U-Net Lesion Segmentation

Useful Links

2D Unet

- https://www.kaggle.com/keegil/keras-u-net-starter-lb-0-277 (https://www.kaggle.com/keegil/keras-u-net-starter-lb-0-277)
- https://github.com/jocicmarko/ultrasound-nerve-segmentation (https://github.com/jocicmarko/ultrasound-nerve-segmentation)
- https://medium.com/@SeoJaeDuk/medical-image-segmentation-part-1-unet-convolutional-networks-with-interactive-code-d07231eb29bf (https://medium.com/@SeoJaeDuk/medical-image-segmentation-part-1-unet-convolutional-networks-with-interactive-code-d07231eb29bf)
- https://github.com/yihui-he/u-net (https://github.com/yihui-he/u-net)
- https://github.com/zhixuhao/unet (https://github.com/zhixuhao/unet)

3D Unet

- Keras https://github.com/ellisdg/3DUnetCNN (https://github.com/ellisdg/3DUnetCNN)
- TF https://github.com/zhengyang-wang/3D-Unet--Tensorflow (https://github.com/zhengyang-wang/3D-Unet--Tensorflow)

In [2]:
```
from keras.models import Model
from keras.preprocessing.image import ImageDataGenerator
from keras.layers import Input, Conv2D, Dropout, MaxPooling2D, Conv2DTranspose, c
from keras.layers import Conv3D, MaxPooling3D, Conv3DTranspose, UpSampling3D
from keras.optimizers import Adam
from keras.callbacks import ModelCheckpoint
from keras.utils import to_categorical, Sequence
from keras import backend as K


from skimage.io import imread, imsave
from skimage.external.tifffile import TiffWriter

from scipy.ndimage import interpolation

from copy import deepcopy
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import os
import glob
import time
```

```
C:\Users\Gerald\Anaconda3\envs\tf3\lib\site-packages\h5py\__init__.py:34: Futur
eWarning: Conversion of the second argument of issubdtype from `float` to `np.f
loating` is deprecated. In future, it will be treated as `np.float64 == np.dtyp
e(float).type`.
  from ._conv import register_converters as _register_converters
Using TensorFlow backend.
```

1) 2-D U-Net with small images

I downsampled and cropped images to be 128 x 128.

Here I will start with 13 training images (only!) taken at evenly spaced intervals from the same volume (one brain). I will test on the rest of the slices of the volume

In [1]:
```
x_train_path = 'data\\small2d\\train_img'
y_train_path = 'data\\small2d\\train_lesion'
x_valid_path = 'data\\small2d\\valid_img'
y_valid_path = 'data\\small2d\\valid_lesion'
x_test_path  = 'data\\small2d\\test_img'
y_test_path  = 'data\\small2d\\test_lesion'

img_size = (128, 64)
```

In [8]:
```
# make data generators

# https://github.com/keras-team/keras/issues/3059#issuecomment-364787723
seed = 2018
data_gen_args = dict(
    rescale=1./255,
    rotation_range=10.,
    width_shift_range=0.1,
    height_shift_range=0.1,
    zoom_range=0.1,
    shear_range=0.1,
    horizontal_flip=True,
    fill_mode='constant',
    cval=0)

# also consider deformation: https://gist.github.com/fmder/e28813c1e8721830ff9c
# https://www.kaggle.com/c/ultrasound-nerve-segmentation/discussion/22062

x_train_datagen = ImageDataGenerator(**data_gen_args)
y_train_datagen = ImageDataGenerator(**data_gen_args)
x_valid_datagen = ImageDataGenerator(rescale=1./255)
y_valid_datagen = ImageDataGenerator(rescale=1./255)
x_test_datagen = ImageDataGenerator(rescale=1./255)
y_test_datagen = ImageDataGenerator(rescale=1./255)

flow_args = dict(target_size=img_size,
                 color_mode='grayscale',
                 batch_size=32,
                 class_mode=None,
                 seed=seed)

x_train_generator = x_train_datagen.flow_from_directory(x_train_path, **flow_args
y_train_generator = y_train_datagen.flow_from_directory(y_train_path, **flow_args
train_generator = zip(x_train_generator, y_train_generator)

x_valid_generator = x_valid_datagen.flow_from_directory(x_valid_path, **flow_args
y_valid_generator = y_valid_datagen.flow_from_directory(y_valid_path, **flow_args
valid_generator = zip(x_valid_generator, y_valid_generator)

x_test_generator = x_test_datagen.flow_from_directory(x_test_path, **flow_args)
y_test_generator = y_test_datagen.flow_from_directory(y_test_path, **flow_args)
test_generator = zip(x_test_generator, y_test_generator)
```

```
Found 35 images belonging to 1 classes.
Found 35 images belonging to 1 classes.
Found 78 images belonging to 1 classes.
Found 78 images belonging to 1 classes.
Found 79 images belonging to 1 classes.
Found 79 images belonging to 1 classes.
```

In [5]:

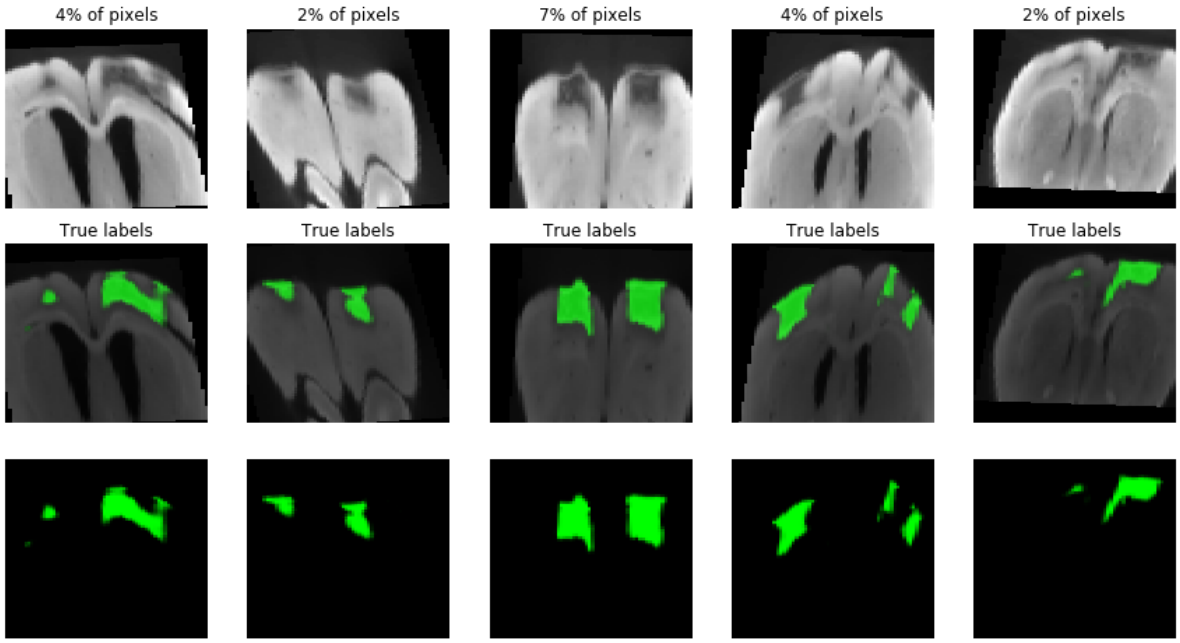
```
# from https://github.com/jocicmarko/ultrasound-nerve-segmentation/blob/master/tr
smooth = 1.

def dice(y_true, y_pred): # for numpy arrays
    y_true_f = y_true.reshape(-1)
    y_pred_f = y_pred.reshape(-1)
    intersection = np.sum(y_true_f*y_pred_f)
    if np.sum(y_true_f + y_pred_f)==0:
        return 1.0
    return (2. * intersection) / (np.sum(y_true_f) + np.sum(y_pred_f))

def dice_coef(y_true, y_pred):
    y_true_f = K.flatten(y_true)
    y_pred_f = K.flatten(y_pred)
    intersection = K.sum(y_true_f * y_pred_f)
    if K.sum(y_true_f + y_pred_f)==0:
        return 1.0
    return (2. * intersection + smooth) / (K.sum(y_true_f) + K.sum(y_pred_f) + sm

def dice_coef_loss(y_true, y_pred):
    return -dice_coef(y_true, y_pred)
```

