Recurrent Neural Network

In this task, we implement RNN cells to understand the computation of RNN. Then we build RNN with different cells for a language modeling task.

In [1]:
```
# As usual, a bit of setup
import time
import numpy as np
import tensorflow as tf
import matplotlib.pyplot as plt


%matplotlib inline
plt.rcParams['figure.figsize'] = (10.0, 8.0) # set default size of plots
plt.rcParams['image.interpolation'] = 'nearest'
plt.rcParams['image.cmap'] = 'gray'

# for auto-reloading external modules
# see http://stackoverflow.com/questions/1907993/autoreload-of-modules-in-i
%load_ext autoreload
%autoreload 2

def rel_error(x, y):
    """ returns relative error """
    return np.max(np.abs(x - y) / (np.maximum(1e-8, np.abs(x) + np.abs(y)))
```

Recurrent Neural Networks

A toy problem

In [2]:
```
## Setup an example. Provide sizes and the input data.

# set sizes
time_steps = 5
batch_size = 4
input_size = 3
hidden_size = 2

# create input data with shape [batch_size, time_steps, num_features]
np.random.seed(15009)
input_data = np.random.rand(batch_size, time_steps, input_size).astype(np.f
```

Implement an RNN and a GRU with tensorflow

In [3]:
```
## Create an RNN model
tf.reset_default_graph()
tf.random.set_random_seed(15009)

# initialize a state of zero for both RNN and GRU
# 'state' is a tensor of shape [batch_size, hidden_size]
init_state = np.zeros([batch_size, hidden_size])
initial_state = tf.Variable(init_state, dtype=tf.float32)

# create a BasicRNNCell
rnn_cell = tf.nn.rnn_cell.BasicRNNCell(hidden_size)


# 'outputs' is a tensor of shape [batch_size, max_time, hidden_size]
# RNN cell outputs the hidden state directly, so the output at each step is
# final_state is the last state of the sequence. final_state == outputs[:,
rnn_outputs, rnn_final_state = tf.nn.dynamic_rnn(rnn_cell, input_data,
                                   initial_state=initial_state,
                                   dtype=tf.float32)



# create a GRUCell
gru_cell = tf.nn.rnn_cell.GRUCell(hidden_size)

# 'outputs' is a tensor of shape [batch_size, time_steps, hidden_size]
# Same as the basic RNN cell, final_state == outputs[:, -1, :]
gru_outputs, gru_final_state = tf.nn.dynamic_rnn(gru_cell, input_data,
                                   initial_state=initial_state,
                                   dtype=tf.float32)




# initialize variables
init = tf.global_variables_initializer()
session = tf.Session()
session.run(init)

# run the RNN model and get outputs and the final state
tfrnn_outputs, tfrnn_final_state = session.run([rnn_outputs, rnn_final_stat

# run the GRU model and get outputs and the final state
tfgru_outputs, tfgru_final_state = session.run([gru_outputs, gru_final_stat
```

```
WARNING:tensorflow:From /Users/thomasklimek/anaconda3/lib/python3.7/site-
packages/tensorflow/python/framework/op_def_library.py:263: colocate_with
(from tensorflow.python.framework.ops) is deprecated and will be removed
in a future version.
Instructions for updating:
Colocations handled automatically by placer.
WARNING:tensorflow:From <ipython-input-3-40b6cc66db36>:11: BasicRNNCell._
_init__ (from tensorflow.python.ops.rnn_cell_impl) is deprecated and will
be removed in a future version.
Instructions for updating:
This class is equivalent as tf.keras.layers.SimpleRNNCell, and will be re
placed by that in Tensorflow 2.0.
WARNING:tensorflow:From <ipython-input-3-40b6cc66db36>:19: dynamic_rnn (f
rom tensorflow.python.ops.rnn) is deprecated and will be removed in a fut
```

```
ure version.
Instructions for updating:
Please use `keras.layers.RNN(cell)`, which is equivalent to this API
WARNING:tensorflow:From <ipython-input-3-40b6cc66db36>:23: GRUCell.__init
__ (from tensorflow.python.ops.rnn_cell_impl) is deprecated and will be r
emoved in a future version.
Instructions for updating:
This class is equivalent as tf.keras.layers.GRUCell, and will be replaced
by that in Tensorflow 2.0.
```

Read out parameters from RNN and GRU cells

In [4]:

```python
from rnn_param_helper import get_rnn_params, get_gru_params

#########################################################################
# 0. Understand TF BasicRNN and GRU parameters (0 points)
# Please read the code and documentation of get_rnn_params and get_gru_para
# what are these parameters. You will need to use these parameters in your
# NO implementation is needed here.
#########################################################################

wt_h, wt_x, bias = get_rnn_params(rnn_cell, session)
wtu_h, wtu_x, biasu, wtr_h, wtr_x, biasr, wtc_h, wtc_x, biasc = get_gru_par
```

Numpy Implementation

Implement your own RNN model with numpy. Your implementation needs to match the tensorflow calculation.

In [6]:
```
##########################################################################
# 1. Implementation (9 points)
# Implement your basic RNN and GRU RNN in implementations/rnn.py and compar
# tensorflow functions
##########################################################################

from implementations.rnn import rnn,gru

# calculation from your own implemenation of a basic RNN
nprnn_outputs, nprnn_final_state = rnn(wt_h, wt_x, bias, init_state, input_

print("Difference between your RNN implementation and tf RNN",
                     rel_error(tfrnn_outputs, nprnn_outputs) + rel_error(tf

# calculation from your own implemenation of a GRU RNN
npgru_outputs, npgru_final_state = gru(wtu_h, wtu_x, biasu, wtr_h, wtr_x, b

print("Difference between your GRU implementation and tf GRU",
      rel_error(tfgru_outputs, npgru_outputs) + rel_error(tfgru_final_state
```

```
Difference between your RNN implementation and tf RNN 2.1863736249496377e
-07
Difference between your GRU implementation and tf GRU 0.9037854511656668
```

GRU includes RNN as a special case

Can you assign a special set of parameters to GRU such that its outputs is almost the same as RNN?

