From Rules to Machine Learning to Deep Learning

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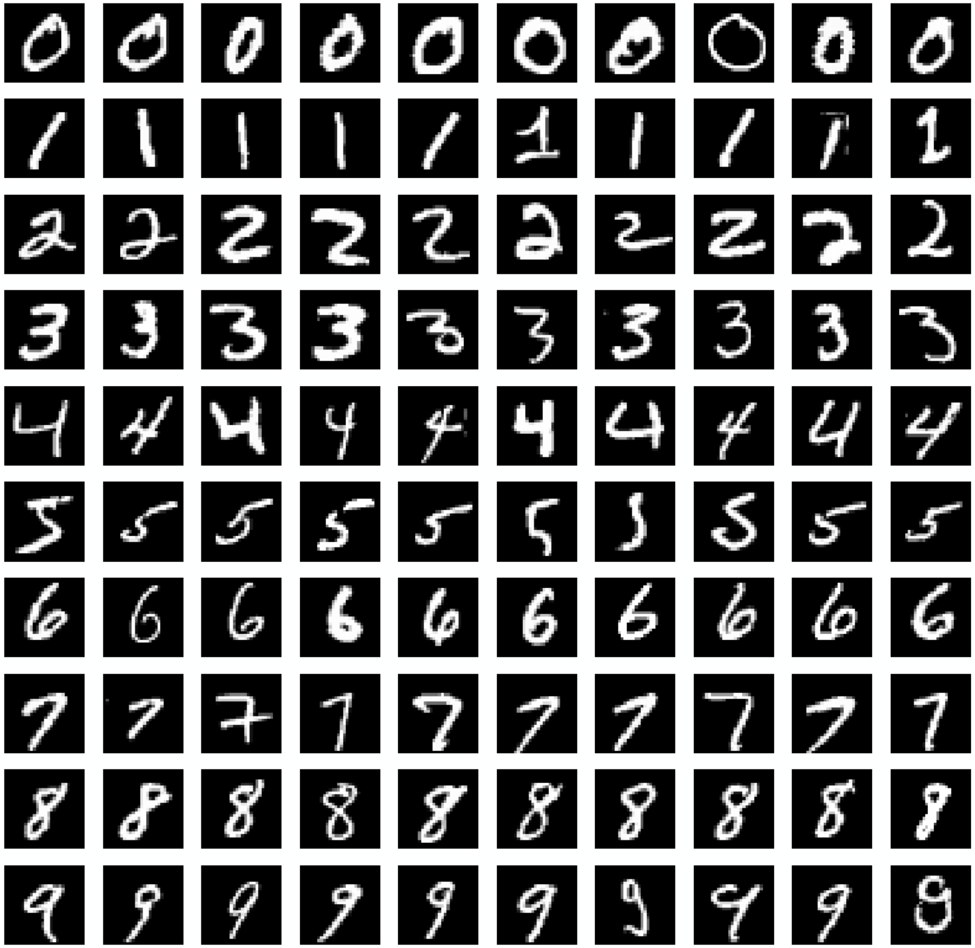
BE BOLD. Shape the Future.

The MNIST Dataset



- 70,000 28x28 pixel digitized images of handwritten digits 0 through 9
- Considered a standard benchmark dataset
- Small enough to
  - Fit in memory
  - Run on a modest machine
- Large enough to
  - Span a reasonable range of appearances
  - Solve an interesting problem

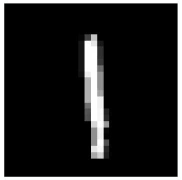
Rules:
How might we as humans describe the difference between handwritten digits?

