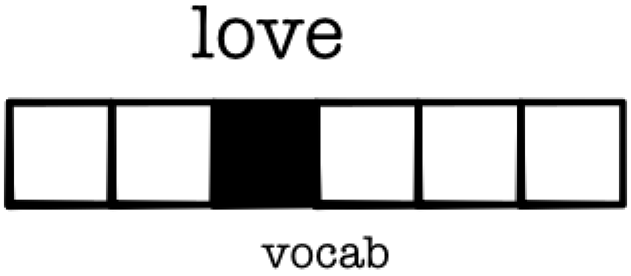
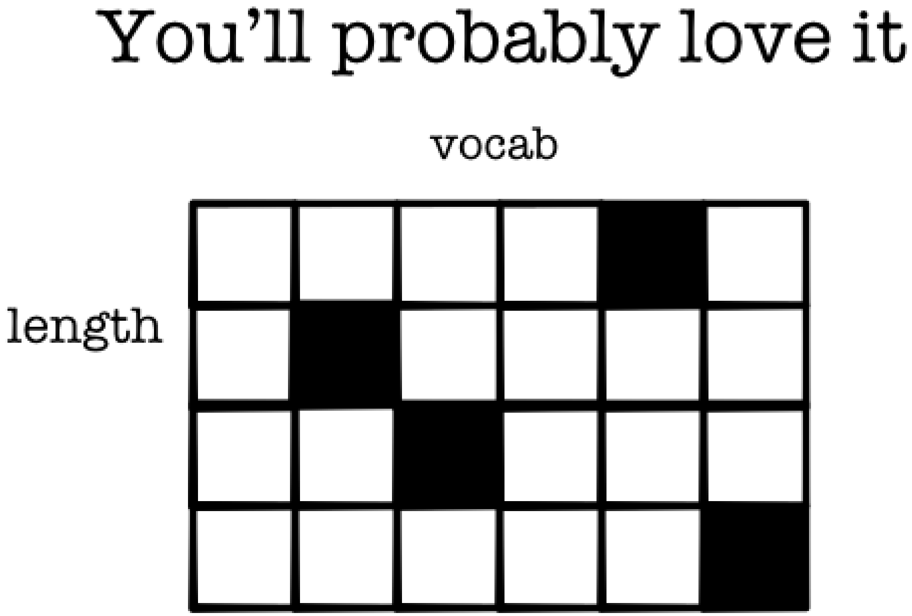
Module 4.1 - Convolutions