In [7]:
```
# Assign some value to a parameter of GRU

##########################################################################
# 2. Setting GRU weights (4 points)
# Get weights/bias from the basic RNN and set them to some GRU weights/bias
# Then set some other parameter of GRU, then GRU recovers RNN.
##########################################################################

#session.run(gru_cell.weights[0].assign(??))
#session.run(gru_cell.weights[1].assign(??))
#session.run(gru_cell.weights[2].assign(??))
#session.run(gru_cell.weights[3].assign(??))

# outputs from the GRU with special parameters.
updated_outputs = session.run(gru_outputs)

# they are the same as the calculation from the basic RNN
print("Difference between RNN and a special GRU", rel_error(tfrnn_outputs,
```

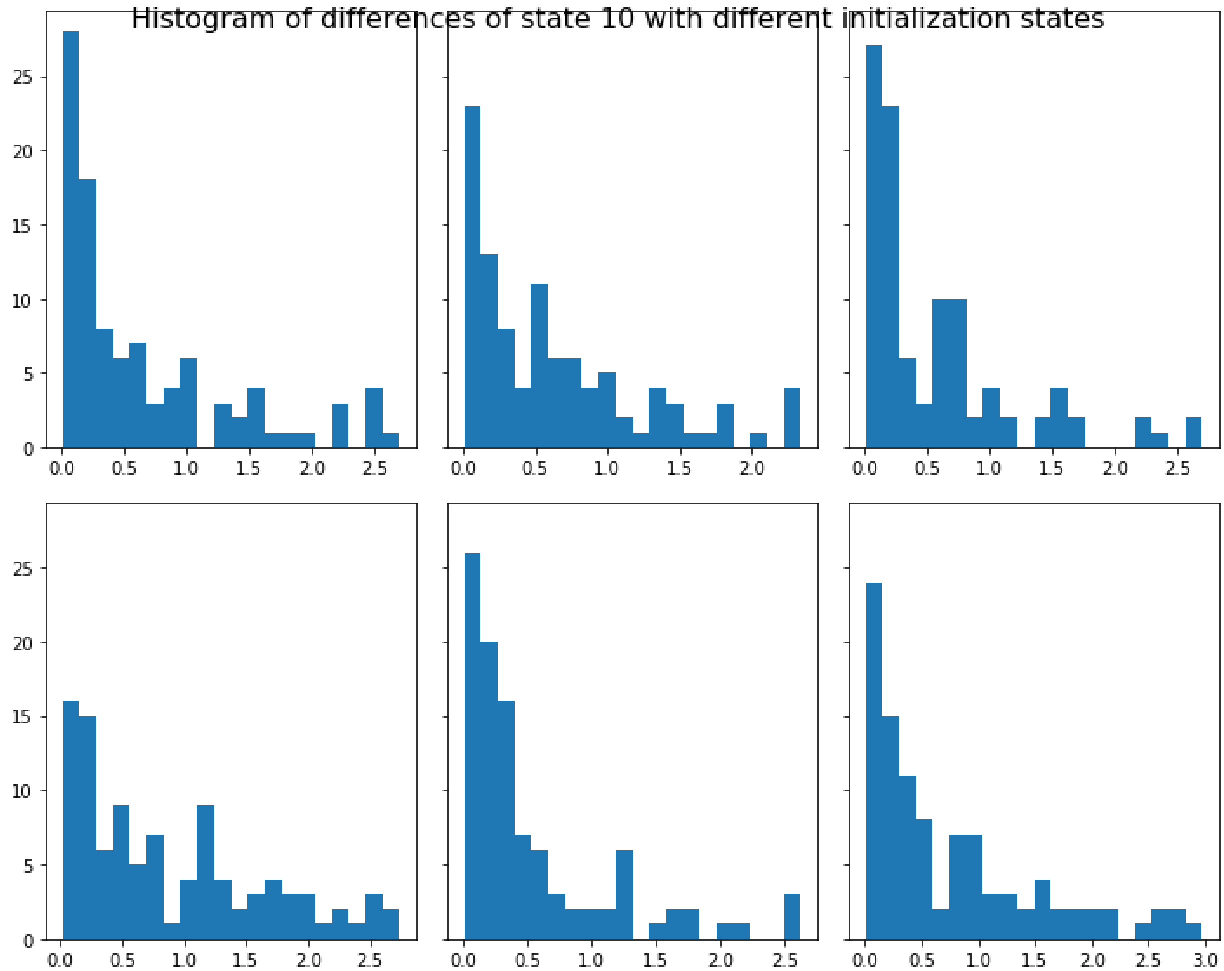
```
Difference between RNN and a special GRU 1.0
```