Discriminating b/w 1 and 7

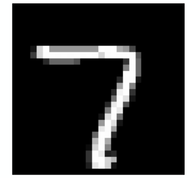
1 7

Discriminating b/w 1 and 7

1



7



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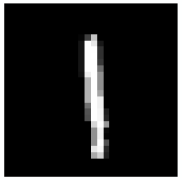
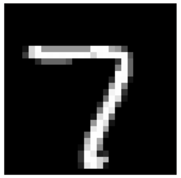


- One line segment

7



- Two line segments

Discriminating b/w 1 and 7

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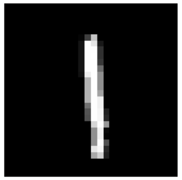

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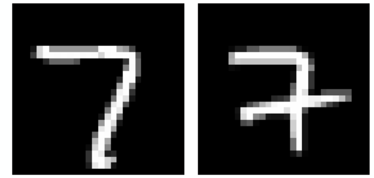

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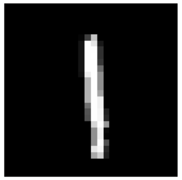

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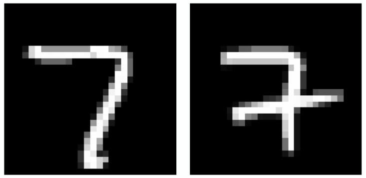

- Two line segments

- OR three line segments

Discriminating b/w 1 and 7

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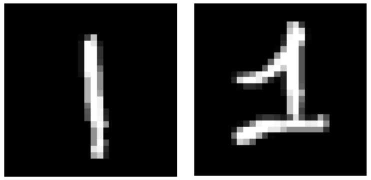

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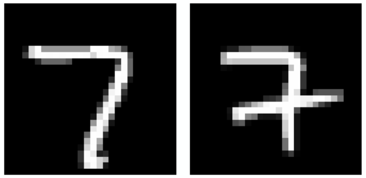

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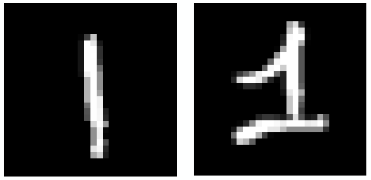

- One line segment

- OR three line segments where two are not perpendicular to the third

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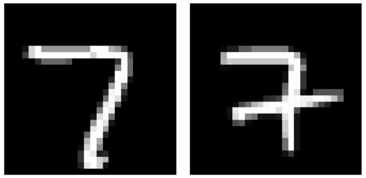

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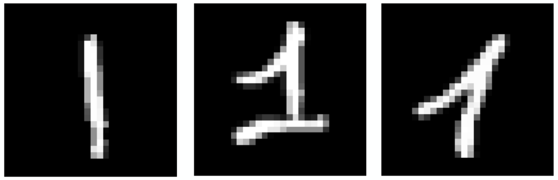

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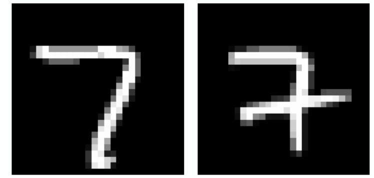

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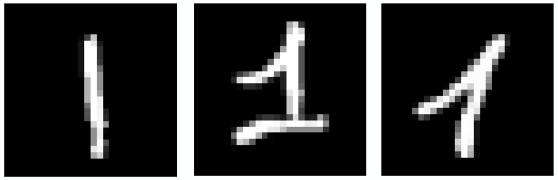

- One line segment
- OR three line segments where two are not perpendicular to the third
- OR two line segments with a small angle between them

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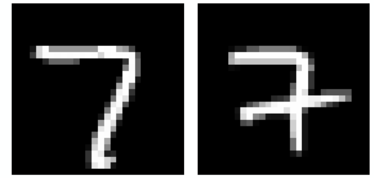

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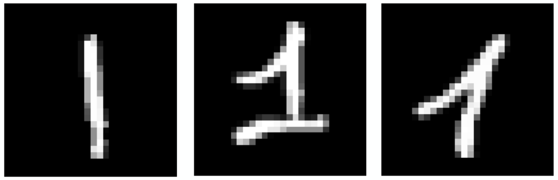

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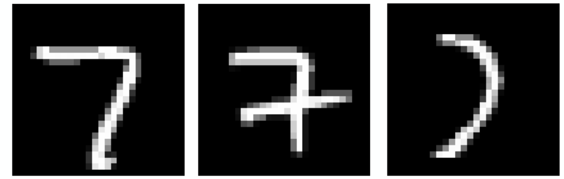

