In [1]:
```
%matplotlib inline

import matplotlib.pyplot as plt
from keras.utils import np_utils
from keras.datasets import mnist
from keras.models import Sequential
from keras.layers import Dense, Dropout, Flatten
from keras.layers import Conv2D, MaxPooling2D
from keras.layers.normalization import BatchNormalization

import seaborn as sns
import numpy as np
import keras
```

```
Using TensorFlow backend.
```

In [3]:
```
(X_train, y_train), (X_test, y_test) = mnist.load_data()

img_rows, img_cols = 28, 28
```

In [4]:
```
#Let's print the shape of training and test data

print("Training data shape: ", X_train.shape)
print("Test data shape", X_test.shape)

print("Training label shape: ", y_train.shape)
print("Test label shape: ", y_test.shape)
print("First 5 training labels: ", y_train[:5])
```

```
Training data shape:  (60000, 28, 28)
Test data shape (10000, 28, 28)
Training label shape:  (60000,)
Test label shape:  (10000,)
First 5 training labels:  [5 0 4 1 9]
```

In [5]:
```
num_classes = 10
batch_size = 128
nb_epoch = 10
```

In [7]:
```
from keras import backend as K

if K.image_data_format() == 'channels_first':
    X_train = X_train.reshape(X_train.shape[0], 1, img_rows, img_cols)
    X_test = X_test.reshape(X_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    X_train = X_train.reshape(X_train.shape[0], img_rows, img_cols, 1)
    X_test = X_test.reshape(X_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

X_train = X_train.astype('float32')
X_test = X_test.astype('float32')
```

In [8]:
```
# Each cell of above matrix is having a value between 0-255
# before applying machine learning algorithms, let's normalize the data # X => (X - Xmin)/(Xmax-Xmin) = X/255

X_train /= 255
X_test /= 255
print('X_train shape:', X_train.shape)
print('No. of train samples: ', X_train.shape[0])
print('No. of test samples: ', X_test.shape[0])
```

```
X_train shape: (60000, 28, 28, 1)
No. of train samples:  60000
No. of test samples:  10000
```

In [9]:
```
# Ket's convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)
```

4 layer CNN Model with 3*3 kernel size

In [10]:
```
model1=Sequential() # Initializing the model

# First ConvNet
model1.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))

model1.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu'))


model1.add(MaxPooling2D(pool_size=(2,2)))
model1.add(Dropout(0.2))

model1.add(Conv2D(128,kernel_size=(3,3),
                 activation='relu'))

model1.add(BatchNormalization())

#maxpooling by (2,2 ) ,dropout,flattening
model1.add(MaxPooling2D(pool_size=(2,2)))

model1.add(Dropout(0.5))


model1.add(Flatten())

#hidden_layer
model1.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model1.add(Dropout(0.5))

model1.add(Dense(num_classes,activation='softmax'))

print(model1.summary())
```

```
WARNING:tensorflow:From C:\Users\pratyush.acharya\AppData\Local\Continuum\anaconda3\lib\site-packages\tensorflow\python\ops\resou
rce_variable_ops.py:435: colocate_with (from tensorflow.python.framework.ops) is deprecated and will be removed in a future versi
on.
Instructions for updating:
Colocations handled automatically by placer.
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 12, 12, 64)        0
_________________________________________________________________
dropout_1 (Dropout)          (None, 12, 12, 64)        0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 10, 10, 128)       73856
_________________________________________________________________
batch_normalization_1 (Batch (None, 10, 10, 128)       512
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 5, 5, 128)         0
_________________________________________________________________
dropout_2 (Dropout)          (None, 5, 5, 128)         0
_________________________________________________________________
flatten_1 (Flatten)          (None, 3200)              0
_________________________________________________________________
dense_1 (Dense)              (None, 256)               819456
_________________________________________________________________
dropout_3 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_2 (Dense)              (None, 10)                2570
=================================================================
Total params: 915,210
Trainable params: 914,954
Non-trainable params: 256
_________________________________________________________________
None
```

In [11]:
```
model1.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [12]:
```
# Training the model

history = model1.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
WARNING:tensorflow:From C:\Users\pratyush.acharya\AppData\Local\Continuum\anaconda3\lib\site-packages\tensorflow\python\ops\math_
ops.py:3066: to_int32 (from tensorflow.python.ops.math_ops) is deprecated and will be removed in a future version.
Instructions for updating:
Use tf.cast instead.
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 527s 9ms/step - loss: 0.2391 - accuracy: 0.9286 - val_loss: 0.1245 - val_accuracy:
0.9855
Epoch 2/10
60000/60000 [==============================] - 537s 9ms/step - loss: 0.0807 - accuracy: 0.9751 - val_loss: 0.0440 - val_accuracy:
0.9860
Epoch 3/10
60000/60000 [==============================] - 535s 9ms/step - loss: 0.0623 - accuracy: 0.9816 - val_loss: 0.0283 - val_accuracy:
0.9910
Epoch 4/10
60000/60000 [==============================] - 551s 9ms/step - loss: 0.0544 - accuracy: 0.9839 - val_loss: 0.0309 - val_accuracy:
0.9907
Epoch 5/10
60000/60000 [==============================] - 550s 9ms/step - loss: 0.0509 - accuracy: 0.9850 - val_loss: 0.0281 - val_accuracy:
0.9919
Epoch 6/10
60000/60000 [==============================] - 539s 9ms/step - loss: 0.0459 - accuracy: 0.9860 - val_loss: 0.0221 - val_accuracy:
0.9921
Epoch 7/10
60000/60000 [==============================] - 464s 8ms/step - loss: 0.0413 - accuracy: 0.9874 - val_loss: 0.0227 - val_accuracy:
0.9933
Epoch 8/10
60000/60000 [==============================] - 376s 6ms/step - loss: 0.0427 - accuracy: 0.9875 - val_loss: 0.0301 - val_accuracy:
0.9925
Epoch 9/10
60000/60000 [==============================] - 342s 6ms/step - loss: 0.0409 - accuracy: 0.9883 - val_loss: 0.0371 - val_accuracy:
0.9908
Epoch 10/10
60000/60000 [==============================] - 339s 6ms/step - loss: 0.0373 - accuracy: 0.9893 - val_loss: 0.0220 - val_accuracy:
0.9930
```

In [13]:
```
score = model1.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

