CS231A CA Session
PSet4 Review

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03/04/2022

Outline

- Extended Kalman Filter
- A brief Introduction to Tensorflow

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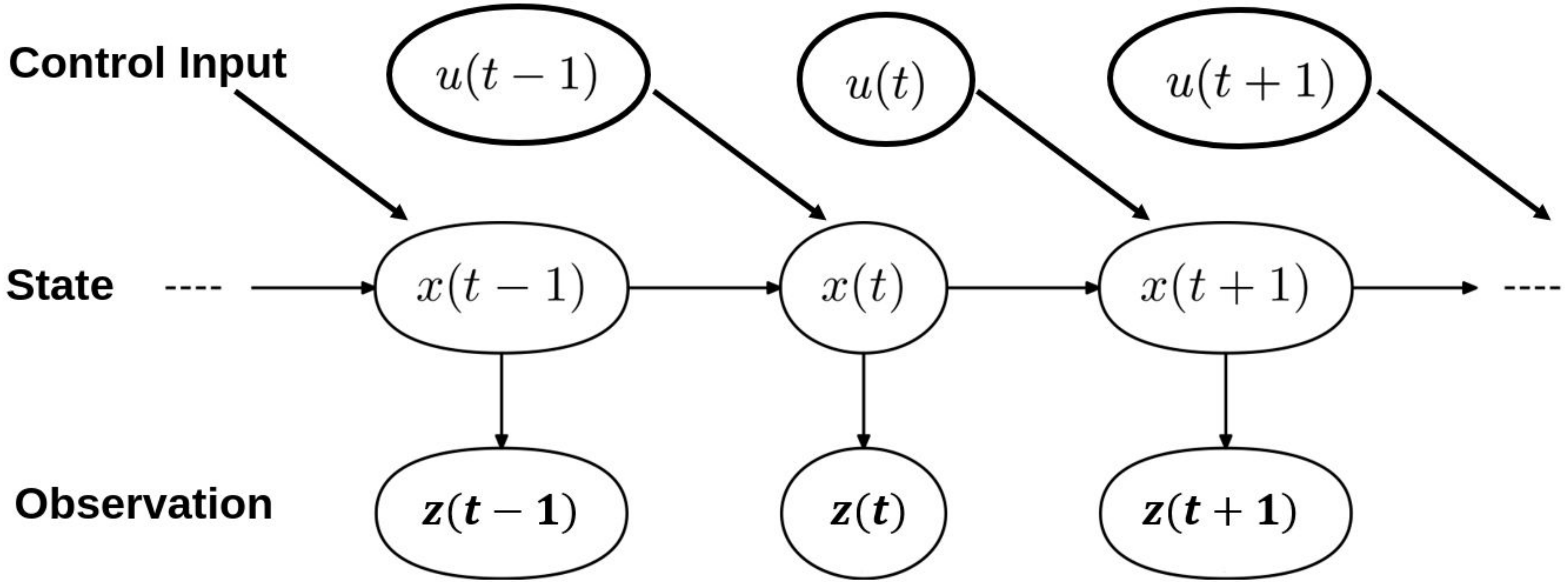
- **Extended Kalman Filter**
- A brief Introduction to Tensorflow

Dynamical System



Kalman Filter

An algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe.

Source: Wikipedia

Kalman Filter

An algorithm that uses a series of **measurements observed over time**, containing **statistical noise** and other inaccuracies, and produces **estimates of unknown variables** that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe.

