In [1]:
```
import sys
import numpy as np
import os

# for reading sound files.
from scipy.io import wavfile

# For training the neural network.
# Install pybrain. e.g. pip install pybrain.

from pybrain.datasets             import ClassificationDataSet
from pybrain.tools.shortcuts     import buildNetwork
from pybrain.supervised.trainers import BackpropTrainer
from pybrain.structure.modules   import SoftmaxLayer
from pybrain.tools.xml.networkreader import NetworkReader
from pybrain.tools.xml.networkwriter import NetworkWriter

from pybrain.structure import FullConnection
from pybrain.structure import SigmoidLayer
from pybrain.structure import FeedForwardNetwork
from pybrain.structure import LinearLayer
from pybrain.structure import SoftmaxLayer
from pybrain.structure import TanhLayer

sq = lambda x: x*x

# A convenient time step.
deltaT = 0.2
lim1 = 5; lim2 = 305
noisy = 0.05   # We have a very clean speech sample!

def getData(fil):
  sampFreq, snd = wavfile.read(fil)
  snd = snd/2E15                           # put in range (-1,1)
  duration = snd.shape[0]/sampFreq
  numChunks = int(duration/deltaT)
  sizeChunk = int(len(snd)/numChunks)

  # Frequencies.
  freqs  = np.fft.rfftfreq(sizeChunk,deltaT)
  chunksF = []
  for lp in range(0,numChunks):
    chunk = snd[lp*sizeChunk:(lp+1)*sizeChunk]      # get a chunk o
f speech.
    chunksF.append(1E9*np.abs(np.fft.rfft(chunk)))  # take the fft,
conveniently normalized.

  mu = np.mean(chunksF)
  newMean = 0.
  ctr = 0
  for i in range(0,numChunks):
```

```
    for j in range(lim1,lim2):
      if abs(chunksF[i][j]) > noisy*mu:         # ignore silent por
tions.
        newMean += chunksF[i][j]
        ctr += 1

  # Delete portions of the sound file when the user is not speaking
.
  mu = newMean/ctr
  zeros = []
  for lp in range(0,numChunks):
    if np.mean(chunksF[lp]) < noisy*mu:  zeros.append(lp)

  data = []
  ctr = 0
  for i in range(0,numChunks):
    if i in zeros: continue         # silent part.
    tmp = []
    for j in range(lim1,lim2): tmp.append(chunksF[i][j])
    data.append(tmp)

  return data

def writeData(data,outFile):

  # Write the speech waveform to file, for plotting purposes.
  l = len(data[0])
  f = open(outFile, "w")
  for i in range(0,len(data)):
    for j in range(0,l):
      f.write(str(i) + " " + str(j) + " " + str(data[i][j]) + "\n")
    f.write("\n")
  f.close()


def getSamples(folders):

  # Each sound file is divided into a number of samples.
  samples = []
  for folder in folders:
    tmp = [v for v in os.listdir(folder) if v <> ".DS_Store"]
    samples.append(tmp)

  # Now samples[0] contains all the files for speaker 1,
  # samples[1] contains all the files for speaker 2, and so on.
  speechSpeakers = []
  ctr = 0
  for sample in samples:
    speechSpeaker = []
    for file in sample:
      lsts = getData(folders[ctr]+file)
      for lst in lsts: speechSpeaker.append(lst)
    speechSpeakers.append(speechSpeaker)
```

```
    ctr += 1

  return speechSpeakers

def XY(speech,numFeatures,N):

  tX = np.mat(np.zeros((N,numFeatures)))
  tY = []
  ctr = 0
  for i in range(0,len(speech)):
    for j in range(0,len(speech[i])):
      for k in range(0,numFeatures):
        tX[ctr,k] = speech[i][j][k]
      ctr += 1
      tY.append(i)

  return tX,tY
```

In [2]:
```
#
# Data comes from the LibriSpeech ASR corpus
# http://www.openslr.org/12/
# File: train-clean-100.tar.gz [6.3G](training set of 100 hours "cl
ean" speech)
# I have converted flac files to wav files.
# 5 male speakers and 5 female speakers.
# Female speakers: 1,3,5,7,9
# Male speakers: 2,4,6,8,10
#

trainingFoldersList = [    "samples/train/speaker1/",
                           "samples/train/speaker2/",
                           "samples/train/speaker3/",
                           "samples/train/speaker4/",
                           "samples/train/speaker5/",
                           "samples/train/speaker6/",
                           "samples/train/speaker7/",
                           "samples/train/speaker8/",
                           "samples/train/speaker9/",
                           "samples/train/speaker10/"
                       ]

tstFoldersList = [   "samples/test/speaker1/",
                     "samples/test/speaker2/",
                     "samples/test/speaker3/",
                     "samples/test/speaker4/",
                     "samples/test/speaker5/",
                     "samples/test/speaker6/",
                     "samples/test/speaker7/",
                     "samples/test/speaker8/",
                     "samples/test/speaker9/",
                     "samples/test/speaker10/"
                   ]

numSpeakers = 10
speech = getSamples(trainingFoldersList)
```