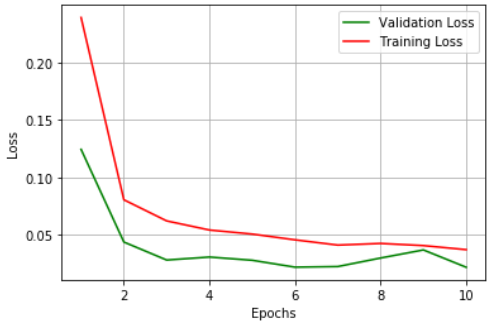
```
10000/10000 [==============================] - 14s 1ms/step
Test loss: 0.022041849251561642
Test accuracy: 0.9929999709129333
```

In [14]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```



Changing the dropout rate to 0.8

In [15]:
```
model1=Sequential() # Initializing the model

# First ConvNet
model1.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))

model1.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu'))


model1.add(MaxPooling2D(pool_size=(2,2)))
model1.add(Dropout(0.8))

model1.add(Conv2D(128,kernel_size=(3,3),
                  activation='relu'))

model1.add(BatchNormalization())

#maxpooling by (2,2 ) ,dropout,flattening
model1.add(MaxPooling2D(pool_size=(2,2)))

model1.add(Dropout(0.8))


model1.add(Flatten())

#hidden_layer
model1.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model1.add(Dropout(0.8))

model1.add(Dense(num_classes,activation='softmax'))

print(model1.summary())
```

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_4 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 12, 12, 64)        0
_________________________________________________________________
dropout_4 (Dropout)          (None, 12, 12, 64)        0
_________________________________________________________________
conv2d_6 (Conv2D)            (None, 10, 10, 128)       73856
_________________________________________________________________
batch_normalization_2 (Batch (None, 10, 10, 128)       512
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 5, 5, 128)         0
_________________________________________________________________
dropout_5 (Dropout)          (None, 5, 5, 128)         0
_________________________________________________________________
flatten_2 (Flatten)          (None, 3200)              0
_________________________________________________________________
dense_3 (Dense)              (None, 256)               819456
_________________________________________________________________
dropout_6 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_4 (Dense)              (None, 10)                2570
=================================================================
Total params: 915,210
Trainable params: 914,954
Non-trainable params: 256
_________________________________________________________________
None
```

In [16]:
```
model1.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [17]:
```
# Training the model

history = model1.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 354s 6ms/step - loss: 1.8717 - accuracy: 0.4944 - val_loss: 1.2311 - val_accuracy:
0.5943
Epoch 2/10
60000/60000 [==============================] - 339s 6ms/step - loss: 0.7126 - accuracy: 0.7703 - val_loss: 0.3755 - val_accuracy:
0.8838
Epoch 3/10
60000/60000 [==============================] - 337s 6ms/step - loss: 0.5028 - accuracy: 0.8438 - val_loss: 0.1594 - val_accuracy:
0.9600
Epoch 4/10
60000/60000 [==============================] - 407s 7ms/step - loss: 0.3878 - accuracy: 0.8838 - val_loss: 0.3313 - val_accuracy:
0.9028
Epoch 5/10
60000/60000 [==============================] - 420s 7ms/step - loss: 0.3306 - accuracy: 0.9019 - val_loss: 0.1561 - val_accuracy:
0.9538
Epoch 6/10
60000/60000 [==============================] - 403s 7ms/step - loss: 0.2974 - accuracy: 0.9145 - val_loss: 0.1993 - val_accuracy:
0.9451
Epoch 7/10
60000/60000 [==============================] - 385s 6ms/step - loss: 0.2826 - accuracy: 0.9189 - val_loss: 0.1173 - val_accuracy:
0.9664
Epoch 8/10
60000/60000 [==============================] - 371s 6ms/step - loss: 0.2609 - accuracy: 0.9247 - val_loss: 0.1695 - val_accuracy:
0.9550
Epoch 9/10
60000/60000 [==============================] - 359s 6ms/step - loss: 0.2491 - accuracy: 0.9276 - val_loss: 0.1613 - val_accuracy:
0.9575
Epoch 10/10
60000/60000 [==============================] - 340s 6ms/step - loss: 0.2467 - accuracy: 0.9296 - val_loss: 0.2272 - val_accuracy:
0.9399
```

In [18]:
```
score = model1.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

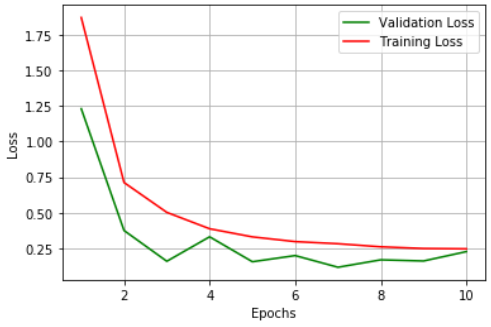
```
10000/10000 [==============================] - 16s 2ms/step
Test loss: 0.22723832533806562
Test accuracy: 0.9398999810218811
```

In [20]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout rate to 0.2

In [21]:
```
model1=Sequential() # Initializing the model

# First ConvNet
model1.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))

model1.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu'))


model1.add(MaxPooling2D(pool_size=(2,2)))
model1.add(Dropout(0.2))

model1.add(Conv2D(128,kernel_size=(3,3),
                 activation='relu'))

model1.add(BatchNormalization())

#maxpooling by (2,2 ) ,dropout,flattening
model1.add(MaxPooling2D(pool_size=(2,2)))

model1.add(Dropout(0.2))


model1.add(Flatten())

#hidden_layer
model1.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model1.add(Dropout(0.2))

model1.add(Dense(num_classes,activation='softmax'))

print(model1.summary())
```

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_7 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 24, 24, 64)        18496
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 12, 12, 64)        0
_________________________________________________________________
dropout_7 (Dropout)          (None, 12, 12, 64)        0
_________________________________________________________________
conv2d_9 (Conv2D)            (None, 10, 10, 128)       73856
_________________________________________________________________
batch_normalization_3 (Batch (None, 10, 10, 128)       512
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 5, 5, 128)         0
_________________________________________________________________
dropout_8 (Dropout)          (None, 5, 5, 128)         0
_________________________________________________________________
flatten_3 (Flatten)          (None, 3200)              0
_________________________________________________________________
dense_5 (Dense)              (None, 256)               819456
_________________________________________________________________
dropout_9 (Dropout)          (None, 256)               0
_________________________________________________________________
dense_6 (Dense)              (None, 10)                2570
=================================================================
Total params: 915,210
Trainable params: 914,954
Non-trainable params: 256
_________________________________________________________________
None
```

