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Dumbbell Laplacian program

Computes the eigenvalues and eigenfunctions of the Laplace operator

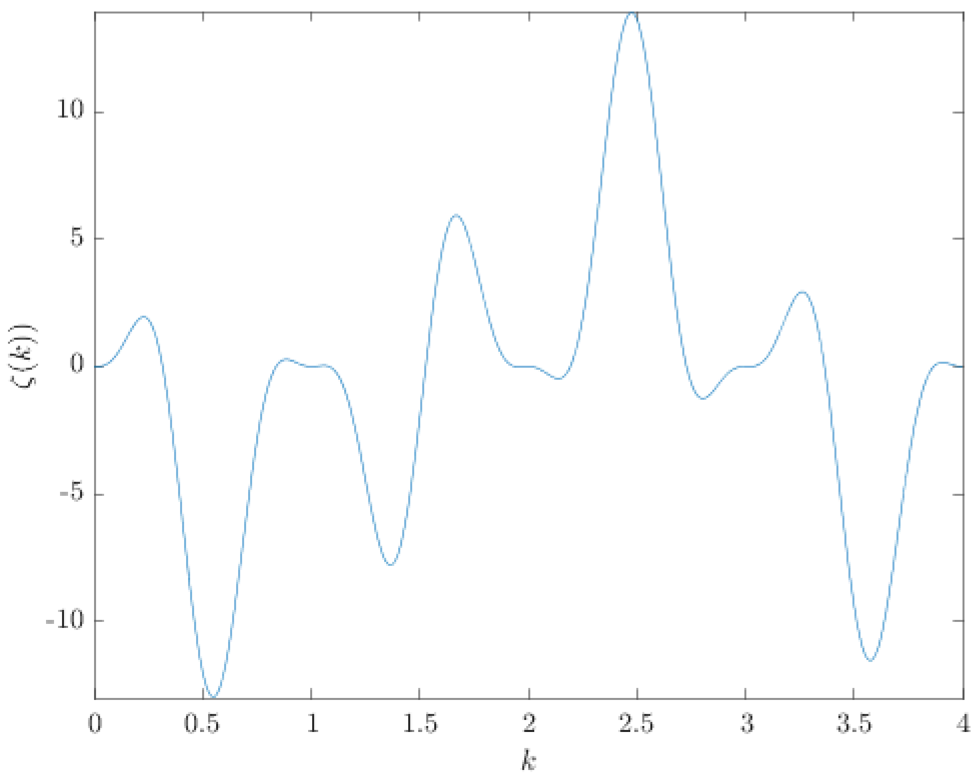
```
function dumbbellEigenfunctions
```

Set up the graph structure and coordinates of the problem

```
LVec=[2*pi,2, 2*pi];
nX=[63, 20, 63];
Phi = quantumGraph([1 1 2],[1 2 2],LVec,'nxVec',nX);
```

Calculate and plot the secular determinant of the quantum graph

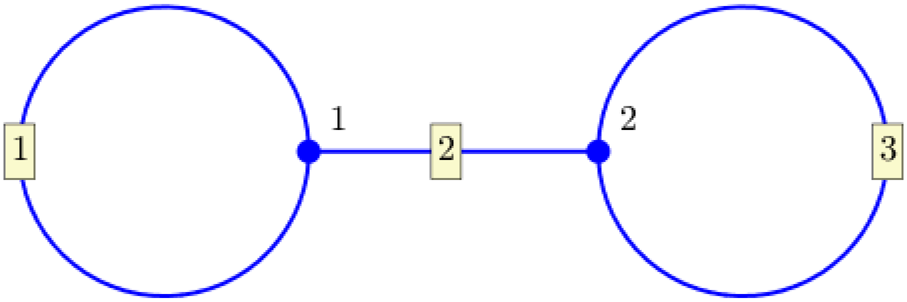
```
f = secularDet(Phi);
fplot(f,[0 4])
xlabel('$k$')
ylabel('$\zeta(k))$')
```



Set up coordinates on which to plot the solutions

Note that the user has to create the plotting function Note further, you could also add this by adding the key-value pair 'PlotCoordinateFcn',@dumbbellPlotCoords to the above line of code Phi = quantumGraph(...

```
Phi.addPlotCoords(@dumbbellPlotCoords);
Phi.plot('layout')
```