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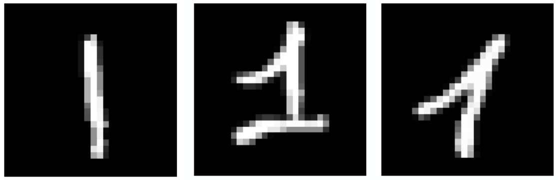

- One line segment

...which has a small curvature to it

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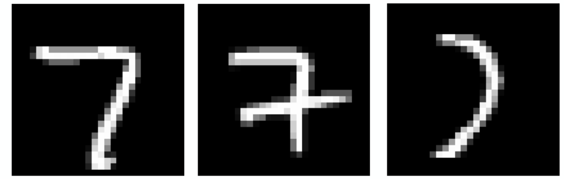

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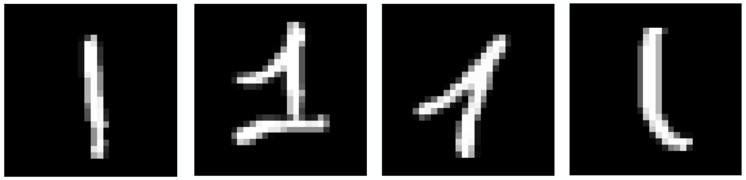

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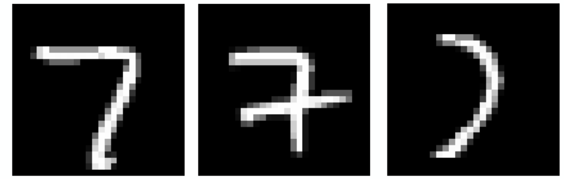

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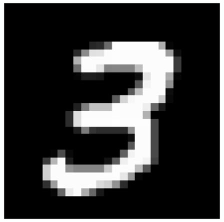
Rule-Based Learning

- Leverage the **human** to provide **labeled training data** (example images matched to labels)—Defines the **ground truth**



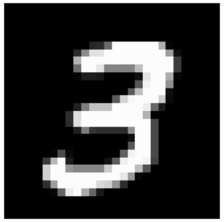
Example Images

"3"

Ground truth

Rule-Based Learning

- Leverage the **human** to provide **labeled training data** (example images matched to labels)—Defines the **ground truth**
- Leverage the **human** to work with specific examples to define a set of discriminatory features—Defines the **feature space**



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Feature Extraction

- # line segments
- Angle between segments
- Curvature
- # pixels
- Orientation

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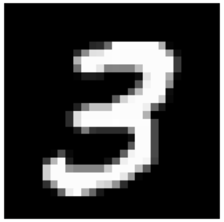

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- Set of rules and thresholds (boundaries)

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Classification

- Set of rules and thresholds (boundaries)

“3”

Predicted Label

- Leverage **computer** to quickly process many samples

Machine Learning: How can we leverage computers to sift through the features and learn to discriminate between handwritten digits?

Classical Machine Learning: Feature Extraction->Classification

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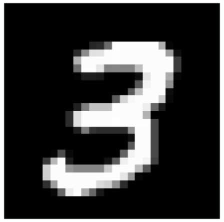

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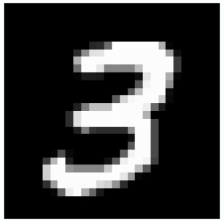

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Classification → "3"