In [22]:
```
model1.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [23]:
```
# Training the model

history = model1.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 442s 7ms/step - loss: 0.1491 - accuracy: 0.9553 - val_loss: 0.0955 - val_accuracy:
0.9895
Epoch 2/10
60000/60000 [==============================] - 387s 6ms/step - loss: 0.0493 - accuracy: 0.9851 - val_loss: 0.0546 - val_accuracy:
0.9840
Epoch 3/10
60000/60000 [==============================] - 416s 7ms/step - loss: 0.0363 - accuracy: 0.9891 - val_loss: 0.0264 - val_accuracy:
0.9914
Epoch 4/10
60000/60000 [==============================] - 394s 7ms/step - loss: 0.0290 - accuracy: 0.9911 - val_loss: 0.0365 - val_accuracy:
0.9894
Epoch 5/10
60000/60000 [==============================] - 449s 7ms/step - loss: 0.0246 - accuracy: 0.9923 - val_loss: 0.0298 - val_accuracy:
0.9920
Epoch 6/10
60000/60000 [==============================] - 410s 7ms/step - loss: 0.0219 - accuracy: 0.9933 - val_loss: 0.0280 - val_accuracy:
0.9917
Epoch 7/10
60000/60000 [==============================] - 366s 6ms/step - loss: 0.0214 - accuracy: 0.9931 - val_loss: 0.0283 - val_accuracy:
0.9921
Epoch 8/10
60000/60000 [==============================] - 376s 6ms/step - loss: 0.0190 - accuracy: 0.9940 - val_loss: 0.0383 - val_accuracy:
0.9910
Epoch 9/10
60000/60000 [==============================] - 372s 6ms/step - loss: 0.0170 - accuracy: 0.9948 - val_loss: 0.0303 - val_accuracy:
0.9919
Epoch 10/10
60000/60000 [==============================] - 397s 7ms/step - loss: 0.0181 - accuracy: 0.9945 - val_loss: 0.0351 - val_accuracy:
0.9921
```

In [24]:
```
score = model1.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

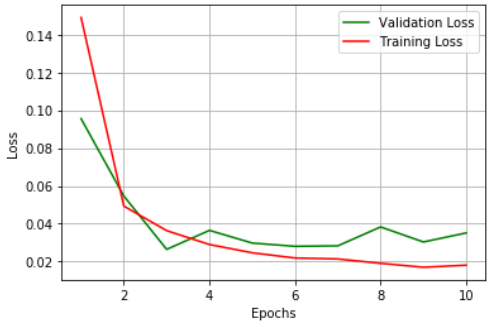
```
10000/10000 [==============================] - 16s 2ms/step
Test loss: 0.035121079186246 24
Test accuracy: 0.9921000003814697
```

In [25]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```



4 Convolution layers with 5*5 kernel size

In [27]:
```
model2=Sequential() # Initializing the model

# First ConvNet
model2.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))

model2.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))


model2.add(MaxPooling2D(pool_size=(2,2)))
model2.add(Dropout(0.2))

model2.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))

model2.add(BatchNormalization())

model2.add(MaxPooling2D(pool_size=(2,2)))

model2.add(Dropout(0.5))


model2.add(Flatten())

#hidden layer
model2.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model2.add(Dropout(0.5))

model2.add(Dense(num_classes,activation='softmax'))

print(model2.summary())
```

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_10 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 10, 10, 64)        0
_________________________________________________________________
dropout_10 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 6, 6, 128)         204928
_________________________________________________________________
batch_normalization_4 (Batch (None, 6, 6, 128)         512
_________________________________________________________________
max_pooling2d_8 (MaxPooling2 (None, 3, 3, 128)         0
_________________________________________________________________
dropout_11 (Dropout)         (None, 3, 3, 128)         0
_________________________________________________________________
flatten_4 (Flatten)          (None, 1152)              0
_________________________________________________________________
dense_7 (Dense)              (None, 256)               295168
_________________________________________________________________
dropout_12 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_8 (Dense)              (None, 10)                2570
=================================================================
Total params: 555,274
Trainable params: 555,018
Non-trainable params: 256
_________________________________________________________________
None
```

In [28]:
```
model2.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [29]:
```
# Training the model
history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 359s 6ms/step - loss: 0.1954 - accuracy: 0.9391 - val_loss: 0.0761 - val_accuracy:
0.9809
Epoch 2/10
60000/60000 [==============================] - 361s 6ms/step - loss: 0.0752 - accuracy: 0.9781 - val_loss: 0.0286 - val_accuracy:
0.9913
Epoch 3/10
60000/60000 [==============================] - 341s 6ms/step - loss: 0.0565 - accuracy: 0.9831 - val_loss: 0.0257 - val_accuracy:
0.9912
Epoch 4/10
60000/60000 [==============================] - 465s 8ms/step - loss: 0.0488 - accuracy: 0.9856 - val_loss: 0.0261 - val_accuracy:
0.9906
Epoch 5/10
60000/60000 [==============================] - 573s 10ms/step - loss: 0.0440 - accuracy: 0.9865 - val_loss: 0.0332 - val_accurac
y: 0.9911
Epoch 6/10
60000/60000 [==============================] - 540s 9ms/step - loss: 0.0422 - accuracy: 0.9878 - val_loss: 0.0309 - val_accuracy:
0.9924
Epoch 7/10
60000/60000 [==============================] - 567s 9ms/step - loss: 0.0398 - accuracy: 0.9884 - val_loss: 0.0296 - val_accuracy:
0.9911
Epoch 8/10
60000/60000 [==============================] - 572s 10ms/step - loss: 0.0374 - accuracy: 0.9888 - val_loss: 0.0222 - val_accurac
y: 0.9936
Epoch 9/10
60000/60000 [==============================] - 561s 9ms/step - loss: 0.0321 - accuracy: 0.9904 - val_loss: 0.0240 - val_accuracy:
0.9938
Epoch 10/10
60000/60000 [==============================] - 547s 9ms/step - loss: 0.0321 - accuracy: 0.9905 - val_loss: 0.0210 - val_accuracy:
0.9943
```

In [30]:
```
score = model2.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

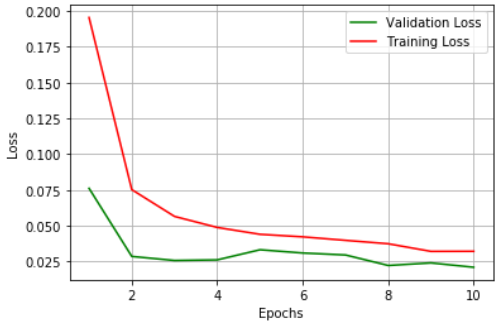
```
10000/10000 [==============================] - 27s 3ms/step
Test loss: 0.020990679916361204
Test accuracy: 0.9943000078201294
```

In [31]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout rate to 0.8

In [32]:
```
model2=Sequential() # Initializing the model