In [3]:
```
N1 = 0; numFeatures = lim2-lim1
for idx in range(0,len(speech)):
  N1 += len(speech[idx])
trainX,trainY = XY(speech,numFeatures,N1)

minArray = []; maxArray = []
for i in range(0,numFeatures):
  minArray.append(np.min(trainX[:,i]))
  maxArray.append(np.max(trainX[:,i]))

f = open("min_max_values.dat", "w")
for i in range(0,numFeatures):
  f.write(str(maxArray[i]) + " " + str(minArray[i]) + "\n")
f.close()

# Put training data in range (0,1)
for i in range(0,N1):
  for j in range(0,numFeatures):
    trainX[i,j] = (trainX[i,j]-minArray[j])/(maxArray[j]-minArray[j
])

speech = getSamples(tstFoldersList)
N2 = 0;
for idx in range(0,len(speech)):
  N2 += len(speech[idx])

tstX,tstY = XY(speech,numFeatures,N2)
for i in range(0,N2):
  for j in range(0,numFeatures):
    tstX[i,j] = (tstX[i,j]-minArray[j])/(maxArray[j]-minArray[j])

trainLabels = np.mat(np.zeros((len(trainY),numSpeakers)))
tstLabels = np.mat(np.zeros((len(tstY),numSpeakers)))

for i in range(0,len(trainY)):
  for j in range(0,numSpeakers):
    if trainY[i] == j: trainLabels[i,j] = 1
    else: trainLabels[i,j] = 0

for i in range(0,len(tstY)):
  for j in range(0,numSpeakers):
    if tstY[i] == j: tstLabels[i,j] = 1
    else: tstLabels[i,j] = 0
```

In [4]:
```
# Test the classifier.
def tstClassifier(nn,tstX,tstY,ss):

  # Index corresponding to start of speaker 'n'
  limits = [0]
  for lp in range(1,numSpeakers):
    for i in range(0,len(tstY)):
      if tstY[i] == lp:  break
```

```
    limits.append(i)
  limits.append(len(tstY))

  # Confusion matrix: Speaker 'm' predicted as speaker 'n'.
  confusion = np.mat(np.zeros((10,10)))
  numS = {}
  answers = []
  yes = 0; total = 0
  step = ss
  for speaker in range(0,numSpeakers):
    for lp in range(limits[speaker],limits[speaker+1]-step,step):
      pred = []
      for x in range(lp,lp+step):
        A = [tstX[x,v] for v in range(0,numFeatures)]
        # Make a prediction.
        res = list(nn.activate(A))
        pred.append(res.index(np.max(res)))

      # There's a probability for every speaker. Let's pick the lar
gest.
      ctr = {}
      for v in pred:
        if v not in ctr: ctr[v] = 1
        else: ctr[v] += 1
      kys = ctr.keys()
      m = 0; best = 0
      for ky in kys:
        if ctr[ky] > m:
          m = ctr[ky]
          best = ky

      #Overall accuracy.
      if best == tstY[lp]: yes += 1

      # Confusion matrix. Speaker 'i' predicted to be speaker 'j'.
      for r in range(0,10):
        if tstY[lp] == r:
          if r not in numS: numS[r] = 1
          else: numS[r] += 1
        for c in range(0,10):
          if tstY[lp] == r and best == c:
            confusion[r,c] += 1

      total += 1
    answers.append(yes*1./total)

  return answers,confusion,numS
```