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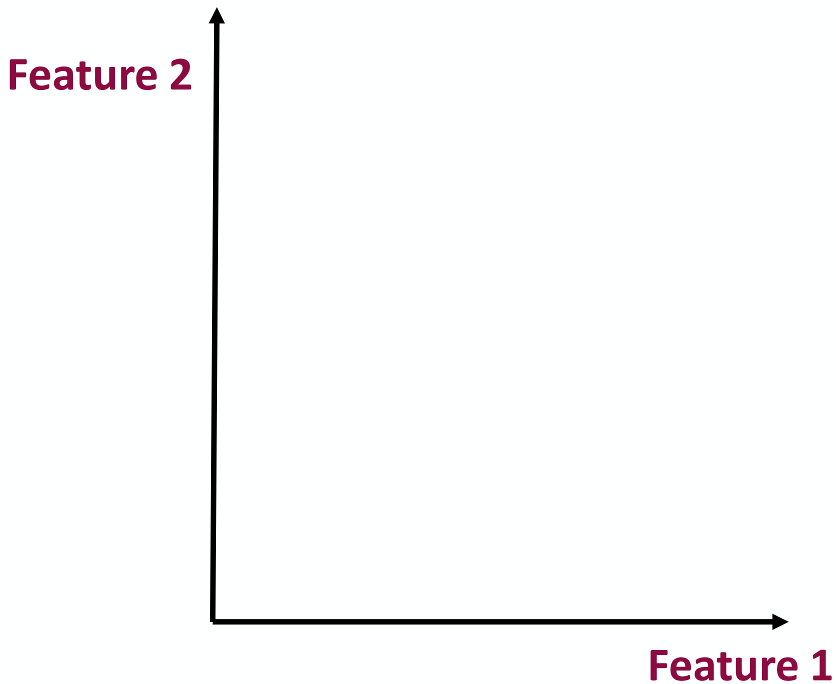

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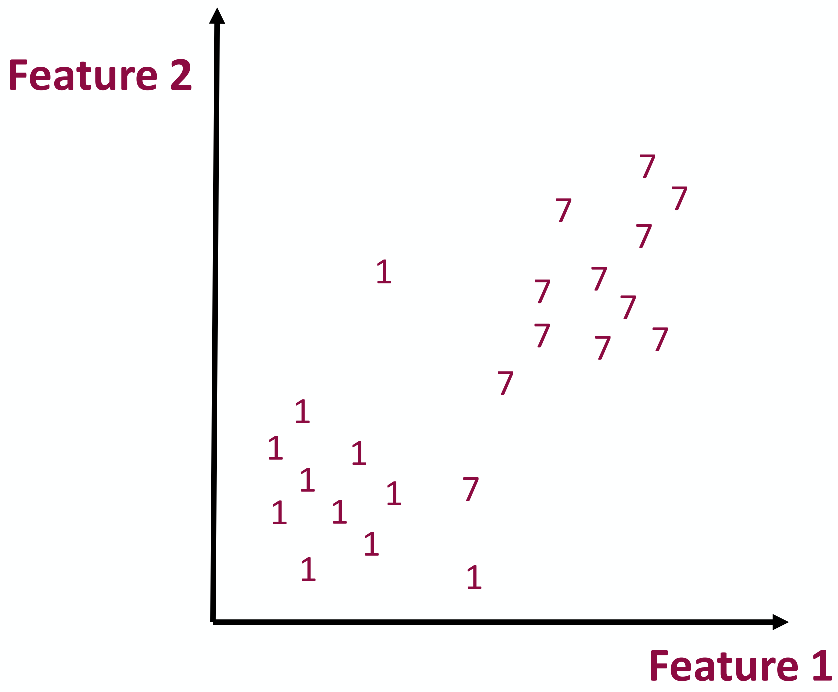

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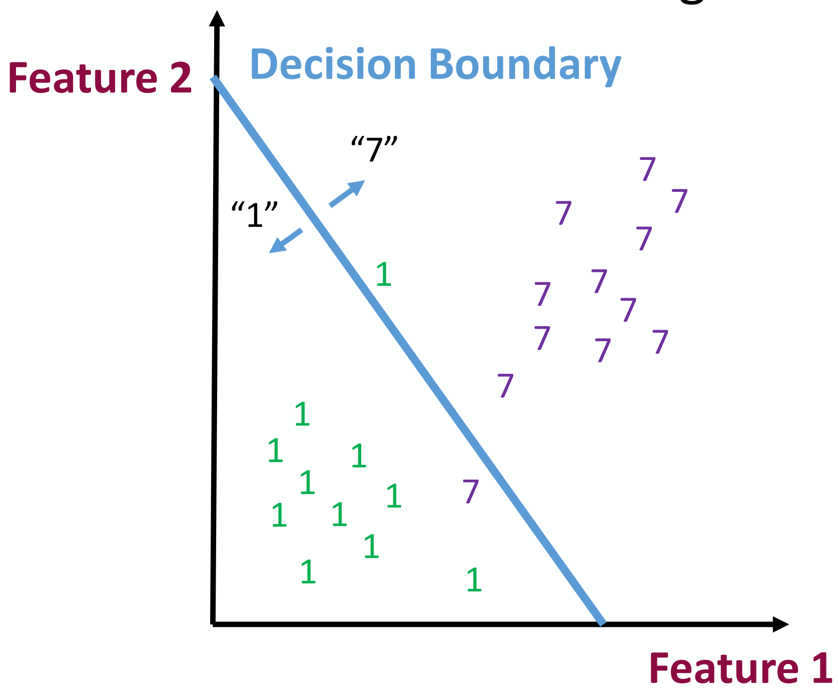