# First ConvNet
model2.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))

model2.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))


model2.add(MaxPooling2D(pool_size=(2,2)))
model2.add(Dropout(0.8))

model2.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))

model2.add(BatchNormalization())

model2.add(MaxPooling2D(pool_size=(2,2)))

model2.add(Dropout(0.8))


model2.add(Flatten())

#hidden layer
model2.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model2.add(Dropout(0.8))

model2.add(Dense(num_classes,activation='softmax'))

print(model2.summary())
```

```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_13 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 10, 10, 64)        0
_________________________________________________________________
dropout_13 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
conv2d_15 (Conv2D)           (None, 6, 6, 128)         204928
_________________________________________________________________
batch_normalization_5 (Batch (None, 6, 6, 128)         512
_________________________________________________________________
max_pooling2d_10 (MaxPooling (None, 3, 3, 128)         0
_________________________________________________________________
dropout_14 (Dropout)         (None, 3, 3, 128)         0
_________________________________________________________________
flatten_5 (Flatten)          (None, 1152)              0
_________________________________________________________________
dense_9 (Dense)              (None, 256)               295168
_________________________________________________________________
dropout_15 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_10 (Dense)             (None, 10)                2570
=================================================================
Total params: 555,274
Trainable params: 555,018
Non-trainable params: 256
_________________________________________________________________
None
```

In [33]:
```
model2.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [34]:
```
# Training the model

history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 548s 9ms/step - loss: 1.6143 - accuracy: 0.4881 - val_loss: 0.7136 - val_accuracy:
0.8021
Epoch 2/10
60000/60000 [==============================] - 540s 9ms/step - loss: 0.4909 - accuracy: 0.8488 - val_loss: 0.1857 - val_accuracy:
0.9520
Epoch 3/10
60000/60000 [==============================] - 548s 9ms/step - loss: 0.3236 - accuracy: 0.9045 - val_loss: 0.0913 - val_accuracy:
0.9740
Epoch 4/10
60000/60000 [==============================] - 530s 9ms/step - loss: 0.2664 - accuracy: 0.9242 - val_loss: 0.1157 - val_accuracy:
0.9725
Epoch 5/10
60000/60000 [==============================] - 533s 9ms/step - loss: 0.2406 - accuracy: 0.9318 - val_loss: 0.0731 - val_accuracy:
0.9802
Epoch 6/10
60000/60000 [==============================] - 532s 9ms/step - loss: 0.2206 - accuracy: 0.9374 - val_loss: 0.1145 - val_accuracy:
0.9733
Epoch 7/10
60000/60000 [==============================] - 545s 9ms/step - loss: 0.2124 - accuracy: 0.9405 - val_loss: 0.1015 - val_accuracy:
0.9770
Epoch 8/10
60000/60000 [==============================] - 532s 9ms/step - loss: 0.2043 - accuracy: 0.9439 - val_loss: 0.1037 - val_accuracy:
0.9768
Epoch 9/10
60000/60000 [==============================] - 529s 9ms/step - loss: 0.1905 - accuracy: 0.9470 - val_loss: 0.0792 - val_accuracy:
0.9814
Epoch 10/10
60000/60000 [==============================] - 543s 9ms/step - loss: 0.1791 - accuracy: 0.9492 - val_loss: 0.0698 - val_accuracy:
0.9834
```

In [35]:
```
score = model2.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

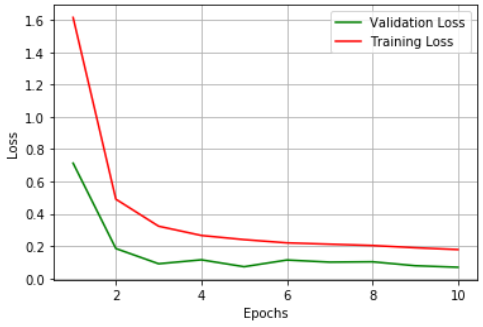
```
10000/10000 [==============================] - 24s 2ms/step
Test loss: 0.06979307891329391
Test accuracy: 0.9833999872207642
```

In [36]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout to 0.2

In [37]:
```
model2=Sequential() # Initializing the model

# First ConvNet
model2.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))

model2.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))


model2.add(MaxPooling2D(pool_size=(2,2)))
model2.add(Dropout(0.2))

model2.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))

model2.add(BatchNormalization())

model2.add(MaxPooling2D(pool_size=(2,2)))

model2.add(Dropout(0.2))


model2.add(Flatten())

#hidden layer
model2.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model2.add(Dropout(0.2))

model2.add(Dense(num_classes,activation='softmax'))

print(model2.summary())
```

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_16 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_11 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_16 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
conv2d_18 (Conv2D)           (None, 6, 6, 128)         204928
_________________________________________________________________
batch_normalization_6 (Batch (None, 6, 6, 128)         512
_________________________________________________________________
max_pooling2d_12 (MaxPooling (None, 3, 3, 128)         0
_________________________________________________________________
dropout_17 (Dropout)         (None, 3, 3, 128)         0
_________________________________________________________________
flatten_6 (Flatten)          (None, 1152)              0
_________________________________________________________________
dense_11 (Dense)             (None, 256)               295168
_________________________________________________________________
dropout_18 (Dropout)         (None, 256)               0
_________________________________________________________________
dense_12 (Dense)             (None, 10)                2570
=================================================================
Total params: 555,274
Trainable params: 555,018
Non-trainable params: 256
_________________________________________________________________
None
```

In [38]:
```
model2.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [39]:
```
# Training the model

history = model2.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 534s 9ms/step - loss: 0.1239 - accuracy: 0.9619 - val_loss: 0.0679 - val_accuracy:
0.9805
Epoch 2/10
60000/60000 [==============================] - 532s 9ms/step - loss: 0.0471 - accuracy: 0.9856 - val_loss: 0.0539 - val_accuracy:
0.9820
Epoch 3/10
60000/60000 [==============================] - 444s 7ms/step - loss: 0.0370 - accuracy: 0.9887 - val_loss: 0.0362 - val_accuracy:
0.9888
Epoch 4/10
60000/60000 [==============================] - 332s 6ms/step - loss: 0.0287 - accuracy: 0.9913 - val_loss: 0.0402 - val_accuracy:
0.9890
Epoch 5/10
60000/60000 [==============================] - 330s 6ms/step - loss: 0.0256 - accuracy: 0.9924 - val_loss: 0.0268 - val_accuracy:
0.9916
Epoch 6/10
60000/60000 [==============================] - 329s 5ms/step - loss: 0.0210 - accuracy: 0.9938 - val_loss: 0.0273 - val_accuracy:
0.9916
Epoch 7/10
60000/60000 [==============================] - 338s 6ms/step - loss: 0.0189 - accuracy: 0.9943 - val_loss: 0.0347 - val_accuracy:
0.9918
Epoch 8/10
60000/60000 [==============================] - 359s 6ms/step - loss: 0.0191 - accuracy: 0.9940 - val_loss: 0.0238 - val_accuracy:
0.9940
Epoch 9/10
60000/60000 [==============================] - 339s 6ms/step - loss: 0.0148 - accuracy: 0.9951 - val_loss: 0.0271 - val_accuracy:
0.9939
Epoch 10/10
60000/60000 [==============================] - 331s 6ms/step - loss: 0.0165 - accuracy: 0.9946 - val_loss: 0.0278 - val_accuracy:
0.9930
```

In [40]:
```
score = model2.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

