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Machine Learning Techniques for Radar ATR

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Chapter 1: Introduction to Radio Frequency ATR

Presenter Information

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Outline of the Short Course

The Presentation will follow our RF ATR Monograph (published in July 2020)

https://us.artechhouse.com/Deep-Learning-for-Radar-and-Communications-Automatic-Target-Recognition-P2074.aspx

Artech House Publisher
Boston | London

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9. RF ATR Performance Evaluation
10 Emerging ML Algorithms for RF ATR

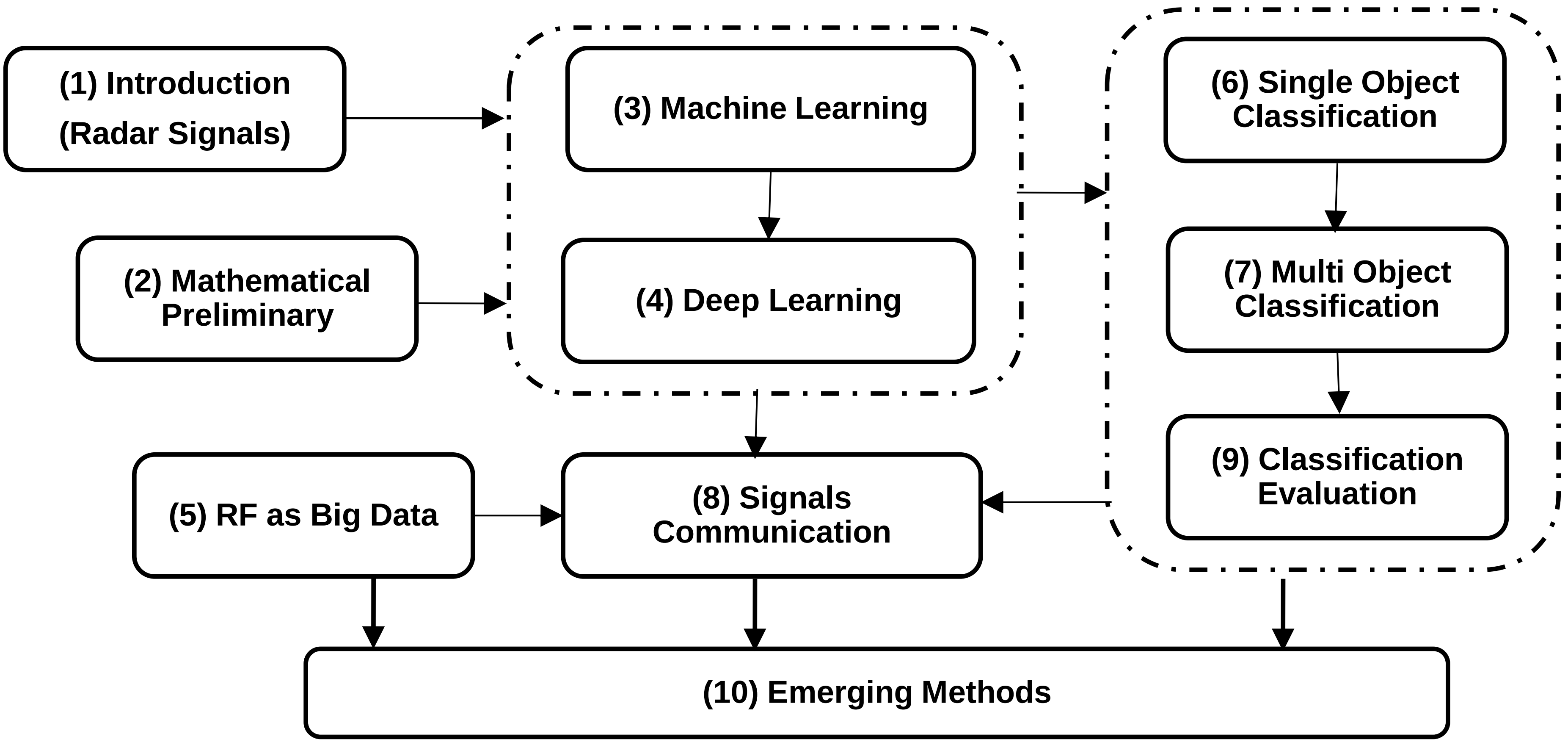
Get Your Copy @,
AMAZON Or Artech House

https://www.amazon.com/Learning-Communications-Automatic-Target-Recognition/dp/163081637X/ref=sr_1_3?crid=3QGCWTJ59ETIP&dchild=1&keywords=deep+learning+for+radar&qid=1596512219&s=books&sprefix=deep+learning+for+radar%2Caps%2C151&sr=1-3