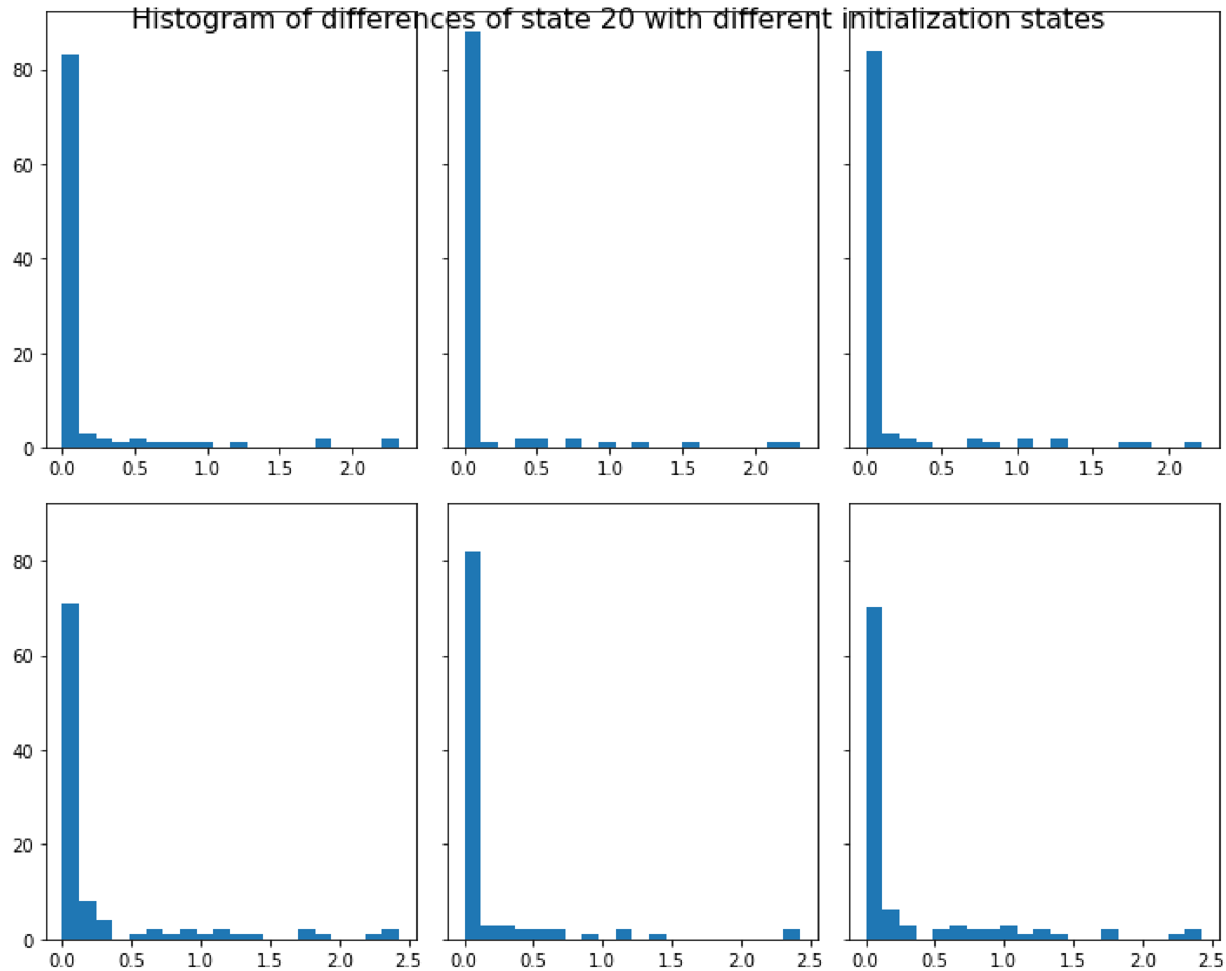
Long term dependency: forward

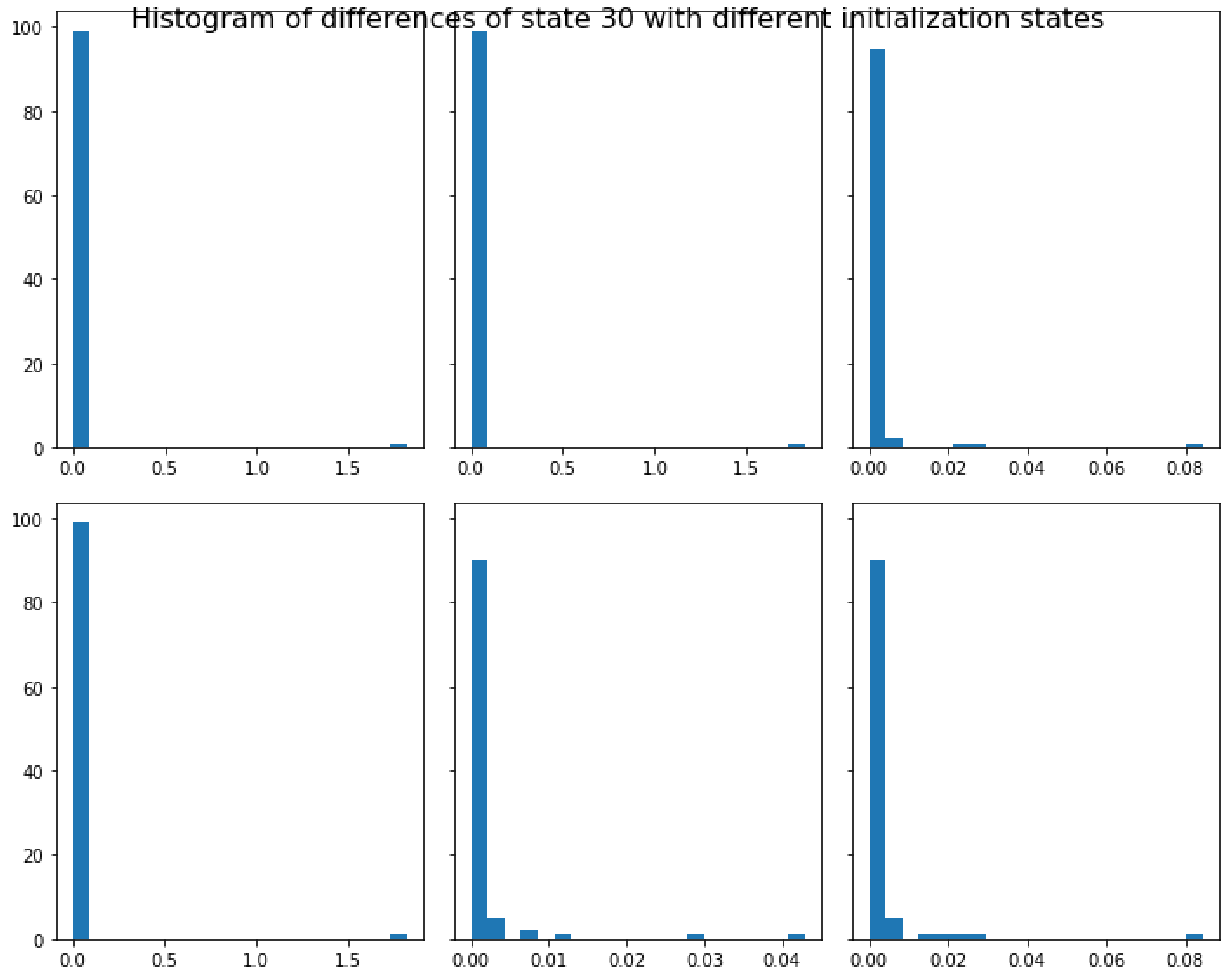
In this experiment, you will see that the basic RNN model is hard to keep long term dependency