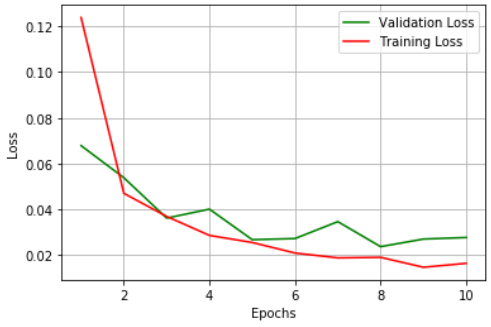
```
10000/10000 [==============================] - 19s 2ms/step
Test loss: 0.027773732883542696
Test accuracy: 0.9929999709129333
```

In [41]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



3 layer convolution layer with 3*3 kernel size

In [42]:
```
model3=Sequential() # Initializing the model

# First ConvNet
model3.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))
model3.add(MaxPooling2D(pool_size=(2,2)))


model3.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu',padding='valid'))


model3.add(Dropout(0.5))


#hidden_Layer
model3.add(Flatten())

model3.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model3.add(Dense(num_classes,activation='softmax'))

print(model3.summary())
```

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_19 (Conv2D)           (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_20 (Conv2D)           (None, 11, 11, 64)        18496
_________________________________________________________________
dropout_19 (Dropout)         (None, 11, 11, 64)        0
_________________________________________________________________
flatten_7 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_13 (Dense)             (None, 256)               1982720
_________________________________________________________________
dense_14 (Dense)             (None, 10)                2570
=================================================================
Total params: 2,004,106
Trainable params: 2,004,106
Non-trainable params: 0
_________________________________________________________________
None
```

In [43]:
```
model3.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [44]:
```
# Training the model

history = model3.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 92s 2ms/step - loss: 0.1748 - accuracy: 0.9464 - val_loss: 0.0502 - val_accuracy:
0.9840
Epoch 2/10
60000/60000 [==============================] - 89s 1ms/step - loss: 0.0566 - accuracy: 0.9824 - val_loss: 0.0368 - val_accuracy:
0.9875
Epoch 3/10
60000/60000 [==============================] - 88s 1ms/step - loss: 0.0390 - accuracy: 0.9876 - val_loss: 0.0301 - val_accuracy:
0.9900
Epoch 4/10
60000/60000 [==============================] - 87s 1ms/step - loss: 0.0302 - accuracy: 0.9906 - val_loss: 0.0304 - val_accuracy:
0.9900
Epoch 5/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0238 - accuracy: 0.9922 - val_loss: 0.0262 - val_accuracy:
0.9915
Epoch 6/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0197 - accuracy: 0.9933 - val_loss: 0.0260 - val_accuracy:
0.9918
Epoch 7/10
60000/60000 [==============================] - 89s 1ms/step - loss: 0.0156 - accuracy: 0.9952 - val_loss: 0.0302 - val_accuracy:
0.9903
Epoch 8/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0150 - accuracy: 0.9952 - val_loss: 0.0284 - val_accuracy:
0.9914
Epoch 9/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0124 - accuracy: 0.9960 - val_loss: 0.0290 - val_accuracy:
0.9914
Epoch 10/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0112 - accuracy: 0.9963 - val_loss: 0.0306 - val_accuracy:
0.9908
```

In [45]:
```
score = model3.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

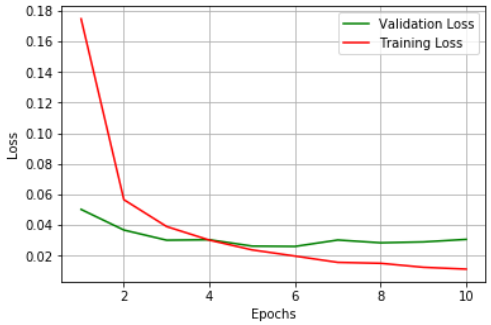
```
10000/10000 [==============================] - 4s 436us/step
Test loss: 0.030644286913338148
Test accuracy: 0.9908000230789185
```

In [46]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout rate to 0.8

In [47]:
```
model3=Sequential() # Initializing the model

# First ConvNet
model3.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))
model3.add(MaxPooling2D(pool_size=(2,2)))


model3.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu',padding='valid'))


model3.add(Dropout(0.8))


#hidden_layer
model3.add(Flatten())

model3.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model3.add(Dense(num_classes,activation='softmax'))

print(model3.summary())
```

```
Model: "sequential_8"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_21 (Conv2D)           (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_22 (Conv2D)           (None, 11, 11, 64)        18496
_________________________________________________________________
dropout_20 (Dropout)         (None, 11, 11, 64)        0
_________________________________________________________________
flatten_8 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_15 (Dense)             (None, 256)               1982720
_________________________________________________________________
dense_16 (Dense)             (None, 10)                2570
=================================================================
Total params: 2,004,106
Trainable params: 2,004,106
Non-trainable params: 0
_________________________________________________________________
None
```

In [48]:
```
model3.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [49]:
```
# Training the model

history = model3.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 87s 1ms/step - loss: 0.2279 - accuracy: 0.9286 - val_loss: 0.0513 - val_accuracy:
0.9828
Epoch 2/10
60000/60000 [==============================] - 89s 1ms/step - loss: 0.0831 - accuracy: 0.9742 - val_loss: 0.0337 - val_accuracy:
0.9890
Epoch 3/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0617 - accuracy: 0.9809 - val_loss: 0.0301 - val_accuracy:
0.9903
Epoch 4/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0514 - accuracy: 0.9841 - val_loss: 0.0268 - val_accuracy:
0.9912
Epoch 5/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0429 - accuracy: 0.9862 - val_loss: 0.0258 - val_accuracy:
0.9917
Epoch 6/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0387 - accuracy: 0.9870 - val_loss: 0.0231 - val_accuracy:
0.9915
Epoch 7/10
60000/60000 [==============================] - 89s 1ms/step - loss: 0.0364 - accuracy: 0.9882 - val_loss: 0.0232 - val_accuracy:
0.9917
Epoch 8/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0327 - accuracy: 0.9895 - val_loss: 0.0216 - val_accuracy:
0.9922
Epoch 9/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0294 - accuracy: 0.9907 - val_loss: 0.0227 - val_accuracy:
0.9925
Epoch 10/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0271 - accuracy: 0.9911 - val_loss: 0.0204 - val_accuracy:
0.9919
```