In [6]:

```
def plot_masks(data, labels, predictions=None):
    plt.figure(figsize=(15, 8))
    if predictions is None:
        predictions = np.zeros_like(labels)

    for i, (img, mask, pred) in enumerate(zip(data, labels, predictions)):
        # image only
        plt.subplot(3,5,i+1)
        h = plt.imshow(np.squeeze(img), aspect='auto')
        h.set_cmap('gray')
        plt.axis('off')
        plt.title('%d%% of pixels' % (100*mask.mean()))

        # overlay mask + image
        plt.subplot(3,5,i+6)
        merged = 0.7*np.tile(img, (1,1,3))
        if pred.max()==0:
            merged[:,:,1] += 0.7*np.squeeze(mask)
        else:
            merged[:,:,0] += 0.7*np.squeeze(pred)
        merged[merged>1] = 1
        h = plt.imshow(merged, aspect='auto')
        plt.axis('off')
        if pred.max()==0:
            plt.title('True labels')
        else:
            plt.title('Predictions')

        # overlay mask + prediction
        plt.subplot(3,5,i+11)
        masks = np.concatenate([pred, np.zeros(mask.shape[:2]+(2,))], axis=2)
        masks[:,:,1] += np.squeeze(mask)
        plt.imshow(masks, aspect='auto')
        plt.axis('off')
        if pred.max()>0:
            plt.title('Dice: %1.3f' % dice(mask, pred))

        if i==4:
            break
```

In [9]:
```
# check dataset
for data_batch, labels_batch in train_generator:
    print('data batch shape:', data_batch.shape)
    print('labels batch shape:', labels_batch.shape)
    break

plot_masks(data_batch, labels_batch)
```

```
data batch shape: (32, 128, 64, 1)
labels batch shape: (32, 128, 64, 1)
```



In [10]:
```
one_weight = 0.95 # class weights
zero_weight = 0.05

# consider pixel weights also:
# https://stackoverflow.com/questions/50255438/pixel-wise-loss-weight-for-image-s

def weighted_binary_crossentropy(y_true, y_pred):

    # Original binary crossentropy (see losses.py):
    # K.mean(K.binary_crossentropy(y_true, y_pred), axis=-1)

    # Calculate the binary crossentropy
    b_ce = K.binary_crossentropy(y_true, y_pred)

    # Apply the weights
    weight_vector = y_true * one_weight + (1. - y_true) * zero_weight
    weighted_b_ce = weight_vector * b_ce

    # Return the mean error
    return K.mean(weighted_b_ce)
```

In [11]:

```
# modified from https://www.kaggle.com/keegil/keras-u-net-starter-lb-0-277
def unet2d(loss_fn=dice_coef_loss, lr=1e-3, act='relu', init='he_normal', pad='sa
    inputs = Input(img_size + (1,))

    c1 = Conv2D(16, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c1 = Dropout(0.1) (c1) if dropout else c1
    c1 = Conv2D(16, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    p1 = MaxPooling2D((2, 2)) (c1)

    c2 = Conv2D(32, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c2 = Dropout(0.1) (c2) if dropout else c2
    c2 = Conv2D(32, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    p2 = MaxPooling2D((2, 2)) (c2)

    c3 = Conv2D(64, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c3 = Dropout(0.2) (c3) if dropout else c3
    c3 = Conv2D(64, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    p3 = MaxPooling2D((2, 2)) (c3)

    c4 = Conv2D(128, (3, 3), activation=act, kernel_initializer=init, padding=pad
    c4 = Dropout(0.2) (c4) if dropout else c4
    c4 = Conv2D(128, (3, 3), activation=act, kernel_initializer=init, padding=pad
    p4 = MaxPooling2D(pool_size=(2, 2)) (c4)

    c5 = Conv2D(256, (3, 3), activation=act, kernel_initializer=init, padding=pad
    c5 = Dropout(0.3) (c5)  if dropout else c5
    c5 = Conv2D(256, (3, 3), activation=act, kernel_initializer=init, padding=pad

    u6 = Conv2DTranspose(128, (2, 2), strides=(2, 2), padding=pad) (c5)
    u6 = concatenate([u6, c4])
    c6 = Conv2D(128, (3, 3), activation=act, kernel_initializer=init, padding=pad
    c6 = Dropout(0.2) (c6) if dropout else c6
    c6 = Conv2D(128, (3, 3), activation=act, kernel_initializer=init, padding=pad

    u7 = Conv2DTranspose(64, (2, 2), strides=(2, 2), padding=pad) (c6)
    u7 = concatenate([u7, c3])
    c7 = Conv2D(64, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c7 = Dropout(0.2) (c7) if dropout else c7
    c7 = Conv2D(64, (3, 3), activation=act, kernel_initializer=init, padding=pad)

    u8 = Conv2DTranspose(32, (2, 2), strides=(2, 2), padding=pad) (c7)
    u8 = concatenate([u8, c2])
    c8 = Conv2D(32, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c8 = Dropout(0.1) (c8) if dropout else c8
    c8 = Conv2D(32, (3, 3), activation=act, kernel_initializer=init, padding=pad)

    u9 = Conv2DTranspose(16, (2, 2), strides=(2, 2), padding=pad) (c8)
    u9 = concatenate([u9, c1], axis=3)
    c9 = Conv2D(16, (3, 3), activation=act, kernel_initializer=init, padding=pad)
    c9 = Dropout(0.1) (c9) if dropout else c9
    c9 = Conv2D(16, (3, 3), activation=act, kernel_initializer=init, padding=pad)

    outputs = Conv2D(1, (1, 1), activation='sigmoid') (c9)

    model = Model(inputs=[inputs], outputs=[outputs])
    model.compile(optimizer=Adam(lr=lr), loss=loss_fn, metrics=[dice_coef])
```

```
    model.summary()

    return model
```

In [63]:
```
K.clear_session()
model = unet2d(loss_fn=weighted_binary_crossentropy)
```

```
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            (None, 128, 64, 1)   0
__________________________________________________________________________________________________
conv2d_1 (Conv2D)               (None, 128, 64, 16)  160         input_1[0][0]
__________________________________________________________________________________________________
conv2d_2 (Conv2D)               (None, 128, 64, 16)  2320        conv2d_1[0][0]
__________________________________________________________________________________________________
max_pooling2d_1 (MaxPooling2D)  (None, 64, 32, 16)   0           conv2d_2[0][0]
__________________________________________________________________________________________________
conv2d_3 (Conv2D)               (None, 64, 32, 32)   4640        max_pooling2d_
1[0][0]
__________________________________________________________________________________________________
conv2d_4 (Conv2D)               (None, 64, 32, 32)   9248        conv2d_3[0][0]
__________________________________________________________________________________________________
max_pooling2d_2 (MaxPooling2D)  (None, 32, 16, 32)   0           conv2d_4[0][0]
__________________________________________________________________________________________________
conv2d_5 (Conv2D)               (None, 32, 16, 64)   18496       max_pooling2d_
2[0][0]
__________________________________________________________________________________________________
conv2d_6 (Conv2D)               (None, 32, 16, 64)   36928       conv2d_5[0][0]
__________________________________________________________________________________________________
max_pooling2d_3 (MaxPooling2D)  (None, 16, 8, 64)    0           conv2d_6[0][0]
__________________________________________________________________________________________________
conv2d_7 (Conv2D)               (None, 16, 8, 128)   73856       max_pooling2d_
3[0][0]
__________________________________________________________________________________________________
conv2d_8 (Conv2D)               (None, 16, 8, 128)   147584      conv2d_7[0][0]
__________________________________________________________________________________________________
```

```
max_pooling2d_4 (MaxPooling2D)  (None, 8, 4, 128)    0           conv2d_8[0][0]
__________________________________________________________________________________________________
conv2d_9 (Conv2D)               (None, 8, 4, 256)    295168      max_pooling2d_
4[0][0]
__________________________________________________________________________________________________
conv2d_10 (Conv2D)              (None, 8, 4, 256)    590080      conv2d_9[0][0]
__________________________________________________________________________________________________
conv2d_transpose_1 (Conv2DTrans (None, 16, 8, 128)   131200      conv2d_10[0]
[0]
__________________________________________________________________________________________________
concatenate_1 (Concatenate)     (None, 16, 8, 256)   0           conv2d_transpo
se_1[0][0]
                                                                 conv2d_8[0][0]
__________________________________________________________________________________________________
conv2d_11 (Conv2D)              (None, 16, 8, 128)   295040      concatenate_1
[0][0]
__________________________________________________________________________________________________
conv2d_12 (Conv2D)              (None, 16, 8, 128)   147584      conv2d_11[0]
[0]
__________________________________________________________________________________________________
conv2d_transpose_2 (Conv2DTrans (None, 32, 16, 64)   32832       conv2d_12[0]
[0]
__________________________________________________________________________________________________
concatenate_2 (Concatenate)     (None, 32, 16, 128)  0           conv2d_transpo
se_2[0][0]
                                                                 conv2d_6[0][0]
__________________________________________________________________________________________________
conv2d_13 (Conv2D)              (None, 32, 16, 64)   73792       concatenate_2
[0][0]
__________________________________________________________________________________________________
conv2d_14 (Conv2D)              (None, 32, 16, 64)   36928       conv2d_13[0]
[0]
__________________________________________________________________________________________________
conv2d_transpose_3 (Conv2DTrans (None, 64, 32, 32)   8224        conv2d_14[0]
[0]
__________________________________________________________________________________________________
concatenate_3 (Concatenate)     (None, 64, 32, 64)   0           conv2d_transpo
se_3[0][0]
                                                                 conv2d_4[0][0]
__________________________________________________________________________________________________
```

```
__________________
conv2d_15 (Conv2D)              (None, 64, 32, 32)   18464       concatenate_3
[0][0]
__________________________________________________________________________________
__________________
conv2d_16 (Conv2D)              (None, 64, 32, 32)   9248        conv2d_15[0]
[0]
__________________________________________________________________________________
__________________
conv2d_transpose_4 (Conv2DTrans (None, 128, 64, 16)  2064        conv2d_16[0]
[0]
__________________________________________________________________________________
__________________
concatenate_4 (Concatenate)     (None, 128, 64, 32)  0           conv2d_transpo
se_4[0][0]
                                                                 conv2d_2[0][0]

__________________________________________________________________________________
__________________
conv2d_17 (Conv2D)              (None, 128, 64, 16)  4624        concatenate_4
[0][0]
__________________________________________________________________________________
__________________
conv2d_18 (Conv2D)              (None, 128, 64, 16)  2320        conv2d_17[0]
[0]
__________________________________________________________________________________
__________________
conv2d_19 (Conv2D)              (None, 128, 64, 1)   17          conv2d_18[0]
[0]
==================================================================================
==================
Total params: 1,940,817
Trainable params: 1,940,817
Non-trainable params: 0
__________________________________________________________________________________
__________________
```