In [346]:
```
from rnn_param_helper import set_rnn_params, set_gru_params

# Create a larger problem

# set sizes
time_steps = 50
batch_size = 100
input_size = 5
hidden_size = 8

# create input data with shape [batch_size, time_steps, num_features]
np.random.seed(15009)
input_data = np.random.rand(batch_size, time_steps, input_size).astype(np.f

## Create an RNN model with GRU
tf.reset_default_graph()
tf.random.set_random_seed(15009)

# copy the basic RNN and the GRU RNN above here:

initial_state = tf.Variable(np.zeros([batch_size, hidden_size]), dtype=tf.f

###########################################################################
# 3. Apply TF RNN functions (2 points)
# Please use the tensorflow function for the basic RNN and the GRU RNN belo
# from the larger problem. Basically you just need to copy some code above
###########################################################################

#rnn_outputs, _ = tf.nn.dynamic_rnn(rnn_cell, ...) # please complete this l
#gru_outputs, _ = tf.nn.dynamic_rnn(gru_cell, ...) # please complete this l

# initialize variables
init = tf.global_variables_initializer()
session = tf.Session()
session.run(init)



def show_hist_of_hidden_values(session, initial_state, state, title):
    """Set `initial_state` to different values and run the `state` value. C
       values due to different initializations. If the model cannot capture
       initialization does not have much effect to the value of `state` at
    """

    batch_size, hiddens_size = state.get_shape()

    # intialize the model with different initial states and then calculate
    init_zero = np.zeros([batch_size, hidden_size])
    session.run(initial_state.assign(init_zero))
    state_zero_init = session.run(state)

    init_rand1 = np.random.rand(batch_size, hidden_size)
    session.run(initial_state.assign(init_rand1))
    state_rand1_init = session.run(state)

    init_rand2 = np.random.rand(batch_size, hidden_size)
```