In [50]:
```
score = model3.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

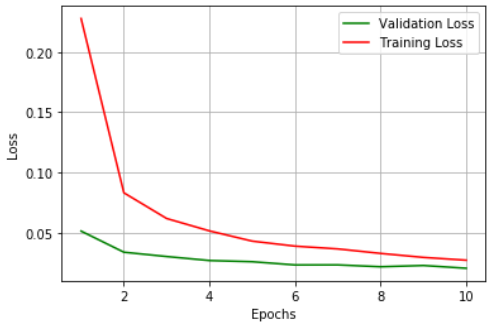
```
10000/10000 [==============================] - 4s 432us/step
Test loss: 0.02036657058280398
Test accuracy: 0.9919000267982483
```

In [51]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing dropout rate to 0.2

In [52]:
```
model3=Sequential() # Initializing the model

# First ConvNet
model3.add(Conv2D(32,kernel_size=(3,3),
                  activation='relu',
                  input_shape=input_shape))
model3.add(MaxPooling2D(pool_size=(2,2)))


model3.add(Conv2D(64,kernel_size=(3,3),
                  activation='relu',padding='valid'))


model3.add(Dropout(0.2))


#hidden_Layer
model3.add(Flatten())

model3.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model3.add(Dense(num_classes,activation='softmax'))

print(model3.summary())
```

```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_23 (Conv2D)           (None, 26, 26, 32)        320
_________________________________________________________________
max_pooling2d_15 (MaxPooling (None, 13, 13, 32)        0
_________________________________________________________________
conv2d_24 (Conv2D)           (None, 11, 11, 64)        18496
_________________________________________________________________
dropout_21 (Dropout)         (None, 11, 11, 64)        0
_________________________________________________________________
flatten_9 (Flatten)          (None, 7744)              0
_________________________________________________________________
dense_17 (Dense)             (None, 256)               1982720
_________________________________________________________________
dense_18 (Dense)             (None, 10)                2570
=================================================================
Total params: 2,004,106
Trainable params: 2,004,106
Non-trainable params: 0
_________________________________________________________________
None
```

In [53]:
```
model3.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [54]:
```
# Training the model

history = model3.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 89s 1ms/step - loss: 0.1458 - accuracy: 0.9572 - val_loss: 0.0412 - val_accuracy:
0.9866
Epoch 2/10
60000/60000 [==============================] - 87s 1ms/step - loss: 0.0413 - accuracy: 0.9873 - val_loss: 0.0330 - val_accuracy:
0.9887
Epoch 3/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0273 - accuracy: 0.9911 - val_loss: 0.0331 - val_accuracy:
0.9890
Epoch 4/10
60000/60000 [==============================] - 86s 1ms/step - loss: 0.0202 - accuracy: 0.9932 - val_loss: 0.0347 - val_accuracy:
0.9885
Epoch 5/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0154 - accuracy: 0.9950 - val_loss: 0.0313 - val_accuracy:
0.9896
Epoch 6/10
60000/60000 [==============================] - 88s 1ms/step - loss: 0.0126 - accuracy: 0.9958 - val_loss: 0.0299 - val_accuracy:
0.9907
Epoch 7/10
60000/60000 [==============================] - 87s 1ms/step - loss: 0.0098 - accuracy: 0.9967 - val_loss: 0.0302 - val_accuracy:
0.9918
Epoch 8/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0066 - accuracy: 0.9977 - val_loss: 0.0356 - val_accuracy:
0.9908
Epoch 9/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0075 - accuracy: 0.9975 - val_loss: 0.0321 - val_accuracy:
0.9922
Epoch 10/10
60000/60000 [==============================] - 85s 1ms/step - loss: 0.0062 - accuracy: 0.9981 - val_loss: 0.0352 - val_accuracy:
0.9909
```

In [55]:
```
score = model3.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

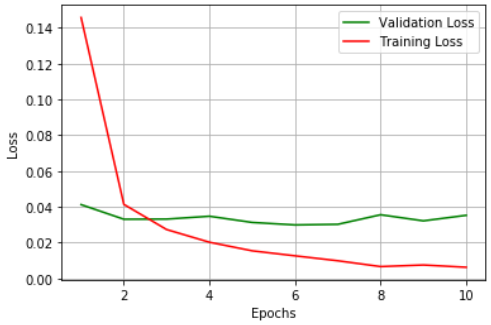
```
10000/10000 [==============================] - 4s 426us/step
Test loss: 0.03524074672339475
Test accuracy: 0.9908999800682068
```

In [56]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



5 layer convolution layer with 5*5 kernel size

In [57]:
```
model4=Sequential() # Initializing the model

# First ConvNet
model4.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))
model4.add(MaxPooling2D(pool_size=(2,2)))

model4.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))

model4.add(BatchNormalization())


model4.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))
model4.add(Dropout(0.5))



model4.add(Flatten())

#hidden_layer
model4.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dense(512,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dropout(0.5))

model4.add(Dense(num_classes,activation='softmax'))