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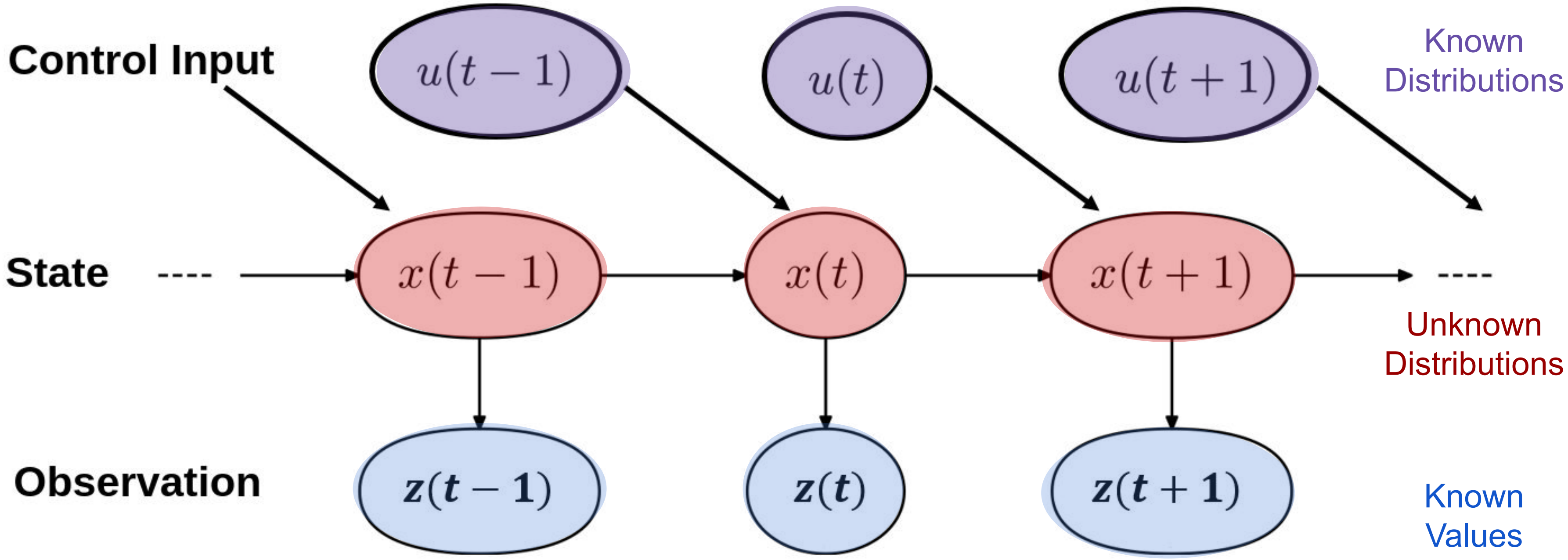
To make it even more illustrative ->

What does Kalman Filter do?



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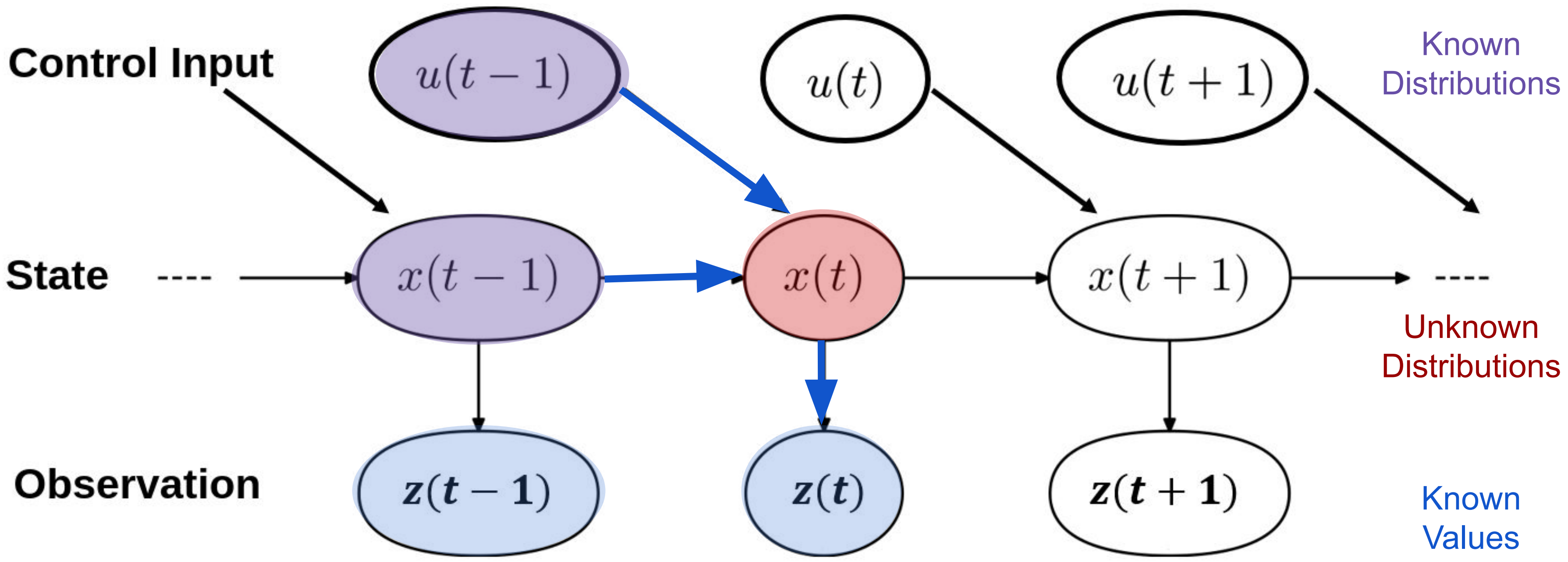