In [64]:
```
# checkpoint = ModelCheckpoint(filepath='weights.h5')
checkpoint = ModelCheckpoint(filepath='weights2.h5', monitor='val_loss', save_bes

history = model.fit_generator(
    train_generator,
    steps_per_epoch=100,
    epochs=20,
    validation_data=valid_generator,
    validation_steps=100,
    verbose=1,
    callbacks=[checkpoint])
```

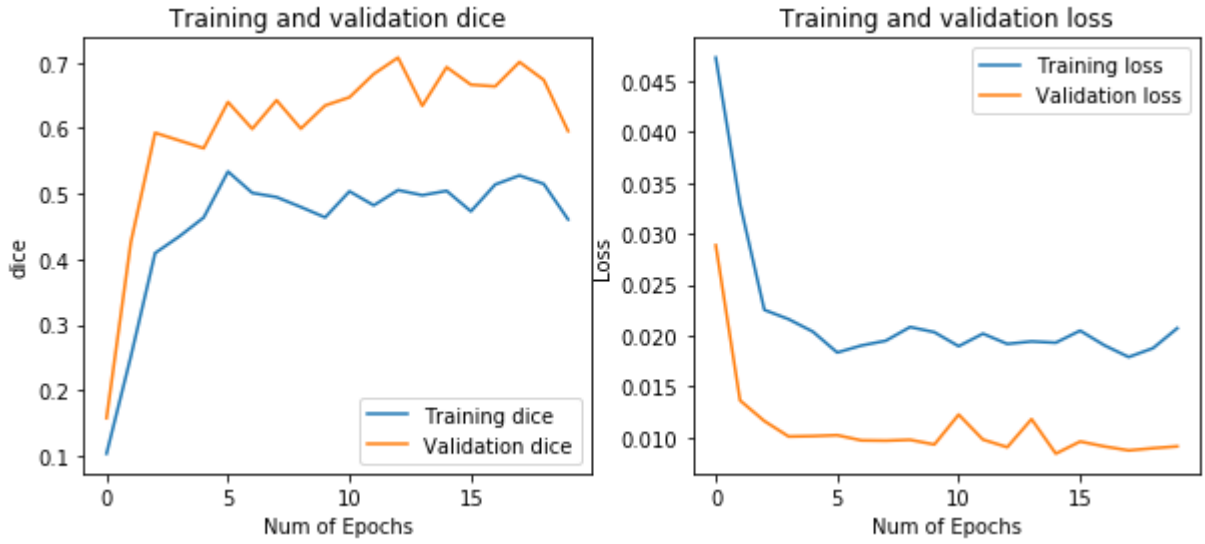
```
Epoch 1/20
100/100 [==============================] - 52s 523ms/step - loss: 0.0475 - dice
_coef: 0.1023 - val_loss: 0.0289 - val_dice_coef: 0.1578
Epoch 2/20
100/100 [==============================] - 49s 495ms/step - loss: 0.0333 - dice
_coef: 0.2439 - val_loss: 0.0136 - val_dice_coef: 0.4260
Epoch 3/20
100/100 [==============================] - 36s 364ms/step - loss: 0.0212 - dice
_coef: 0.3931 - val_loss: 0.0116 - val_dice_coef: 0.5929
Epoch 4/20
100/100 [==============================] - 51s 507ms/step - loss: 0.0206 - dice
_coef: 0.4165 - val_loss: 0.0101 - val_dice_coef: 0.5812
Epoch 5/20
100/100 [==============================] - 64s 637ms/step - loss: 0.0197 - dice
_coef: 0.4530 - val_loss: 0.0101 - val_dice_coef: 0.5694
Epoch 6/20
100/100 [==============================] - 40s 398ms/step - loss: 0.0163 - dice
_coef: 0.5278 - val_loss: 0.0102 - val_dice_coef: 0.6399
Epoch 7/20
100/100 [==============================] - 49s 492ms/step - loss: 0.0184 - dice
_coef: 0.4866 - val_loss: 0.0097 - val_dice_coef: 0.5990
Epoch 8/20
100/100 [==============================] - 49s 491ms/step - loss: 0.0188 - dice
_coef: 0.4835 - val_loss: 0.0097 - val_dice_coef: 0.6427
Epoch 9/20
100/100 [==============================] - 40s 403ms/step - loss: 0.0189 - dice
_coef: 0.4823 - val_loss: 0.0098 - val_dice_coef: 0.5993
Epoch 10/20
100/100 [==============================] - 51s 505ms/step - loss: 0.0197 - dice
_coef: 0.4618 - val_loss: 0.0093 - val_dice_coef: 0.6347
Epoch 11/20
100/100 [==============================] - 40s 402ms/step - loss: 0.0176 - dice
_coef: 0.4763 - val_loss: 0.0122 - val_dice_coef: 0.6471
Epoch 12/20
100/100 [==============================] - 34s 339ms/step - loss: 0.0197 - dice
_coef: 0.4674 - val_loss: 0.0098 - val_dice_coef: 0.6827
Epoch 13/20
100/100 [==============================] - 44s 436ms/step - loss: 0.0178 - dice
_coef: 0.5026 - val_loss: 0.0090 - val_dice_coef: 0.7077
Epoch 14/20
100/100 [==============================] - 146s 1s/step - loss: 0.0181 - dice_c
oef: 0.4888 - val_loss: 0.0118 - val_dice_coef: 0.6341
Epoch 15/20
100/100 [==============================] - 113s 1s/step - loss: 0.0173 - dice_c
```

```
oef: 0.4773 - val_loss: 0.0084 - val_dice_coef: 0.6931
Epoch 16/20
100/100 [==============================] - 106s 1s/step - loss: 0.0196 - dice_c
oef: 0.4671 - val_loss: 0.0096 - val_dice_coef: 0.6664
Epoch 17/20
100/100 [==============================] - 96s 964ms/step - loss: 0.0179 - dice
_coef: 0.5012 - val_loss: 0.0091 - val_dice_coef: 0.6638
Epoch 18/20
100/100 [==============================] - 92s 916ms/step - loss: 0.0173 - dice
_coef: 0.5194 - val_loss: 0.0087 - val_dice_coef: 0.7010
Epoch 19/20
100/100 [==============================] - 42s 416ms/step - loss: 0.0169 - dice
_coef: 0.4929 - val_loss: 0.0089 - val_dice_coef: 0.6736
Epoch 20/20
100/100 [==============================] - 42s 420ms/step - loss: 0.0214 - dice
_coef: 0.4560 - val_loss: 0.0091 - val_dice_coef: 0.5957
```