print(model4.summary())
```

```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_25 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_26 (Conv2D)           (None, 8, 8, 64)          51264
_________________________________________________________________
batch_normalization_7 (Batch (None, 8, 8, 64)          256
_________________________________________________________________
conv2d_27 (Conv2D)           (None, 4, 4, 128)         204928
_________________________________________________________________
dropout_22 (Dropout)         (None, 4, 4, 128)         0
_________________________________________________________________
flatten_10 (Flatten)         (None, 2048)              0
_________________________________________________________________
dense_19 (Dense)             (None, 256)               524544
_________________________________________________________________
dense_20 (Dense)             (None, 512)               131584
_________________________________________________________________
dropout_23 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_21 (Dense)             (None, 10)                5130
=================================================================
Total params: 918,538
Trainable params: 918,410
Non-trainable params: 128
_________________________________________________________________
None
```

In [58]:
```
model4.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [59]:
```
# Training the model

history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.1540 - accuracy: 0.9521 - val_loss: 0.0855 - val_accuracy:
0.9843
Epoch 2/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0571 - accuracy: 0.9838 - val_loss: 0.0429 - val_accuracy:
0.9863
Epoch 3/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0420 - accuracy: 0.9885 - val_loss: 0.0632 - val_accuracy:
0.9838
Epoch 4/10
60000/60000 [==============================] - 139s 2ms/step - loss: 0.0354 - accuracy: 0.9904 - val_loss: 0.0400 - val_accuracy:
0.9900
Epoch 5/10
60000/60000 [==============================] - 142s 2ms/step - loss: 0.0348 - accuracy: 0.9910 - val_loss: 0.0307 - val_accuracy:
0.9916
Epoch 6/10
60000/60000 [==============================] - 139s 2ms/step - loss: 0.0294 - accuracy: 0.9919 - val_loss: 0.0318 - val_accuracy:
0.9918
Epoch 7/10
60000/60000 [==============================] - 140s 2ms/step - loss: 0.0286 - accuracy: 0.9926 - val_loss: 0.0478 - val_accuracy:
0.9879
Epoch 8/10
60000/60000 [==============================] - 132s 2ms/step - loss: 0.0222 - accuracy: 0.9942 - val_loss: 0.0405 - val_accuracy:
0.9910
Epoch 9/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0236 - accuracy: 0.9938 - val_loss: 0.0400 - val_accuracy:
0.9902
Epoch 10/10
60000/60000 [==============================] - 133s 2ms/step - loss: 0.0228 - accuracy: 0.9942 - val_loss: 0.0442 - val_accuracy:
0.9907
```

In [60]:
```
score = model4.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

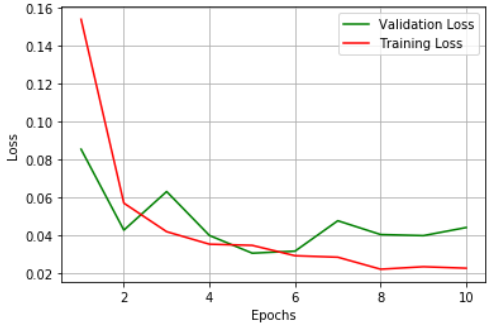
```
10000/10000 [==============================] - 7s 730us/step
Test loss: 0.044226658638985825
Test accuracy: 0.9907000064849854
```

In [61]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout rate to 0.8

In [62]:
```
model4=Sequential() # Initializing the model

# First ConvNet
model4.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))
model4.add(MaxPooling2D(pool_size=(2,2)))

model4.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))

model4.add(BatchNormalization())


model4.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))
model4.add(Dropout(0.8))



model4.add(Flatten())

#hidden_layer
model4.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dense(512,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dropout(0.8))

model4.add(Dense(num_classes,activation='softmax'))

print(model4.summary())
```

```
Model: "sequential_11"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_28 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_29 (Conv2D)           (None, 8, 8, 64)          51264
_________________________________________________________________
batch_normalization_8 (Batch (None, 8, 8, 64)          256
_________________________________________________________________
conv2d_30 (Conv2D)           (None, 4, 4, 128)         204928
_________________________________________________________________
dropout_24 (Dropout)         (None, 4, 4, 128)         0
_________________________________________________________________
flatten_11 (Flatten)         (None, 2048)              0
_________________________________________________________________
dense_22 (Dense)             (None, 256)               524544
_________________________________________________________________
dense_23 (Dense)             (None, 512)               131584
_________________________________________________________________
dropout_25 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_24 (Dense)             (None, 10)                5130
=================================================================
Total params: 918,538
Trainable params: 918,410
Non-trainable params: 128
_________________________________________________________________
None
```

In [63]:
```
model4.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [64]:
```
# Training the model

history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.3136 - accuracy: 0.9008 - val_loss: 0.0799 - val_accuracy:
0.9799
Epoch 2/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0907 - accuracy: 0.9767 - val_loss: 0.0639 - val_accuracy:
0.9834
Epoch 3/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0745 - accuracy: 0.9816 - val_loss: 0.0393 - val_accuracy:
0.9904
Epoch 4/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0632 - accuracy: 0.9840 - val_loss: 0.0421 - val_accuracy:
0.9906
Epoch 5/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0656 - accuracy: 0.9847 - val_loss: 0.0316 - val_accuracy:
0.9923
Epoch 6/10
60000/60000 [==============================] - 135s 2ms/step - loss: 0.0590 - accuracy: 0.9855 - val_loss: 0.0375 - val_accuracy:
0.9912
Epoch 7/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0555 - accuracy: 0.9866 - val_loss: 0.0328 - val_accuracy:
0.9921
Epoch 8/10
60000/60000 [==============================] - 129s 2ms/step - loss: 0.0494 - accuracy: 0.9890 - val_loss: 0.0301 - val_accuracy:
0.9922
Epoch 9/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0529 - accuracy: 0.9882 - val_loss: 0.0421 - val_accuracy:
0.9923
Epoch 10/10
60000/60000 [==============================] - 131s 2ms/step - loss: 0.0485 - accuracy: 0.9888 - val_loss: 0.0411 - val_accuracy:
0.9920
```

In [65]:
```
score = model4.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

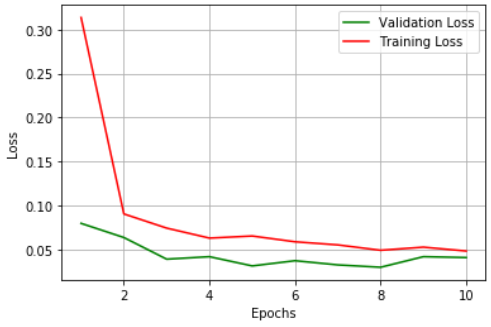
```
10000/10000 [==============================] - 8s 757us/step
Test loss: 0.04110135558335446
Test accuracy: 0.9919999837875366
```

In [66]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show()
```



Changing the dropout rate to 0.2

In [67]:
```
model4=Sequential() # Initializing the model

# First ConvNet
model4.add(Conv2D(32,kernel_size=(5,5),
                  activation='relu',
                  input_shape=input_shape))
model4.add(MaxPooling2D(pool_size=(2,2)))

model4.add(Conv2D(64,kernel_size=(5,5),
                  activation='relu'))

model4.add(BatchNormalization())


model4.add(Conv2D(128,kernel_size=(5,5),
                  activation='relu'))
model4.add(Dropout(0.2))



model4.add(Flatten())

#hidden_layer
model4.add(Dense(256,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dense(512,activation='relu',kernel_initializer='random_uniform'))

model4.add(Dropout(0.2))

model4.add(Dense(num_classes,activation='softmax'))

print(model4.summary())
```