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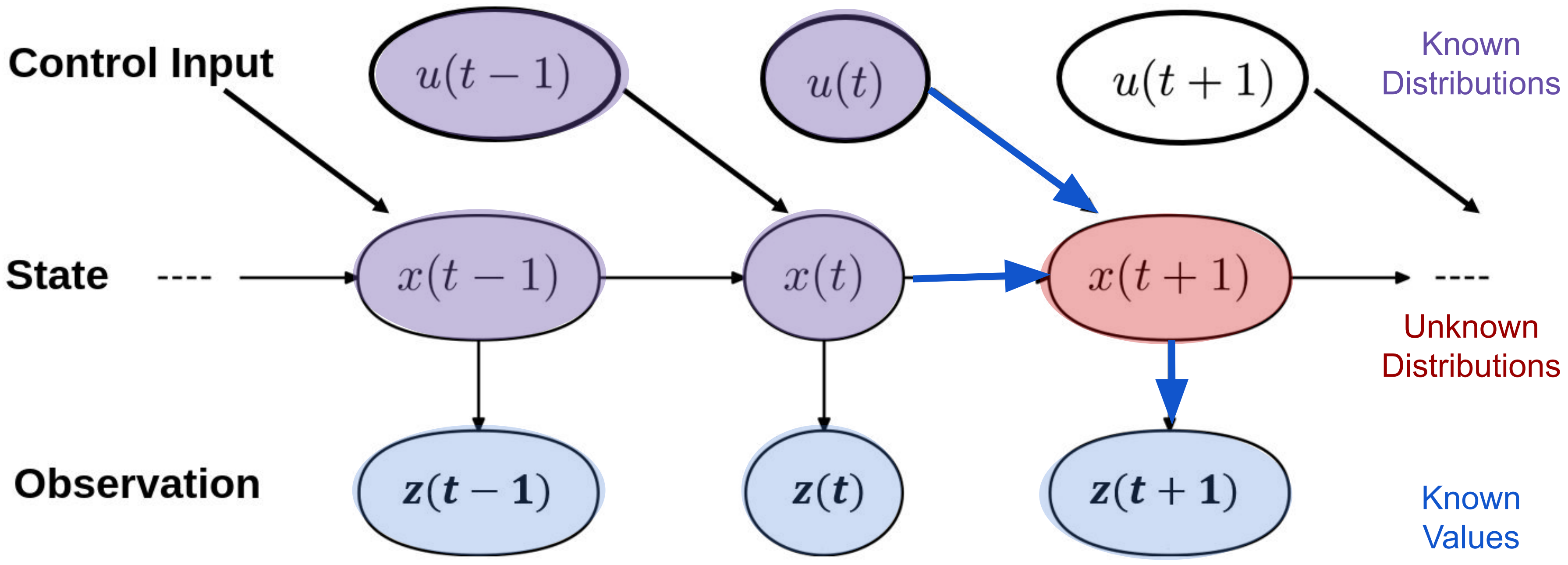

Extended Kalman Filter

- Extended Kalman filter (EKF) is heuristic for nonlinear filtering problem.
- Often works well (when tuned properly), but sometimes not.
- Widely used in practice.

Based on

- Linearizing dynamics and output functions at current estimate.
- Propagating an approximation of the conditional expectation and covariance.