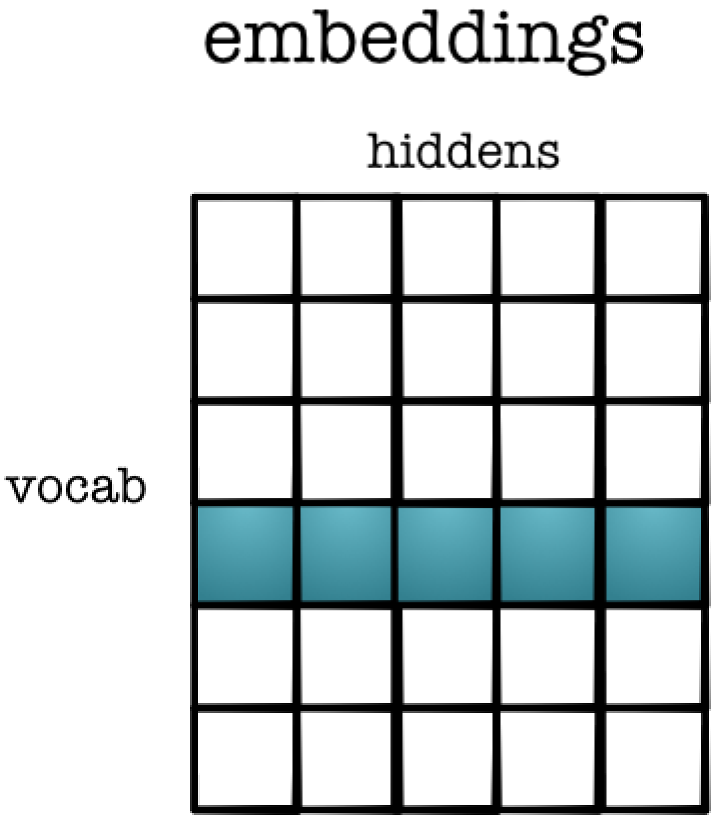
Vector Form



Challenge: Length Dimension



Embedding Table



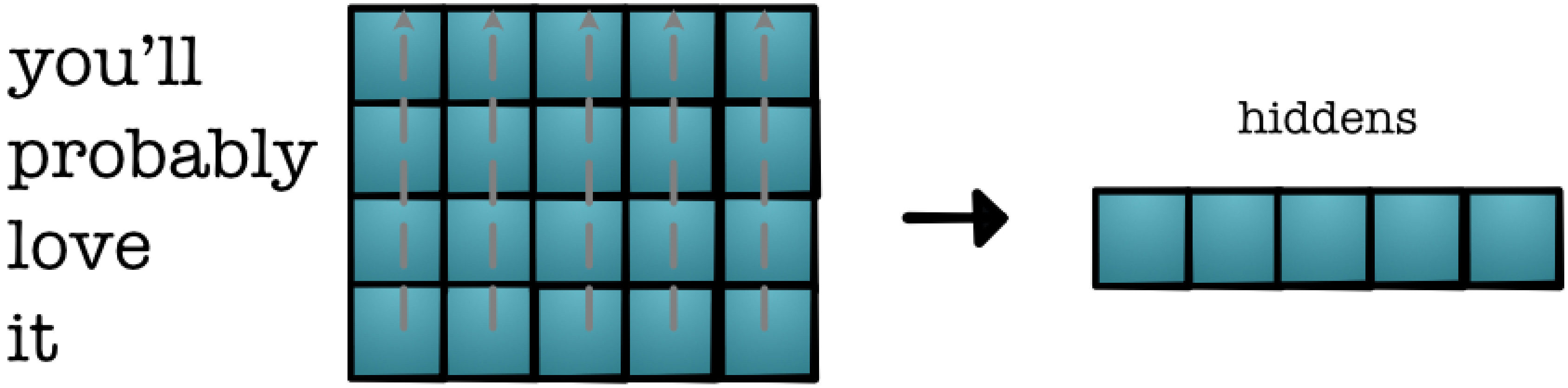
Embedding Layer

Easy to write as a layer

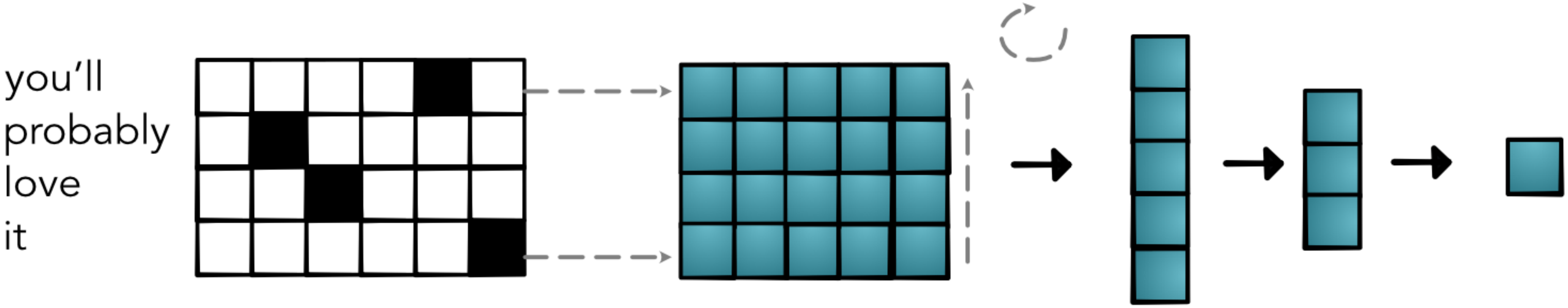
```
class Embedding(minitorch.Module):
    def __init__(self, vocab_size, emb_size):
        super().__init__()
        self.weights = \
            minitorch.Parameter(minitorch.rand((vocab_size, emb_size)))
        self.vocab_size = vocab_size

    def forward(input):
        return (input @ self.weights.values)
```

Reduction / "Pooling"



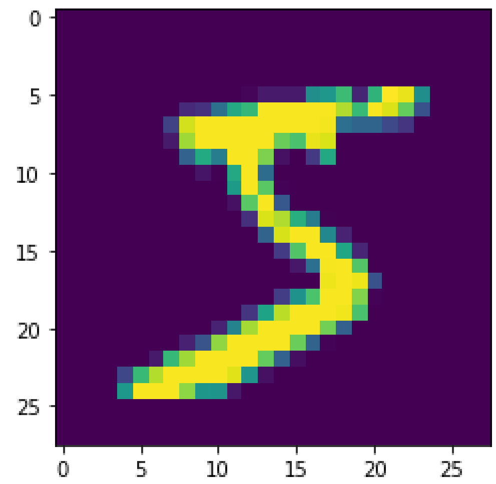
Full Model



Issues

- Completely ignores relative order
- Completley ignores absolute order
- Embeddings for all words, even rare ones

Challenge 1: Input Representation



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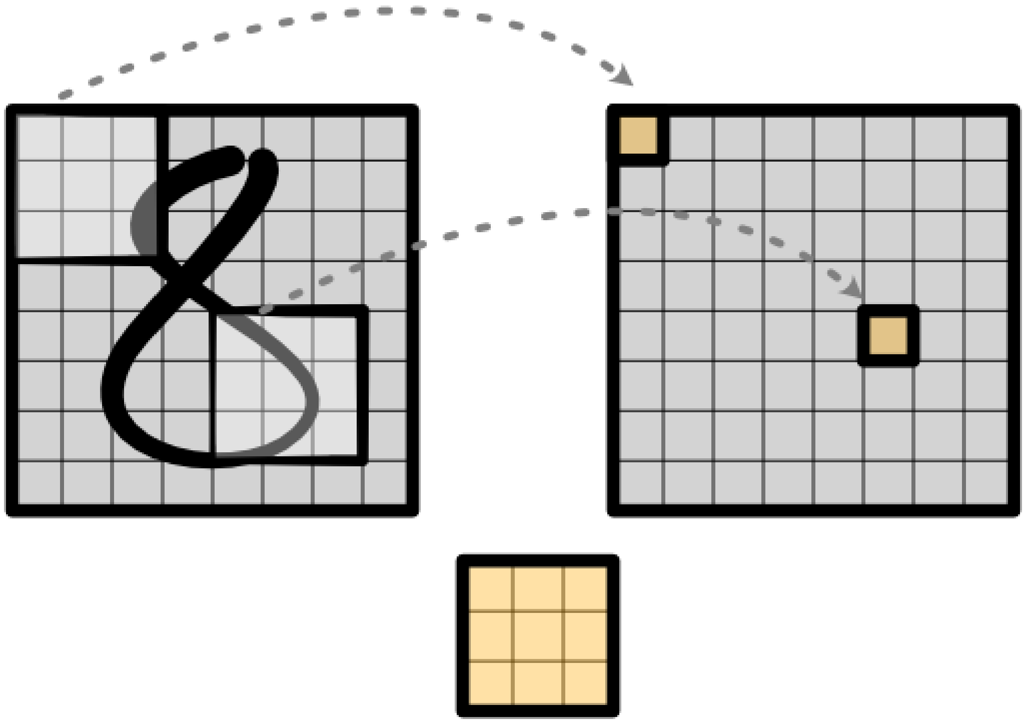
Challenge 1: Input Features