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_31 (Conv2D)           (None, 24, 24, 32)        832
_________________________________________________________________
max_pooling2d_18 (MaxPooling (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_32 (Conv2D)           (None, 8, 8, 64)          51264
_________________________________________________________________
batch_normalization_9 (Batch (None, 8, 8, 64)          256
_________________________________________________________________
conv2d_33 (Conv2D)           (None, 4, 4, 128)         204928
_________________________________________________________________
dropout_26 (Dropout)         (None, 4, 4, 128)         0
_________________________________________________________________
flatten_12 (Flatten)         (None, 2048)              0
_________________________________________________________________
dense_25 (Dense)             (None, 256)               524544
_________________________________________________________________
dense_26 (Dense)             (None, 512)               131584
_________________________________________________________________
dropout_27 (Dropout)         (None, 512)               0
_________________________________________________________________
dense_27 (Dense)             (None, 10)                5130
=================================================================
Total params: 918,538
Trainable params: 918,410
Non-trainable params: 128
_________________________________________________________________
None
```

In [68]:
```
model4.compile(optimizer='adam',
               loss='categorical_crossentropy',
               metrics=['accuracy'])
```

In [69]:
```
# Training the model

history = model4.fit(X_train, y_train, batch_size = batch_size, epochs=nb_epoch, verbose=1, validation_data=(X_test, y_test))
```

```
Train on 60000 samples, validate on 10000 samples
Epoch 1/10
60000/60000 [==============================] - 132s 2ms/step - loss: 0.1256 - accuracy: 0.9615 - val_loss: 0.0762 - val_accuracy:
0.9854
Epoch 2/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0473 - accuracy: 0.9866 - val_loss: 0.0387 - val_accuracy:
0.9881
Epoch 3/10
60000/60000 [==============================] - 131s 2ms/step - loss: 0.0355 - accuracy: 0.9898 - val_loss: 0.0367 - val_accuracy:
0.9896
Epoch 4/10
60000/60000 [==============================] - 132s 2ms/step - loss: 0.0297 - accuracy: 0.9916 - val_loss: 0.0579 - val_accuracy:
0.9829
Epoch 5/10
60000/60000 [==============================] - 133s 2ms/step - loss: 0.0237 - accuracy: 0.9937 - val_loss: 0.0329 - val_accuracy:
0.9920
Epoch 6/10
60000/60000 [==============================] - 132s 2ms/step - loss: 0.0207 - accuracy: 0.9938 - val_loss: 0.0552 - val_accuracy:
0.9866
Epoch 7/10
60000/60000 [==============================] - 130s 2ms/step - loss: 0.0218 - accuracy: 0.9942 - val_loss: 0.0320 - val_accuracy:
0.9922
Epoch 8/10
60000/60000 [==============================] - 133s 2ms/step - loss: 0.0178 - accuracy: 0.9950 - val_loss: 0.0344 - val_accuracy:
0.9919
Epoch 9/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0155 - accuracy: 0.9955 - val_loss: 0.0542 - val_accuracy:
0.9898
Epoch 10/10
60000/60000 [==============================] - 134s 2ms/step - loss: 0.0172 - accuracy: 0.9953 - val_loss: 0.0381 - val_accuracy:
0.9927
```

In [70]:
```
score = model4.evaluate(X_test, y_test, verbose=1)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

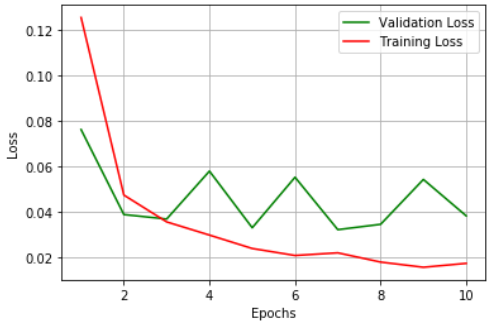
```
10000/10000 [==============================] - 7s 745us/step
Test loss: 0.038139941784558276
Test accuracy: 0.9926999807357788
```

In [71]:
```
fig,ax = plt.subplots(1,1)
ax.set_xlabel('Epochs') ; ax.set_ylabel('Loss')

# list of epoch numbers
list_of_epoch = list(range(1,nb_epoch+1))

train_loss = history.history['loss']
val_loss = history.history['val_loss']

ax.plot(list_of_epoch, val_loss, 'g', label="Validation Loss")
ax.plot(list_of_epoch, train_loss, 'r', label="Training Loss")
plt.legend()
plt.grid()
plt.show();
```



Conclusions

In [73]:
```
# Please compare all your models using Prettytable library
from prettytable import PrettyTable

x = PrettyTable()

x.field_names = ["Numer of Layers", "Kernel Size", "BatchNormalization", "Dropout", "Accuracy"]

x.add_row(["3",'3*3', 'NO','0.5', 99.08])
x.add_row(["3",'3*3', 'NO','0.8', 99.19])
x.add_row(["3",'3*3', 'NO','0.2', 99.08])


x.add_row(["4",'3*3', 'YES','0.5', 99.29])
x.add_row(["4",'3*3', 'YES','0.8', 93.98])
x.add_row(["4",'3*3', 'YES','0.2', 99.21])

x.add_row(["4",'5*5', 'YES','0.5', 99.43])
x.add_row(["4",'5*5', 'YES','0.8', 98.33])
x.add_row(["4",'5*5', 'YES','0.2', 99.29])

x.add_row(["5",'5*5', 'YES','0.5', 99.07])
x.add_row(["5",'5*5', 'YES','0.8', 99.19])
x.add_row(["5",'5*5', 'YES','0.2', 99.26])



print(x)
```

```
+-----------------+-------------+--------------------+---------+----------+
| Numer of Layers | Kernel Size | BatchNormalization | Dropout | Accuracy |
+-----------------+-------------+--------------------+---------+----------+
|        3        |     3*3     |         NO         |   0.5   |  99.08   |
|        3        |     3*3     |         NO         |   0.8   |  99.19   |
|        3        |     3*3     |         NO         |   0.2   |  99.08   |
|        4        |     3*3     |        YES         |   0.5   |  99.29   |
|        4        |     3*3     |        YES         |   0.8   |  93.98   |
|        4        |     3*3     |        YES         |   0.2   |  99.21   |
|        4        |     5*5     |        YES         |   0.5   |  99.43   |
|        4        |     5*5     |        YES         |   0.8   |  98.33   |
|        4        |     5*5     |        YES         |   0.2   |  99.29   |
|        5        |     5*5     |        YES         |   0.5   |  99.07   |
|        5        |     5*5     |        YES         |   0.8   |  99.19   |
|        5        |     5*5     |        YES         |   0.2   |  99.26   |
+-----------------+-------------+--------------------+---------+----------+
```