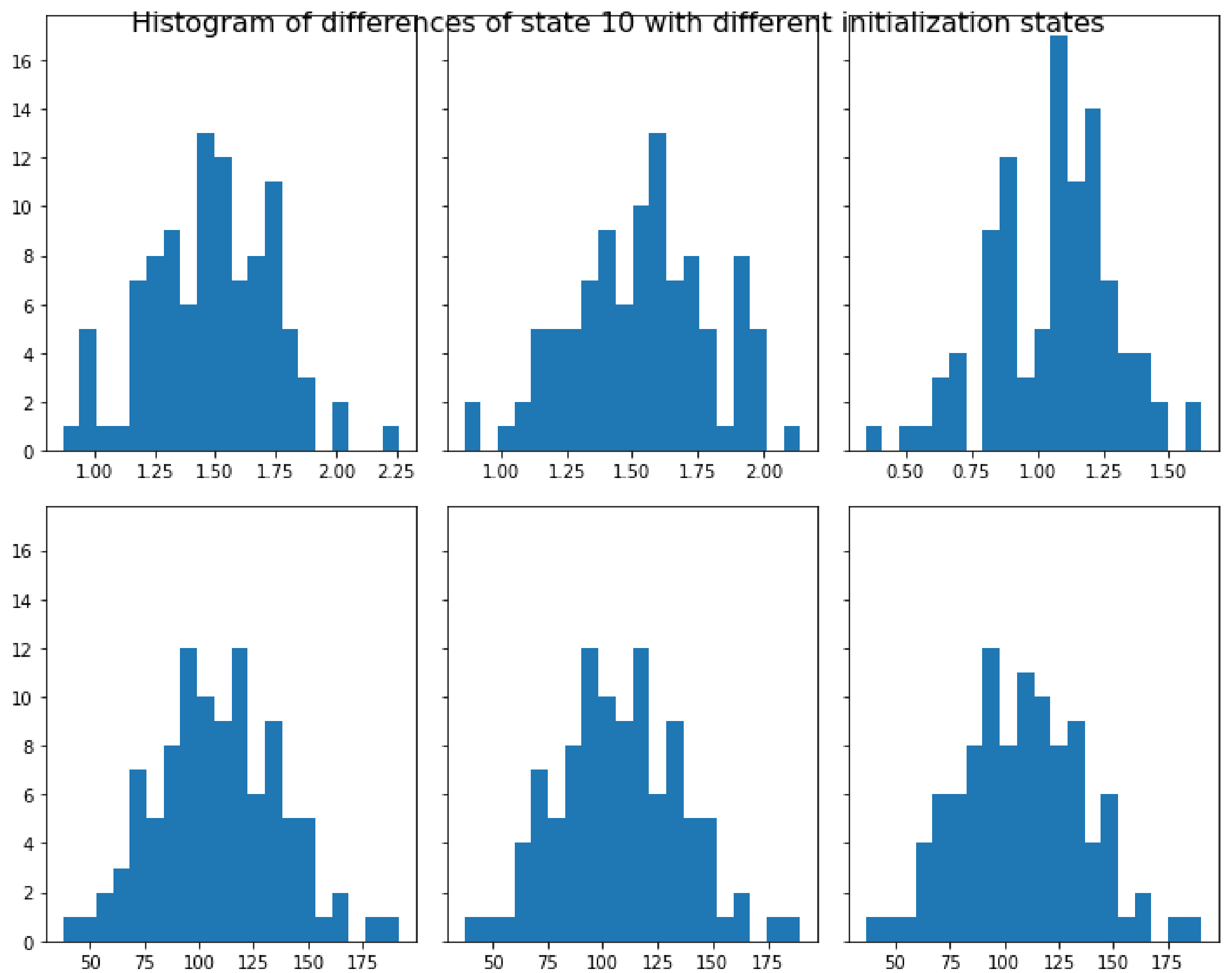
```
    session.run(initial_state.assign(init_rand2))
    state_rand2_init = session.run(state)

    init_scaleup1 = init_rand1 * 100
    session.run(initial_state.assign(init_scaleup1))
    state_scaleup1_init = session.run(state)

    # plot the difference between the four difference settings

    # For each sequence, calculate the norm of the difference of the states
    norm_diff1 = np.linalg.norm(state_zero_init - state_rand1_init, axis=1)
    norm_diff2 = np.linalg.norm(state_zero_init - state_rand2_init, axis=1)
    norm_diff3 = np.linalg.norm(state_rand1_init - state_rand2_init, axis=1
    norm_diff4 = np.linalg.norm(state_scaleup1_init - state_zero_init, axis
    norm_diff5 = np.linalg.norm(state_scaleup1_init - state_rand1_init, axi
    norm_diff6 = np.linalg.norm(state_scaleup1_init - state_rand2_init, axi

    # plot the histogram of norms of differences
    n_bins = 20
    fig, axs = plt.subplots(2, 3, sharey=True, tight_layout=True)
    plt.suptitle(title, fontsize=16)

    axs[0, 0].hist(norm_diff1, bins=n_bins)
    axs[0, 1].hist(norm_diff2, bins=n_bins)
    axs[0, 2].hist(norm_diff3, bins=n_bins)
    axs[1, 0].hist(norm_diff4, bins=n_bins)
    axs[1, 1].hist(norm_diff5, bins=n_bins)
    axs[1, 2].hist(norm_diff6, bins=n_bins)




# set values for the basic RNN model

# play with the scale, and see if you can find any value that achieves long
scale = 2.0
wt_h = (np.random.rand(hidden_size, hidden_size) - 0.5) * scale
wt_x = (np.random.rand(input_size, hidden_size) - 0.5) * scale
bias = (np.random.rand(hidden_size) - 0.5) * scale

set_rnn_params(rnn_cell, session, wt_h, wt_x, bias)

# get the 10th state and check its dependency on the initial state
rnn_state10 = tf.transpose(rnn_outputs, [1, 0, 2])[10]
show_hist_of_hidden_values(session, initial_state, rnn_state10,
                           'Histogram of differences of state 10 with diffe

# get the 20th state and check its dependency on the initial state
rnn_state20 = tf.transpose(rnn_outputs, [1, 0, 2])[20]
show_hist_of_hidden_values(session, initial_state, rnn_state20,
                           'Histogram of differences of state 20 with diffe

# get the 20th state and check its dependency on the initial state
rnn_state30 = tf.transpose(rnn_outputs, [1, 0, 2])[30]
show_hist_of_hidden_values(session, initial_state, rnn_state30,
                           'Histogram of differences of state 30 with diffe
```