Construct the Laplacian and calculate its eigenvalues and eigenvectors

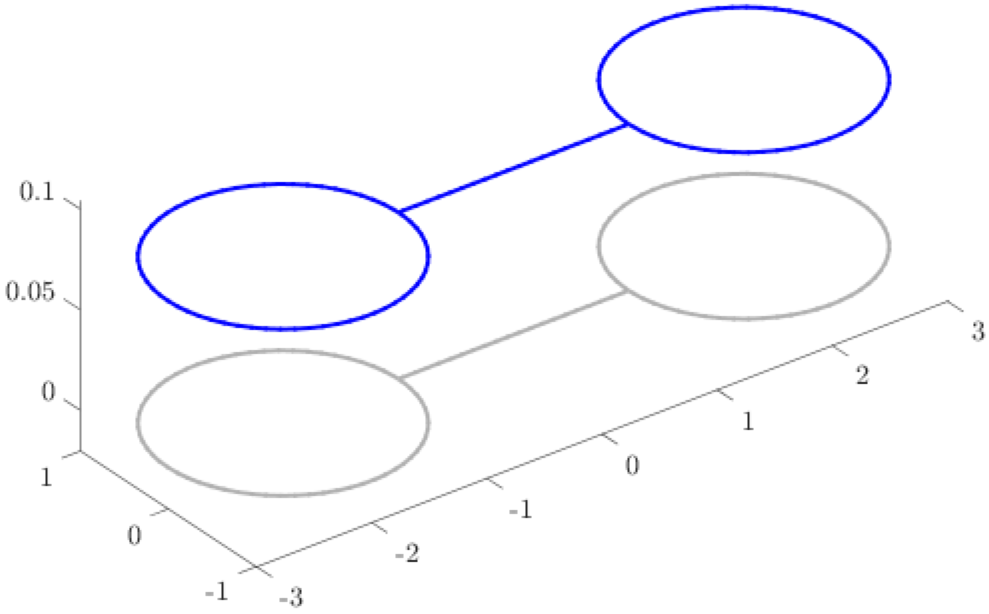
A little cleanup needed because the null eigenvalue is sometimes calculated as positive and sometimes as negative and this screws up the sorting.

```
[V,lambda]=eig(Phi);
[singles,doubles,~]=separateEigs(lambda); % No triple eigenvalue
 unless handle and hoops resonant
nToPlot=4;
letters='acbd';
```

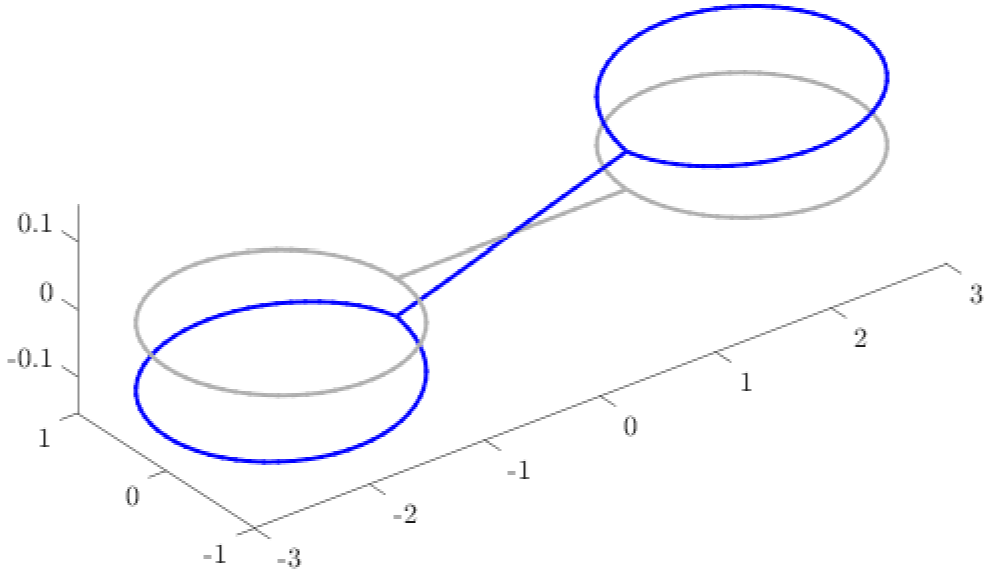
Plot the first few multiplicity-one eigenfunctions

```
for k=1:nToPlot

    figure
    Phi.plot(V(:,singles(k)))
    title(sprintf('(%s) $\\lambda = %0.3f$',
 letters(k),lambda(singles(k))));
```