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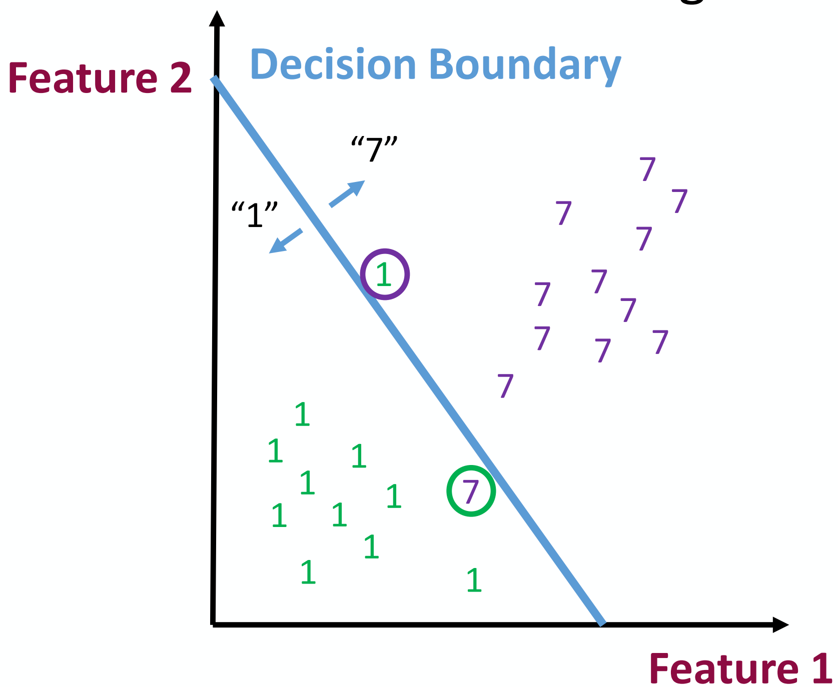

- Misclassifications:
  - Are they due to a **feature space** which is not descriptive enough?
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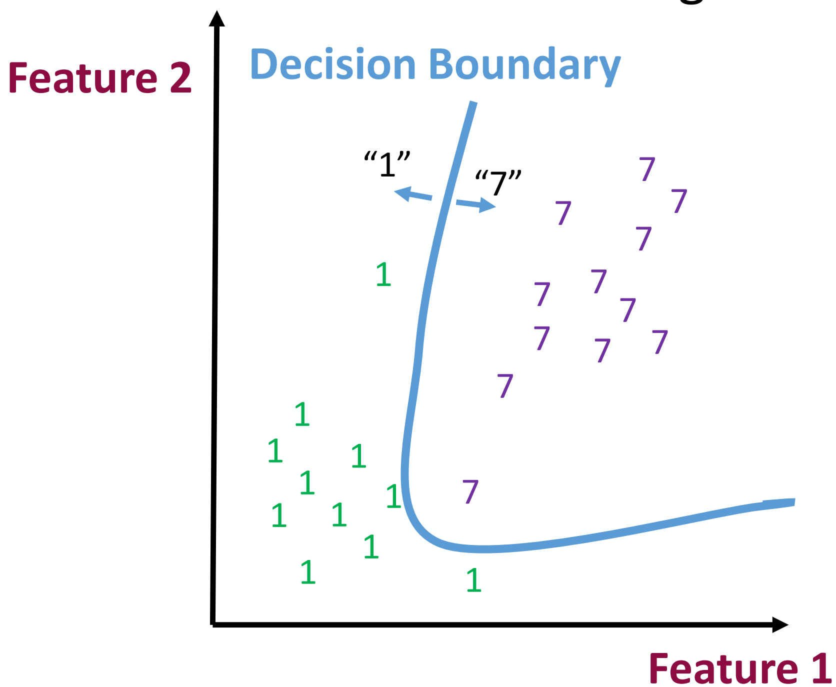

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Deep Learning: How can we leverage computers to learn the features AND how to use those features to discriminate between handwritten digits?

