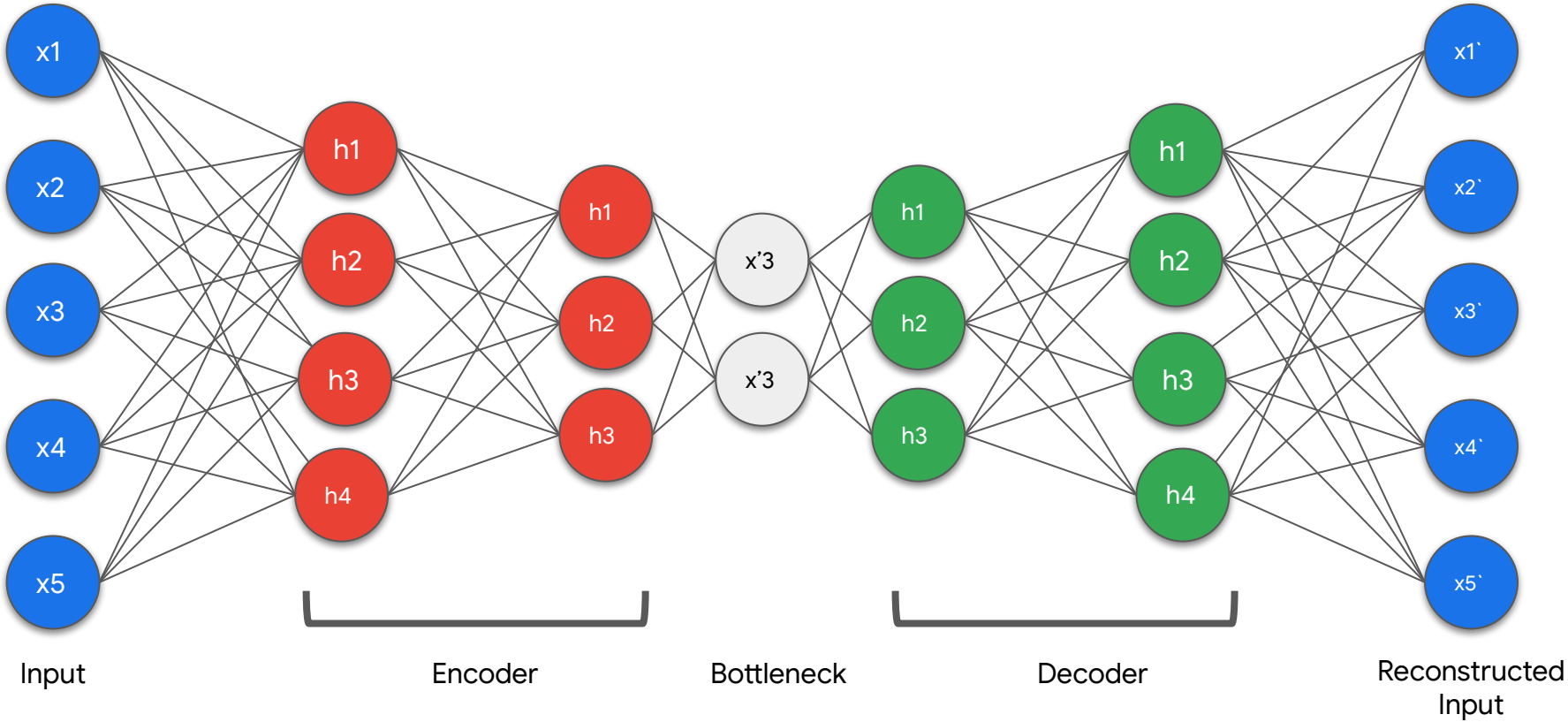
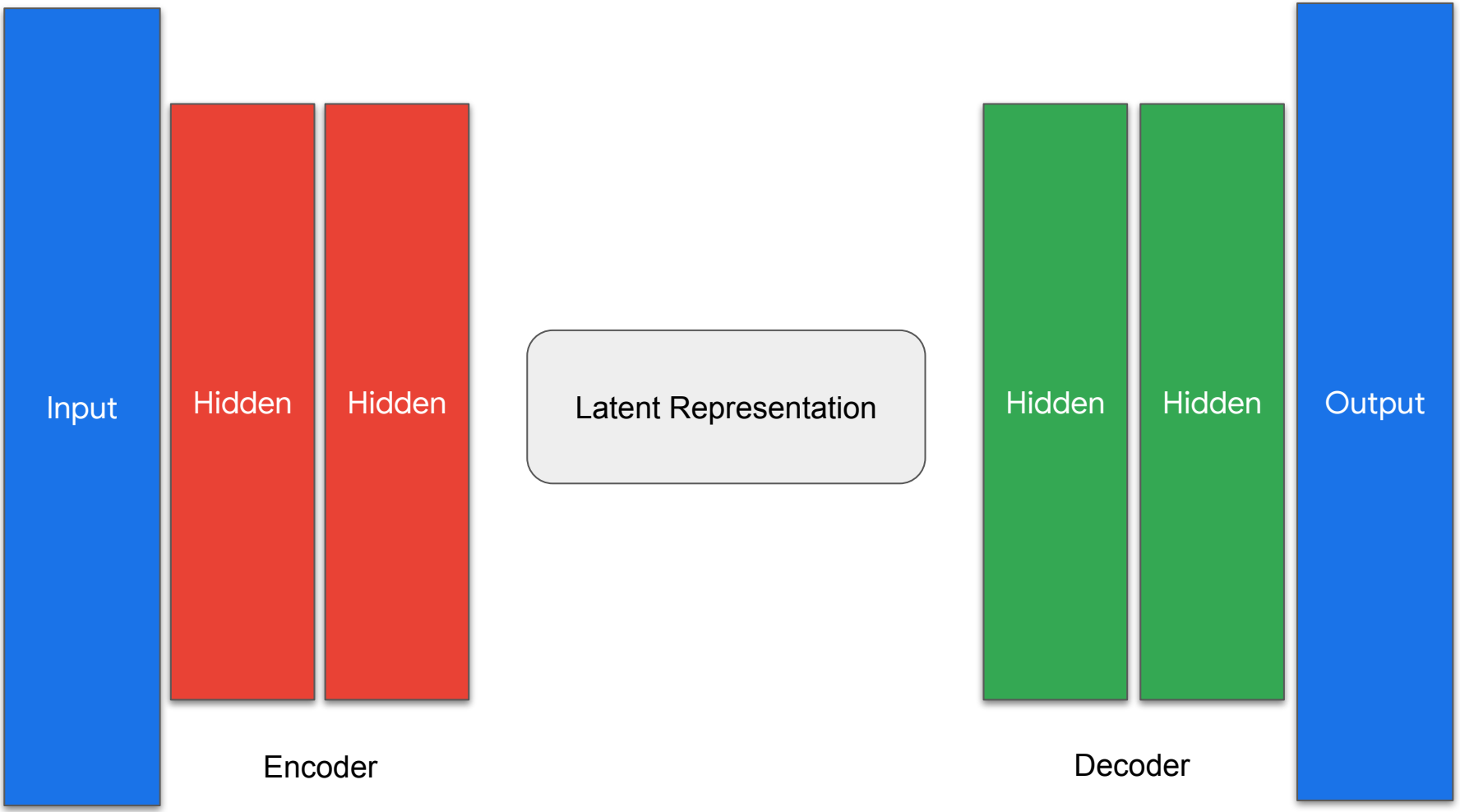
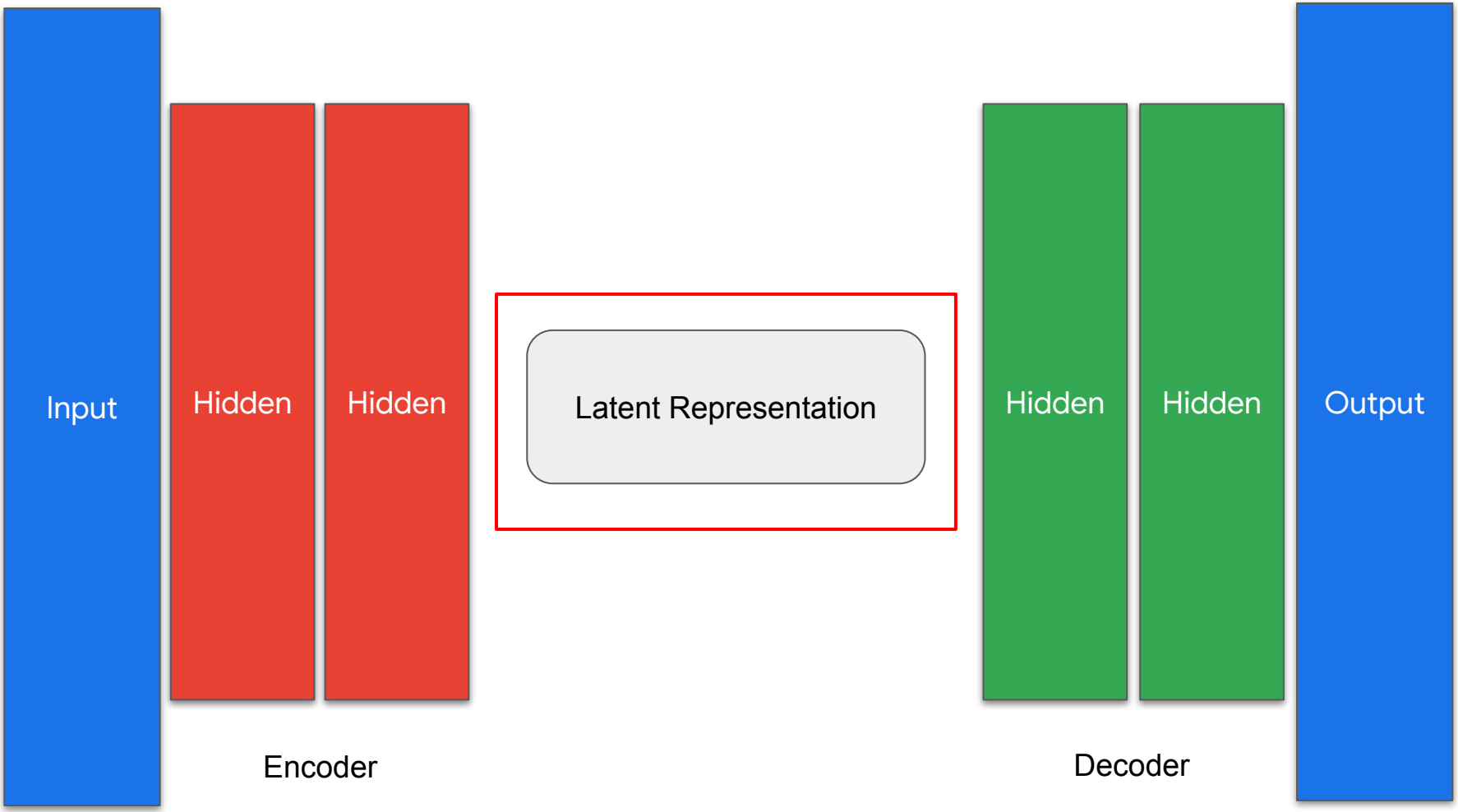
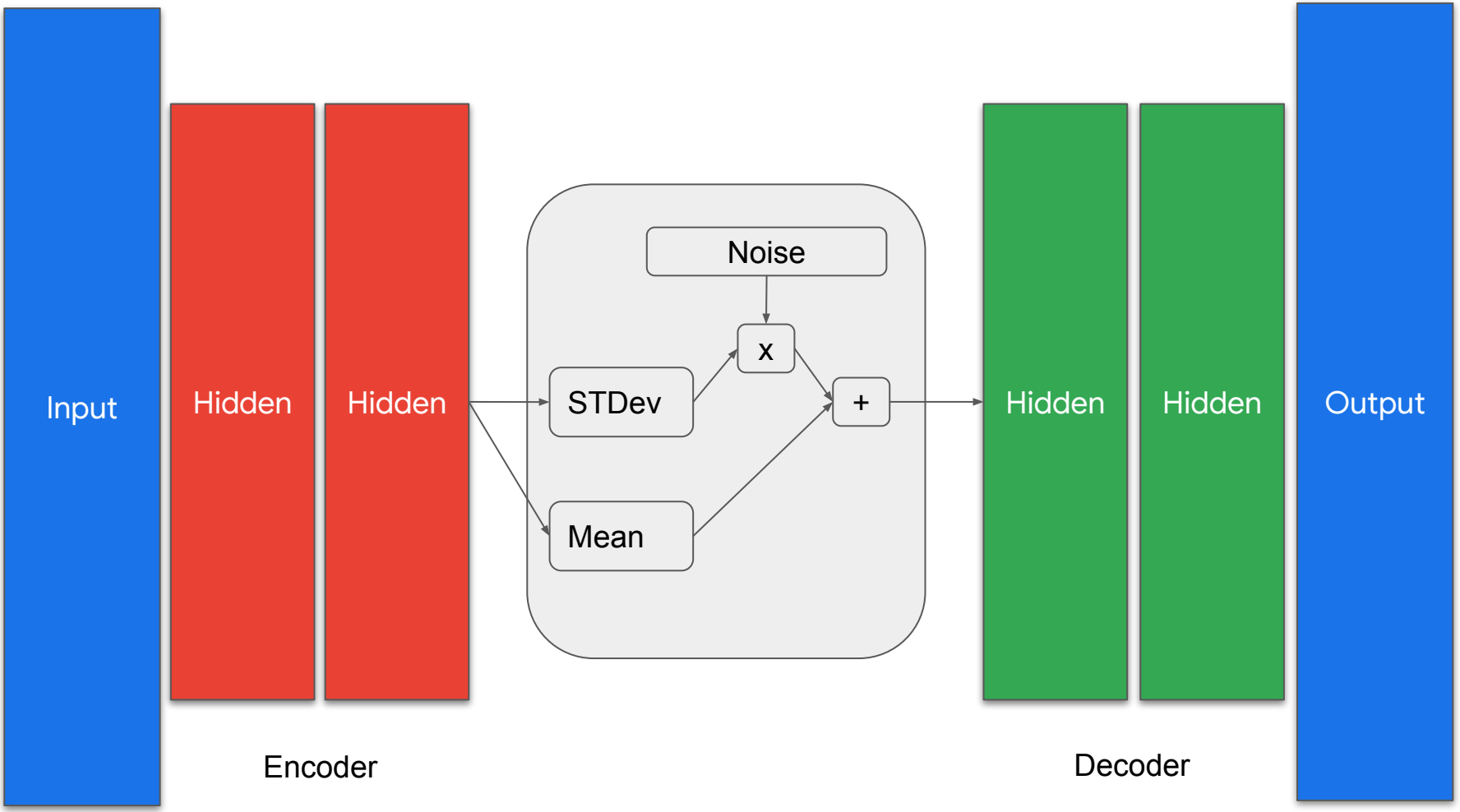
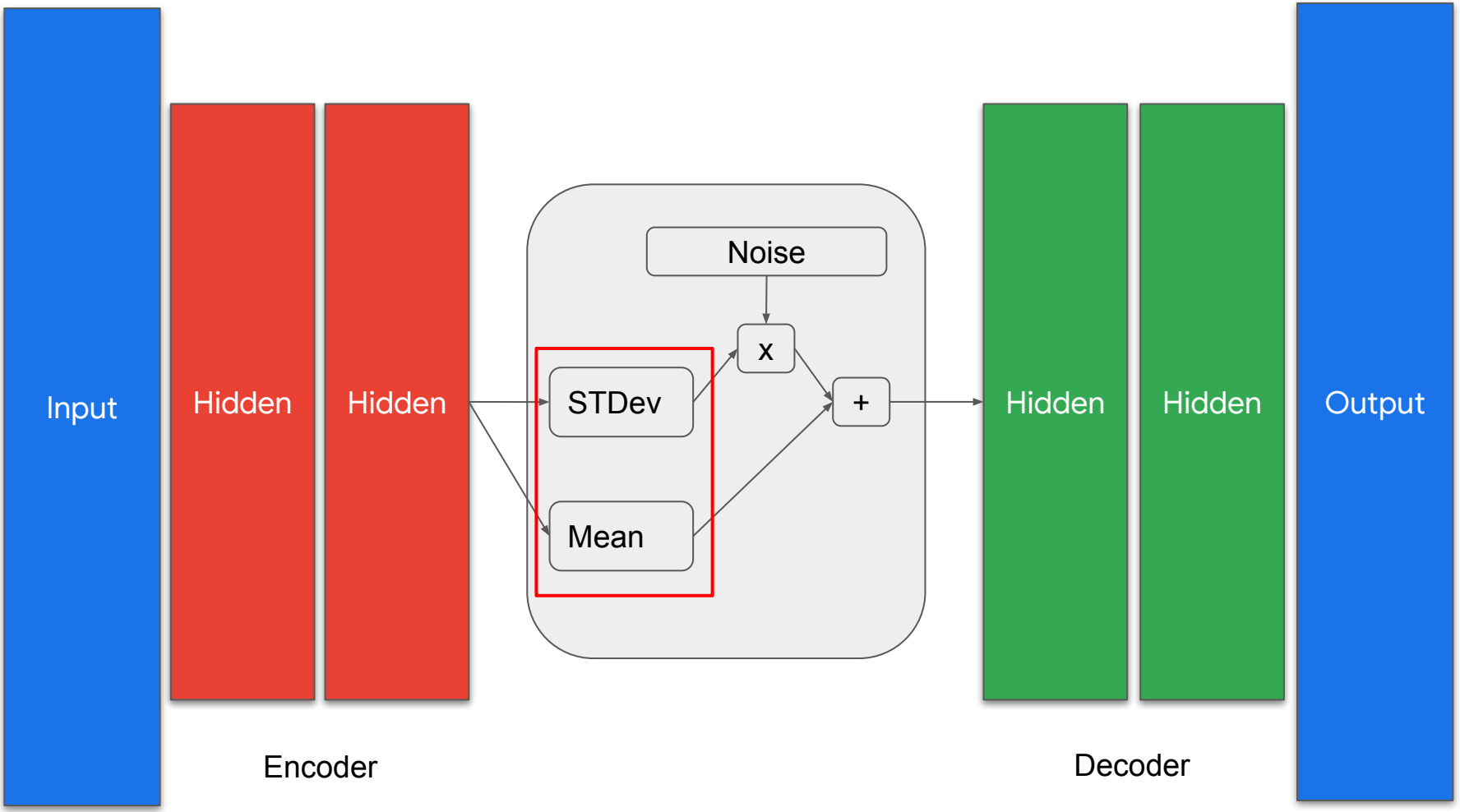
Copyright Notice

