [0, 1, 2, 3, 4, 4, 4, 4, 5, 6],
9  [0, 1, 2, 3, 4, 4, 4, 4, 5, 6],
10 [0, 1, 2, 3, 4, 5, 5, 5, 5, 6],
11 [0, 1, 2, 3, 4, 5, 6, 6, 6, 6],
12 [0, 1, 2, 3, 4, 5, 6, 7, 7, 7],
13 [0, 1, 2, 3, 4, 5, 6, 7, 8, 8]]
```



Reading out an LCS

Backtracking on the table from the lower-right corner

```
1 def backTrack(C, X, Y, i, j):
2     if i == 0 or j == 0:
3         return ""
4     elif X[i-1] == Y[j-1]:
5         return backTrack(C, X, Y, i-1, j-1) + X[i-1]
6     else:
7         if C[i][j-1] > C[i-1][j]:
8             return backTrack(C, X, Y, i, j-1)
9         else:
10            return backTrack(C, X, Y, i-1, j)
```



Usage example — backTrack function

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1 >>> X = "AATCC"
2 >>> Y = "ACACG"
3 >>> m = len(X)
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5 >>> C = LCS(X, Y)
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```
1 >>> X = "AATCC"
2 >>> Y = "ACACG"
3 >>> m = len(X)
4 >>> n = len(Y)
5 >>> C = LCS(X, Y)
```

```
1 >>> print "Some_LCS:_'%s'" % backTrack(C, X, Y, m, n)
2 Some LCS: 'AAC'
```



Usage example — backTrack function

```
1 >>> X = "ATGGCCTGGAC"
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Usage example — backTrack function

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3 >>> m = len(X)  
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5 >>> C = LCS(X, Y)
```

```
1 >>> print "Some_LCS:_'%s'" % backTrack(C, X, Y, m, n)  
2 Some LCS: 'ATCCGGAC'
```



Reading out all LCSs

```
1 def backTrackAll(C, X, Y, i, j):
2     if i == 0 or j == 0:
3         return set([""])
4     elif X[i-1] == Y[j-1]:
5         return set([Z + X[i-1]
6                     for Z in backTrackAll(C, X, Y, i-1, j-1)
7                     ])
8     else:
9         R = set()
10        if C[i][j-1] >= C[i-1][j]:
11            R.update(backTrackAll(C, X, Y, i, j-1))
12        if C[i-1][j] >= C[i][j-1]:
13            R.update(backTrackAll(C, X, Y, i-1, j))
14        return R
```



Usage example — backTrackAll function

```
1 >>> X = "AATCC"
2 >>> Y = "ACACG"
3 >>> m = len(X)
4 >>> n = len(Y)
5 >>> C = LCS(X, Y)
```



Usage example — backTrackAll function

```
1 >>> X = "AATCC"
2 >>> Y = "ACACG"
3 >>> m = len(X)
4 >>> n = len(Y)
5 >>> C = LCS(X, Y)
```

```
1 >>> print "All LCSs: _%s" % backTrackAll(C, X, Y, m, n)
2 All LCSs: set(['ACC', 'AAC'])
```



Usage example — backTrackAll function

```
1 >>> X = "ATGGCCTGGAC"  
2 >>> Y = "ATCCGGACC"  
3 >>> m = len(X)  
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```



Usage example — backTrackAll function

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1 >>> X = "ATGGCCTGGAC"
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3 >>> m = len(X)
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5 >>> C = LCS(X, Y)
```

```
1 >>> print "All LCSs: _%s" % backTrackAll(C, X, Y, m, n)
2 All LCSs: set(['ATCCGGAC'])
```



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Comparison of nucleotide or protein sequences

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- ▶ BLAST makes it easy to examine a large group of potential gene candidates



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- ▶ There is no need to manually cut and paste a 100 sequences in to the BLAST web pages
- ▶ Using the BLAST web pages it is possible to input "batches" of sequences into one form and retrieve the results
- ▶ There are two methods to do batch BLAST jobs
- ▶ The first is through the web interface and the second is using the standalone BLAST binaries and downloaded NCBI databases



BLAST

Example

- ▶ BLAST paper
- ▶ QuickStart: Example-Driven Web-Based BLAST Tutorial



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Example

FASTA stands for FAST-ALL, reflecting the fact that it can be used for a fast protein comparison or a fast nucleotide comparison

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- ▶ Increasing the ktp decreases the number of background hits



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- ▶ The high speed of this program is achieved by using the observed pattern of word hits to identify potential matches before attempting the more time consuming optimised search
- ▶ The trade-off between speed and sensitivity is controlled by the ktup parameter, which specifies the size of the word
- ▶ Increasing the ktup decreases the number of background hits
- ▶ Not every word hit is investigated but instead initially looks for segment's containing several nearby hits



FASTA Web services

Both REST and SOAP web service interfaces are exposed

REST Sample clients are provided for a number of programming languages.

SOAP RPC/encoded SOAP service