In [43]:

```python
def plot_performance(history):
    dicec = history.history['dice_coef']
    val_dice = history.history['val_dice_coef']
    loss = history.history['loss']
    val_loss = history.history['val_loss']

    epochs = range(len(dicec))
    plt.figure(figsize=(10, 4))
    plt.subplot(1,2,1)
    plt.plot(epochs, dicec, label='Training dice')
    plt.plot(epochs, val_dice, label='Validation dice')
    plt.xlabel("Num of Epochs")
    plt.ylabel("dice")
    plt.title('Training and validation dice')
    plt.legend()

    plt.subplot(1,2,2)

    plt.plot(epochs, loss, label='Training loss')
    plt.plot(epochs, val_loss, label='Validation loss')
    plt.xlabel("Num of Epochs")
    plt.ylabel("Loss")
    plt.title('Training and validation loss')
    plt.legend()

    plt.show()
```

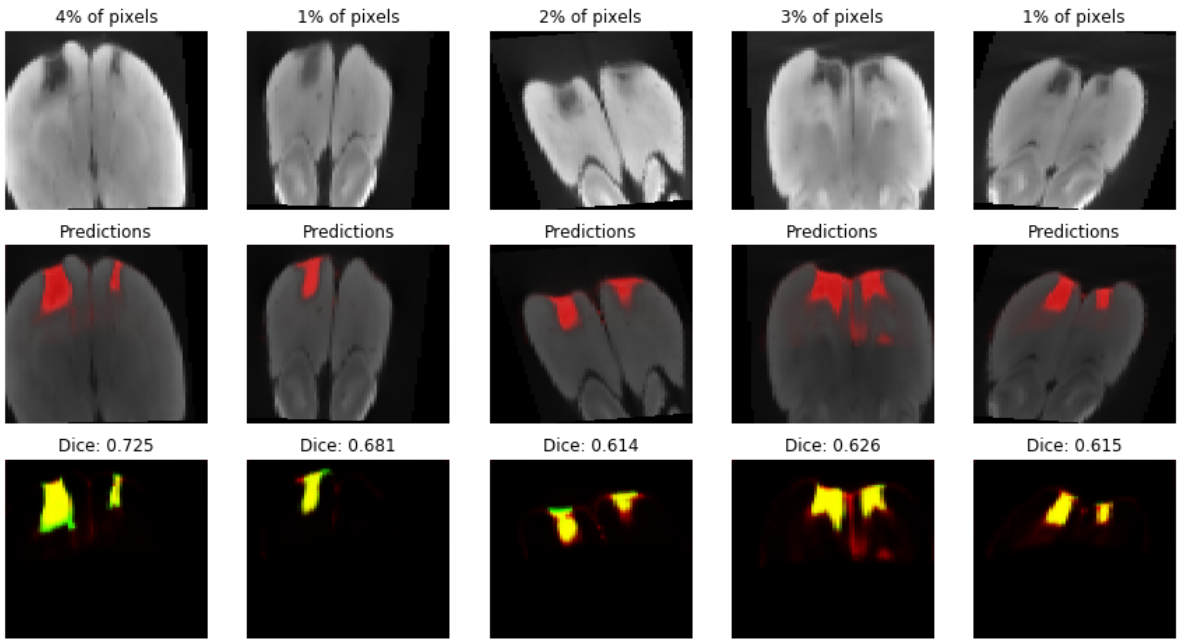
In [65]:
```
plot_performance(history)
```



In [ ]:
```
# load best model
model.load_weights('weights2.h5')
```

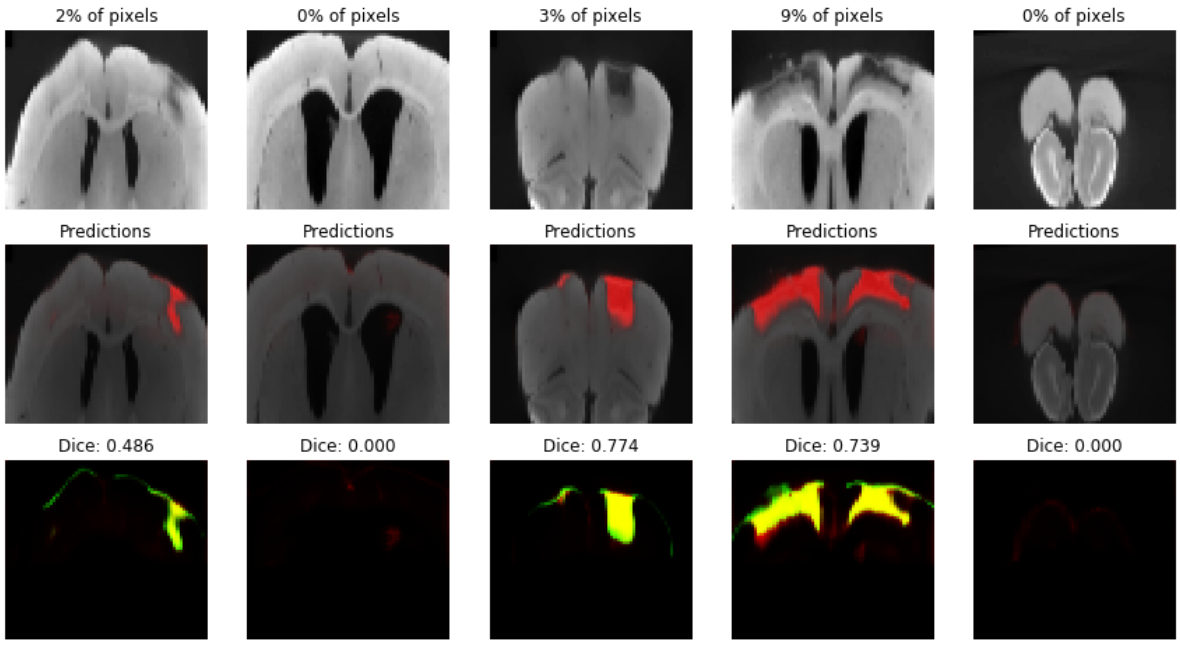
In [25]:
```
# training set performance
for data_batch, labels_batch in train_generator:
    print('data batch shape:', data_batch.shape)
    print('labels batch shape:', labels_batch.shape)
    break

predict_batch = model.predict_on_batch(data_batch)

plot_masks(data_batch, labels_batch, predict_batch)
```

```
data batch shape: (32, 128, 64, 1)
labels batch shape: (32, 128, 64, 1)
```