Source: EE363

Extended Kalman Filter

- Extended Kalman filter (EKF) is heuristic for **nonlinear** filtering problem.
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Source: EE363

Implementing Extended Kalman Filter

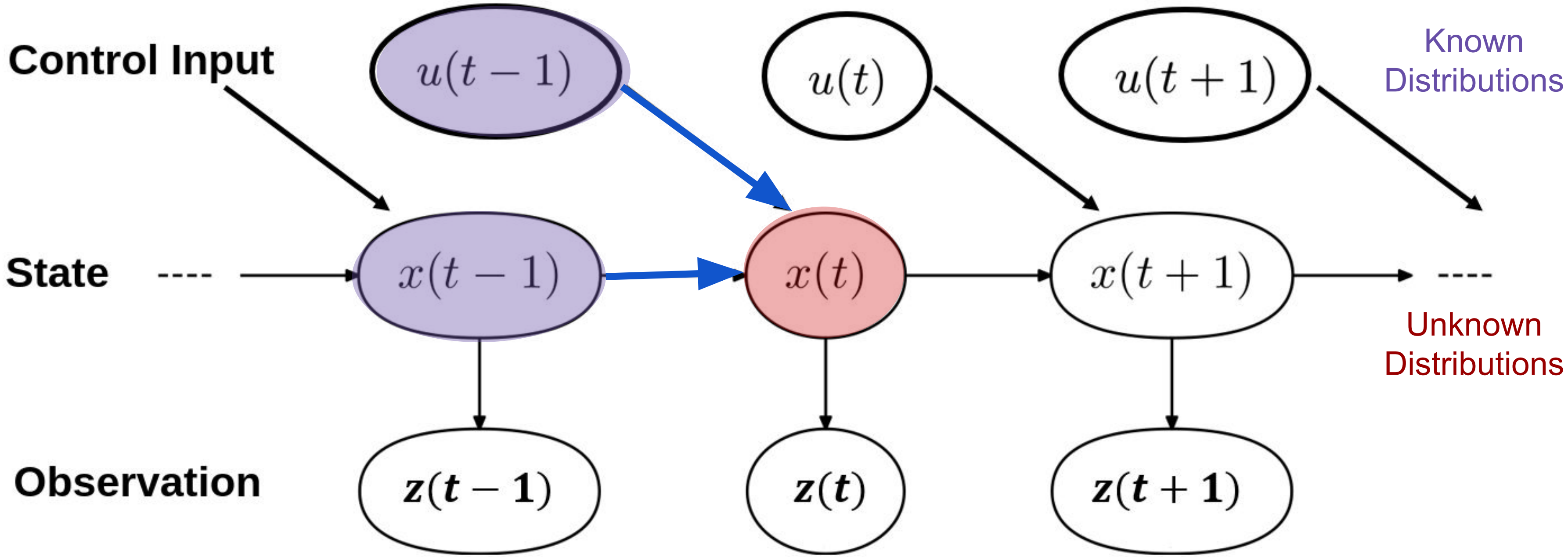
- Define the state, the control, and the noise
- Derive the system and the observation
- Compute the current Jacobian matrix (*linearizing dynamics*)
- Compute the distribution of the current state
- Iterate this process across time

Define the State

$$x_t = \begin{bmatrix} p_t^x \\ p_t^y \\ p_t^z \\ v_t^x \\ v_t^y \\ v_t^z \end{bmatrix}$$

State: 6-dimensional vector (position, velocity)