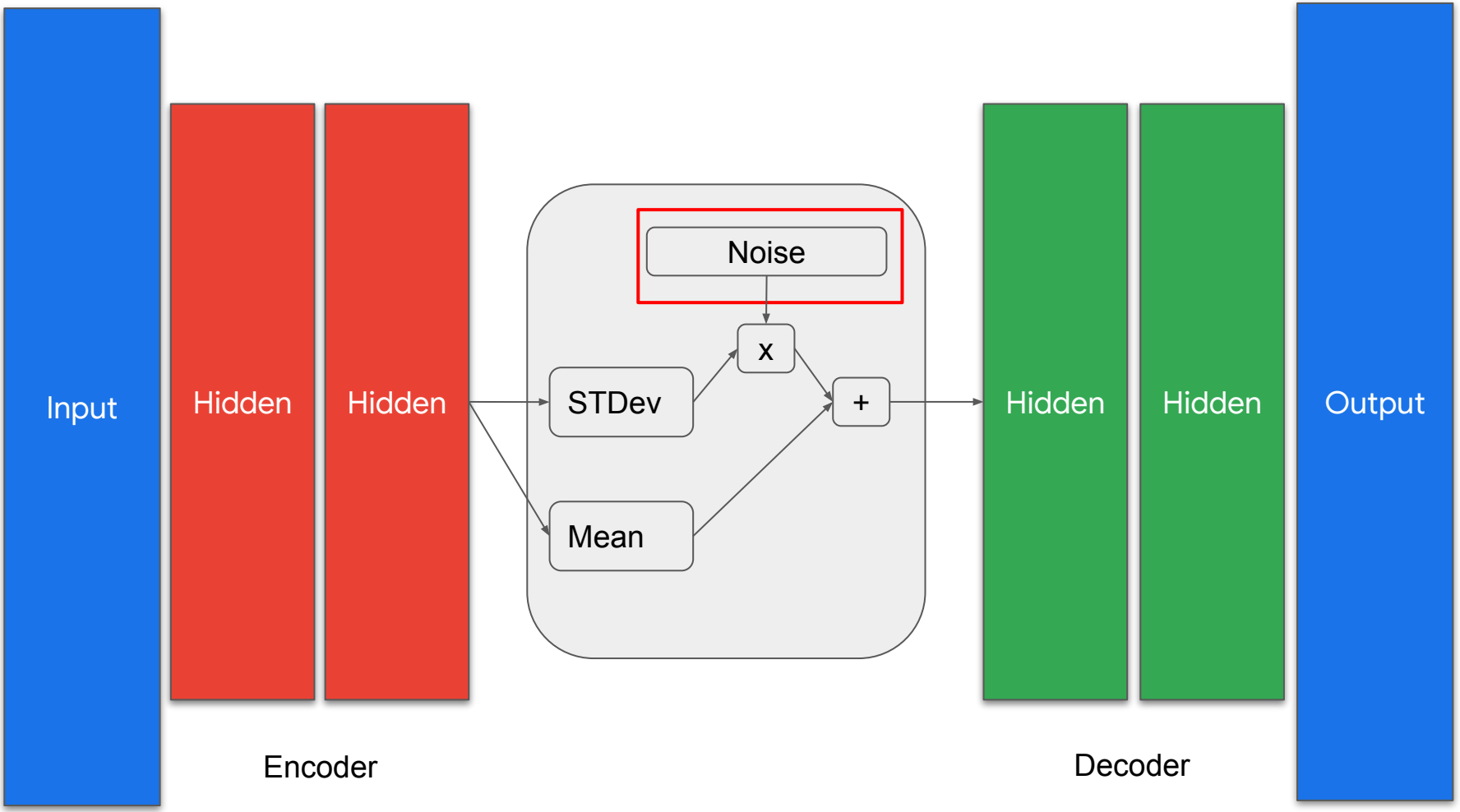

x1
x2
x3
x4
x5
h1
h2
h3
h4
h1
h2
h3
x'3
x'3
h1
h2
h3
h1
h2
h3
h4
x1`
x2`
x3`
x4`
x5`
Input
Encoder
Bottleneck
Decoder
Reconstructed Input