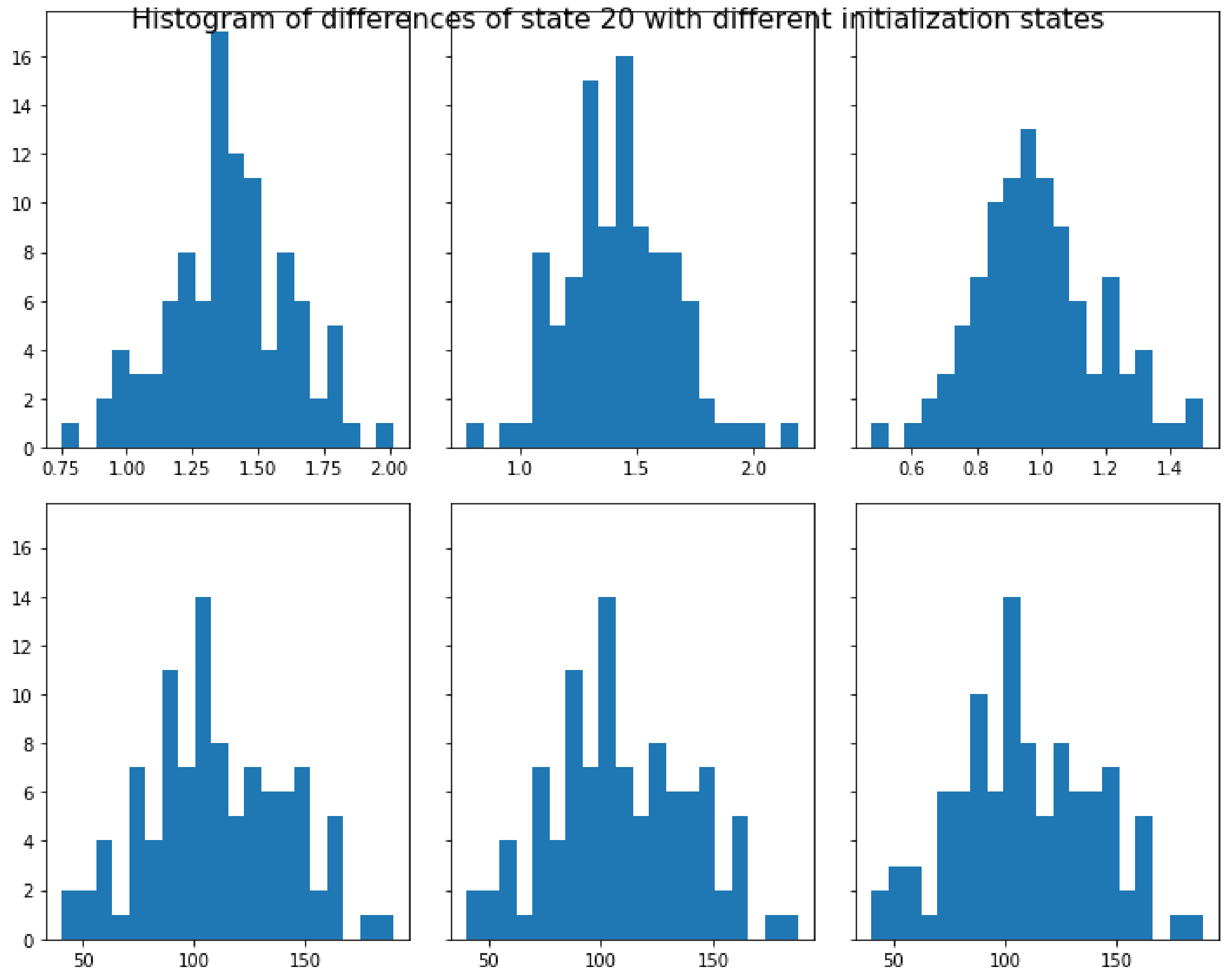

Histogram of differences of state 10 with different initialization states
0
5
10
15
20
25
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Histogram of differences of state 20 with different initialization states
0
20
40
60
80
0.0
0.5
1.0
1.5
2.0
2.5