Define the System Matrix

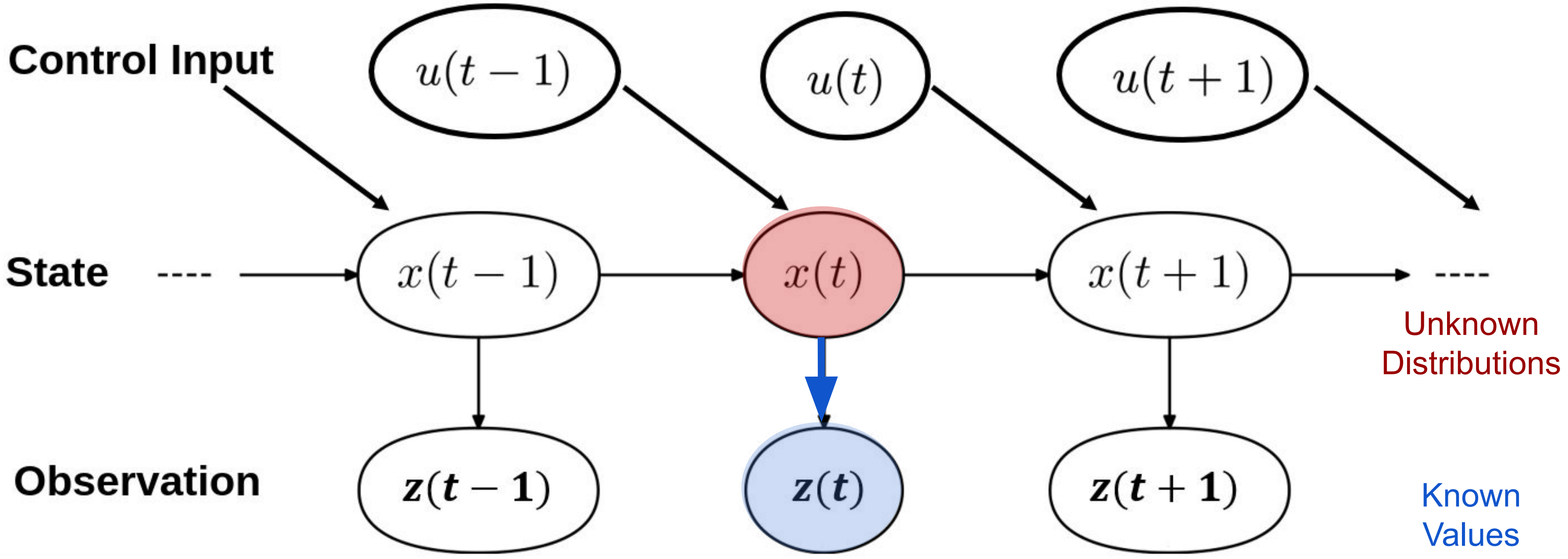


Define the System Matrix

$$x_t = \begin{bmatrix} p_t^x \\ p_t^y \\ p_t^z \\ v_t^x \\ v_t^y \\ v_t^z \end{bmatrix}$$

$$x_{t+1} = Ax_t + \epsilon_t$$

Define the Observation



Define the Observation

$$z_t = h(x_t) + v_t$$

Observation in Q1: 2-dimensional vector (pixel location)

Observation in Q2: 3-dimensional vector (pixel location, disparity)

$h(x_t)$ can be derived using the camera model we learned from previous lectures.

Computing the Jacobian

$$\mathbf{J} = \begin{bmatrix} \dfrac{\partial \mathbf{f}}{\partial x_1} & \cdots & \dfrac{\partial \mathbf{f}}{\partial x_n} \end{bmatrix} = \begin{bmatrix} \nabla^{\mathrm{T}} f_1 \\ \vdots \\ \nabla^{\mathrm{T}} f_m \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f_1}{\partial x_1} & \cdots & \dfrac{\partial f_1}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \dfrac{\partial f_m}{\partial x_1} & \cdots & \dfrac{\partial f_m}{\partial x_n} \end{bmatrix}$$

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- **A brief Introduction to Tensorflow**

Tensorflow v.s. PyTorch

Tensorflow

```
input = tf.placeholder(shape=[None, 480, 640, 3], dtype=tf.float32)
label = tf.placeholder(shape=[None, 3], dtype = tf.float32)
predict = make_model(input)
loss, optimizer = make_optimizer(predict, label)
saver = tf.train.Saver()

batch_size = 16
num_epochs = 15

sess=tf.Session()
sess.run(tf.global_variables_initializer())
train_losses = []
test_losses = []
for i in tqdm(range(num_epochs), desc='Training'):
    train_index = np.random.permutation(label_train.shape[0])
    current = 0

    losses = []
    while current < label_train.shape[0]:
        batch_image_train = image_train[train_index[current:min(current+batch_size, label_train.shape[0])]]
        batch_label_train = label_train[train_index[current:min(current+batch_size, label_train.shape[0])]]
        loss_val, _ = sess.run([loss, optimizer], feed_dict={input:batch_image_train, label:batch_label_train})
        losses.append(loss_val)
        current = min(current+batch_size, label_train.shape[0])
    train_losses.append(np.mean(losses))

    test_index = np.random.permutation(label_test.shape[0])
    current = 0
    losses = []
    while current < label_test.shape[0]:
        batch_image_test = image_test[test_index[current:min(current+batch_size, label_test.shape[0])]]
        batch_label_test = label_test[test_index[current:min(current+batch_size, label_test.shape[0])]]
        loss_val = sess.run(loss, feed_dict={input:batch_image_test, label:batch_label_test})
        losses.append(loss_val)
        current = min(current+batch_size, label_test.shape[0])
    test_losses.append(np.mean(losses))

    saver.save(sess, 'trained_model')
    if i > 1:
      clear_output()
      fig, (ax1, ax2) = plt.subplots(1, 2)
      ax1.plot(train_losses)
      ax2.plot(test_losses)
      ax1.set_xlabel('Epoch')
      ax1.set_ylabel('Train Loss')
      ax2.set_xlabel('Epoch')
      ax2.set_ylabel('Test Loss')
      plt.show()
print("Final training loss: ", train_losses[-1])
print("Final testing loss: ", test_losses[-1])
```