Input
Hidden
Hidden
Latent Representation
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Latent Representation
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
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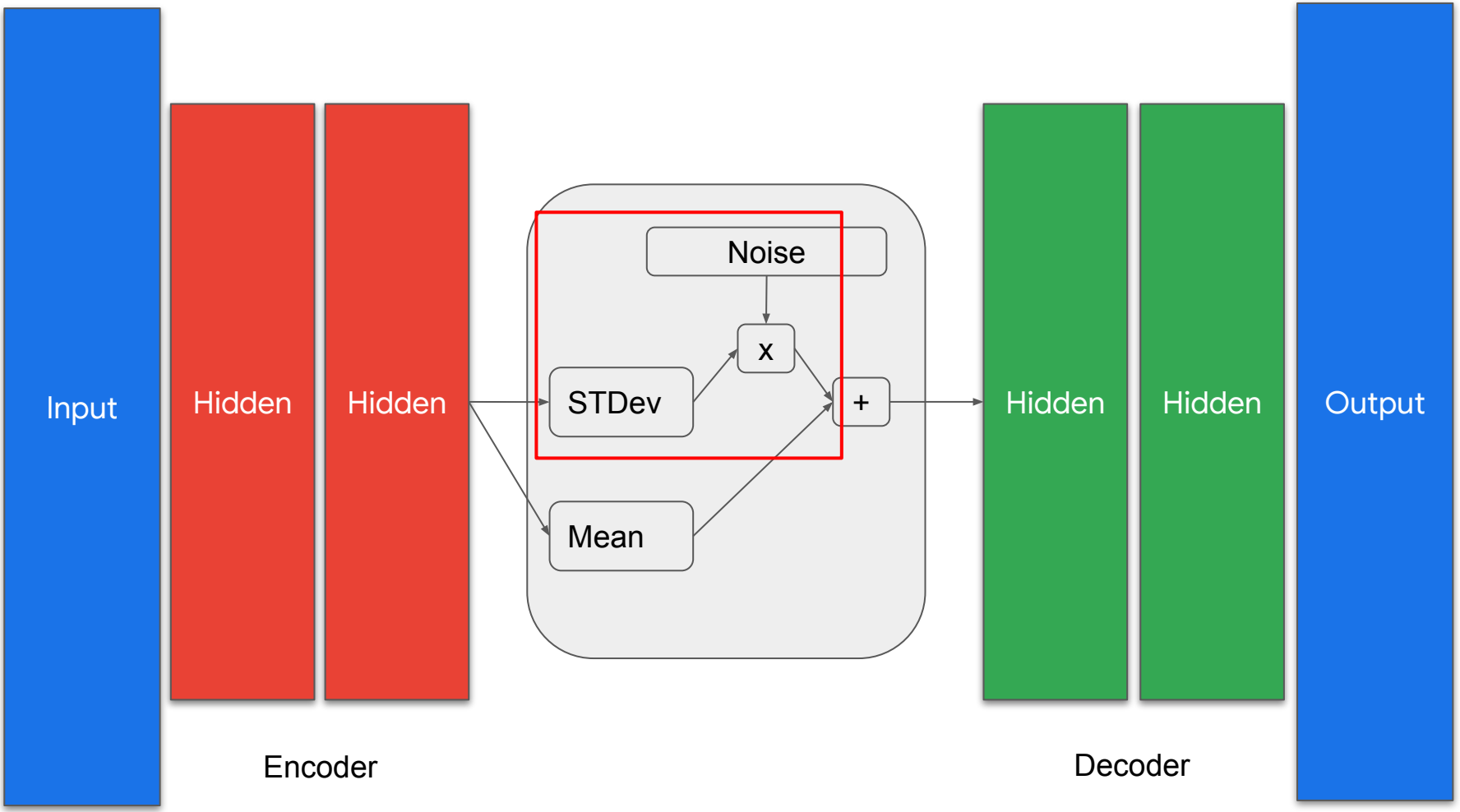
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
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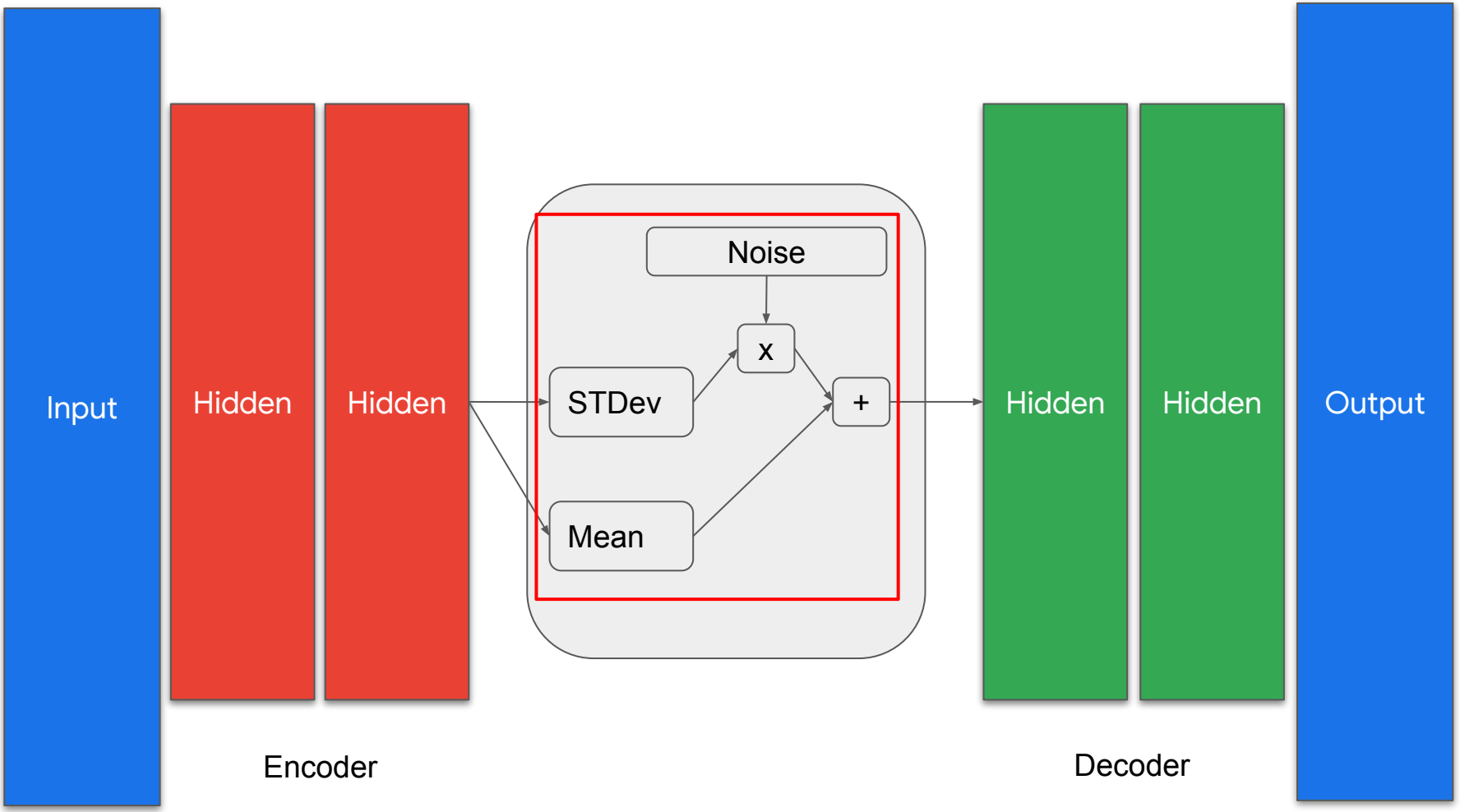
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
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Hidden
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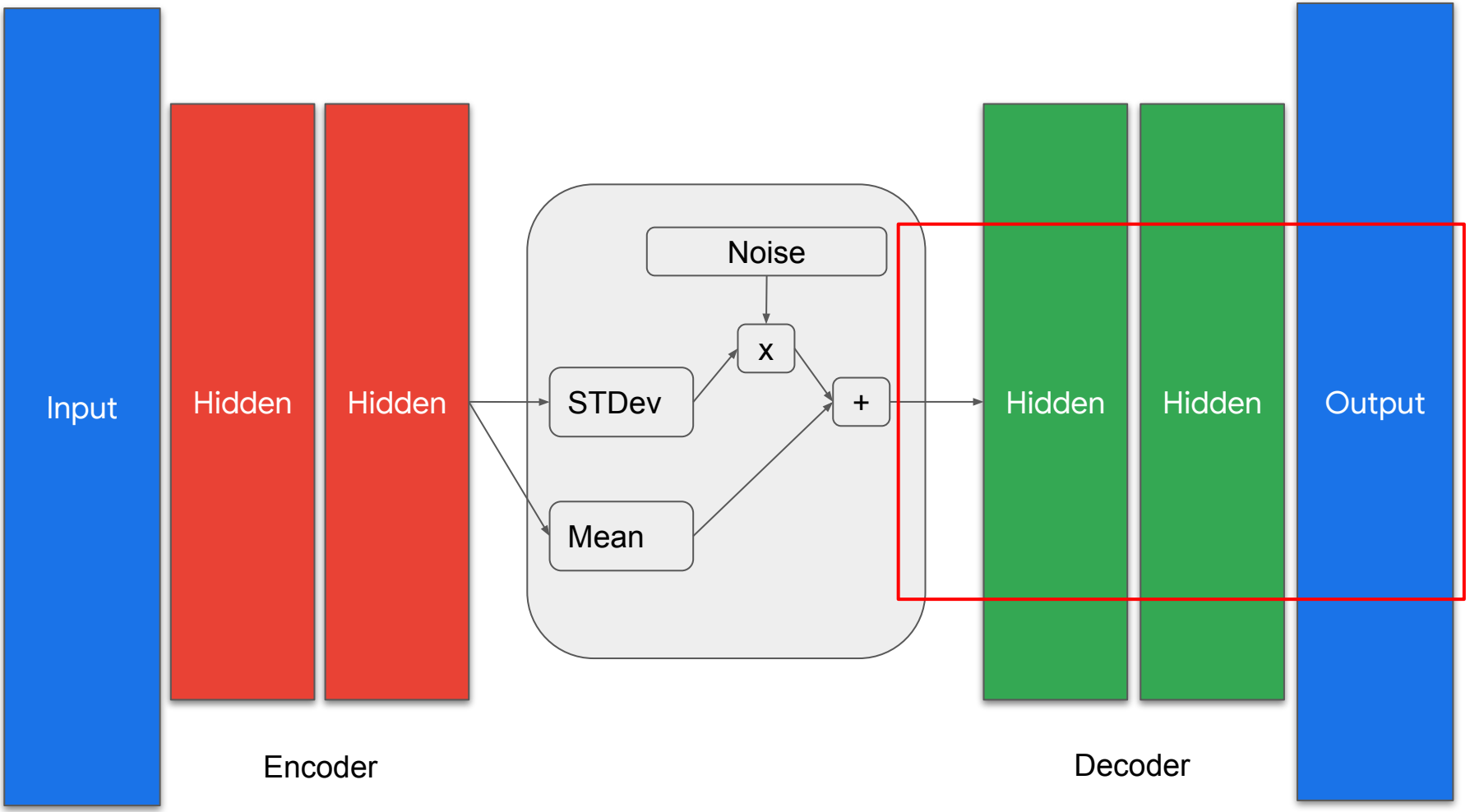
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
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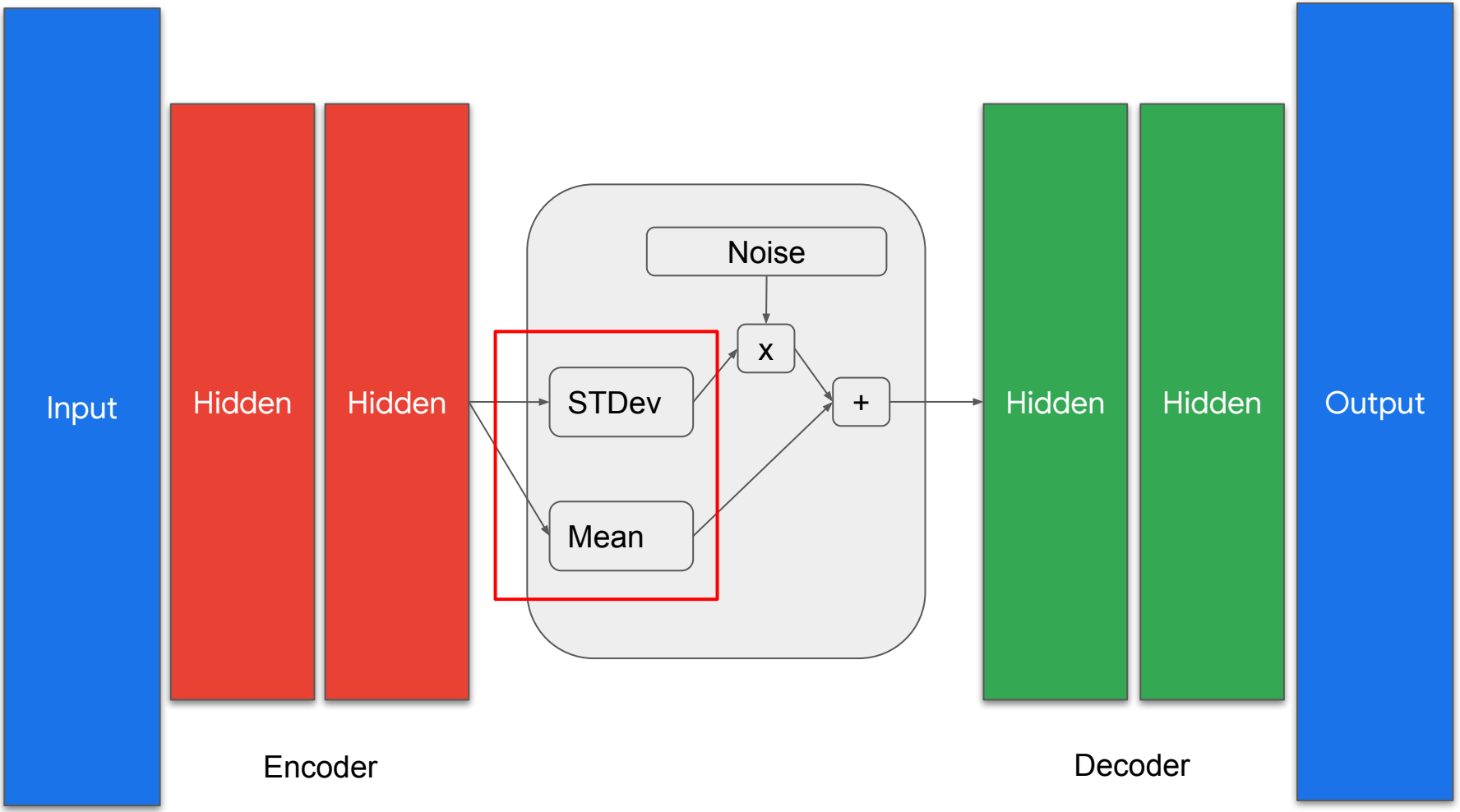
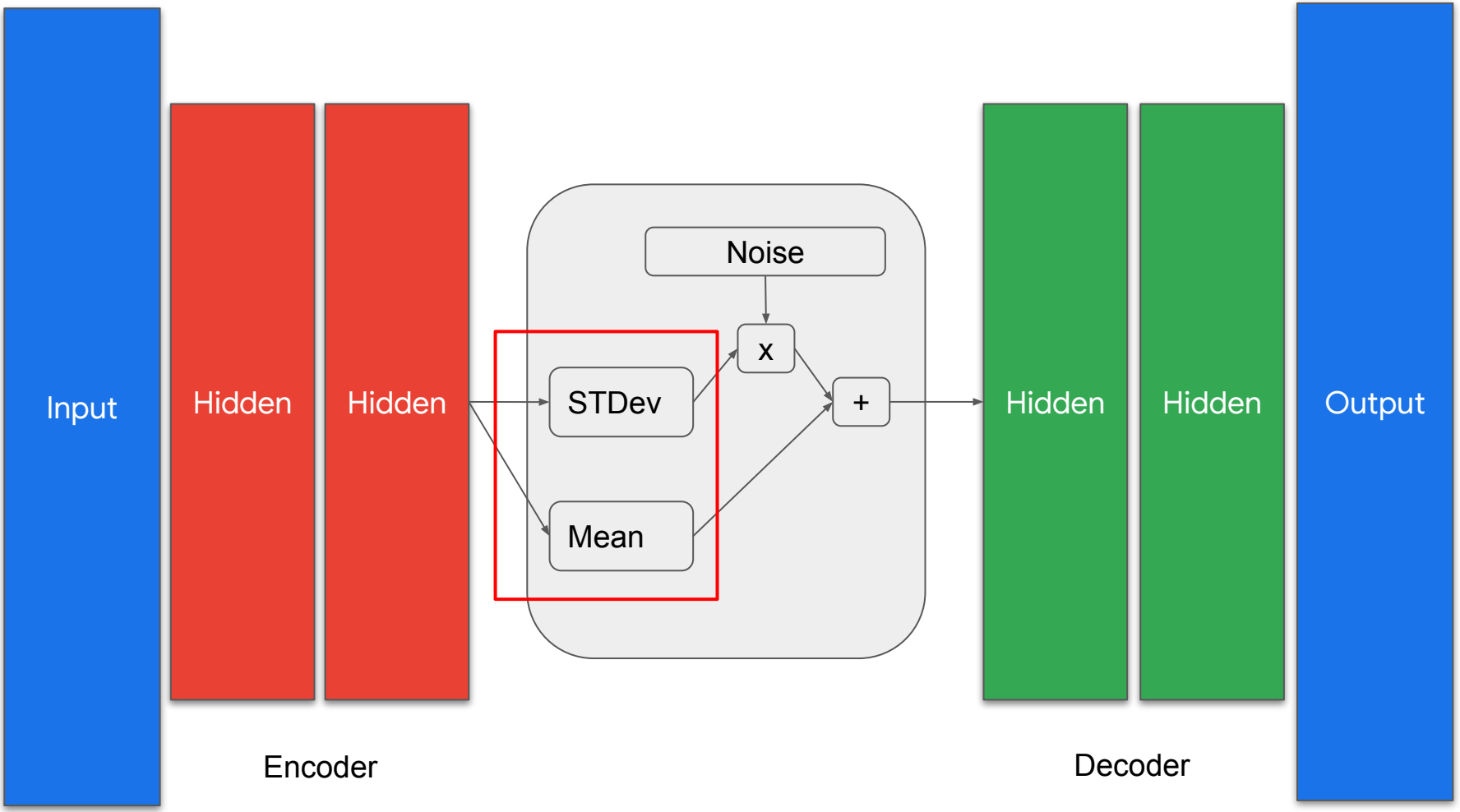
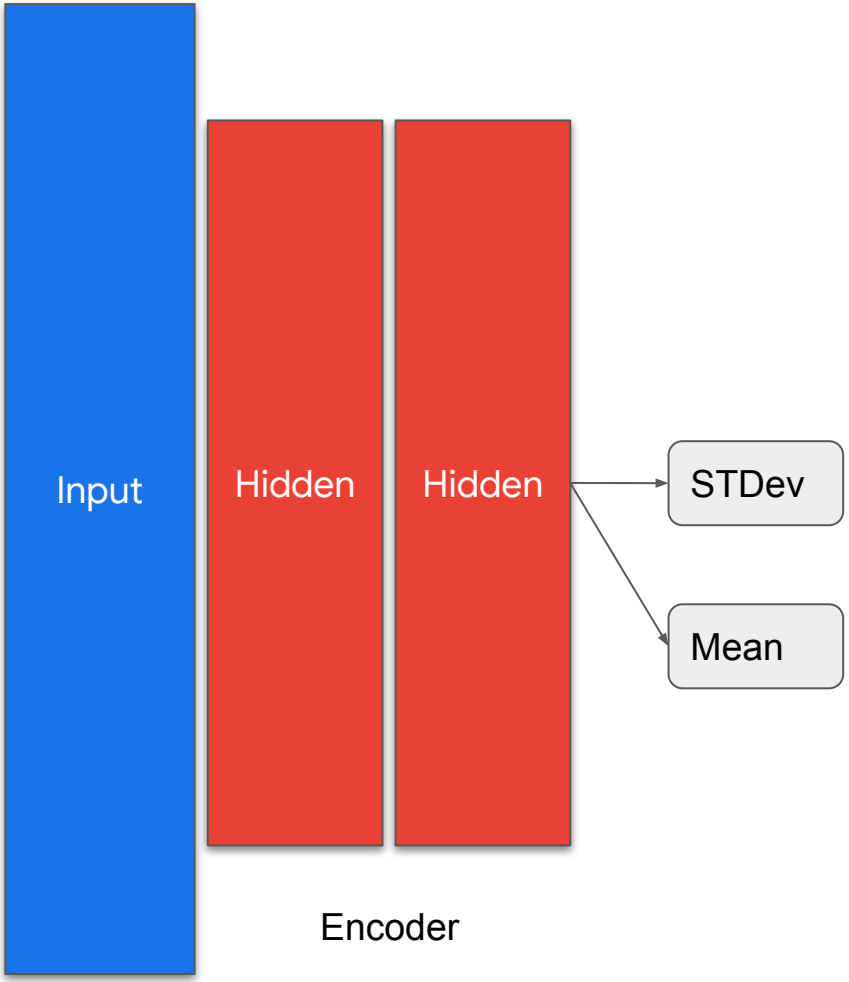
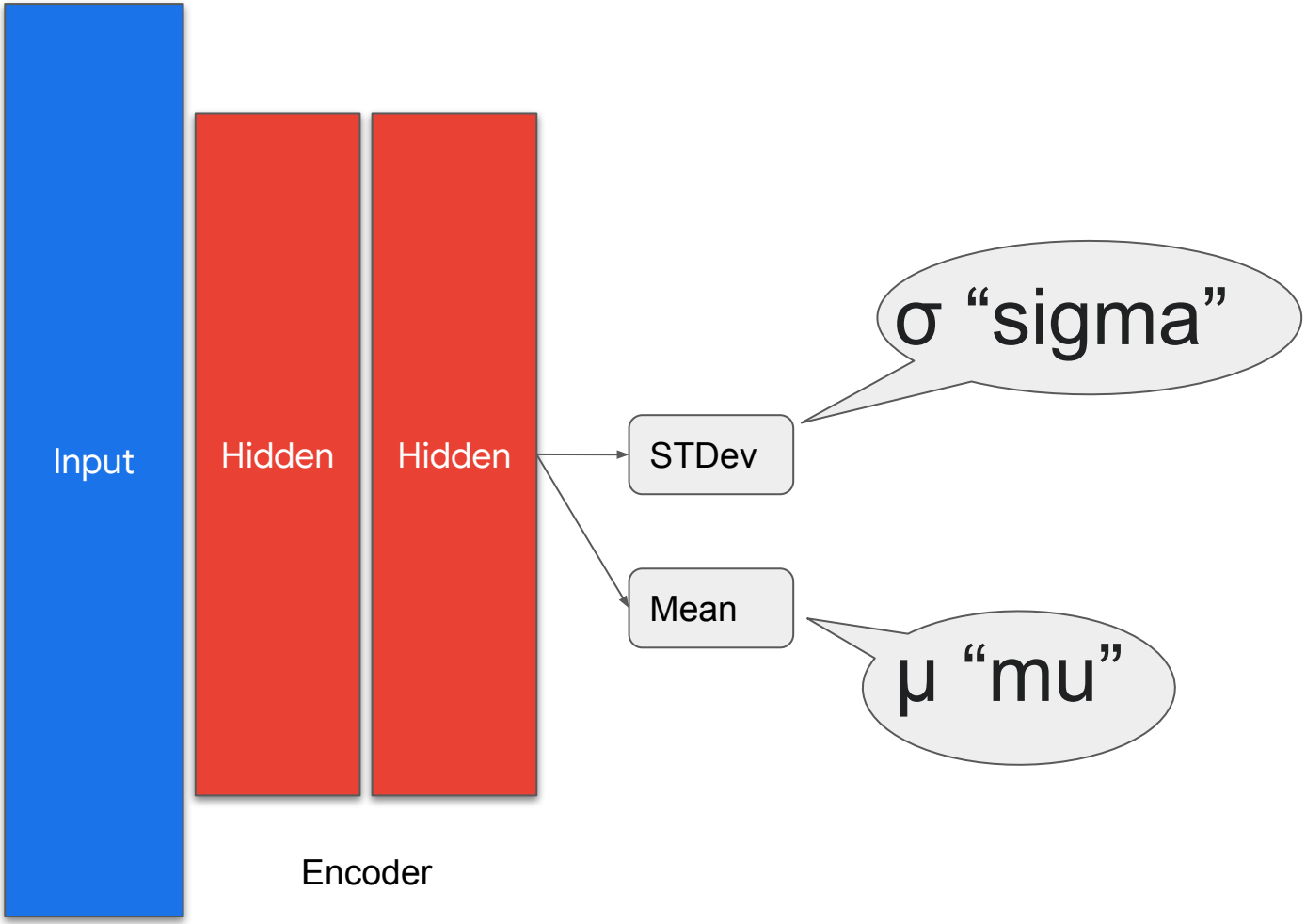
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Noise
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
STDev
Mean
Encoder