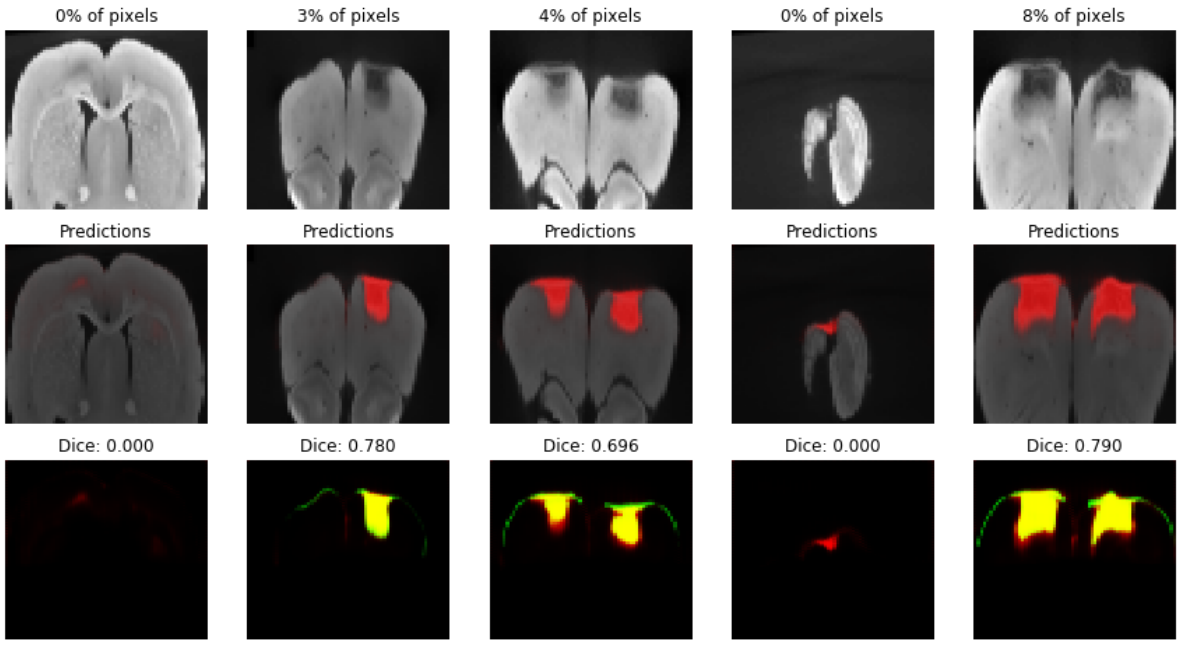
In [18]:
```
# validation set performance
for data_batch, labels_batch in valid_generator:
    print('data batch shape:', data_batch.shape)
    print('labels batch shape:', labels_batch.shape)
    break

predict_batch = model.predict_on_batch(data_batch)

plot_masks(data_batch, labels_batch, predict_batch)
```

```
data batch shape: (32, 128, 64, 1)
labels batch shape: (32, 128, 64, 1)
```



In [31]:
```
# test set performance
for data_batch, labels_batch in test_generator:
    print('data batch shape:', data_batch.shape)
    print('labels batch shape:', labels_batch.shape)
    break

predict_batch = model.predict_on_batch(data_batch)

plot_masks(data_batch, labels_batch, predict_batch)
```

```
data batch shape: (32, 128, 64, 1)
labels batch shape: (32, 128, 64, 1)
```



3D U-Net

In [32]:

```
vol_folder = 'data\\small3d\\'

vols = ['GP1825', 'GP1826', 'GP1827']

for (i, vol) in enumerate(vols):
    train_vol = imread(os.path.join(vol_folder,vol)+'.tif')
    train_vol = train_vol.astype('float') / train_vol.max()
    train_labels = imread(os.path.join(vol_folder,vol)+'_lesion.tif')

    factor = train_labels[train_labels>0].min()
    train_labels = np.round(train_labels/factor).astype('uint8')

    if i==0:
        X_train = np.moveaxis(np.expand_dims(np.expand_dims(train_vol, axis=3), a
        y_train = np.moveaxis(np.expand_dims(np.expand_dims(train_labels, axis=3)
    else:
        X_train = np.append(X_train, np.moveaxis(np.expand_dims(np.expand_dims(tr
        y_train = np.append(y_train, np.moveaxis(np.expand_dims(np.expand_dims(tr
```

In [33]:
```
# since Keras' ImageDataGenerator doesn't support 3D data, we make our own genera

# https://stanford.edu/~shervine/blog/keras-how-to-generate-data-on-the-fly

class VolumeDataGenerator(Sequence):
    def __init__(self, filenames, root, label_suffix='lesion', batch_size=1, dim=
                 rotation_range=10, zoom_range=[0.9, 1.1], brightness_range=[0.8,
        self.dim = dim
        self.batch_size = batch_size
        self.n_channels = n_channels
        self.filenames = filenames
        self.root = root
        if self.batch_size>len(self.filenames):
            self.batch_size=len(self.filenames)
        self.label = label_suffix
        self.shuffle = shuffle
        self.reset_index()

        # augmentation parameters
        self.rotation_range = rotation_range
        self.zoom_range = zoom_range
        self.brightness_range = brightness_range
        self.flip_axes = np.roll(flip_axes,-1) # y, z, x --> x, y, z
        self.shift_range = shift_range

    def __len__(self):
        # number of batches per epoch
        return int(np.floor(len(self.filenames) / self.batch_size))

    def __getitem__(self, index):
        # Generate one batch of data
        indexes = self.indexes[index*self.batch_size:(index+1)*self.batch_size]

        files = [self.filenames[k] for k in indexes]

        X, y = self.load_files(files)

        for i, (Xi, yi) in enumerate(zip(X, y)):
            Xi, yi = self.augmentit(np.squeeze(Xi), np.squeeze(yi))
            X[i] = np.expand_dims(Xi, axis=3)
            y[i] = np.expand_dims(yi, axis=3)

        return X, y

    def reset_index(self):
        # Updates indexes after each epoch
        self.indexes = np.arange(len(self.filenames))
        if self.shuffle == True:
            np.random.shuffle(self.indexes)

    def load_files(self, files):

        X = np.empty((self.batch_size, *self.dim, self.n_channels))
        y = np.empty((self.batch_size, *self.dim, self.n_channels), dtype=int)

        for i, file in enumerate(files):
```

```
            img = imread(os.path.join(self.root, file)+'.tif')
            img = img.astype('float') / img.max()
            X[i] = np.expand_dims(img, axis=3)

            label = imread(os.path.join(self.root, file)+'_'+self.label+'.tif')
            factor = label[label>0].min()
            label = np.round(label/factor).astype('uint8')
            y[i] = np.expand_dims(label, axis=3)

        return X, y

    ## the following augmentation functions are copied from
    # https://mlnotebook.github.io/post/dataaug/

    def augmentit(self, thisim, thisseg):
        dims = self.dim
        aug = False

        if self.rotation_range>0:
            theta   = np.random.uniform(-self.rotation_range,self.rotation_range,
            thisim  = self.rotateit(thisim, theta)
            thisseg = self.rotateit(thisseg, theta, isseg=True)
            aug = True

        if not np.equal(self.zoom_range, 1).all():
            scalefactor  = float(np.around(np.random.uniform(self.zoom_range[0],
            thisim  = self.scaleit(thisim, scalefactor)
            thisseg = self.scaleit(thisseg, scalefactor, isseg=True)
            aug = True

        if not np.equal(self.brightness_range, 1).all():
            factor  = float(np.around(np.random.uniform(self.brightness_range[0],
            thisim  = self.intensifyit(thisim, factor)
            aug = True
            #no intensity change on segmentation

        if not np.equal(self.flip_axes, 0).all():
            thisim  = self.flipit(thisim, self.flip_axes)
            thisseg = self.flipit(thisseg, self.flip_axes)
            aug = True

        if self.shift_range>0:
            offset  = list(np.random.randint(-self.shift_range,self.shift_range,
            thisim  = self.translateit(thisim, offset)
            thisseg = self.translateit(thisseg, offset, isseg=True)
            aug = True

        if aug:
            thisim, thisseg = self.cropit(thisim, thisseg)
            thisseg         = self.resampleit(thisseg, dims, isseg=True)
            thisim          = self.resampleit(thisim, dims)

        return thisim, thisseg

    def scaleit(self, image, factor, isseg=False):
        order = 0 if isseg == True else 3
```