Deep Learning: Feature Extraction & Classification

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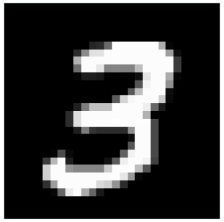

Example Images

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Ground truth

Deep Learning: Feature Extraction & Classification

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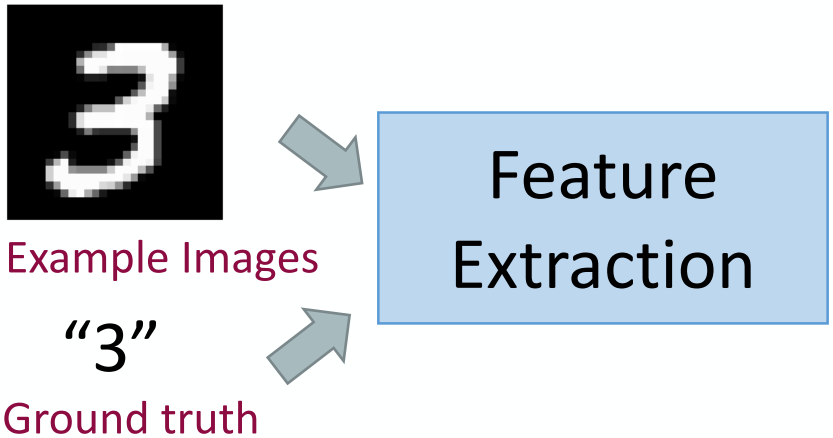

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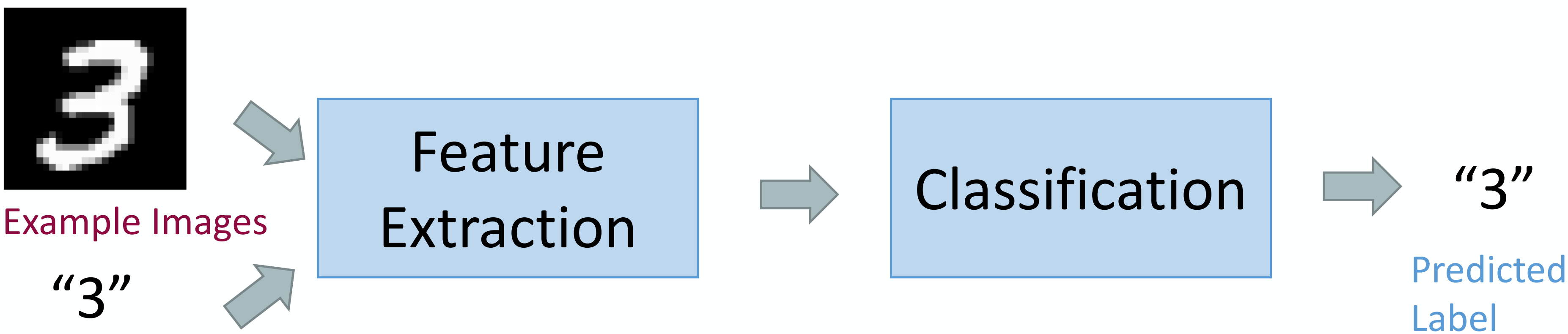

- Leverage **computer** to quickly process many samples

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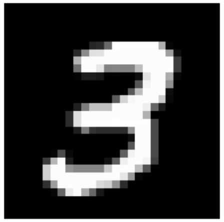

Example Images

"3"

Ground truth

Feature Extraction → Classification → "3"

Predicted Label

Neural Networks…

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