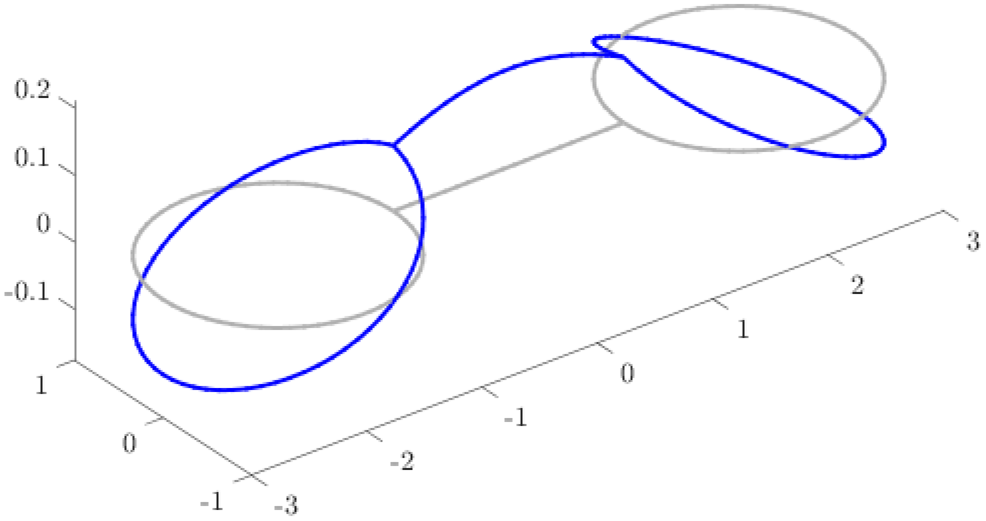
(a) $\lambda = 0.000$



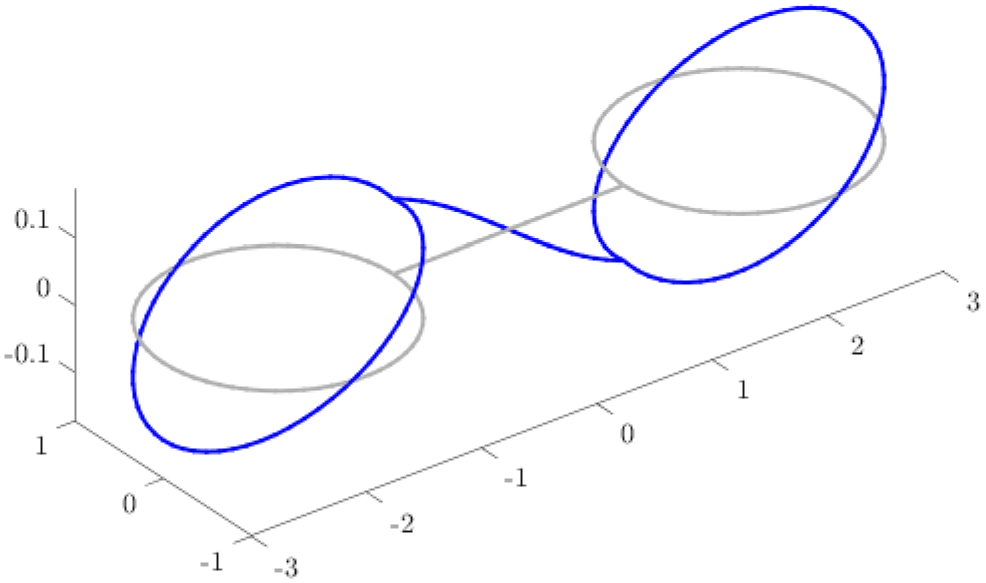
(c) $\lambda = 0.100$



(b) $\lambda = 0.703$



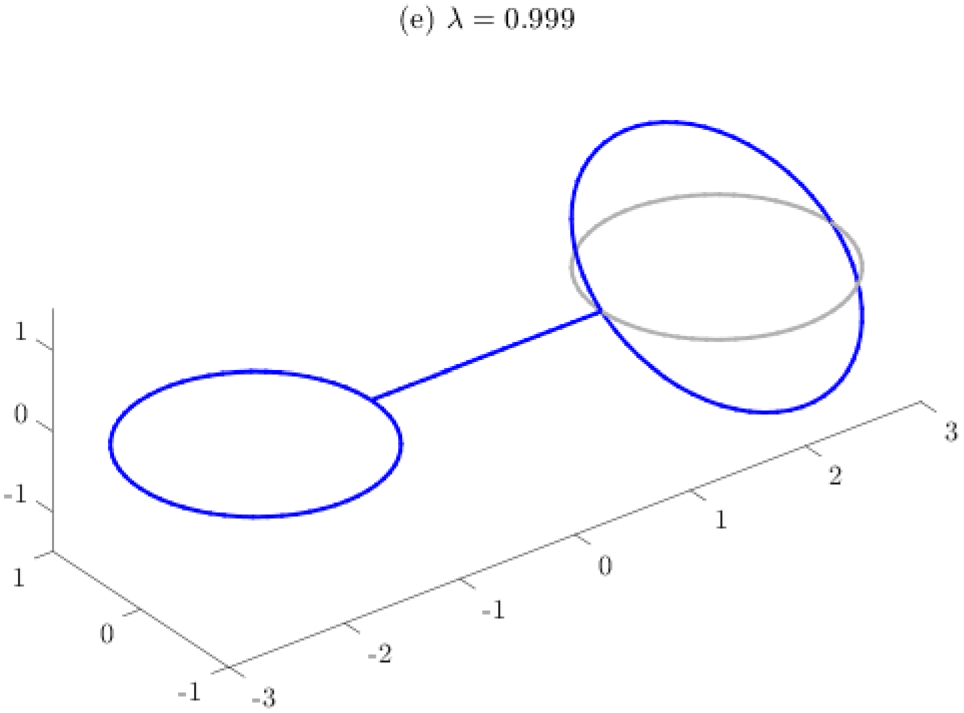
(d) $\lambda = 1.171$

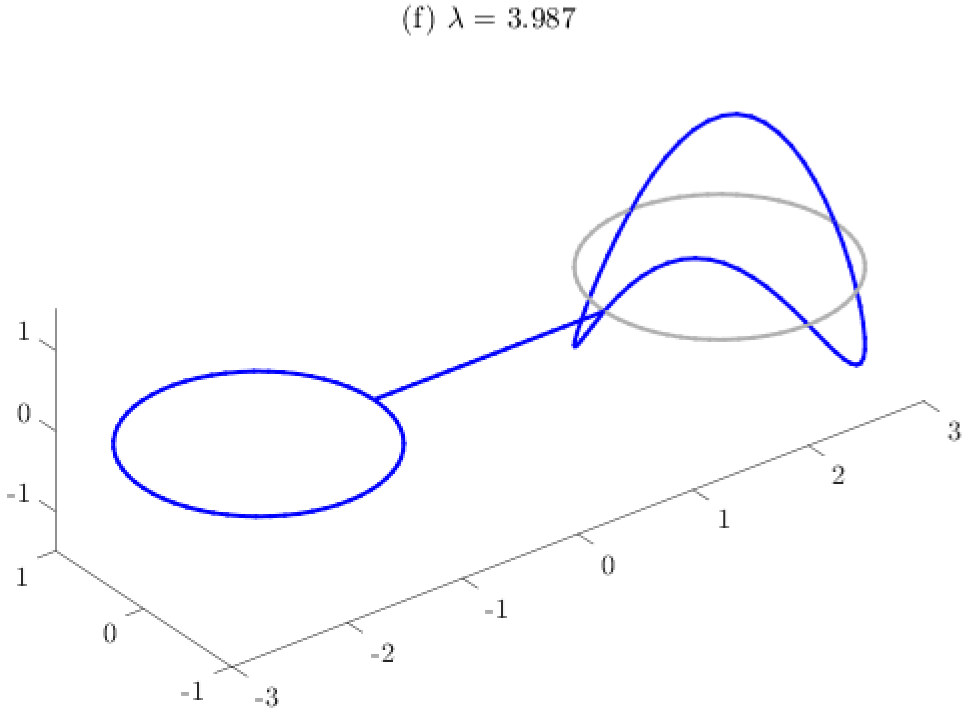


```
end

letters='ef';
```

Plot the first few multiplicity-two eigenfunctions

```
for k=1:nToPlot/2

    figure
    [v1,~]=dumbbellResolveDoubles(V,doubles(k));
    Phi.plot(v1)
    title(sprintf('(%s) $\\lambda = %0.3f$', letters(k),
 lambda(doubles(k))));
    %    title(sprintf('Eigenfunction %i, \\lambda =
 %0.3f',doubles(k), lambda(doubles(k))));
```





```
end
```

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