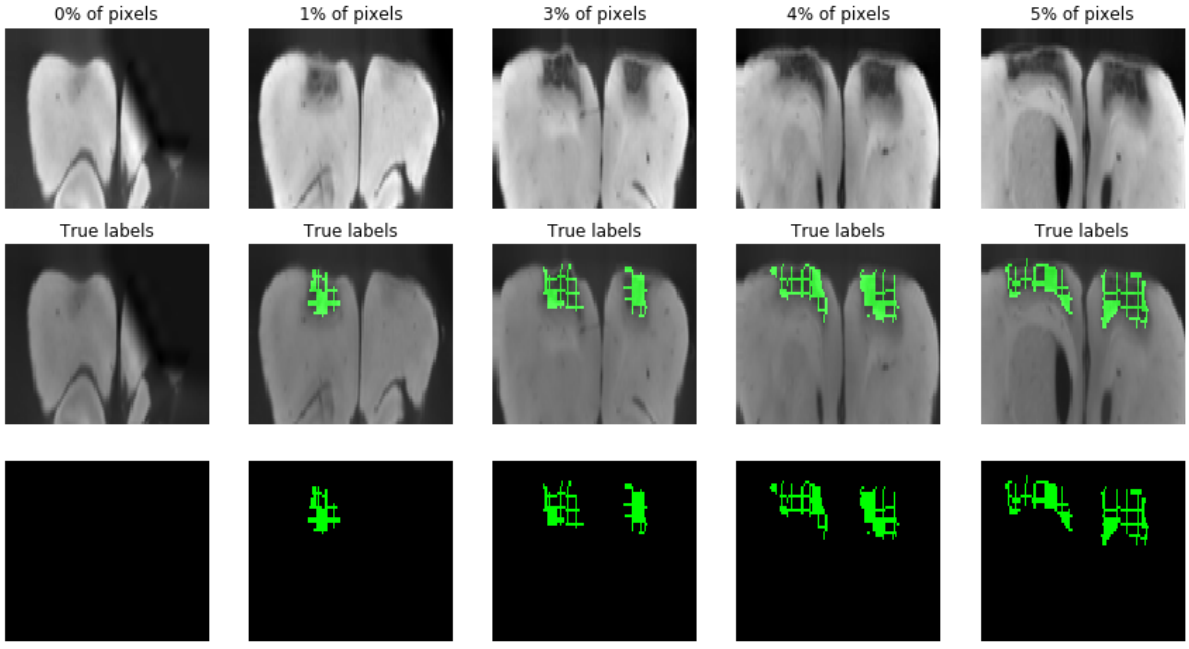
```
        height, width,depth = image.shape
        zheight             = int(np.round(factor * height))
        zwidth              = int(np.round(factor * width))

        if factor < 1.0:
            newimg  = np.zeros_like(image)
            row     = int((height - zheight) / 2)
            col     = int((width - zwidth) / 2)
            newimg[row:row+zheight, col:col+zwidth, :] = interpolation.zoom(image

            return newimg

        elif factor > 1.0:
            row     = (zheight - height) // 2
            col     = (zwidth - width) // 2

            newimg = interpolation.zoom(image[row:row+zheight, col:col+zwidth], (

            extrah = (newimg.shape[0] - height) // 2
            extraw = (newimg.shape[1] - width) // 2
            newimg = newimg[extrah:extrah+height, extraw:extraw+width, :]

            return newimg

        else:
            return image

    def resampleit(self, image, dims, isseg=False):
        order = 0 if isseg == True else 5

        image = interpolation.zoom(image, np.array(dims)/np.array(image.shape, dt

        if isseg:
            image[np.where(image==4)]=3

        return image if isseg else (image-image.min())/(image.max()-image.min())


    def translateit(self, image, offset, isseg=False, mode='nearest'):
        order   = 0 if isseg else 5
        mode    ='nearest'
        offset  = (int(offset[0]), int(offset[1]), int(offset[2]))

        return interpolation.shift(image, offset , order=order, mode=mode)


    def rotateit(self, image, theta, isseg=False):
        # modified using https://stackoverflow.com/questions/43922198/how-to-rota
        order = 0 if isseg == True else 5
        for i, angle in enumerate(theta):
            image = interpolation.rotate(image, angle, mode='nearest', axes=(int(

        return image


    def flipit(self, image, axes):
```

```
        if axes[0]:
            image = np.fliplr(image)
        if axes[1]:
            image = np.flipud(image)
        if axes[2]:
            image = np.flip(image, axis=2)

        return image


    def intensifyit(self, image, factor):

        return image*float(factor)


    def cropit(self, image, seg=None, margin=5):

        shortaxis = np.argmin(image.shape[:2])
        trimaxes  = 0 if shortaxis == 1 else 1

        trim    = image.shape[shortaxis]
        center  = image.shape[trimaxes] // 2
        lrcenter = image.shape[shortaxis] // 2

        if seg is not None:

            hits = np.where(seg!=0)
            mins = np.amin(hits, axis=1)
            maxs = np.amax(hits, axis=1)
            segtrim = max(maxs-mins) + margin

            trim = segtrim
            center  = np.mean(hits, 1, dtype=int)[0]
            lrcenter = np.mean(hits, 1, dtype=int)[1]

            if center - (trim // 2) > mins[0]:
                while center - (trim // 2) > mins[0]:
                    center = center - 1
                center = center

            if center + (trim // 2) < maxs[0]:
                while center + (trim // 2) < maxs[0]:
                    center = center + 1
                center = center

            if lrcenter - (trim // 2) > mins[1]:
                while lrcenter - (trim // 2) > mins[1]:
                    lrcenter = lrcenter - 1
                lrcenter = lrcenter

            if lrcenter + (trim // 2) < maxs[1]:
                while lrcenter + (trim // 2) < maxs[1]:
                    lrcenter = lrcenter + 1
                lrcenter = lrcenter

        top    = max(0, center - (trim //2) - margin//2)
        bottom = trim + margin if top == 0 else top + trim + (margin//2)
```

```
        left = max(0, lrcenter - (trim//2) - margin//2)
        right = trim + margin if left == 0 else left + trim + (margin//2)

        # image[center-5:center+5, lrcenter-5:lrcenter+5, :] = 255
        # image[top:bottom, left-2:left+2, :] = 255
        # image[top:bottom, right-2:right+2, :] = 255
        # image[top-2:top+2, left:right, :] = 255
        # image[bottom-2:bottom+2, left:right, :] = 255

        if bottom > image.shape[trimaxes]:
            bottom = image.shape[trimaxes]
            top = bottom - trim

        if right > image.shape[shortaxis]:
            right = image.shape[shortaxis]
            left = right - trim

        image   = image[top: bottom, left:right]

        if seg is not None:
            seg   = seg[top: bottom, left:right]

            return image, seg
        else:
            return image
```

In [34]:
```
filenames = ['GP1825', 'GP1826', 'GP1827']
root = 'data\\small3d\\'

vol_size = (64, 64, 128)
train_gen = VolumeDataGenerator(filenames, root, rotation_range=10, zoom_range=[0
                                flip_axes=[1,0,1], shift_range=5)

noaug_gen = VolumeDataGenerator(filenames, root, rotation_range=0, zoom_range=[1,
                                flip_axes=[0,0,0], shift_range=0, shuffle=False,

start = time.time()
X, y = train_gen.__getitem__(0)
print(time.time()-start)

# preview the augmentation
plot_masks(X[0][4:-1:8], y[0][4:-1:8]>1)
```

```
C:\Users\Gerald\Anaconda3\envs\tf3\lib\site-packages\scipy\ndimage\interpolatio
n.py:600: UserWarning: From scipy 0.13.0, the output shape of zoom() is calcula
ted with round() instead of int() - for these inputs the size of the returned a
rray has changed.
  "the returned array has changed.", UserWarning)

1.9856905937194824
```



The masks look like checkboards because I only sparsely annotated the volumes in each orthogonal dimension -- they are not perfect checkboards because of the random rotation.

In [36]:

```
n_classes = y.max()+1
class_weights = np.array([0, 0.05, 0.95])

def weighted_categorical_crossentropy(y_true, y_pred):

    # categorical cross entropy
    y_true_fixed = K.relu(y_true-1) # shift category labels
    c_ce = K.sparse_categorical_crossentropy(y_true_fixed, y_pred)

    # Apply class weights
    weight_vector = K.squeeze(K.sum(K.one_hot(K.cast(y_true, 'int32'), n_classes)
#     weight_vector = y_true * one_weight + (1. - y_true) * zero_weight
    weighted_c_ce = weight_vector * c_ce
#     weighted_c_ce = c_ce
#     weighted_c_ce = c_ce*class_weights

    # Return the mean error
    return K.mean(weighted_c_ce)
```