Input
Hidden
Hidden
STDev
Mean
σ “sigma”
μ “mu”
Encoder

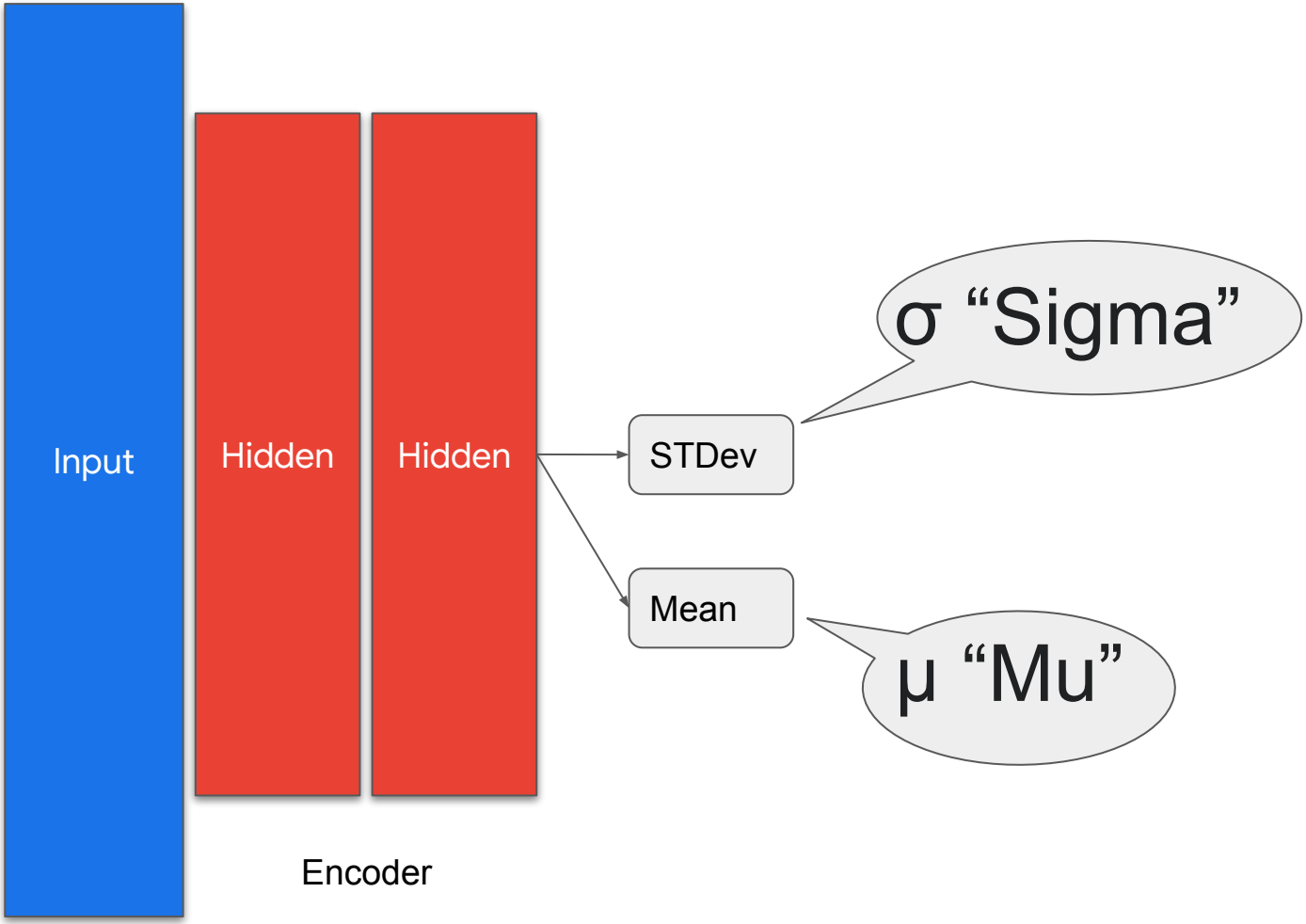
Probability Distribution

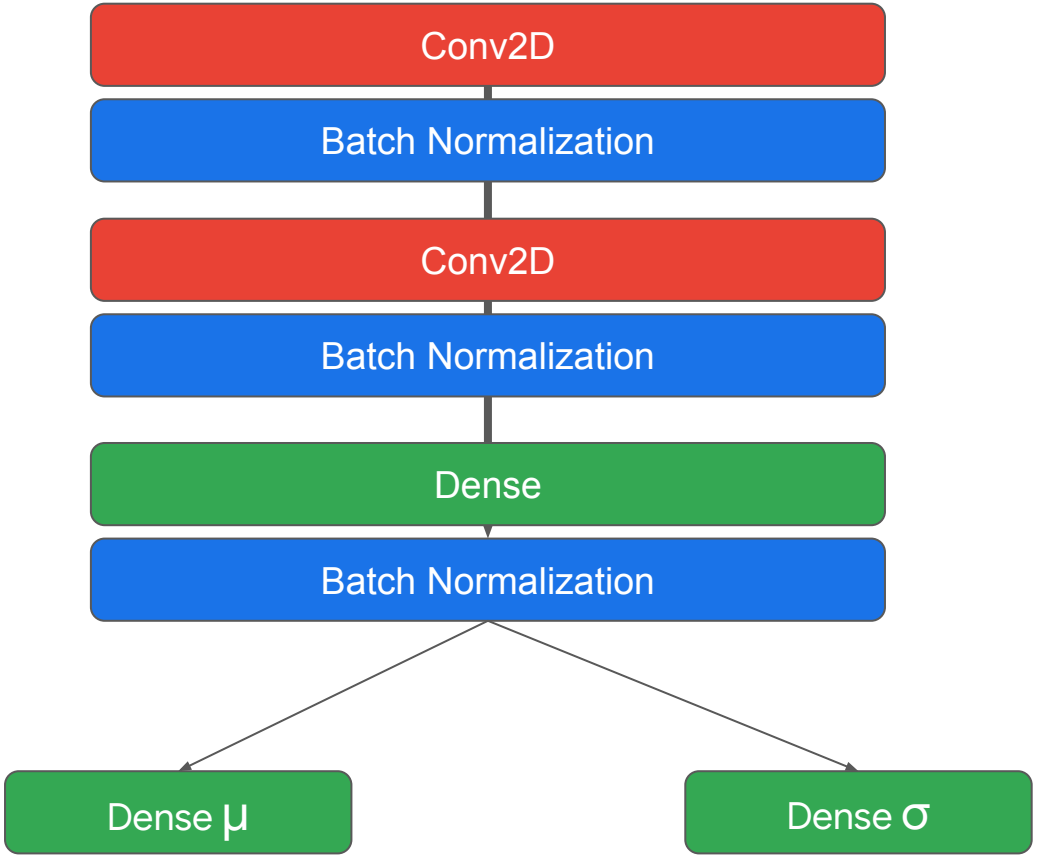
Gaussian probability density function or **Normal Distribution.**

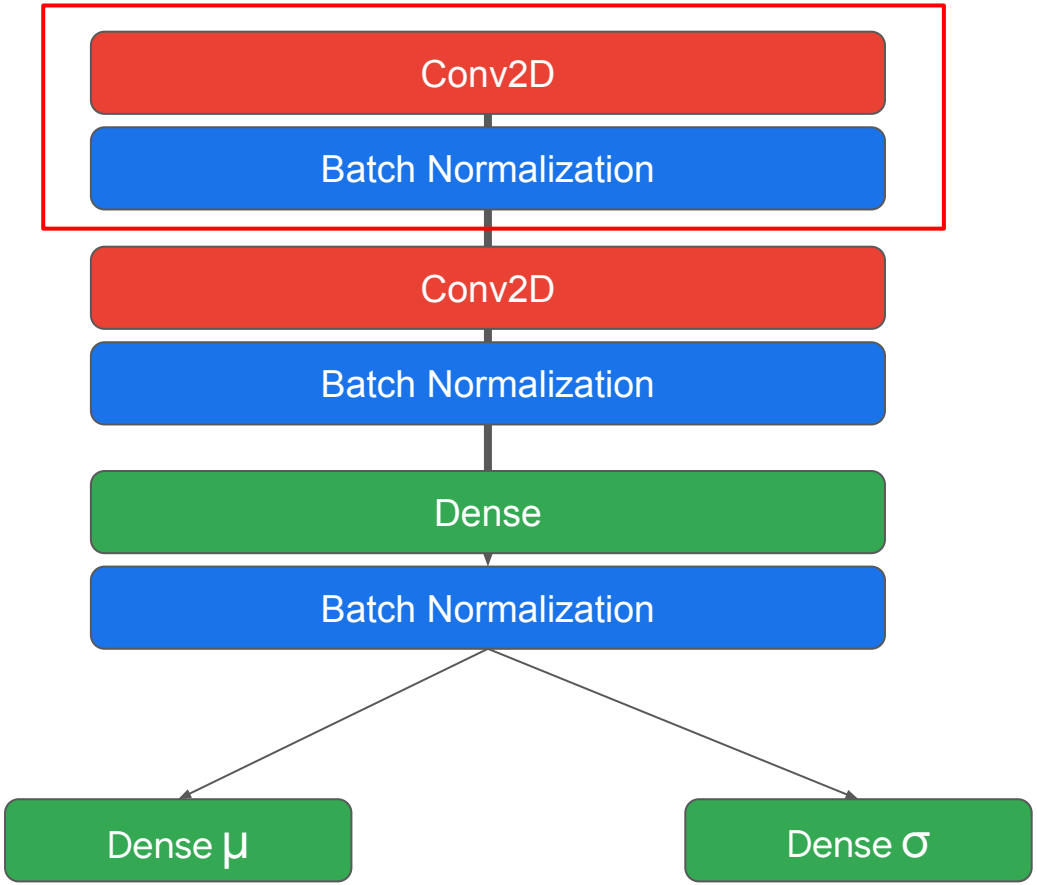
Normal Distribution is controlled by:

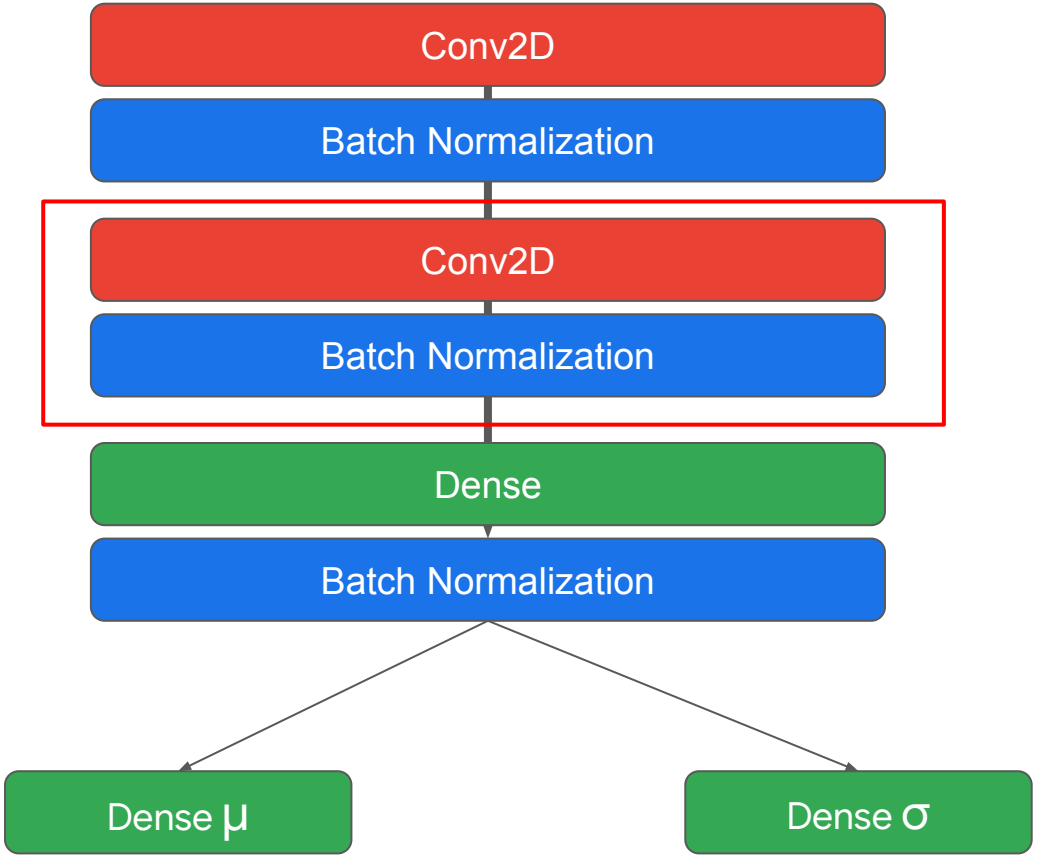
- **μ “mean”**
- **σ “standard deviation”**