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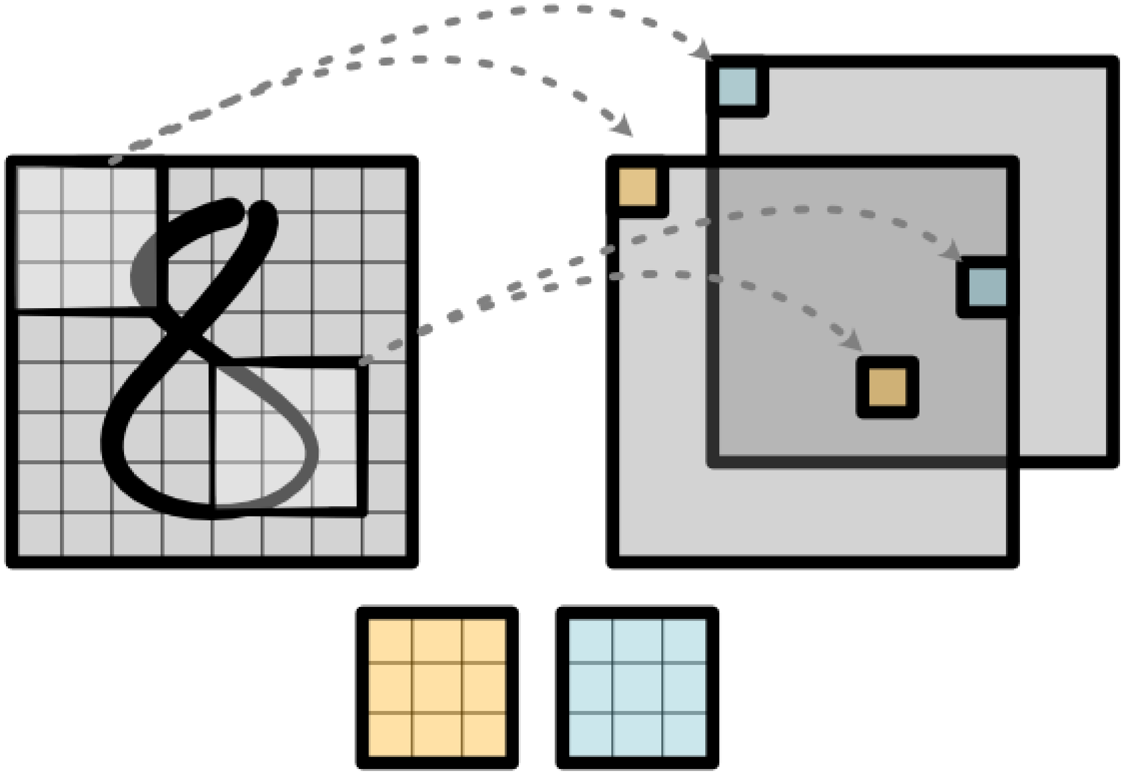
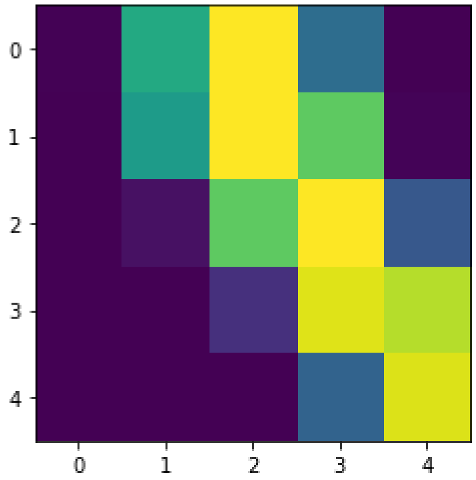
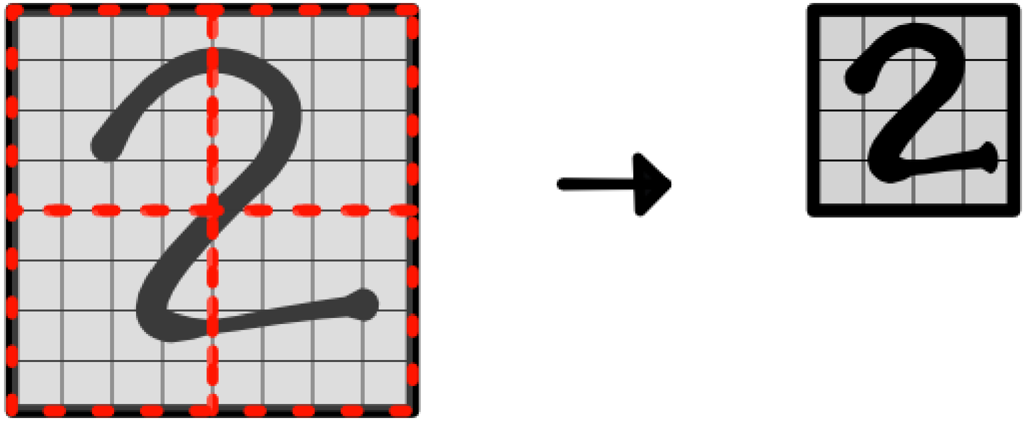
Challenge 1: Input Features



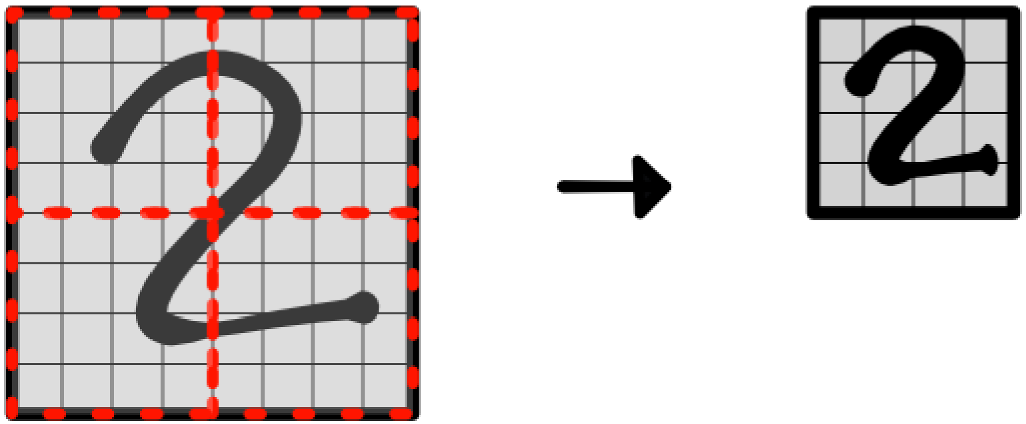
Challenge 1: Input Representation



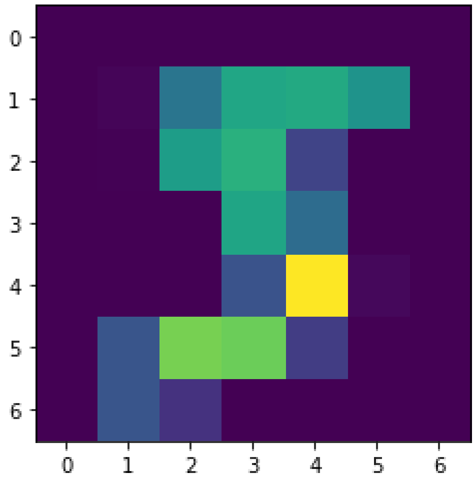
Challenge 2: Variable Size Area



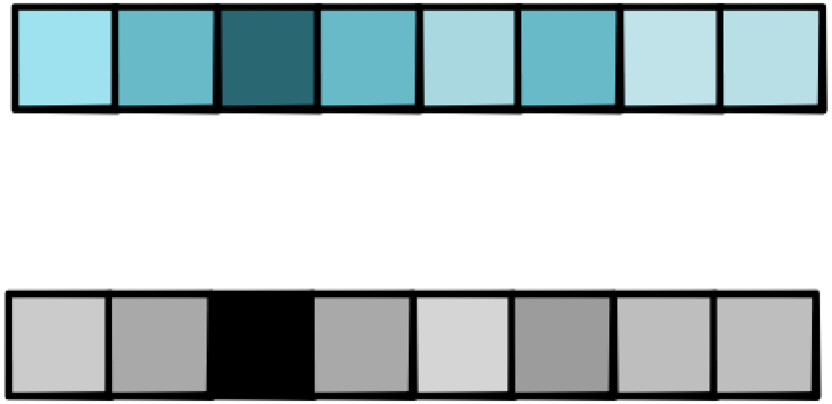
Challenge 2: Variable Size Area



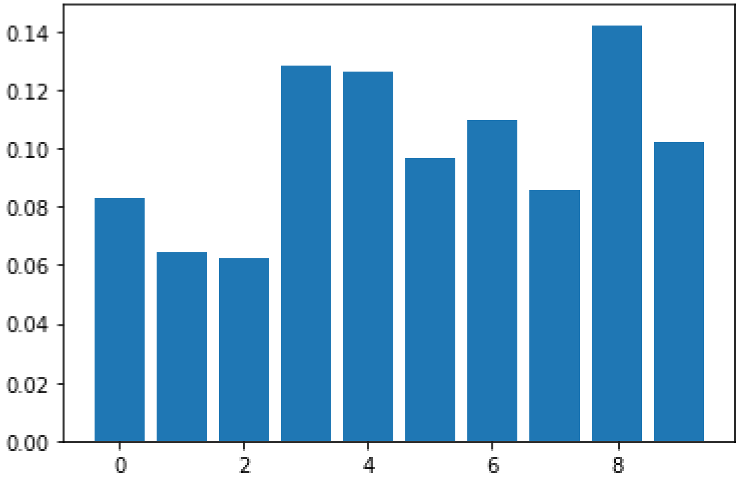
Challenge 2: MNist Zoom



Challenge 3: Multiple Output



Challenge 3: Multiple Output



Quiz

Quiz

Today's Class

- Conv 1D
- Channels
- Conv 2D

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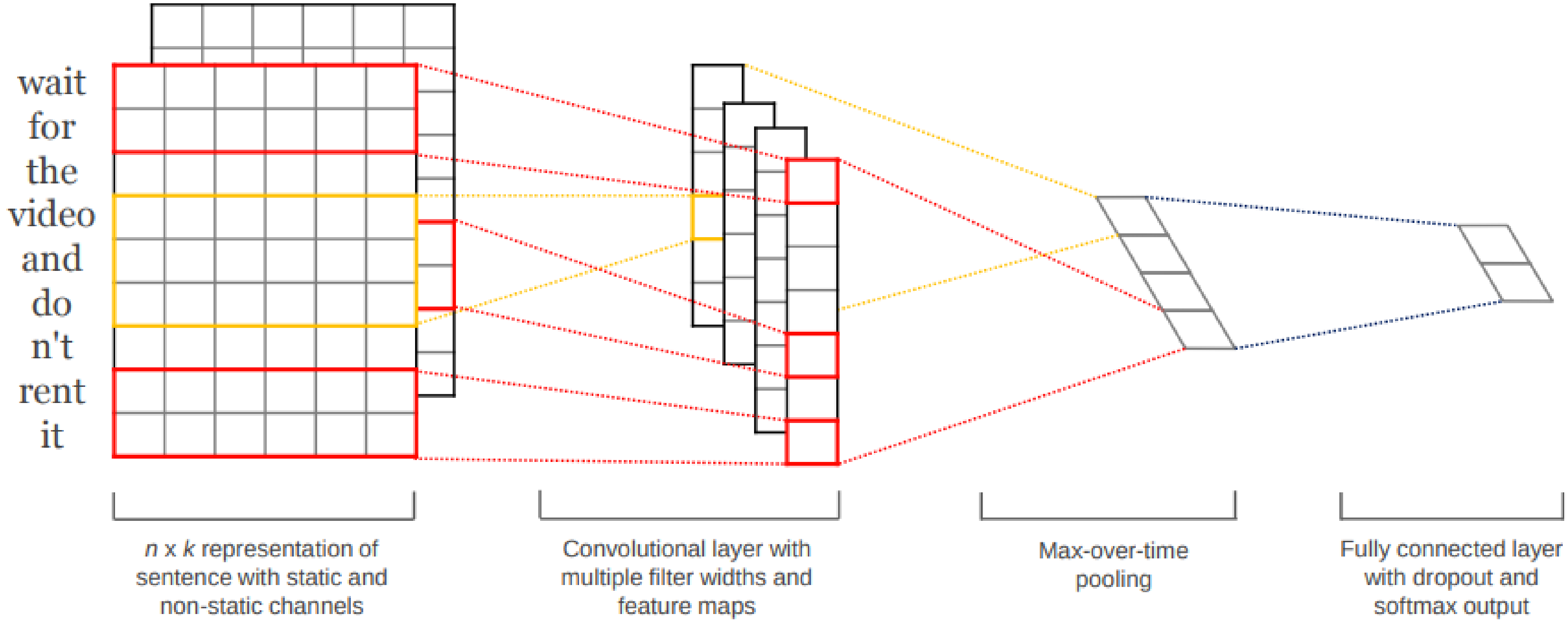
Challenge

How do we handle locality in features?

NLP



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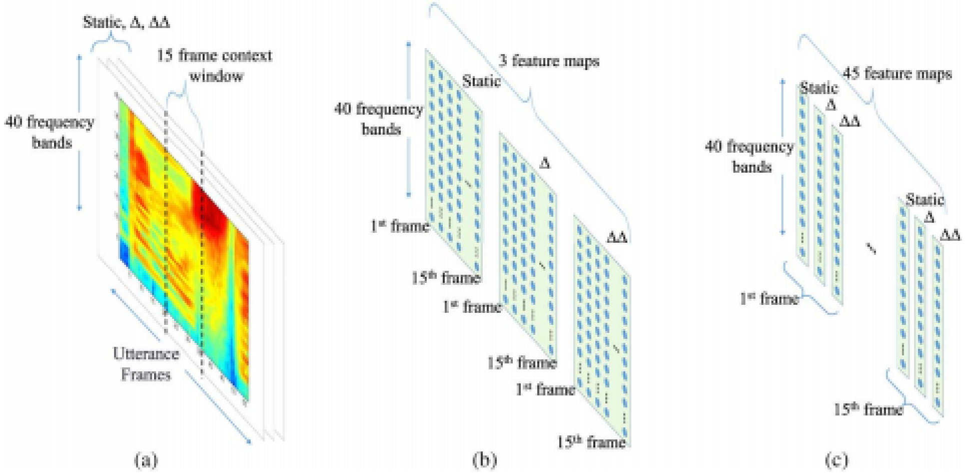
Speech Recognition



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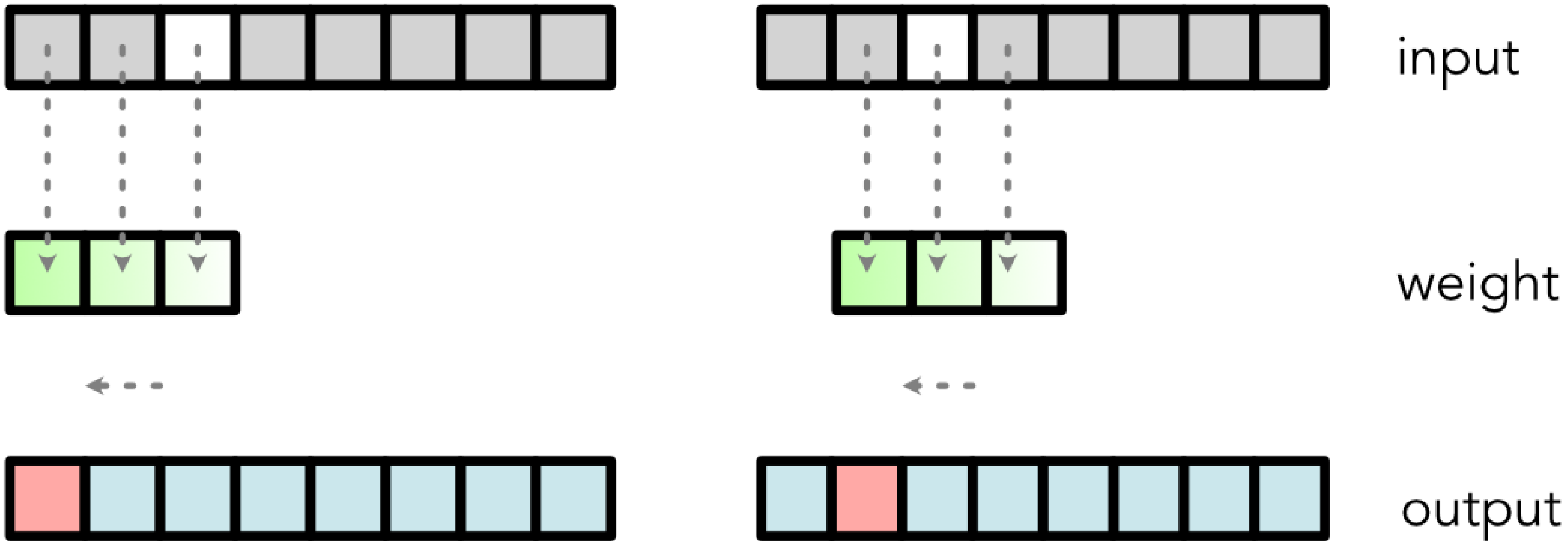
Intuition

- Apply a linear model.
- Run it as a sliding window
- Hope for splits to detect patterns

Convolution Forward



Computation

Output Values

```
output[0] = weight[0] * input[0] + weight[1] * input[1]  + weight[2] * input[2]
output[1] = weight[0] * input[1] + weight[1] * input[2]  + weight[2] * input[3]
output[2] = weight[0] * input[2] + weight[1] * input[3]  + weight[2] * input[4]
```

Alternative View

Unroll

```
def unroll(input, T, K):
    out = [[input[i + k] if i + k < T else 0
            for k in range(K)]
           for i in range(T)]
    return tensor(out)
```

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Alternative View

Unroll

```
input = tensor([1, 2, 3, 4, 5, 6])
K = 3
T = input.shape[0]
unrolled_input = unroll(input, T, K)
print(unrolled_input)
```

```
[
        [1.00 2.00 3.00]
        [2.00 3.00 4.00]
        [3.00 4.00 5.00]
        [4.00 5.00 6.00]
        [5.00 6.00 0.00]
        [6.00 0.00 0.00]]
```

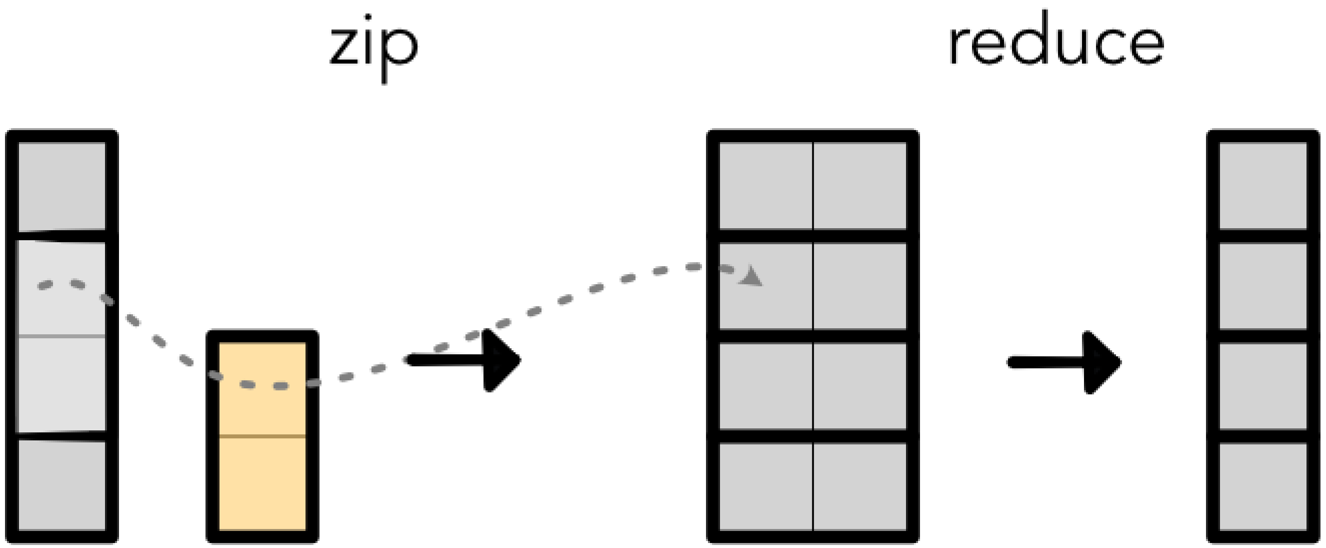
Alternative View

Unroll + zip + reduce ::

```
weight = tensor([5, 2, 3])
output = (unrolled_input @ weight.view(K, 1)).view(T)
print(output)
```

```
[18.00 28.00 38.00 48.00 37.00 30.00]
```

Alternative View



Gradient

Output Values

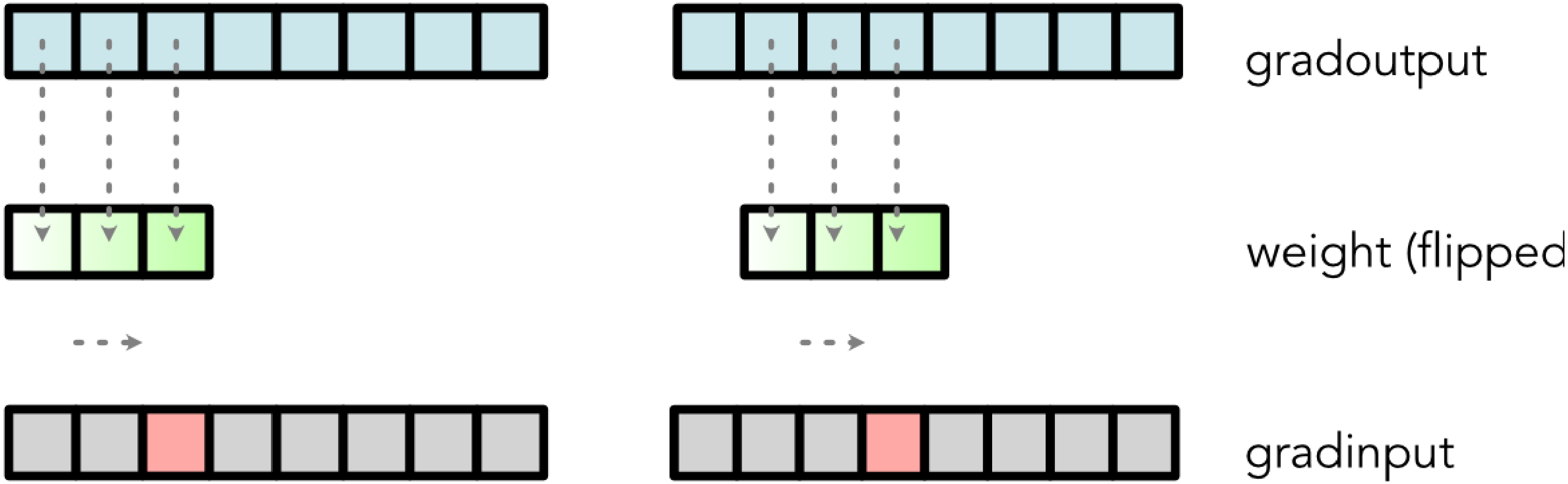
```
output[0] = weight[0] * input[0] + weight[1] * input[1]  + weight[2] * input[2]
output[1] = weight[0] * input[1] + weight[1] * input[2]  + weight[2] * input[3]
output[2] = weight[0] * input[2] + weight[1] * input[3]  + weight[2] * input[4]
```

Gradient

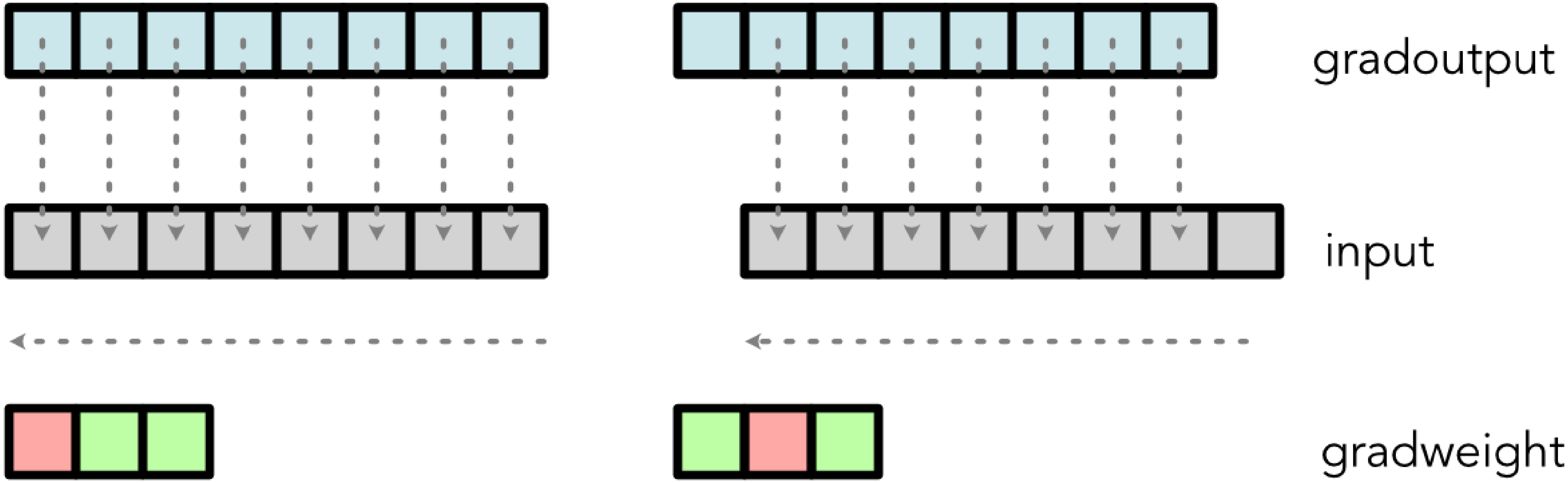
```python
class Conv:

    @staticmethod
    def backward(ctx, d):
        ...
        grad_input[2] = weight[0] * d[2] + weight[1] * d[1]  + weight[2] * d[0]
        ...
```

Conv Back - Input

Reverse the convolutional anchor



Conv Back - Weight



Channels

Intuition

- Each position may have multiple values
- These may be meaningful - i.e. color channels
- These may be learned - i.e. hidden states

Key Points

- Convolution is a Linear applied to all channels in position
- If weight is length K and there are 10 channels, the input to the linear is 10 * K.
- Output channels are just like the output of the Linear.

Graphical Representation

Code

```python
def unroll_chan(input, T, C, K):
    out = [[input[i + k, c] if i + k < T else 0
             for k in range(K)
            for c in range(C)]
           for i in range(T)]

    return tensor(out)

in_channels = 2
input = rand(T, in_channels)
unrolled_input = unroll_chan(input, T, in_channels, K)
print(unrolled_input.shape) # Shape: T x (in_channels * K)
```

```
(6, 6)
```

Graphical Representation

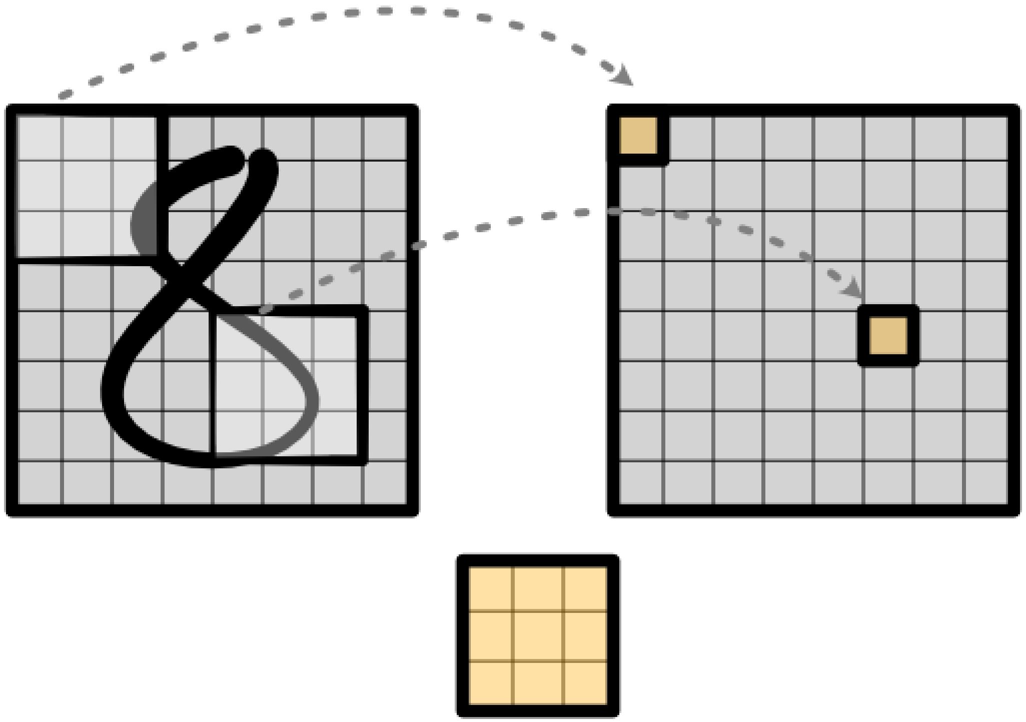
Implementation

- All about understanding sizes.
- Should be similar to matmul, start with output
- If outside boundaries, use 0

Two Dimensional Convolution

- Instead of line, now use box
- Box is anchored at the top-left
- Zip-reduce is over full box!

Convolution

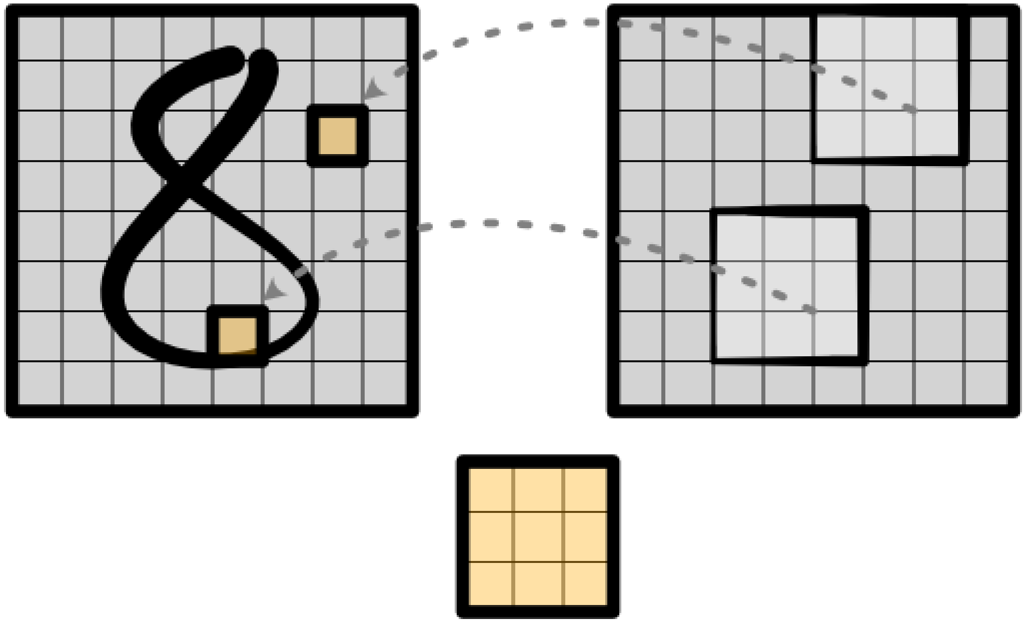


Conventions

Sizes

```
# Input image - batch x in_channel x height x width
# Weight - out_channel x in_channel x kernel_height x kernel_width
# Output image - batch x out_channel x height x width
```

Backward



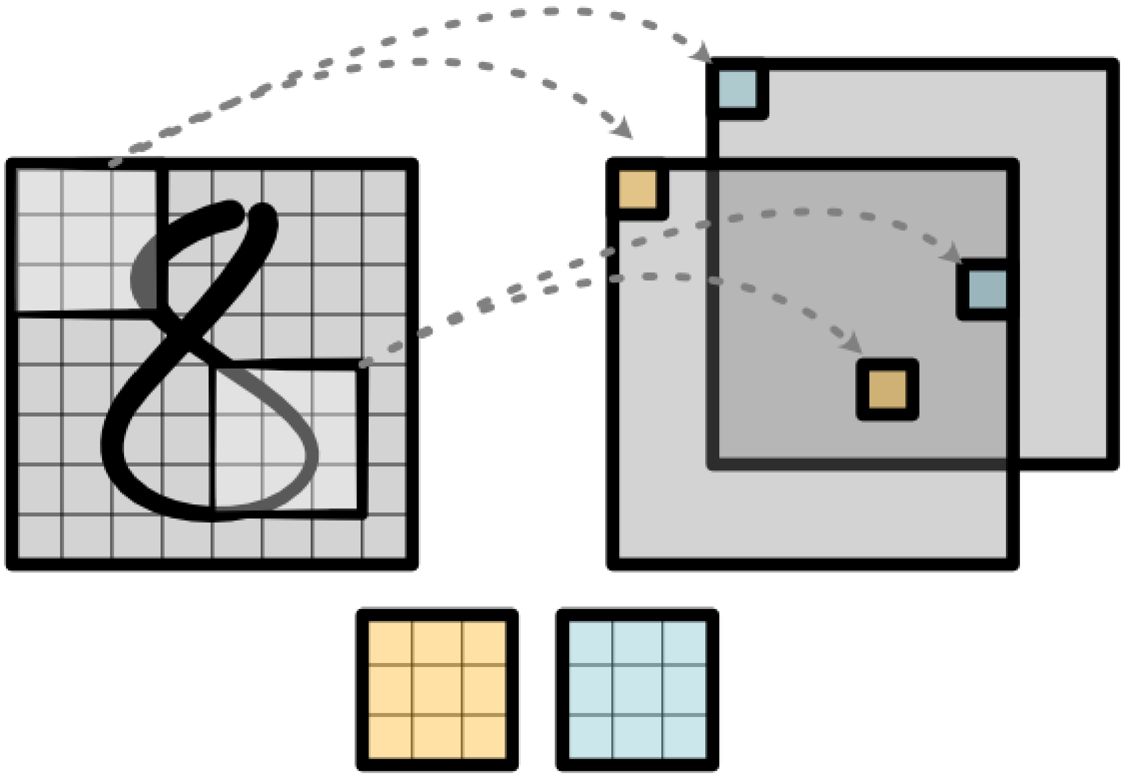
Backward

Same idea as 1D

- Reverse weight (bottom-top, left-right)
- Anchor bottom-right
- Compute convolution

Channels

Nothing different from 1D version



Implementation

- All about understanding sizes.
- Should be similar to matmul, start with output
- If outside boundaries, use 0

Advice

- Implement 1D first it is easier
- Compute a couple manually yourself.
- All about indexing

Where are we?

https://poloclub.github.io/cnn-explainer/