In [5]:
```
#
# Now, we train the neural network.
#
numClasses = len(speech)
```

```
numHiddenNodes = 10     # Nodes per hidden layer.
numHiddenLayers = 5     # 5 layers.
possibleOutputs = 1     # Only 1 kind of output, i.e. each sample i
s one speaker.
numTrainingEpochs = 10  # Train 10 epochs.

trndata = ClassificationDataSet(numFeatures, possibleOutputs, nb_cl
asses=numClasses)
ctr = 0
for row in range(0,N1):
  tempListOut = []; tempListIn = []
  tempListOut.append(int(trainY[row]))
  for i in range(0,numFeatures):
    tempListIn.append(trainX[row,i])

  trndata.addSample(tempListIn,tempListOut)
trndata._convertToOneOfMany()

#first = True
first = False
outfolder = "networks/"
nnFile = "nn49.xml" # Most recent.
st = 50

# For the first time, we need to create the neural network.
# After that, we just need to train.

if first:
  nn = FeedForwardNetwork()
  inputLayer = LinearLayer(numFeatures)
  nn.addInputModule(inputLayer)
  hiddenLayers = []
  for x in range(numHiddenLayers):
    hiddenLayer = SigmoidLayer(numHiddenNodes)
    nn.addModule(hiddenLayer)
    hiddenLayers.append(hiddenLayer)
  outputLayer = SoftmaxLayer(len(speech))
  nn.addOutputModule(outputLayer)

  inputConnection = FullConnection(inputLayer,hiddenLayers[0])
  outputConnection = FullConnection(hiddenLayers[numHiddenLayers-1]
,outputLayer)
  for x in range(numHiddenLayers-1):
    connect = FullConnection(hiddenLayers[x],hiddenLayers[x-1])
    nn.addConnection(connect)
  nn.addConnection(inputConnection)
  nn.addConnection(outputConnection)
  nn.sortModules()

else:  # We already have a network!
  nn = NetworkReader.readFrom(outfolder+nnFile)

trainer = BackpropTrainer(nn, dataset=trndata, momentum=0., verbose
```

```
=True, weightdecay=0.)
for i in range(numTrainingEpochs):
  trainer.trainOnDataset(dataset=trndata)
  if (i+1)%5 == 0:
    A,c,n = tstClassifier(nn,tstX,tstY,1)
    print np.mean(A)
    # Save the network, to save time.
    NetworkWriter.writeToFile(nn, outfolder+"nn" + str(st)+".xml")
    st += 1
    print i+1
```

```
Total error: 0.0143656603969
Total error: 0.0143977004382
Total error: 0.0143211886429
Total error: 0.0143559193331
Total error: 0.0142860859515
0.722311963042
5
Total error: 0.0143589772517
Total error: 0.014311991756
Total error: 0.0143279073167
Total error: 0.0143395705399
Total error: 0.0143196161645
0.756046610387
10
```