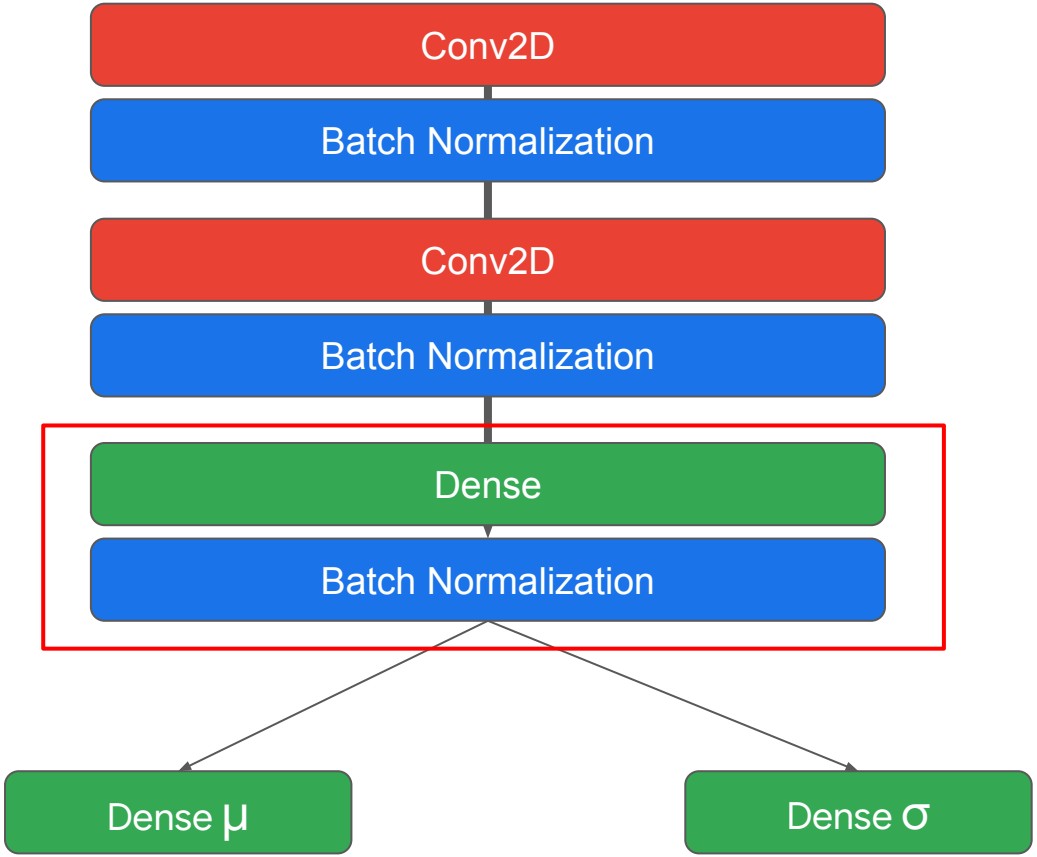
$$N(\mu, \sigma)$$

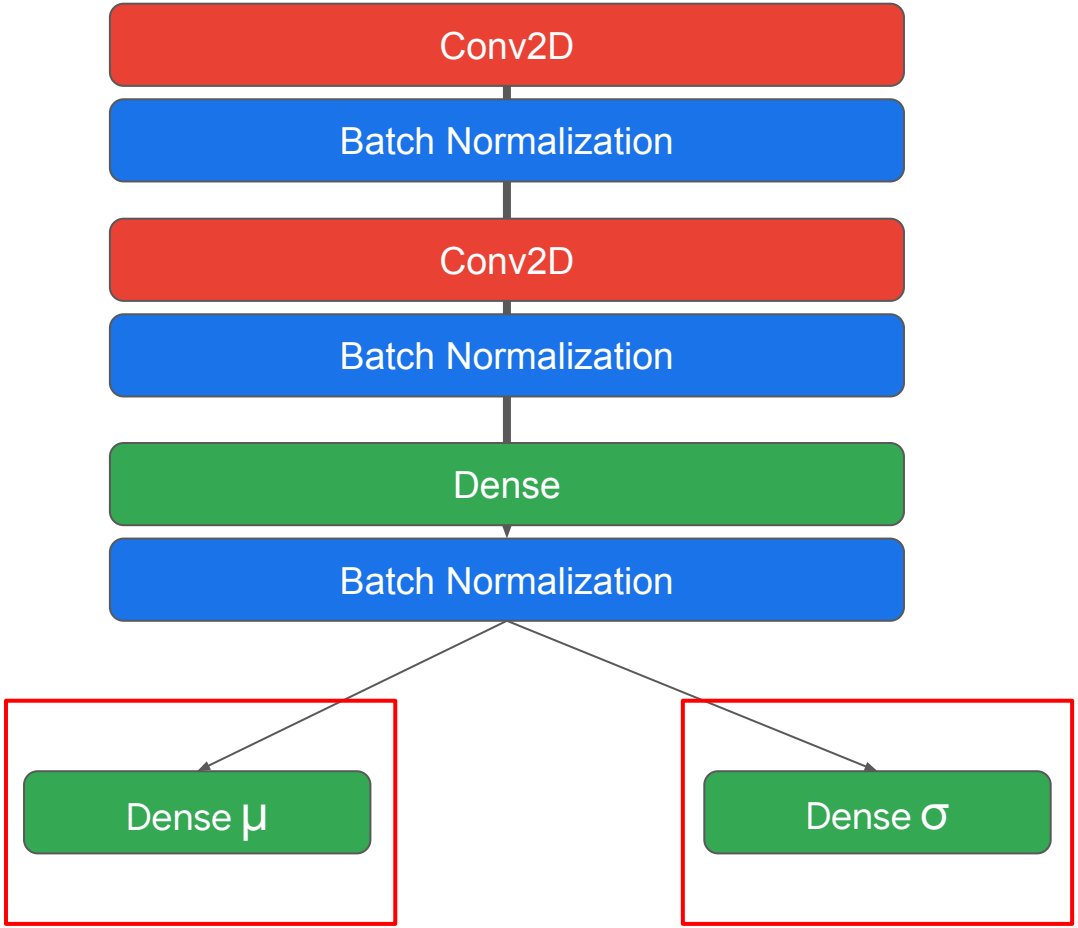

Input
Hidden
Hidden
STDev
Mean
σ “Sigma”
μ “Mu”
Encoder

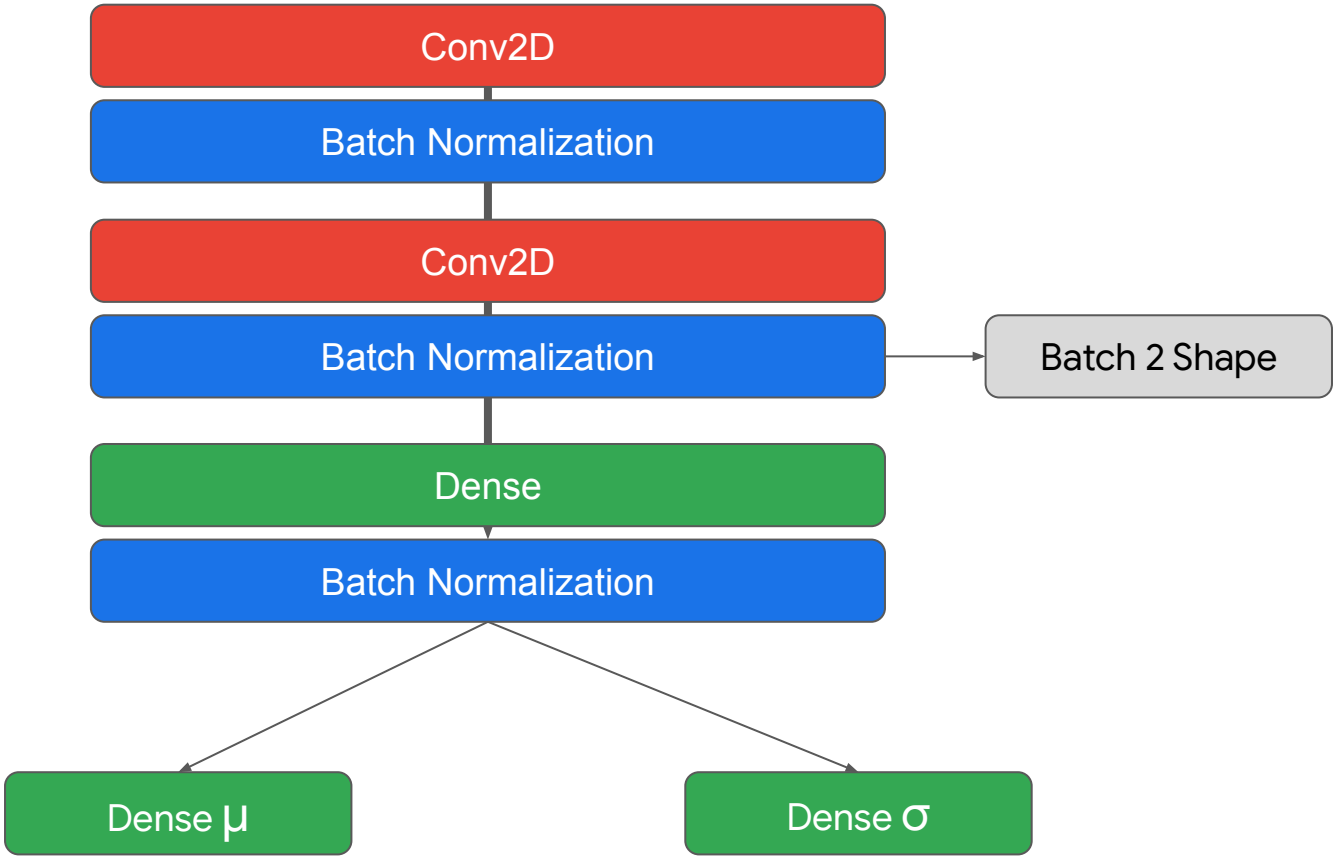

Conv2D
Batch Normalization
Conv2D
Batch Normalization
Dense
Batch Normalization
Dense μ
Dense σ


Conv2D
Batch Normalization
Conv2D
Batch Normalization
Dense
Batch Normalization
Dense μ
Dense σ


Conv2D
Batch Normalization
Conv2D
Batch Normalization
Dense
Batch Normalization
Dense μ
Dense σ


Conv2D
Batch Normalization
Conv2D
Batch Normalization
Dense
Batch Normalization
Dense μ
Dense σ


Conv2D
Batch Normalization
Conv2D
Batch Normalization
Dense
Batch Normalization
Dense μ
Dense σ