Tensorflow

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        losses.append(loss_val)
        current = min(current+batch_size, label_train.shape[0])
    train_losses.append(np.mean(losses))

    test_index = np.random.permutation(label_test.shape[0])
    current = 0
    losses = []
    while current < label_test.shape[0]:
        batch_image_test = image_test[test_index[current:min(current+batch_size, label_test.shape[0])]]
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        loss_val = sess.run(loss, feed_dict={input:batch_image_test, label:batch_label_test})
        losses.append(loss_val)
        current = min(current+batch_size, label_test.shape[0])
    test_losses.append(np.mean(losses))

    saver.save(sess, 'trained_model')
    if i > 1:
      clear_output()
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      ax1.plot(train_losses)
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      ax1.set_xlabel('Epoch')
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Define the graph

Initialize the session

Run the session

Defining the Graph

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Running the Session

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loss_val = sess.run(loss, feed_dict={input:batch_image_test, label:batch_label_test})
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Running the Session

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```
loss_val = sess.run(loss, feed_dict={input:batch_image_test, label:batch_label_test})
```

Neural Network Architecture

```
def make_model(input):
    conv1_1 = tf.layers.conv2d(input, 32, 3, padding='same')
    conv1_1 = tf.layers.batch_normalization(conv1_1)
    conv1_1 = tf.nn.relu(conv1_1)
    conv1_2 = tf.layers.conv2d(conv1_1, 32, 3, padding='same')
    conv1_2 = tf.layers.batch_normalization(conv1_2)
    conv1_2 = tf.nn.relu(conv1_2)
    pool_1 = tf.nn.max_pool(conv1_2, [1, 2, 2, 1], [1, 2, 2, 1],
                            padding='SAME')
    conv2_1 = tf.layers.conv2d(pool_1, 64, 3, padding='same')
    conv2_1 = tf.layers.batch_normalization(conv2_1)
    conv2_1 = tf.nn.relu(conv2_1)
    conv2_2 = tf.layers.conv2d(conv2_1, 64, 3, padding='same')
    conv2_2 = tf.layers.batch_normalization(conv2_2)
    conv2_2 = tf.nn.relu(conv2_2)
    pool_2 = tf.nn.max_pool(conv2_2, [1, 2, 2, 1], [1, 2, 2, 1],
                            padding='SAME')
    conv3_1 = tf.layers.conv2d(pool_2, 128, 3, padding='same')
    conv3_1 = tf.layers.batch_normalization(conv3_1)
    conv3_1 = tf.nn.relu(conv3_1)
    conv3_2 = tf.layers.conv2d(conv3_1, 128, 3, padding='same')
    conv3_2 = tf.layers.batch_normalization(conv3_2)
    conv3_2 = tf.nn.relu(conv3_2)
    conv3_3 = tf.layers.conv2d(conv3_2, 128, 3, padding='same')
    feature_points = tf.contrib.layers.spatial_softmax(conv3_3)
    fc1 = tf.layers.dense(feature_points, 64)
    fc1 = tf.layers.batch_normalization(fc1)
    fc1 = tf.nn.relu(fc1)
    fc2 = tf.layers.dense(fc1, 64)
    fc2 = tf.layers.batch_normalization(fc2)
    fc2 = tf.nn.relu(fc2)
    fc3 = tf.layers.dense(fc2, 3)
    return fc3
```

Conv Layers

FC Layers

Objective Function

```
def make_optimizer(pred, label):
    loss = tf.reduce_mean(tf.reduce_sum((pred - label) ** 2, axis=-1))
    optimizer = tf.train.AdamOptimizer(learning_rate=3e-4).minimize(loss)
    return loss, optimizer
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