In [37]:

```
# modified from https://www.kaggle.com/keegil/keras-u-net-starter-lb-0-277
def unet3d(loss_fn=weighted_categorical_crossentropy, lr=1e-3, act='relu', init='
    inputs = Input(vol_size + (1,))

    c1 = Conv3D(16, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c1 = Dropout(0.1) (c1) if dropout else c1
    c1 = Conv3D(16, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    p1 = MaxPooling3D((2, 2, 2)) (c1)

    c2 = Conv3D(32, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c2 = Dropout(0.1) (c2) if dropout else c2
    c2 = Conv3D(32, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    p2 = MaxPooling3D((2, 2, 2)) (c2)

    c3 = Conv3D(64, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c3 = Dropout(0.2) (c3) if dropout else c3
    c3 = Conv3D(64, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    p3 = MaxPooling3D((2, 2, 2)) (c3)

    c4 = Conv3D(128, (3, 3, 3), activation=act, kernel_initializer=init, padding=
    c4 = Dropout(0.2) (c4) if dropout else c4
    c4 = Conv3D(128, (3, 3, 3), activation=act, kernel_initializer=init, padding=

    # remove one layer of depth to save on model size / memory
    p4 = MaxPooling3D(pool_size=(2, 2, 2)) (c4)

    c5 = Conv3D(256, (3, 3, 3), activation=act, kernel_initializer=init, padding=
    c5 = Dropout(0.3) (c5)  if dropout else c5
    c5 = Conv3D(256, (3, 3, 3), activation=act, kernel_initializer=init, padding=

    u6 = Conv3DTranspose(128, (2, 2, 2), strides=(2, 2, 2), padding=pad) (c5)
    u6 = concatenate([u6, c4])
    c6 = Conv3D(128, (3, 3, 3), activation=act, kernel_initializer=init, padding=
    c6 = Dropout(0.2) (c6) if dropout else c6
    c6 = Conv3D(128, (3, 3, 3), activation=act, kernel_initializer=init, padding=
    # end remove

    u7 = Conv3DTranspose(64, (2, 2, 2), strides=(2, 2, 2), padding=pad) (c6)
    u7 = concatenate([u7, c3])
    c7 = Conv3D(64, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c7 = Dropout(0.2) (c7) if dropout else c7
    c7 = Conv3D(64, (3, 3, 3), activation=act, kernel_initializer=init, padding=p

    u8 = Conv3DTranspose(32, (2, 2, 2), strides=(2, 2, 2), padding=pad) (c7)
    u8 = concatenate([u8, c2])
    c8 = Conv3D(32, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c8 = Dropout(0.1) (c8) if dropout else c8
    c8 = Conv3D(32, (3, 3, 3), activation=act, kernel_initializer=init, padding=p

    u9 = Conv3DTranspose(16, (2, 2, 2), strides=(2, 2, 2), padding=pad) (c8)
    u9 = concatenate([u9, c1])
    c9 = Conv3D(16, (3, 3, 3), activation=act, kernel_initializer=init, padding=p
    c9 = Dropout(0.1) (c9) if dropout else c9
    c9 = Conv3D(16, (3, 3, 3), activation=act, kernel_initializer=init, padding=p

    outputs = Conv3D(n_classes-1, (1, 1, 1), activation='softmax') (c9)
```

```
    model = Model(inputs=[inputs], outputs=[outputs])
    model.compile(optimizer=Adam(lr=lr), loss=loss_fn, metrics=[loss_fn])
    model.summary()

    return model
```

In [38]:
```
K.clear_session()
model = unet3d(loss_fn=weighted_categorical_crossentropy, dropout=False)
```

```
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            (None, 64, 64, 128,  0
__________________________________________________________________________________________________
conv3d_1 (Conv3D)               (None, 64, 64, 128,  448         input_1[0][0]
__________________________________________________________________________________________________
conv3d_2 (Conv3D)               (None, 64, 64, 128,  6928        conv3d_1[0][0]
__________________________________________________________________________________________________
max_pooling3d_1 (MaxPooling3D)  (None, 32, 32, 64, 1 0           conv3d_2[0][0]
__________________________________________________________________________________________________
conv3d_3 (Conv3D)               (None, 32, 32, 64, 3 13856       max_pooling3d_
1[0][0]
__________________________________________________________________________________________________
conv3d_4 (Conv3D)               (None, 32, 32, 64, 3 27680       conv3d_3[0][0]
__________________________________________________________________________________________________
max_pooling3d_2 (MaxPooling3D)  (None, 16, 16, 32, 3 0           conv3d_4[0][0]
__________________________________________________________________________________________________
conv3d_5 (Conv3D)               (None, 16, 16, 32, 6 55360       max_pooling3d_
2[0][0]
__________________________________________________________________________________________________
conv3d_6 (Conv3D)               (None, 16, 16, 32, 6 110656      conv3d_5[0][0]
__________________________________________________________________________________________________
max_pooling3d_3 (MaxPooling3D)  (None, 8, 8, 16, 64) 0           conv3d_6[0][0]
__________________________________________________________________________________________________
conv3d_7 (Conv3D)               (None, 8, 8, 16, 128 221312      max_pooling3d_
3[0][0]
__________________________________________________________________________________________________
conv3d_8 (Conv3D)               (None, 8, 8, 16, 128 442496      conv3d_7[0][0]
__________________________________________________________________________________________________
```

```
max_pooling3d_4 (MaxPooling3D)  (None, 4, 4, 8, 128) 0           conv3d_8[0][0]

__________________________________________________________________________________________
conv3d_9 (Conv3D)               (None, 4, 4, 8, 256) 884992      max_pooling3d_
4[0][0]
__________________________________________________________________________________________
conv3d_10 (Conv3D)              (None, 4, 4, 8, 256) 1769728     conv3d_9[0][0]

__________________________________________________________________________________________
conv3d_transpose_1 (Conv3DTrans (None, 8, 8, 16, 128 262272      conv3d_10[0]
[0]
__________________________________________________________________________________________
concatenate_1 (Concatenate)     (None, 8, 8, 16, 256 0           conv3d_transpo
se_1[0][0]
                                                                 conv3d_8[0][0]

__________________________________________________________________________________________
conv3d_11 (Conv3D)              (None, 8, 8, 16, 128 884864      concatenate_1
[0][0]
__________________________________________________________________________________________
conv3d_12 (Conv3D)              (None, 8, 8, 16, 128 442496      conv3d_11[0]
[0]
__________________________________________________________________________________________
conv3d_transpose_2 (Conv3DTrans (None, 16, 16, 32, 6 65600       conv3d_12[0]
[0]
__________________________________________________________________________________________
concatenate_2 (Concatenate)     (None, 16, 16, 32, 1 0           conv3d_transpo
se_2[0][0]
                                                                 conv3d_6[0][0]

__________________________________________________________________________________________
conv3d_13 (Conv3D)              (None, 16, 16, 32, 6 221248      concatenate_2
[0][0]
__________________________________________________________________________________________
conv3d_14 (Conv3D)              (None, 16, 16, 32, 6 110656      conv3d_13[0]
[0]
__________________________________________________________________________________________
conv3d_transpose_3 (Conv3DTrans (None, 32, 32, 64, 3 16416       conv3d_14[0]
[0]
__________________________________________________________________________________________
concatenate_3 (Concatenate)     (None, 32, 32, 64, 6 0           conv3d_transpo
se_3[0][0]
                                                                 conv3d_4[0][0]

__________________________________________________________________________________________
```

```
_____________________
conv3d_15 (Conv3D)              (None, 32, 32, 64, 3 55328       concatenate_3
[0][0]
_____________________
conv3d_16 (Conv3D)              (None, 32, 32, 64, 3 27680       conv3d_15[0]
[0]
_____________________
conv3d_transpose_4 (Conv3DTrans (None, 64, 64, 128,  4112        conv3d_16[0]
[0]
_____________________
concatenate_4 (Concatenate)     (None, 64, 64, 128,  0           conv3d_transpo
se_4[0][0]
                                                                 conv3d_2[0][0]

_____________________
conv3d_17 (Conv3D)              (None, 64, 64, 128,  13840       concatenate_4
[0][0]
_____________________
conv3d_18 (Conv3D)              (None, 64, 64, 128,  6928        conv3d_17[0]
[0]
_____________________
conv3d_19 (Conv3D)              (None, 64, 64, 128,  34          conv3d_18[0]
[0]
==========================================================================
==================
Total params: 5,644,930
Trainable params: 5,644,930
Non-trainable params: 0
_____________________
```

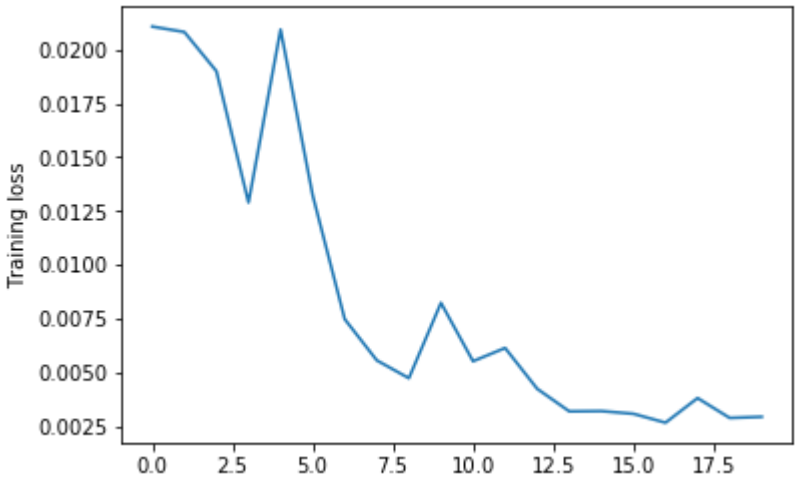
In [39]:
```
# history = model.fit(x=X_train, y=y_train, batch_size=2, epochs=50, verbose=1)
# history = model.fit_generator(noaug_gen, steps_per_epoch=3, epochs=20, verbose=1
checkpoint = ModelCheckpoint(filepath='weights3.h5')

history = model.fit_generator(train_gen, steps_per_epoch=30, epochs=20, verbose=1
```

```
Epoch 1/20
 2/30 [=>............................] - ETA: 1:16 - loss: 0.0189 - weighted_ca
tegorical_crossentropy: 0.0189

C:\Users\Gerald\Anaconda3\envs\tf3\lib\site-packages\scipy\ndimage\interpolatio
n.py:600: UserWarning: From scipy 0.13.0, the output shape of zoom() is calcula
ted with round() instead of int() - for these inputs the size of the returned a
rray has changed.
  "the returned array has changed.", UserWarning)

30/30 [==============================] - 58s 2s/step - loss: 0.0211 - weighted_
categorical_crossentropy: 0.0211
Epoch 2/20
30/30 [==============================] - 54s 2s/step - loss: 0.0208 - weighted_
categorical_crossentropy: 0.0208
Epoch 3/20
30/30 [==============================] - 55s 2s/step - loss: 0.0190 - weighted_
categorical_crossentropy: 0.0190
Epoch 4/20
30/30 [==============================] - 56s 2s/step - loss: 0.0129 - weighted_
categorical_crossentropy: 0.0129
Epoch 5/20
30/30 [==============================] - 57s 2s/step - loss: 0.0209 - weighted_
categorical_crossentropy: 0.0209
Epoch 6/20
30/30 [==============================] - 56s 2s/step - loss: 0.0132 - weighted_
categorical_crossentropy: 0.0132
Epoch 7/20
30/30 [==============================] - 55s 2s/step - loss: 0.0075 - weighted_
categorical_crossentropy: 0.0075
Epoch 8/20
30/30 [==============================] - 55s 2s/step - loss: 0.0056 - weighted_
categorical_crossentropy: 0.0056
Epoch 9/20
30/30 [==============================] - 56s 2s/step - loss: 0.0047 - weighted_
categorical_crossentropy: 0.0047
Epoch 10/20
30/30 [==============================] - 55s 2s/step - loss: 0.0082 - weighted_
categorical_crossentropy: 0.0082
Epoch 11/20
30/30 [==============================] - 55s 2s/step - loss: 0.0055 - weighted_
categorical_crossentropy: 0.0055
Epoch 12/20
30/30 [==============================] - 55s 2s/step - loss: 0.0061 - weighted_
categorical_crossentropy: 0.0061
Epoch 13/20
30/30 [==============================] - 55s 2s/step - loss: 0.0042 - weighted_
categorical_crossentropy: 0.0042
Epoch 14/20
30/30 [==============================] - 56s 2s/step - loss: 0.0032 - weighted_
```

```
categorical_crossentropy: 0.0032
Epoch 15/20
30/30 [==============================] - 56s 2s/step - loss: 0.0032 - weighted_
categorical_crossentropy: 0.0032
Epoch 16/20
30/30 [==============================] - 56s 2s/step - loss: 0.0031 - weighted_
categorical_crossentropy: 0.0031
Epoch 17/20
30/30 [==============================] - 56s 2s/step - loss: 0.0027 - weighted_
categorical_crossentropy: 0.0027
Epoch 18/20
30/30 [==============================] - 55s 2s/step - loss: 0.0038 - weighted_
categorical_crossentropy: 0.0038
Epoch 19/20
30/30 [==============================] - 55s 2s/step - loss: 0.0029 - weighted_
categorical_crossentropy: 0.0029
Epoch 20/20
30/30 [==============================] - 55s 2s/step - loss: 0.0029 - weighted_
categorical_crossentropy: 0.0029
```

In [46]:
```
plt.plot(history.history['loss'])
plt.ylabel('Training loss')
```

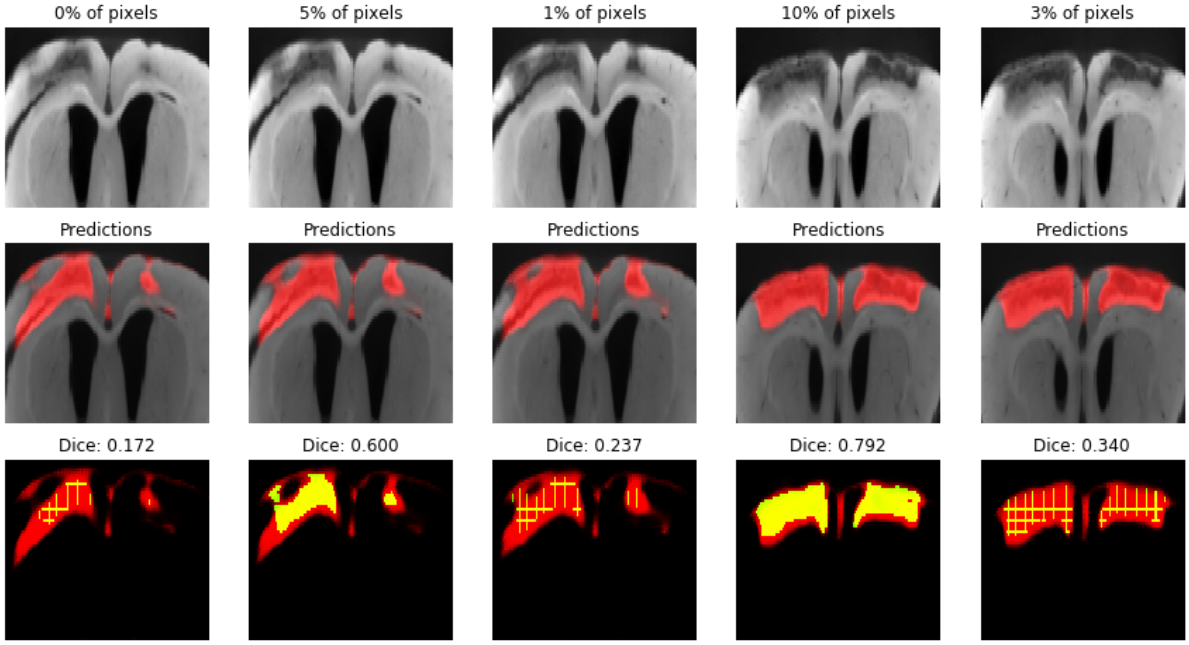
Out[46]:
```
<matplotlib.text.Text at 0x1e099cb87f0>
```



In [62]:

```
# make predictions on non-augmented data
noaug_gen.reset_index()
y_predict = model.predict_generator(noaug_gen)

# plot predictions
noaug_gen.reset_index()
X, y_true = noaug_gen.__getitem__(0)
y_pred=np.expand_dims(y_predict[:,:,:,:,1],axis=4)
# plot the predictions
idx = [18, 19, 20, 27, 28]
plot_masks(X[2][idx], (y_true[2][idx]>1).astype('float'), y_pred[2][idx])

# save class labels
y_argmax = np.argmax(y_predict, axis=4).astype('float')
y_argmax *= 255/y_argmax.max()
y_argmax = np.round(y_argmax).astype('uint8')

# prediction probability
y_predict = y_predict[:,:,:,:,1]*255
y_predict = y_predict.astype('uint8')
print(y_predict.mean())

# save prediction volumes to disk
for (i, vol) in enumerate(vols):
    print(vol)
    outfile = os.path.join(vol_folder,vol) + '_prob.tif'
    imsave(outfile, y_predict[i])

    outfile = os.path.join(vol_folder,vol) + '_pred.tif'
    imsave(outfile, y_argmax[i])
```

```
13.136070251464844
GP1825
GP1826
GP1827
```


0% of pixels
5% of pixels
1% of pixels
10% of pixels
3% of pixels
Predictions
Predictions
Predictions
Predictions
Predictions
Dice: 0.172
Dice: 0.600
Dice: 0.237
Dice: 0.792
Dice: 0.340