Conv2D
Batch Normalization
Conv2D
Batch Normalization
Batch 2 Shape
Dense
Batch Normalization
Dense μ
Dense σ

```
# This function defines the encoder's layers
def encoder_layers(inputs, latent_dim):
  x = tf.keras.layers.Conv2D(filters=32, kernel_size=3, strides=2,
                             padding="same", activation='relu',
                             name="encode_conv1")(inputs)
  x = tf.keras.layers.BatchNormalization()(x)

  x = tf.keras.layers.Conv2D(filters=64, kernel_size=3, strides=2,
                             padding='same', activation='relu',
                             name="encode_conv2")(x)
  batch_2 = tf.keras.layers.BatchNormalization()(x)

  x = tf.keras.layers.Flatten(name="encode_flatten")(batch_2)
  x = tf.keras.layers.Dense(20, activation='relu', name="encode_dense")(x)
  x = tf.keras.layers.BatchNormalization()(x)

  mu = tf.keras.layers.Dense(latent_dim, name='latent_mu')(x)
  sigma = tf.keras.layers.Dense(latent_dim, name ='latent_sigma')(x)


  return mu, sigma, batch_2.shape
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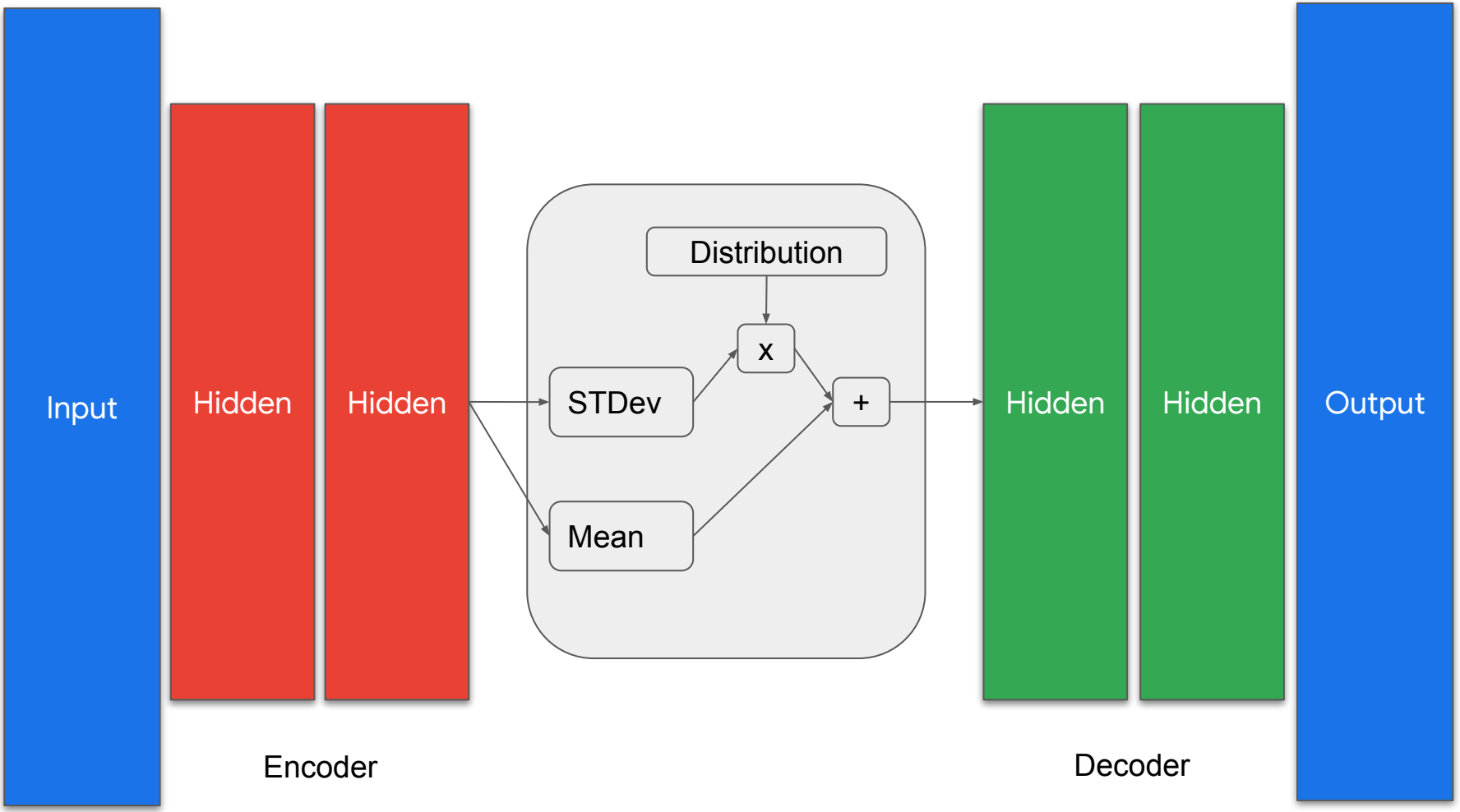
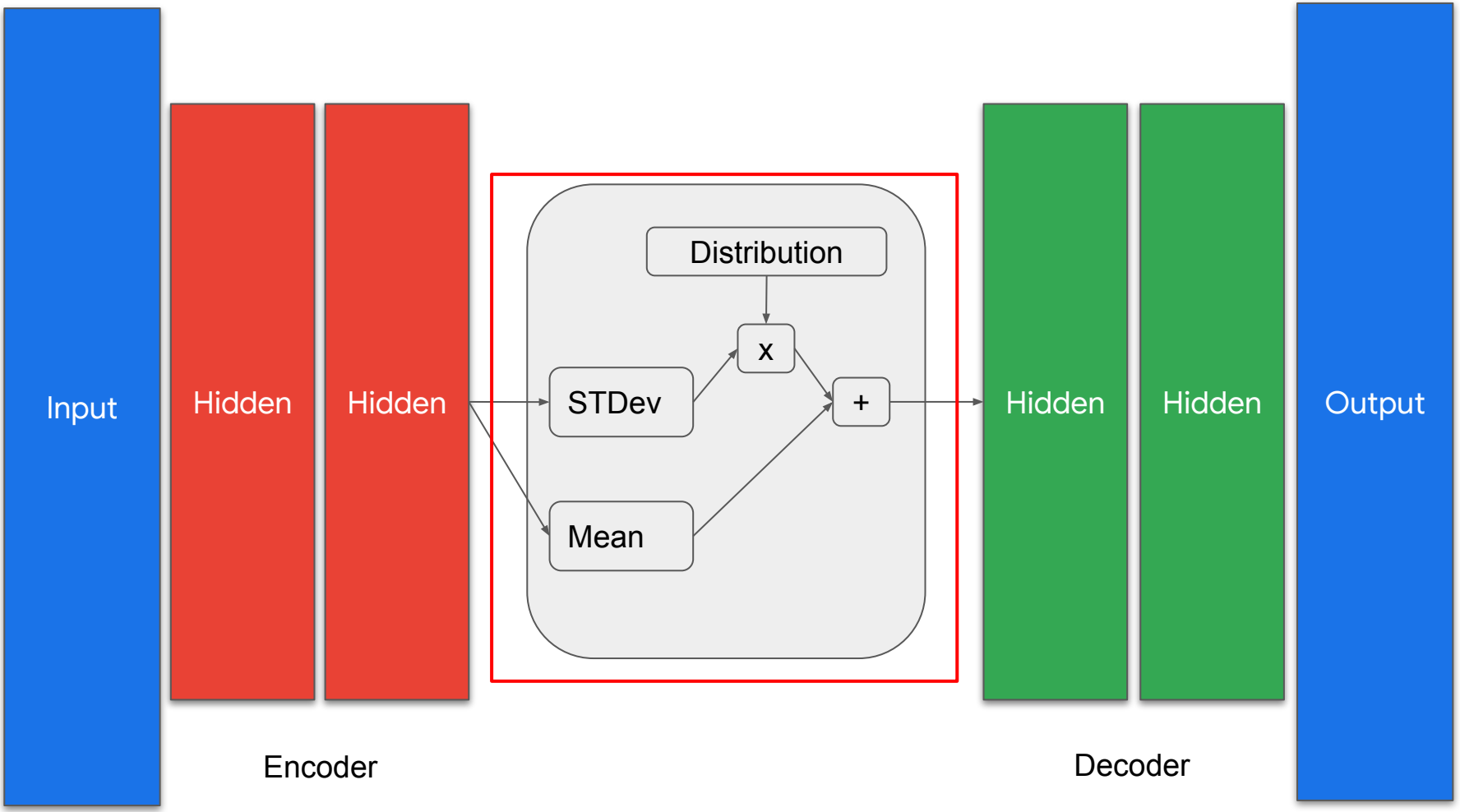

Input
Hidden
Hidden
Distribution
x
STDev
+
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Distribution
x
STDev
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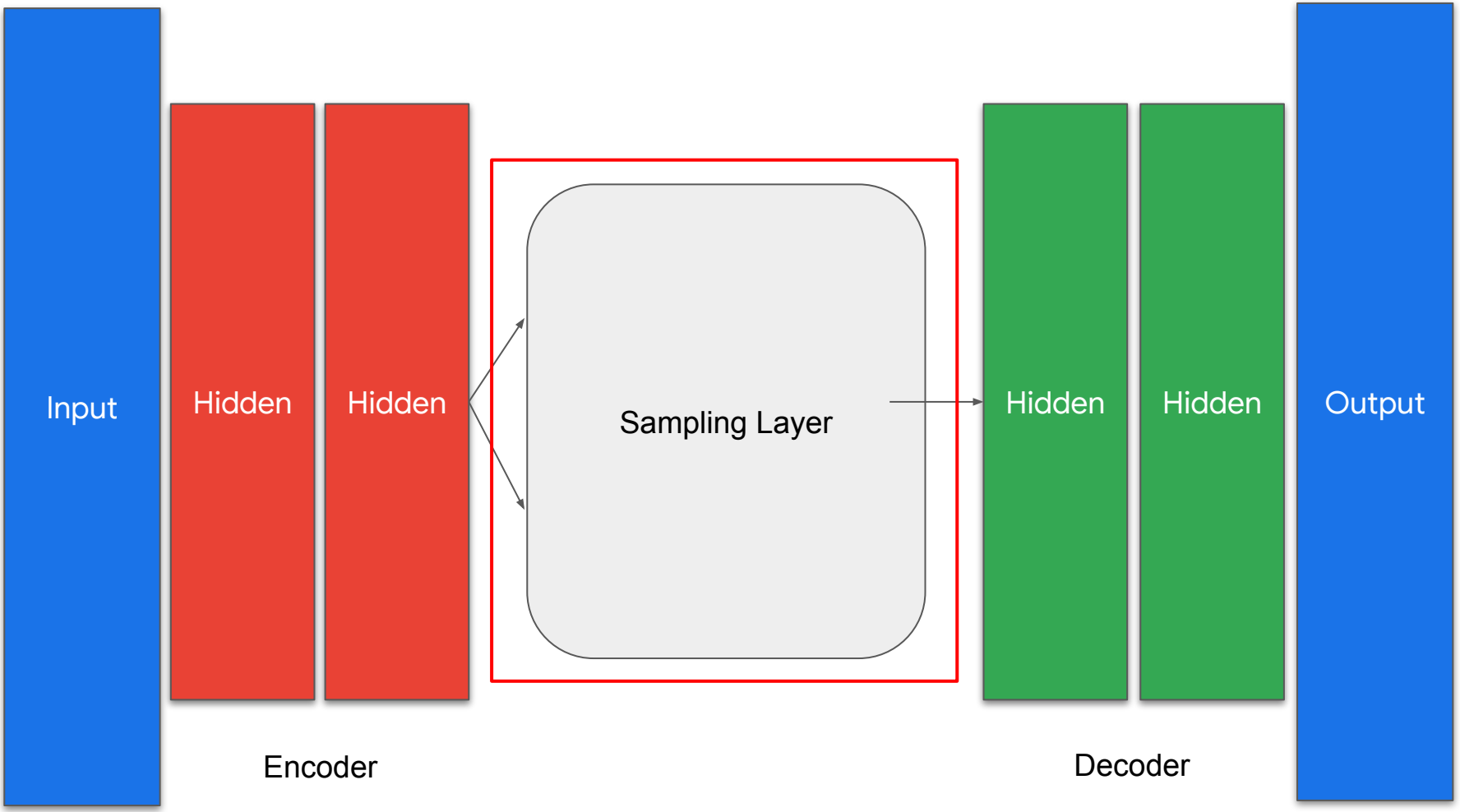
Mean
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Sampling Layer
Hidden
Hidden
Output
Encoder
Decoder

```
class Sampling(tf.keras.layers.Layer):
  def call(self, inputs):
    mu, sigma = inputs
    batch = tf.shape(mu)[0]
    dim = tf.shape(mu)[1]
    epsilon = tf.keras.backend.random_normal(shape=(batch, dim))
    return mu + tf.exp(0.5 * sigma) * epsilon
```

```python
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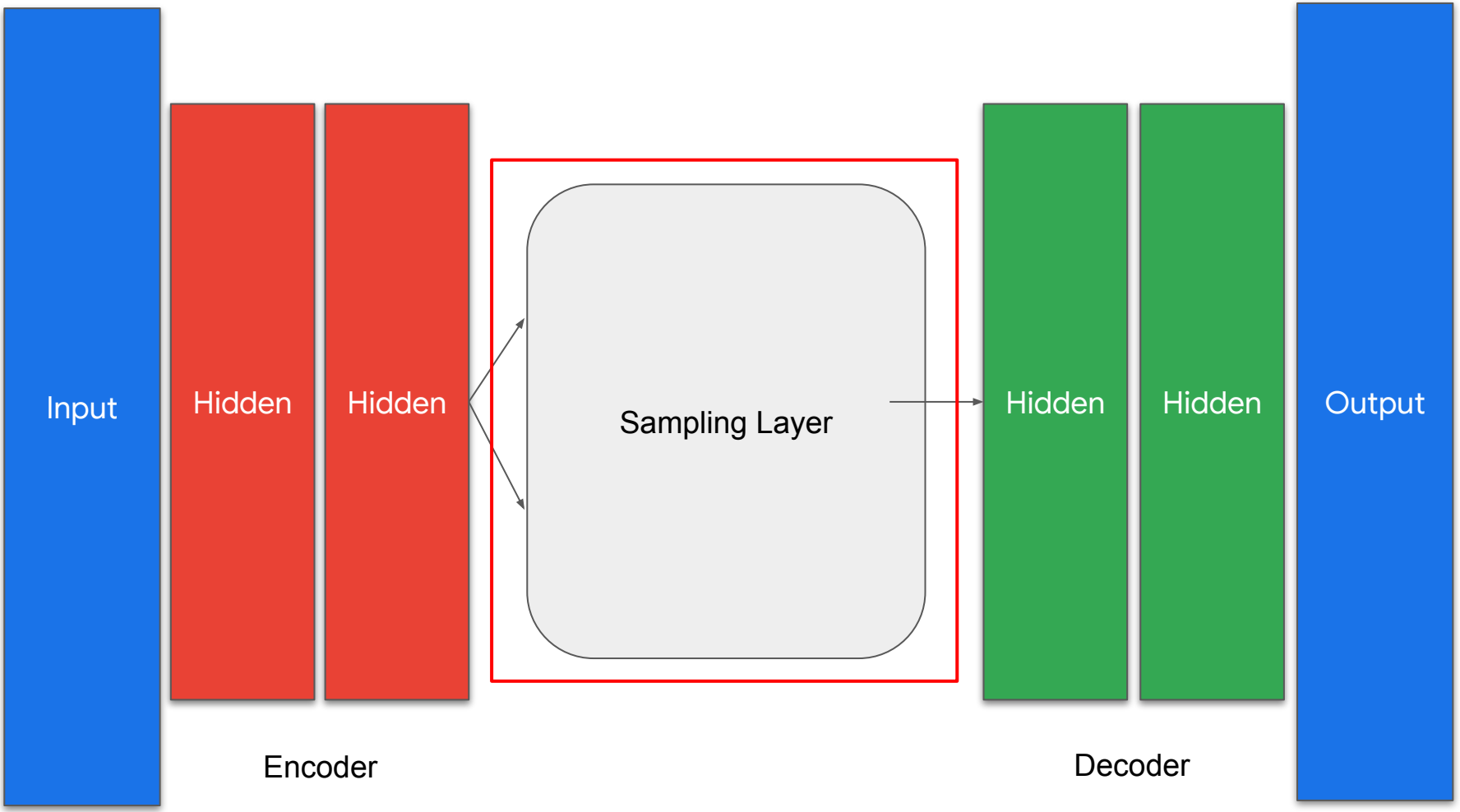
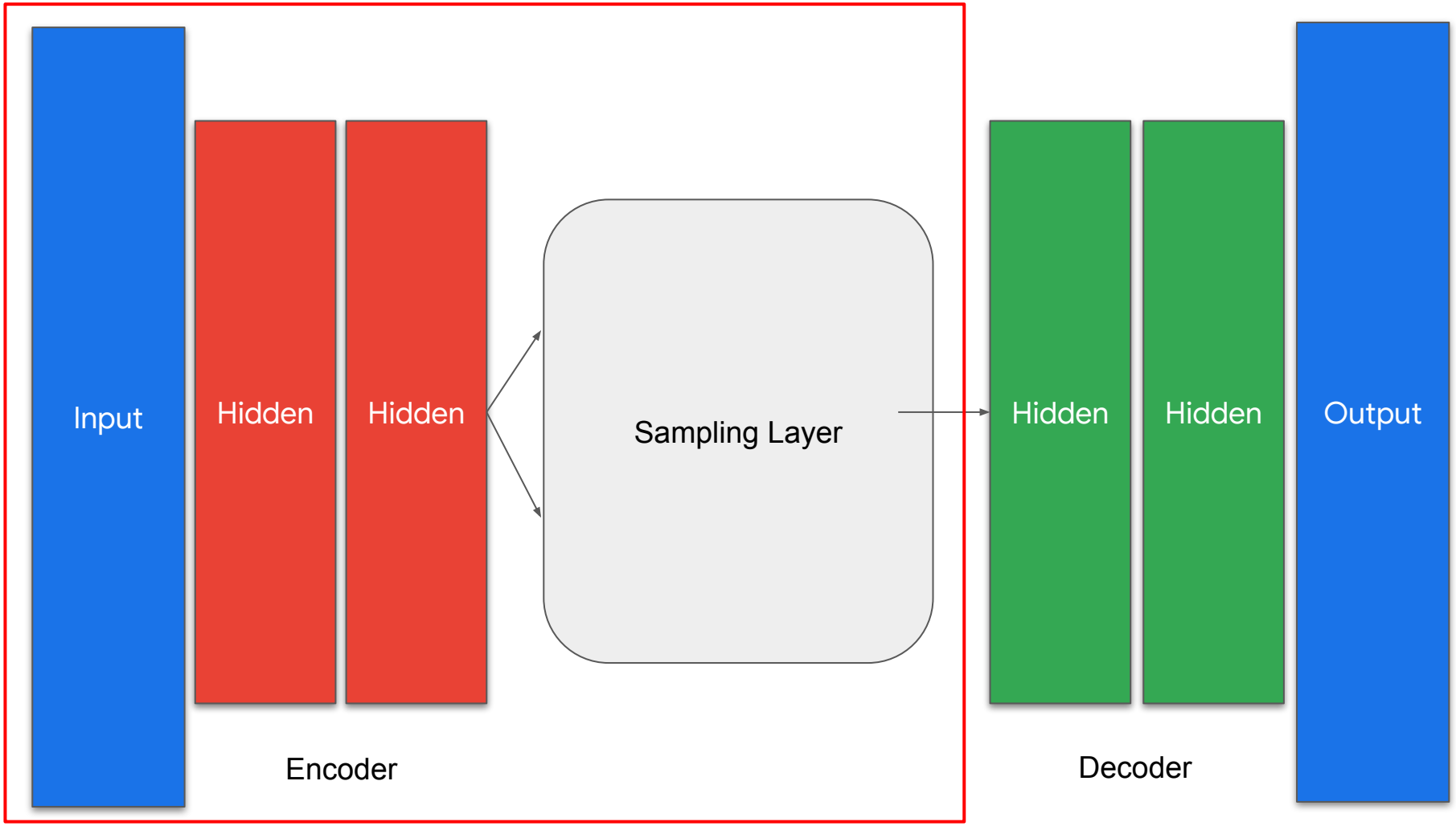

Input
Hidden
Hidden
Sampling Layer
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Sampling Layer
Hidden
Hidden
Output
Encoder
Decoder

```
def encoder_model(LATENT_DIM, input_shape):
  inputs = tf.keras.layers.Input(shape=input_shape)
  mu, sigma, conv_shape = encoder_layers(inputs, latent_dim=LATENT_DIM)
  z = Sampling()((mu, sigma))
  model = tf.keras.Model(inputs, outputs=[mu, sigma, z])
  return model, conv_shape
```

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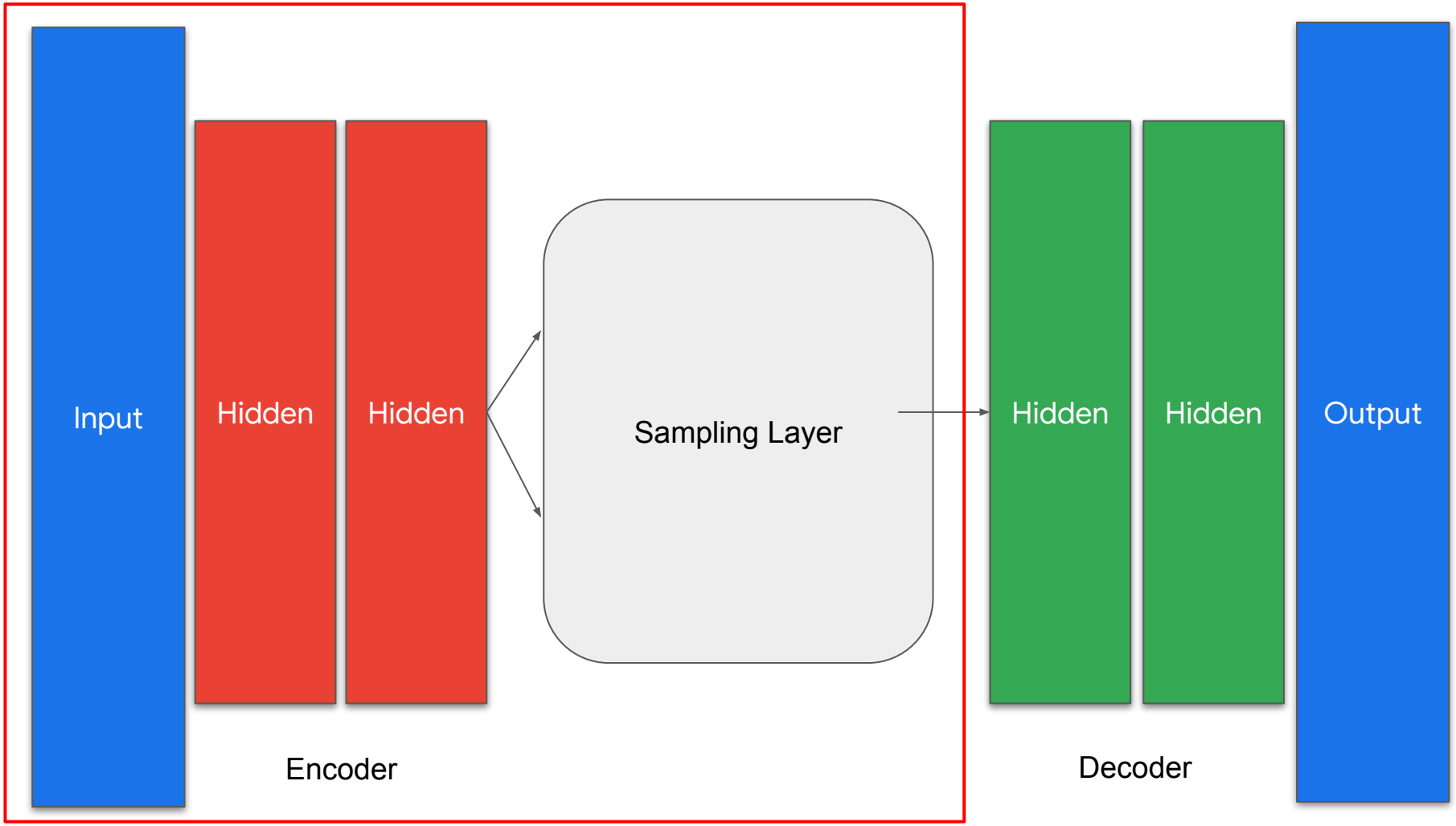
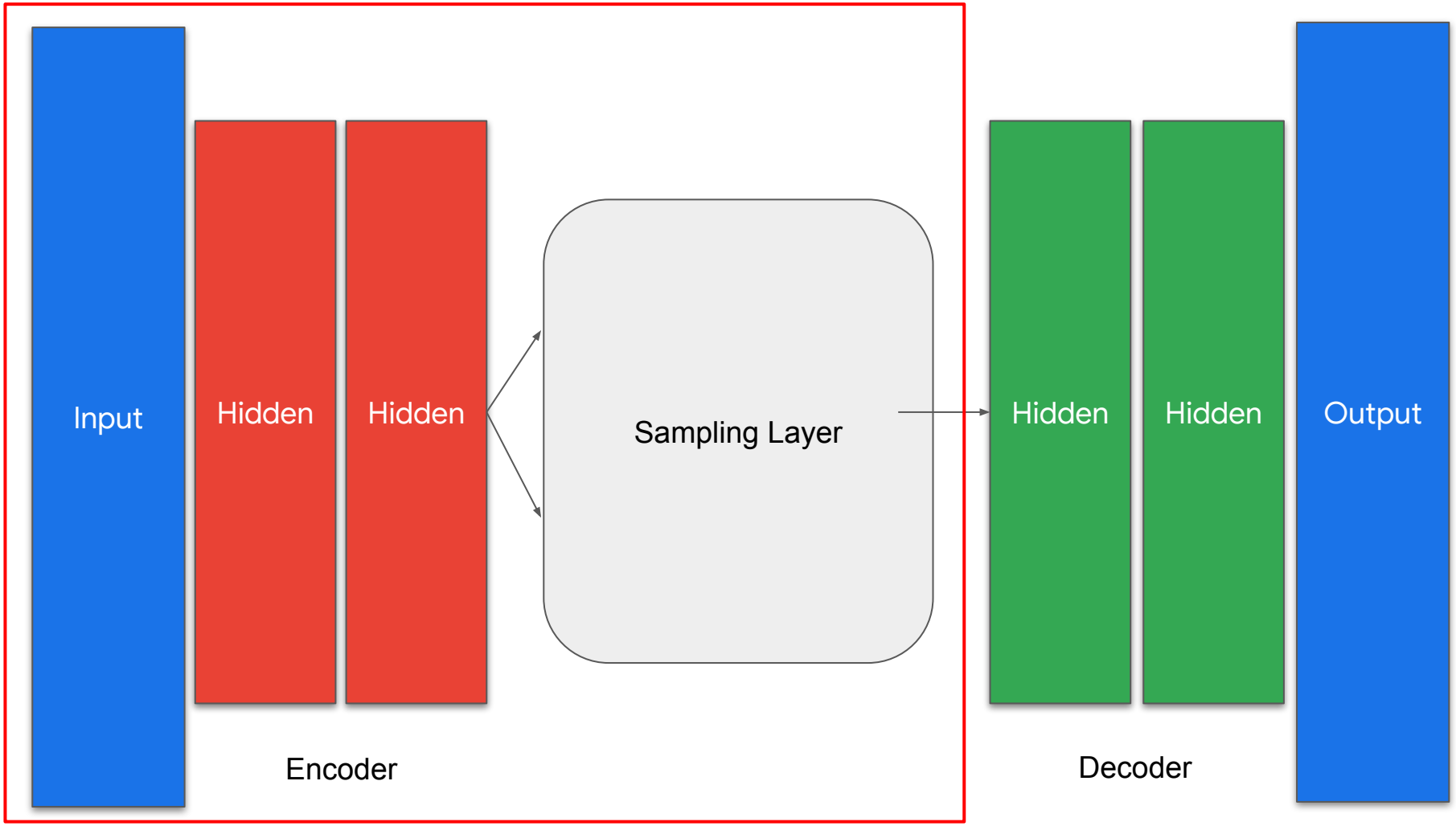
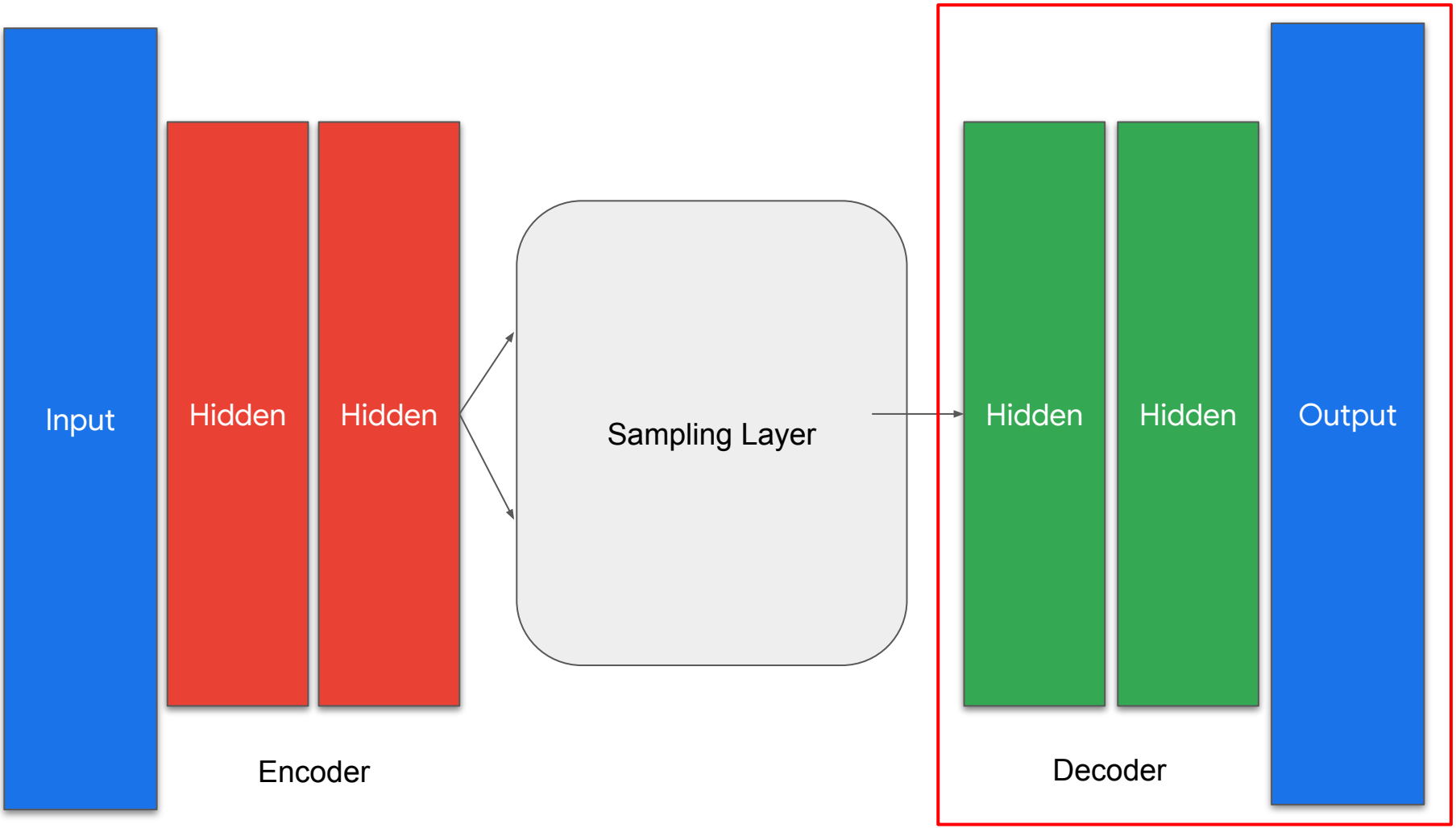

Input
Hidden
Hidden
Sampling Layer
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Sampling Layer
Hidden
Hidden
Output
Encoder
Decoder