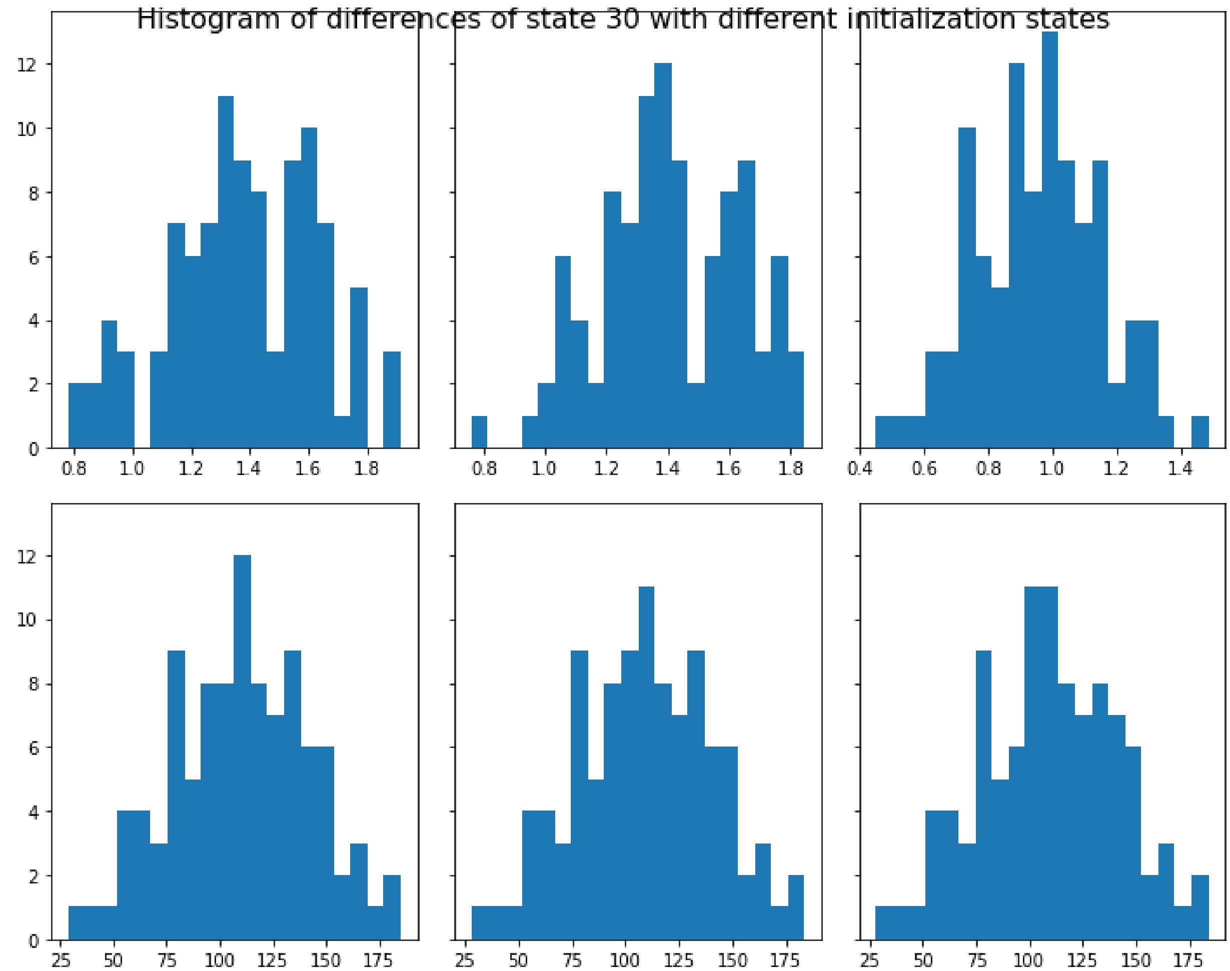

Histogram of differences of state 30 with different initialization states
100
80
60
40
20
0
0.0
0.5
1.0
1.5
0.00
0.01
0.02
0.03
0.04
0.06
0.08

In [347]:
```
# Can you set GRU parameters such that it maintains the initial state in th

scale_gru = 5.0

##########################################################################
# 4. Setting GRU parameters (4 points)                                   #
# Set GRU parameters here so that it can capture long term dependency    #
##########################################################################

# get the 10th state
gru_state10 = tf.transpose(gru_outputs, [1, 0, 2])[10]
show_hist_of_hidden_values(session, gru_state10,
                           'Histogram of differences of state 10 with diffe

# get the 20th state
gru_state20 = tf.transpose(gru_outputs, [1, 0, 2])[20]
show_hist_of_hidden_values(session, gru_state20,
                           'Histogram of differences of state 20 with diffe

# get the 20th state
gru_state30 = tf.transpose(gru_outputs, [1, 0, 2])[30]
show_hist_of_hidden_values(session, gru_state30,
                           'Histogram of differences of state 30 with diffe
```





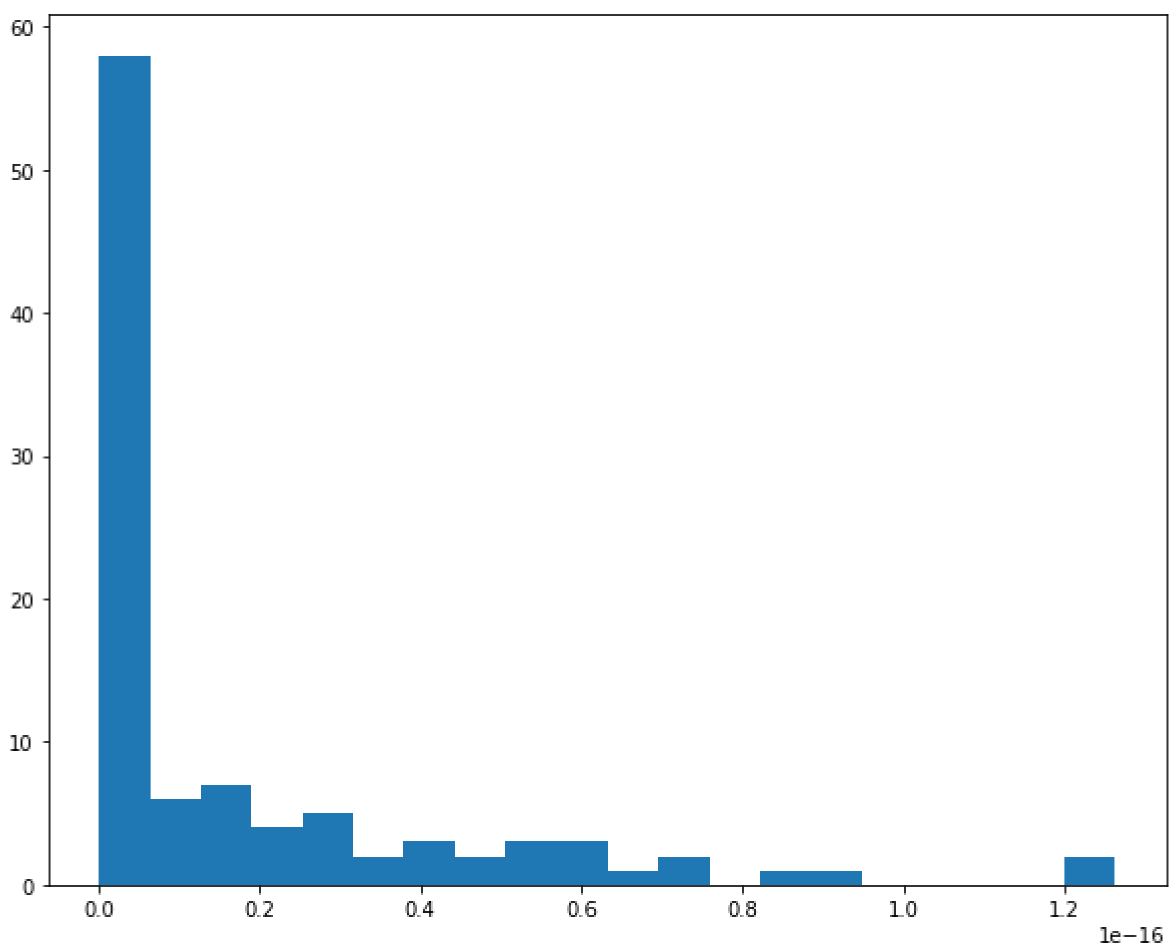
Histogram of differences of state 20 with different initialization states
0 2 4 6 8 10 12 14 16
0.75 1.00 1.25 1.50 1.75 2.00
1.0 1.5 2.0
0.6 0.8 1.0 1.2 1.4
50 100 150