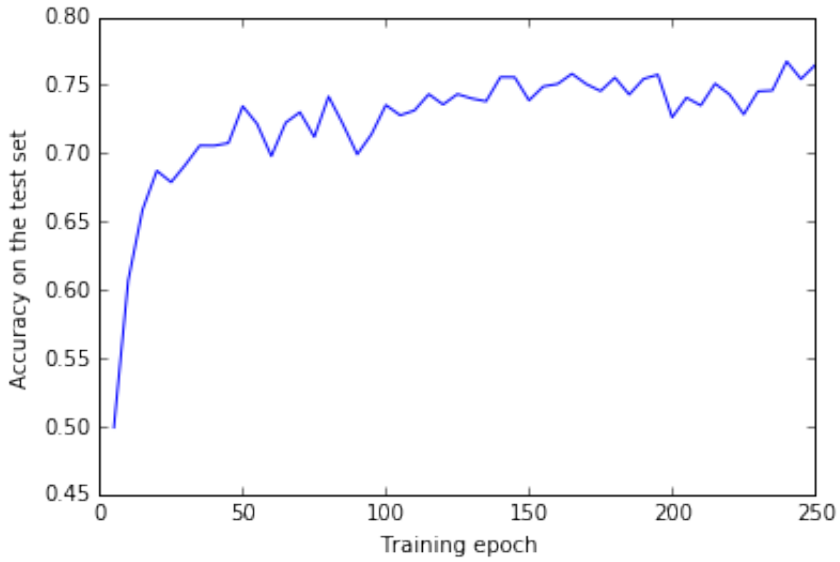
In [6]:
```
# Performance on the test set, as a function of training epoch.
# We stop when we see signs of overfitting.
# On 0.2 seconds of data.
X = []; Y = []
for q in range(0,50):
  net = outfolder+"nn"+str(q)+".xml"
  nn = NetworkReader.readFrom(net)
  for st in range(1,2):
    A,c,n = tstClassifier(nn,tstX,tstY,st)
    print net,st*0.2,np.mean(A)
    X.append((q+1)*5)
    Y.append(np.mean(A))
```

```
networks/nn0.xml 0.2 0.499117365279
networks/nn1.xml 0.2 0.606735008497
networks/nn2.xml 0.2 0.658612074048
networks/nn3.xml 0.2 0.687217270725
networks/nn4.xml 0.2 0.678839085583
networks/nn5.xml 0.2 0.691663503931
networks/nn6.xml 0.2 0.70569523695
networks/nn7.xml 0.2 0.705575432812
networks/nn8.xml 0.2 0.707493912766
networks/nn9.xml 0.2 0.734532046763
networks/nn10.xml 0.2 0.721658134573
networks/nn11.xml 0.2 0.69792158567
networks/nn12.xml 0.2 0.722454719856
networks/nn13.xml 0.2 0.730107163484
networks/nn14.xml 0.2 0.71199923055
networks/nn15.xml 0.2 0.741639031398
networks/nn16.xml 0.2 0.721392526894
networks/nn17.xml 0.2 0.699211075745
networks/nn18.xml 0.2 0.714028139647
networks/nn19.xml 0.2 0.735380289029
networks/nn20.xml 0.2 0.727852097769
networks/nn21.xml 0.2 0.731408256126
networks/nn22.xml 0.2 0.74333246088
networks/nn23.xml 0.2 0.735741602678
networks/nn24.xml 0.2 0.74336675822
networks/nn25.xml 0.2 0.740176638619
networks/nn26.xml 0.2 0.738092425488
networks/nn27.xml 0.2 0.755807847721
networks/nn28.xml 0.2 0.755728904487
networks/nn29.xml 0.2 0.738764799336
networks/nn30.xml 0.2 0.74898643378
networks/nn31.xml 0.2 0.750807955146
networks/nn32.xml 0.2 0.758286110826
networks/nn33.xml 0.2 0.750738614695
networks/nn34.xml 0.2 0.745580158554
networks/nn35.xml 0.2 0.755489276652
networks/nn36.xml 0.2 0.743030160332
networks/nn37.xml 0.2 0.75452486153
networks/nn38.xml 0.2 0.757615434961
networks/nn39.xml 0.2 0.726292842459
networks/nn40.xml 0.2 0.740774548985
networks/nn41.xml 0.2 0.735083574425
networks/nn42.xml 0.2 0.751037253371
networks/nn43.xml 0.2 0.743174669379
networks/nn44.xml 0.2 0.728544240451
networks/nn45.xml 0.2 0.745473067619
networks/nn46.xml 0.2 0.746040045286
networks/nn47.xml 0.2 0.767353797432
networks/nn48.xml 0.2 0.754406474536
networks/nn49.xml 0.2 0.764805305461
```

In [7]:
```
# Plot performance with training epoch, on 0.2 seconds of data.
%matplotlib inline
import matplotlib.pyplot as plt

plt.plot(X,Y)
plt.xlabel("Training epoch")
plt.ylabel("Accuracy on the test set")
plt.show()
```

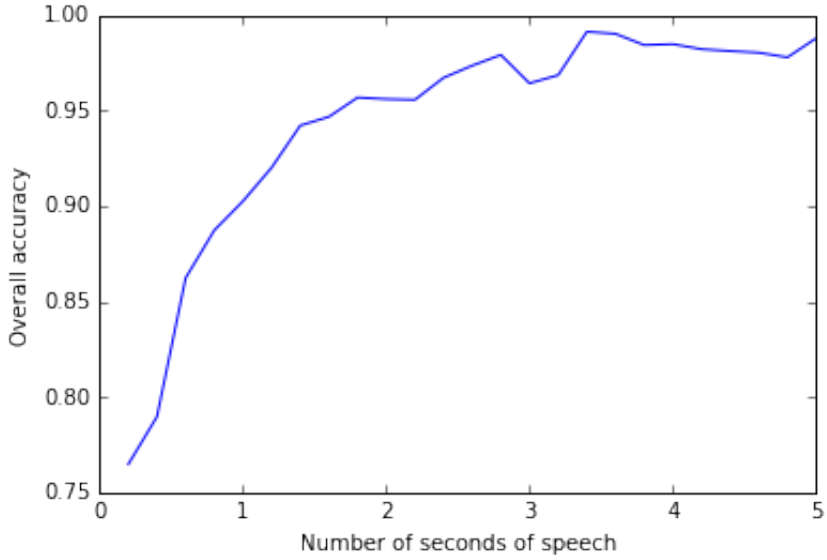
```
/usr/local/lib/python2.7/site-packages/matplotlib/font_manager.py:
273: UserWarning: Matplotlib is building the font cache using fc-l
ist. This may take a moment.
  warnings.warn('Matplotlib is building the font cache using fc-li
st. This may take a moment.')
```



In [8]:
```
# Performance on the test set, with 't' seconds of data,
# Accuracy for t = 0.2,0.4,0.6,0.8,1.0,... seconds.
net = "nn49.xml"
nn = NetworkReader.readFrom(outfolder+net)
X = []; Y = []
for st in range(1,26):
  A,c,n = tstClassifier(nn,tstX,tstY,st)
  print st*0.2,np.mean(A)
  X.append(st*0.2)
  Y.append(np.mean(A))
```

```
0.2 0.764805305461
0.4 0.789697890647
0.6 0.862283498213
0.8 0.887237110684
1.0 0.902481170611
1.2 0.920037707295
1.4 0.942073795735
1.6 0.946633467992
1.8 0.956715834479
2.0 0.955903690434
2.2 0.955550675976
2.4 0.967076487337
2.6 0.973441010539
2.8 0.979029237841
3.0 0.964161177113
3.2 0.968436822912
3.4 0.991153253831
3.6 0.990071200278
3.8 0.984173735962
4.0 0.984659795058
4.2 0.982023390668
4.4 0.981033772819
4.6 0.980199788274
4.8 0.977751442503
5.0 0.987732329963
```

In [9]:
```
plt.plot(X,Y)
plt.xlabel("Number of seconds of speech")
plt.ylabel("Overall accuracy")
plt.show()
```




In [10]:
```
net = "nn49.xml"
nn = NetworkReader.readFrom(outfolder+net)
for st in [1,5,10]:
  A,c,n = tstClassifier(nn,tstX,tstY,st)
  # Columns are predictions.
  # First row: Speaker 0: Number of samples predicted as Speaker 0,
1,2,. . .
  print "With " + str(st*0.2) + " second(s) of speech"
  print c
  print "\n"[:-1]
```

```
With 0.2 second(s) of speech
[[ 515.    2.    3.    0.    1.    0.    0.    2.    4.    0.]
 [   2.  332.   17.   66.   35.   18.    5.   60.    1.   22.]
 [   2.   23.  312.    6.   54.    4.   61.    4.   43.    2.]
 [   2.   35.    7.  374.   33.    4.    3.    9.    1.   24.]
 [   6.    9.   26.    9.  486.    1.   34.   13.   19.    1.]
 [   0.   26.    3.    1.    1.  365.    4.   17.    0.   29.]
 [   0.   14.   50.    0.   59.    0.  378.    2.  100.    7.]
 [   1.   24.    4.   78.   23.   20.    0.  300.    0.   48.]
 [  16.    3.   32.    1.   47.    0.    7.    5.  489.    1.]
 [   0.   37.   11.   29.   15.   18.   32.   14.    8.  384.]]

With 1.0 second(s) of speech
[[ 105.    0.    0.    0.    0.    0.    0.    0.    0.    0.]
 [   0.   92.    0.   10.    2.    2.    0.    3.    1.    1.]
 [   0.    4.   81.    0.    8.    1.    3.    0.    5.    0.]
 [   0.    1.    0.   95.    1.    0.    0.    0.    0.    1.]
 [   0.    0.    2.    0.  113.    0.    2.    0.    3.    0.]
 [   0.    1.    1.    0.    0.   80.    0.    0.    0.    7.]
 [   0.    0.    4.    0.    8.    0.   93.    0.   17.    0.]
 [   0.    2.    0.   10.    1.    1.    0.   78.    0.    7.]
 [   0.    0.    1.    0.    1.    0.    0.    0.  118.    0.]
 [   0.    2.    0.    0.    2.    1.    1.    0.    0.  103.]]

With 2.0 second(s) of speech
[[ 52.   0.   0.   0.   0.   0.   0.   0.   0.   0.]
 [  0.  49.   0.   5.   0.   1.   0.   0.   0.   0.]
 [  0.   0.  46.   0.   3.   0.   2.   0.   0.   0.]
 [  0.   0.   0.  49.   0.   0.   0.   0.   0.   0.]
 [  0.   0.   0.   0.  59.   0.   0.   0.   1.   0.]
 [  0.   0.   0.   0.   0.  42.   0.   0.   0.   2.]
 [  0.   0.   0.   0.   0.   0.  58.   0.   3.   0.]
 [  0.   0.   0.   2.   0.   1.   0.  46.   0.   0.]
 [  0.   0.   0.   0.   0.   0.   0.   0.  60.   0.]
 [  0.   0.   0.   0.   0.   0.   0.   0.   0.  54.]]
```