Input
Hidden
Hidden
Sampling Layer
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Encoder
Decoder

```
def decoder_layers(inputs, conv_shape):
  units = conv_shape[1] * conv_shape[2] * conv_shape[3]
  x = tf.keras.layers.Dense(units, activation = 'relu',
                            name="decode_dense1")(inputs)
  x = tf.keras.layers.BatchNormalization()(x)

  x = tf.keras.layers.Reshape((conv_shape[1], conv_shape[2], conv_shape[3]),
                              name="decode_reshape")(x)
  x = tf.keras.layers.Conv2DTranspose(filters=64, kernel_size=3, strides=2,
                                      padding='same', activation='relu',
                                      name="decode_conv2d_2")(x)
  x = tf.keras.layers.BatchNormalization()(x)

  x = tf.keras.layers.Conv2DTranspose(filters=32, kernel_size=3, strides=2,
                                      padding='same', activation='relu',
                                      name="decode_conv2d3")(x)
  x = tf.keras.layers.BatchNormalization()(x)

  x = tf.keras.layers.Conv2DTranspose(filters=1, kernel_size=3, strides=1, padding='same',
                                      activation='sigmoid', name="decode_final")(x)

  return x
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  units = conv_shape[1] * conv_shape[2] * conv_shape[3]
  x = tf.keras.layers.Dense(units, activation = 'relu',
                            name="decode_dense1")(inputs)
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                                      padding='same', activation='relu',
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  x = tf.keras.layers.BatchNormalization()(x)

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def decoder_model(latent_dim, conv_shape):
  inputs = tf.keras.layers.Input(shape=(latent_dim,))
  outputs = decoder_layers(inputs, conv_shape)
  model = tf.keras.Model(inputs, outputs)
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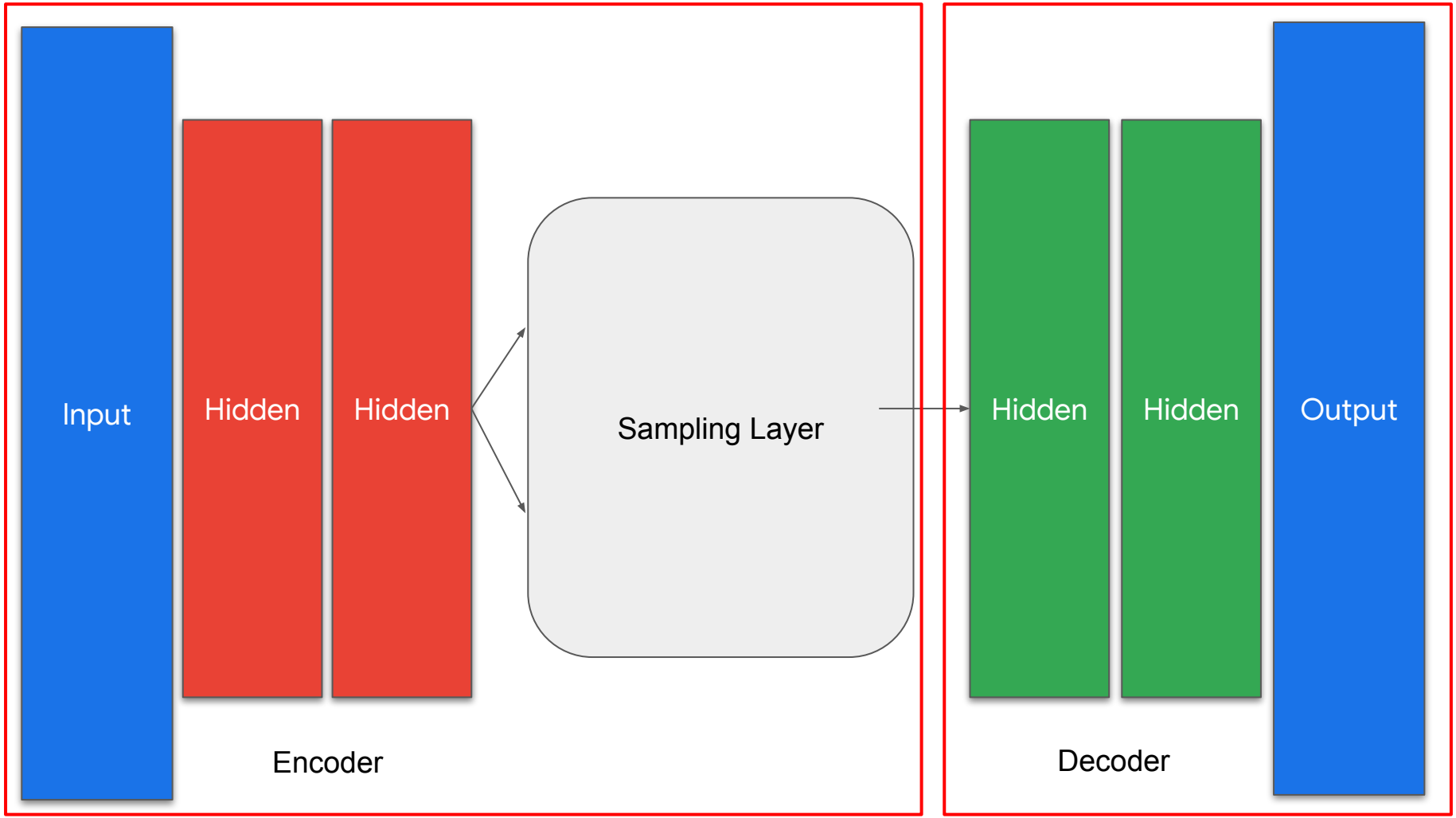
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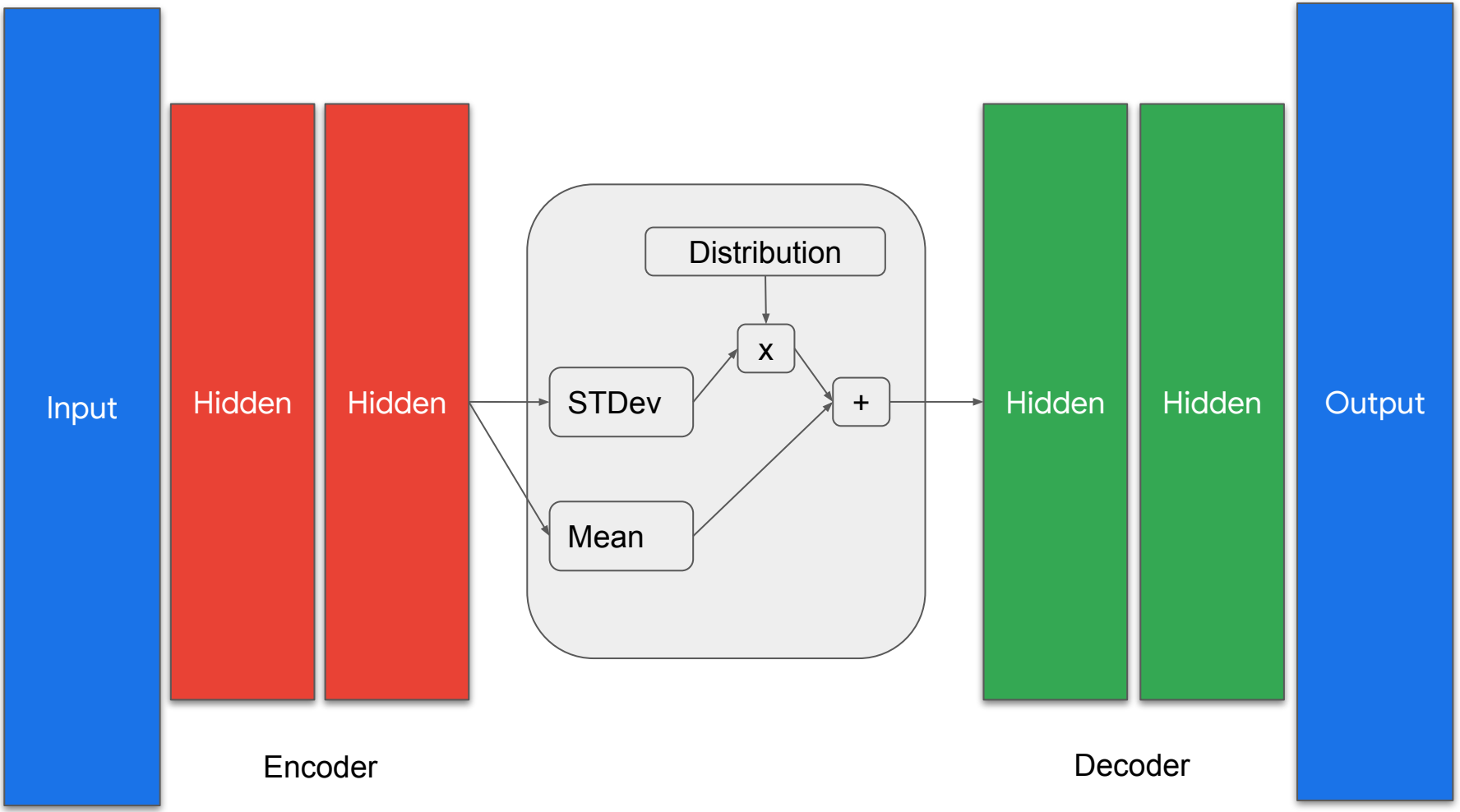
Input
Hidden
Hidden
Distribution
x
STDev
+
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Hidden
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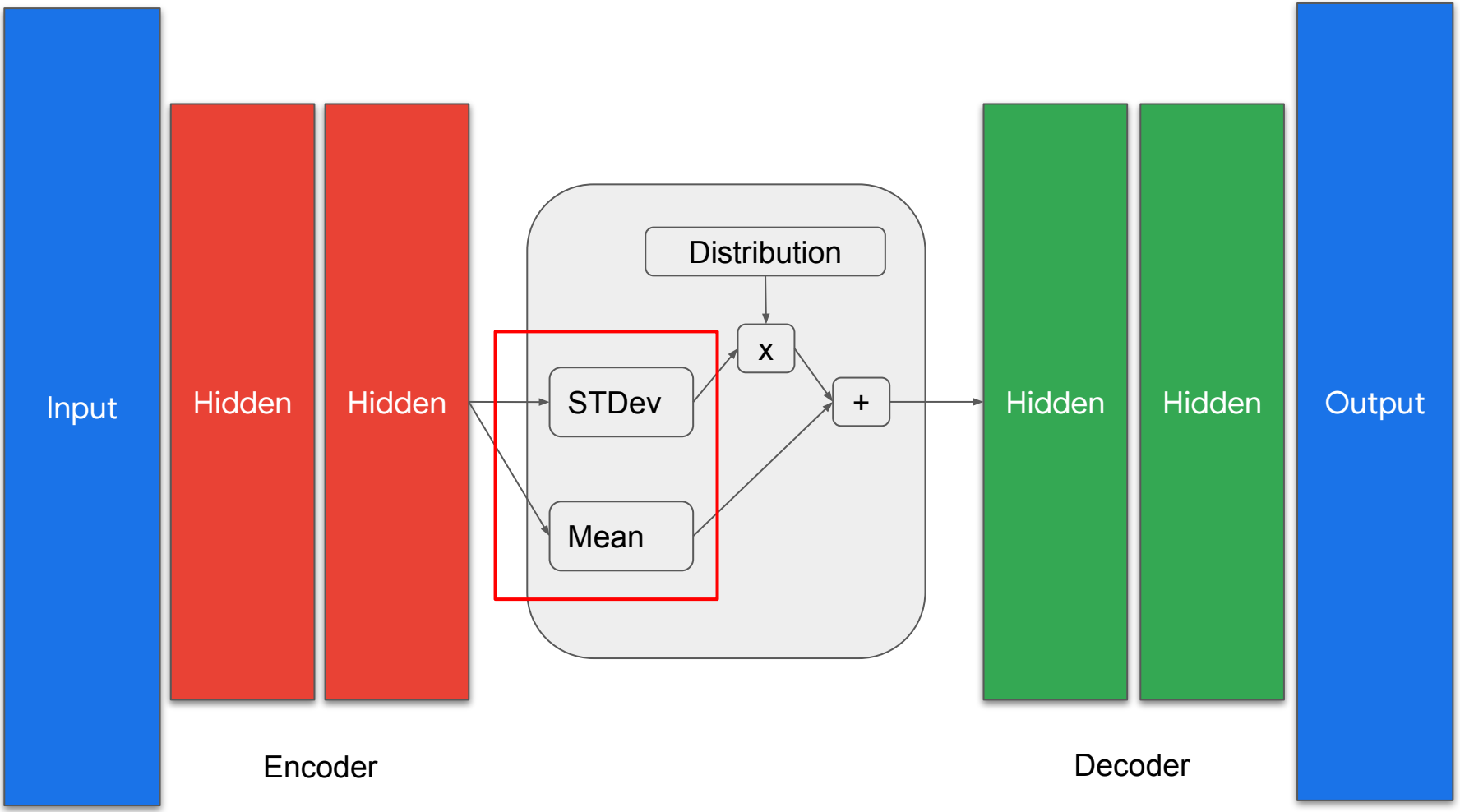
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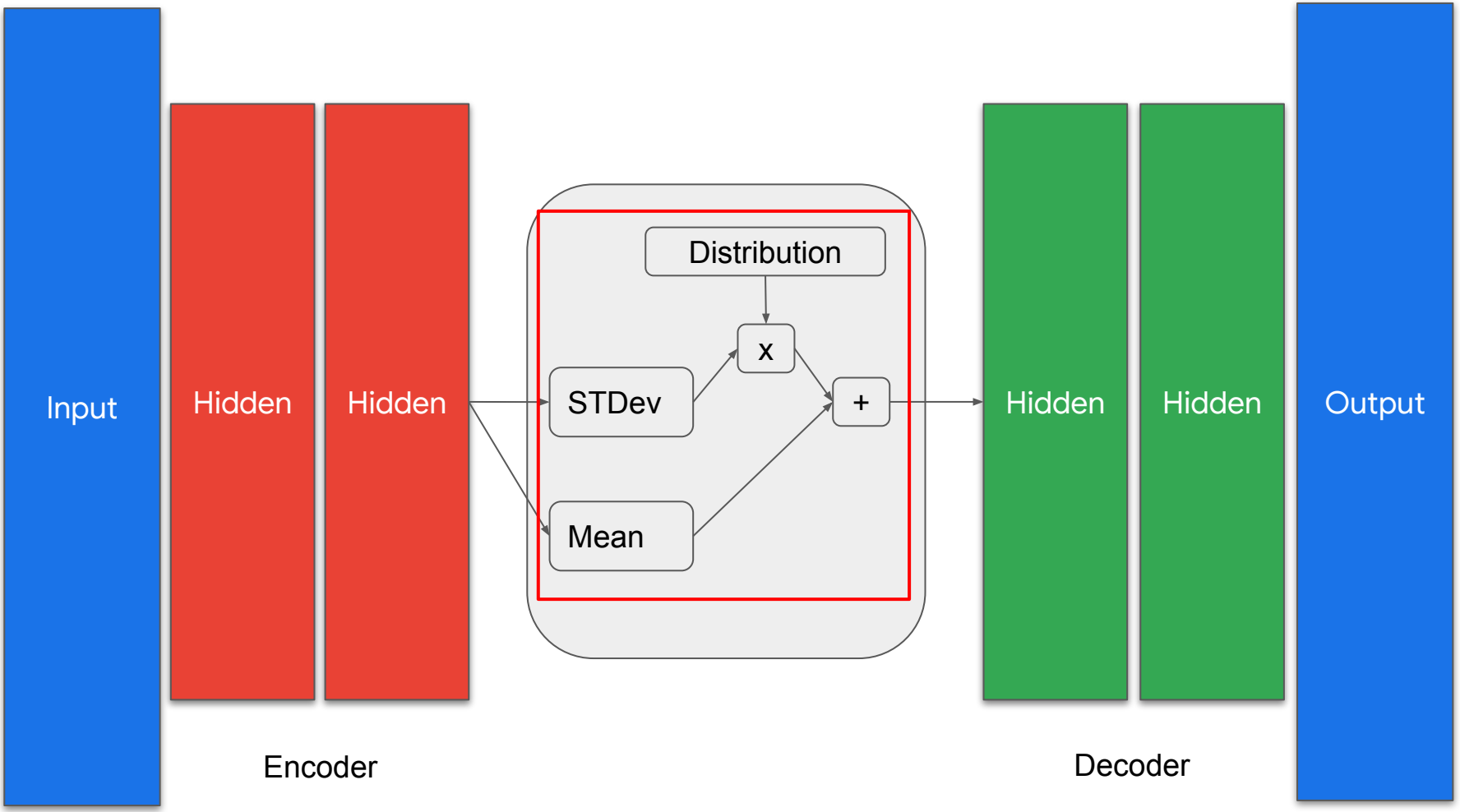
Input
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```python
# Define a kl reconstruction loss function
def kl_reconstruction_loss(inputs, outputs, mu, sigma):
  kl_loss = 1 + sigma - tf.square(mu) - tf.math.exp(sigma)
  return tf.reduce_mean(kl_loss) * -0.5
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https://en.wikipedia.org/wiki/Kullback%E2%80%93Leibler_divergence

https://arxiv.org/abs/2002.07514

```
def vae_model(encoder, decoder, input_shape):
  inputs = tf.keras.layers.Input(shape=input_shape)
  mu = encoder(inputs)[0]
  sigma = encoder(inputs)[1]
  z = encoder(inputs)[2]
  reconstructed = decoder(z)
  model = tf.keras.Model(inputs=inputs, outputs=reconstructed)
  loss = kl_reconstruction_loss(inputs, z, mu, sigma)
  model.add_loss(loss)
  return model
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  return model
```

```
for epoch in range(epochs):
  for step, x_batch_train in enumerate(train_dataset):
    with tf.GradientTape() as tape:
      reconstructed = vae(x_batch_train)
      flattened_inputs = tf.reshape(x_batch_train, shape=[-1])
      flattened_outputs = tf.reshape(reconstructed, shape=[-1])
      loss = bce_loss(flattened_inputs, flattened_outputs) * 784
      loss += sum(vae.losses)  # Add KLD regularization loss

    grads = tape.gradient(loss, vae.trainable_weights)
    optimizer.apply_gradients(zip(grads, vae.trainable_weights))
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```

epoch: 99, step: 400