Lecture Outline

1. **Radio Frequency ATR: Past, Present, and Future:**
   20 min
2. **Mathematics for Machine Learning / Deep Learning:**
   20 min
3. **Review of ML Algorithms: 30 min**
4. **Deep Learning Algorithms: 30 min**
5. **RF Data for ML Research: 15 min**
6. **DL for Single Target Classification: 25 min**
7. **DL for Many Targets Classification: 20 min**
8. **RF Signals Classification: 15 min**
9. **RF ATR Performance Evaluation: 25 min**
10. **Emerging ML Algorithms for RF ATR: 35 min**

Teaching/Learning Deep Learning Based Radio Frequency (RF) Automatic Target Recognition (ATR)



Learning Outcomes

- ✓ An understanding of machine learning (ML) algorithms
- ✓ Identifying objects in radio frequency (RF) imagery
- ✓ Construct a machine learning (ML) system to classify objects from RF imagery
- ✓ Compare technical challenges involving radar and video image classification
- ✓ Benefits of deep learning (DL) based RF object classification
- ✓ RF ATR Evaluation
- ✓ Emerging RF ATR Algorithms

Introduction to ML

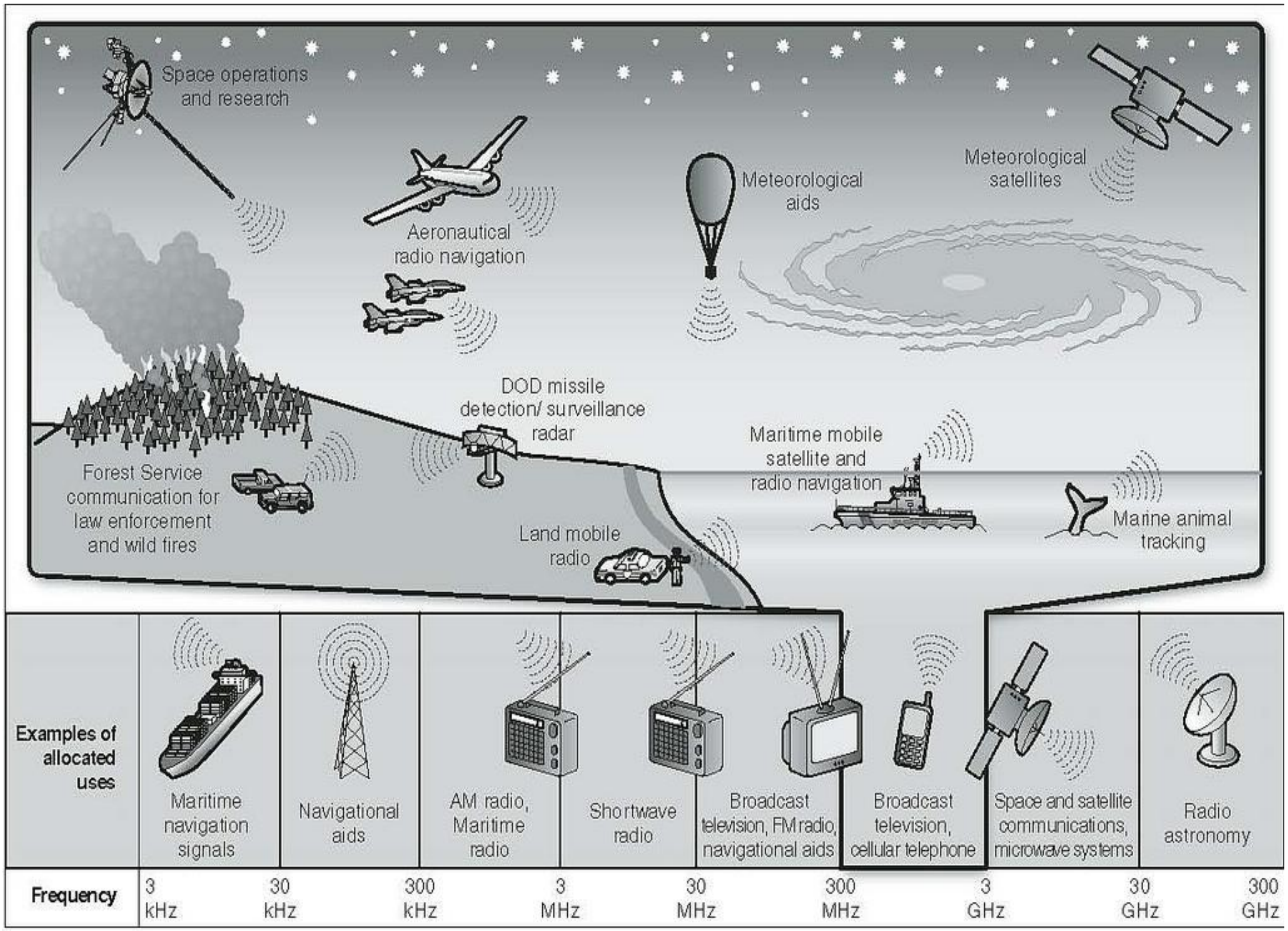
- **Over the years, Machine Learning (ML) algorithms have evolved**
  - Improved accuracy
  - Real-time execution
  - Solving more complex problems
- **Top ML Tools/Software**
  - TensorFlow (Google), Caffe (UC Berkley)
  - Theano, Torch (Facebook)
- **ML for Big Data Analytics**
  - Image Classification
  - Natural Language Processing
  - Autonomous Systems
  - Sentiment Analysis
  - Biomedical Applications

This Short Course….