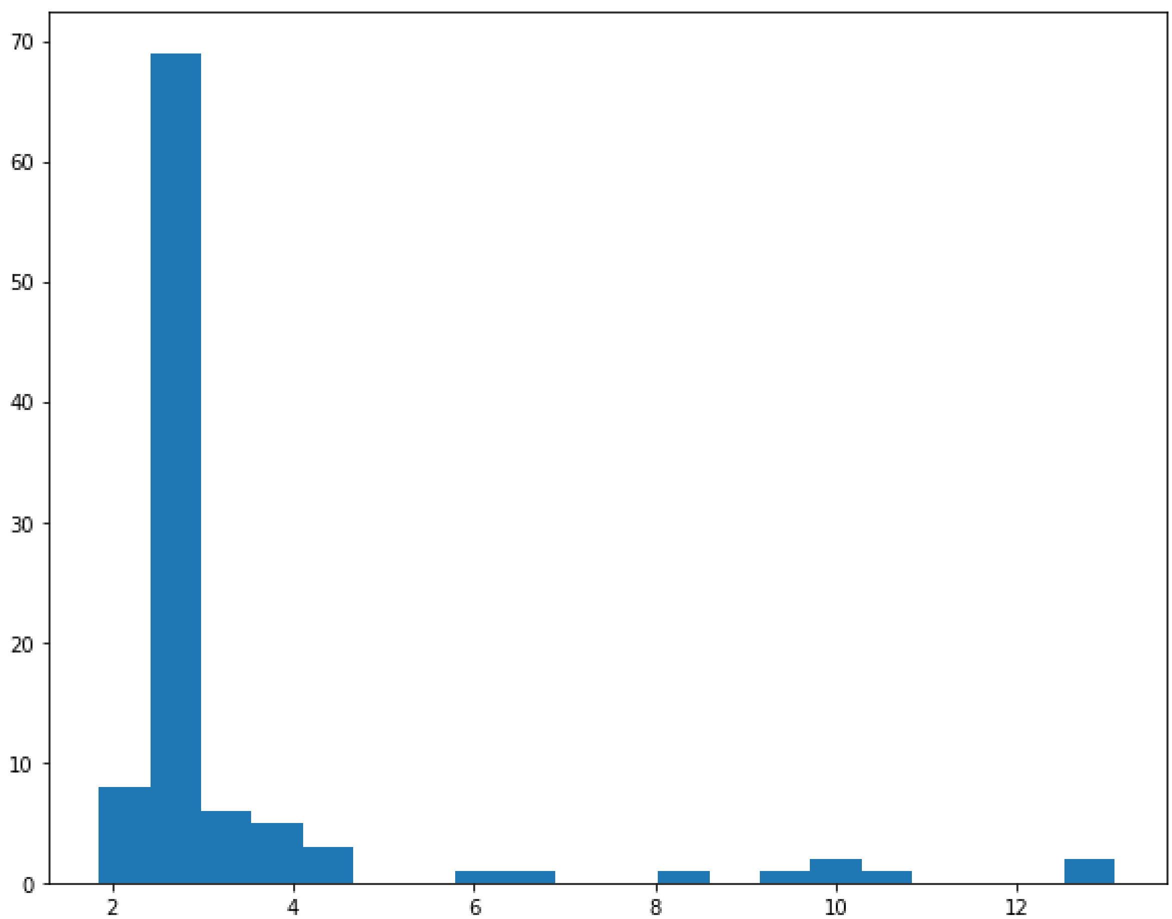
Backpropagation: vanishing gradients and exploding gradients

In the experiment, you will observe vanishing gradients and exploding gradients

In [372]:
```
# Calculate gradient with respect to the initial state

# the gradient with respect to state 30 is [1, 1, ..., 1]. Propagate the gr
rnn_loss30 = tf.reduce_sum(rnn_state30)
rnn_gradh = tf.gradients([rnn_loss30], [initial_state])[0]

scale = 1.0
wt_h = (np.random.rand(hidden_size, hidden_size) - 0.5) * scale
wt_x = (np.random.rand(input_size, hidden_size) - 0.5) * scale
bias = (np.random.rand(hidden_size) - 0.5) * scale
set_rnn_params(rnn_cell, session, wt_h, wt_x, bias)


##########################################################################
# 5. Observe vanishing gradients (3 points)
# Try a different settings of the parameters and see if you still get vanis
##########################################################################


# show the norms of gradients. Most of them are zero.
np_rnn_gradh = session.run(rnn_gradh)
rnn_grad_norm = np.linalg.norm(np_rnn_gradh, axis=1)

n_bins = 20
_ = plt.hist(rnn_grad_norm, bins=n_bins)
```



In [376]:
```
# Can you set GRU parameters such that the gradient does not vanish?

# the gradient with respect to state 30 is [1, 1, ..., 1]. Propagate the gr
gru_loss30 = tf.reduce_sum(gru_state30)
gru_gradh = tf.gradients([gru_loss30], [initial_state])[0]



##########################################################################
# 6. GRU parameters that don't have vanishing gradients (3 points)
# Set GRU parameters so that the gradient of a later state with respect to
# initial state is not near zero.
##########################################################################

# show norms of gradients
np_gru_gradh = session.run(gru_gradh)
gru_grad_norm = np.linalg.norm(np_gru_gradh, axis=1)

n_bins = 20
_ = plt.hist(gru_grad_norm, bins=n_bins)
```



In [ ]: