MATLAB EXPO 2018
UNITED KINGDOM
3 October | Silverstone, Northamptonshire
Register at matlabexpo.co.uk
Image Processing, Computer Vision, and Deep Learning

Image Processing

Computer Vision

Deep Learning

MATLAB EXPO 2018
Deep Learning vs Image Processing

The perception:

“Deep learning has made ‘traditional’ image processing obsolete.”

or

“Deep learning needs millions of examples and is only good for classifying pictures of cats anyway.”
Deep Learning and Image Processing

The reality:

Deep learning and image processing are effective tools to solve different problems.

and

Computer Vision tasks are complex, use the right tool for the job.
What are real world problems like?
An Example

![Sudoku Puzzle](image)

MATLAB EXPO 2018
The Sydney Morning Herald

The game's up: jurors playing Sudoku abort trial

By Malcolm Knox
11 June 2008 — 10:00am

AFTER 105 witnesses and three months of evidence, a drug trial costing $1 million was aborted yesterday when it emerged that jurors had been playing Sudoku since the trial’s second week.
Take a picture → Solve the puzzle
Breaking down the problem

Find the puzzle

Find the boxes

Read the numbers

Solve

Deep Learning

Image Processing

Deep Learning

Optimisation

MATLAB EXPO 2018
Step 1 – Find the puzzle

Find the puzzle

Find the boxes

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>4</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Read the numbers

\[
\begin{bmatrix}
4 & 1 & \cdots & ? & ? \\
7 & ? & \cdots & ? & ? \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
? & ? & \cdots & 7 & ? \\
? & 7 & \cdots & ? & ?
\end{bmatrix}
\]

Solve

\[
\begin{bmatrix}
4 & 1 & \cdots & 6 & 8 \\
7 & 8 & \cdots & 3 & 2 \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
4 & 2 & \cdots & 7 & 5 \\
6 & 7 & \cdots & 4 & 1
\end{bmatrix}
\]
Step 1 – Find the puzzle

- Varied background and object of interest
- Uncontrolled image acquisition
- Good problem for deep learning
Finding things with deep learning

Object detection

Semantic segmentation
To label an ROI, you must first define one or more of the following label types:
- Rectangle label
- Pixel label

To label a scene, you must first define a scene label.
How do we train a semantic segmentation network?

- Manage input data and apply pre-processing
  ```matlab
  inputSize = [512, 512, 3];
  train = pixelLabelImageDatastore(imagesTrain, labelsTrain, ...
  'OutputSize', inputSize(1:2));
  test = pixelLabelImageDatastore(imagesTest, labelsTest, ...
  'OutputSize', inputSize(1:2));
  ```

- Use a well established network architecture configured for our problem
  ```matlab
  numClasses = 2;
  baseNetwork = 'vgg16';
  layers = segnetLayers(inputSize, numClasses, baseNetwork);
  layers = sudoku.weightLossByFrequency(layers, train);
  ```

- Set up training options
  ```matlab
  opts = trainingOptions('sgdm', ...
  'InitialLearnRate', 0.01, ...
  'ValidationData', test, ...
  'MaxEpochs', 10, ...
  'Plots', 'training-progress');
  ```

- Train the network
  ```matlab
  net = trainNetwork(train, layers, opts);
  ```
```python
# Import necessary libraries
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# Generate some example data
np.random.seed(1)
data = np.random.randn(100, 2)

# Create a DataFrame
df = pd.DataFrame(data, columns=['x', 'y'])

# Plot the data
plt.scatter(df['x'], df['y'])
plt.show()
```
An Example – Sudoku Solver

Find the puzzle

Find the boxes

Read the numbers

Solve

Deep Learning
Step 2 – Find the boxes

Find the puzzle

Find the boxes

Read the numbers

Solve

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th>⋯</th>
<th>?</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>?</td>
<td>⋯</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>⋯</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>⋯</td>
<td>7</td>
<td>?</td>
</tr>
<tr>
<td>?</td>
<td>7</td>
<td>⋯</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th>⋯</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td>⋯</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
<td>⋯</td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>⋯</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>⋯</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>
Step 2 – Find the boxes

- Well defined problem:
  - 4 intersecting straight lines
  - Dark ink on light paper
  - Grid of 9 x 9 equally sized boxes

- Need good precision to localise individual boxes.

- Good image processing problem.
Step 2 – Find the boxes

Image processing pipeline

Adaptive thresholding

imbinarize

↓

Morphological operations

imopen/imclose

↓

Region property analysis

regionprops

↓

Robust line detection

hough/houghpeaks

↓

Geometric warping

fitgeotrans/imwarp
An Example – Sudoku Solver

Find the puzzle

Find the boxes

Read the numbers

Solve

Deep Learning

Image Processing
Step 3 – Read the numbers

Find the puzzle

Find the boxes

Read the numbers

Solve

\[
\begin{bmatrix}
4 & 1 & \ldots & ? & ? \\
7 & ? & \ldots & ? & ? \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
? & ? & \ldots & 7 & ? \\
? & 7 & \ldots & ? & ?
\end{bmatrix}
\]

\[
\begin{bmatrix}
4 & 1 & \ldots & 6 & 8 \\
7 & 8 & \ldots & 3 & 2 \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
4 & 2 & \ldots & 7 & 5 \\
6 & 7 & \ldots & 4 & 1
\end{bmatrix}
\]
Step 3 – Read the numbers
How can we read numbers?

Optical Character Recognition (OCR)
How can we read numbers?

Deep Learning
We can make synthetic training data
We can make (lots of) synthetic training data
We can make (lots of) synthetic training data
Debugging a network

97.8% accuracy
Debugging a network

activations()
Debugging a network with t-SNE
An Example – Sudoku Solver

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes

Find the puzzle

Find the boxes
Step 4 – Solve

Find the puzzle

Find the boxes

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

Read the numbers

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>

Solve

<table>
<thead>
<tr>
<th>4</th>
<th>1</th>
<th></th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>8</td>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td></td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td></td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>
How can we solve a sudoku?

Solving Sudoku with MATLAB

By Cleve Moler, MathWorks

Human puzzle-solvers and computer programs use very different Sudoku-solving techniques. The fascination with solving Sudoku by hand derives from the discovery and mastery of a myriad of subtle combinations and patterns that provide hints about the final solution. It is not easy to program a computer to duplicate these human pattern-recognition capabilities. For this reason, most Sudoku-solving programs take a very different approach, relying on the computer’s almost limitless capacity to carry out brute-force trial and error. This is the approach that I used for the MATLAB program.

The Sudoku Challenge

As you probably know, solving a Sudoku involves filling in a 9-by-9 grid so that each row, column, and major 3-by-3 block contains all the digits 1 through 9. The initial grid is populated with a few digits, known as clues. In contrast to magic squares and other numeric puzzles, no arithmetic is involved; the elements in a Sudoku grid could just as well be letters of the alphabet or any other symbols.

Figure 1 shows an initial grid. I especially like the symmetry in this example, which is due to Gordon Royle of the University of Western Australia. Figure 2 shows the solution.
### Step 4 – Solve

Below is a 9x9 Sudoku puzzle. The goal is to fill in the blanks so that each row, column, and 3x3 subgrid contains all the digits from 1 to 9. The partially filled grid is provided.

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>9</td>
<td></td>
<td>6</td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td></td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>2</td>
<td></td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>8</td>
<td></td>
<td>5</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td></td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

This puzzle can be solved using various algorithms and strategies, such as the naked singles, hidden singles, and naked pairs techniques.
Image Processing
Optimisation
An Example – Sudoku Solver

Find the puzzle

Find the boxes

Read the numbers

Solve

Deep Learning

Image Processing

Deep Learning

Optimisation
Both deep learning and image processing are great tools for computer vision.

Use the right combination of tools to get the job done.

MATLAB makes it easy and efficient to do both image processing and deep learning together.

MATLAB helps you integrate a computer vision algorithm into the rest of your workflow.
Try out the example code (Search for: Deep Sudoku Solver)

Try what’s new in Image Processing and Computer Vision toolboxes

Talk to us about your (computer vision) problems