- Applying ML to Radio Frequency (RF) Signals
  - Object Classification from Synthetic Aperture Radar (SAR) imagery
  - Communication signal classification

- ML for object classification from video imagery is more known to the researcher
  - These algorithms could be applied to the RF domain

Radio Frequency Applications

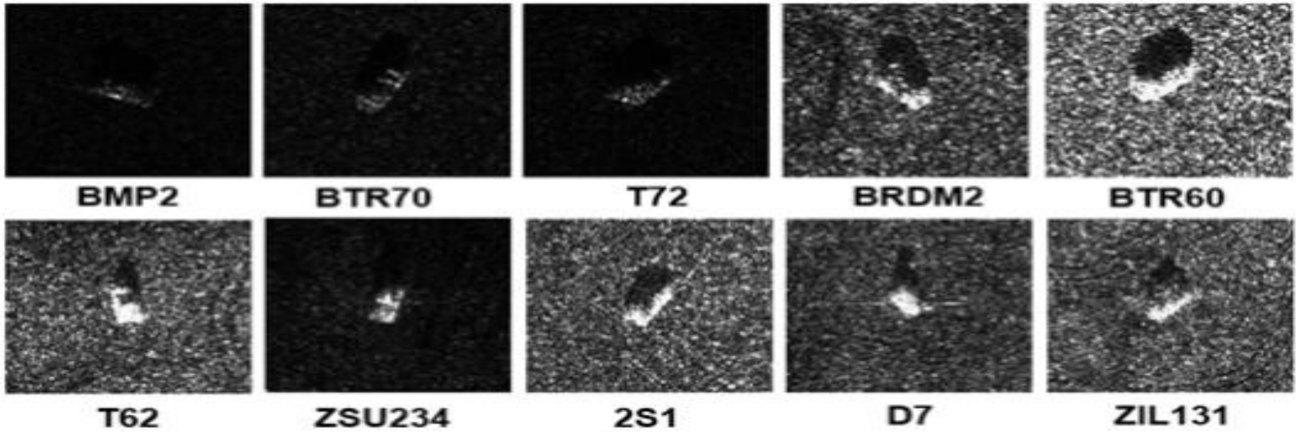


Source: GAO analysis of NTIA, federal agencies, and industry information.

From(labeled reuse): https://www.flickr.com/photos/usgao/5727623528

Electro-Optics Vs. Radar Imagery

Electro-optic Images of Objects



SAR Images of Objects

RF (SAR) Imagery Example:

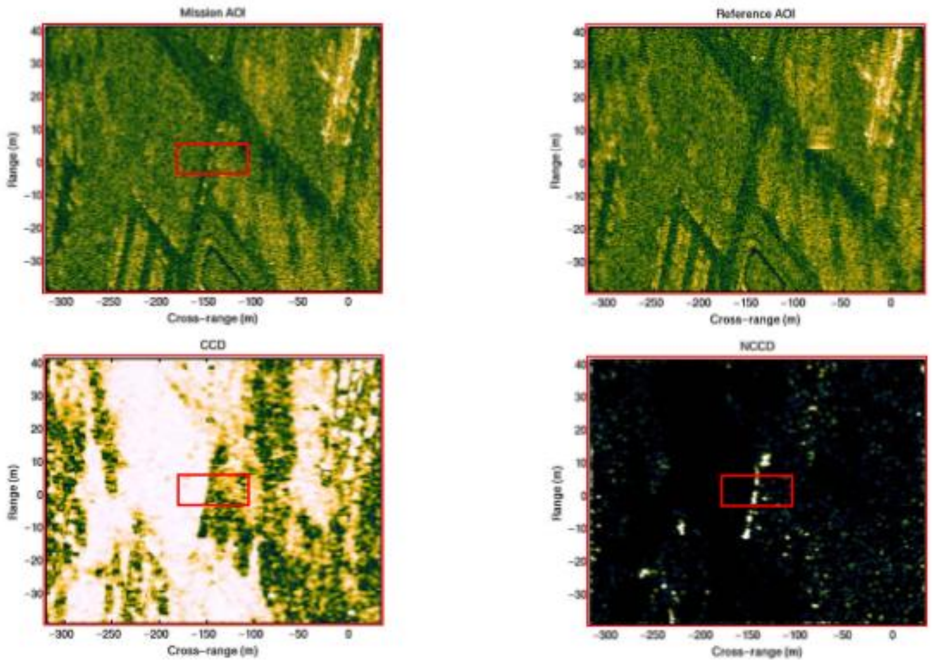
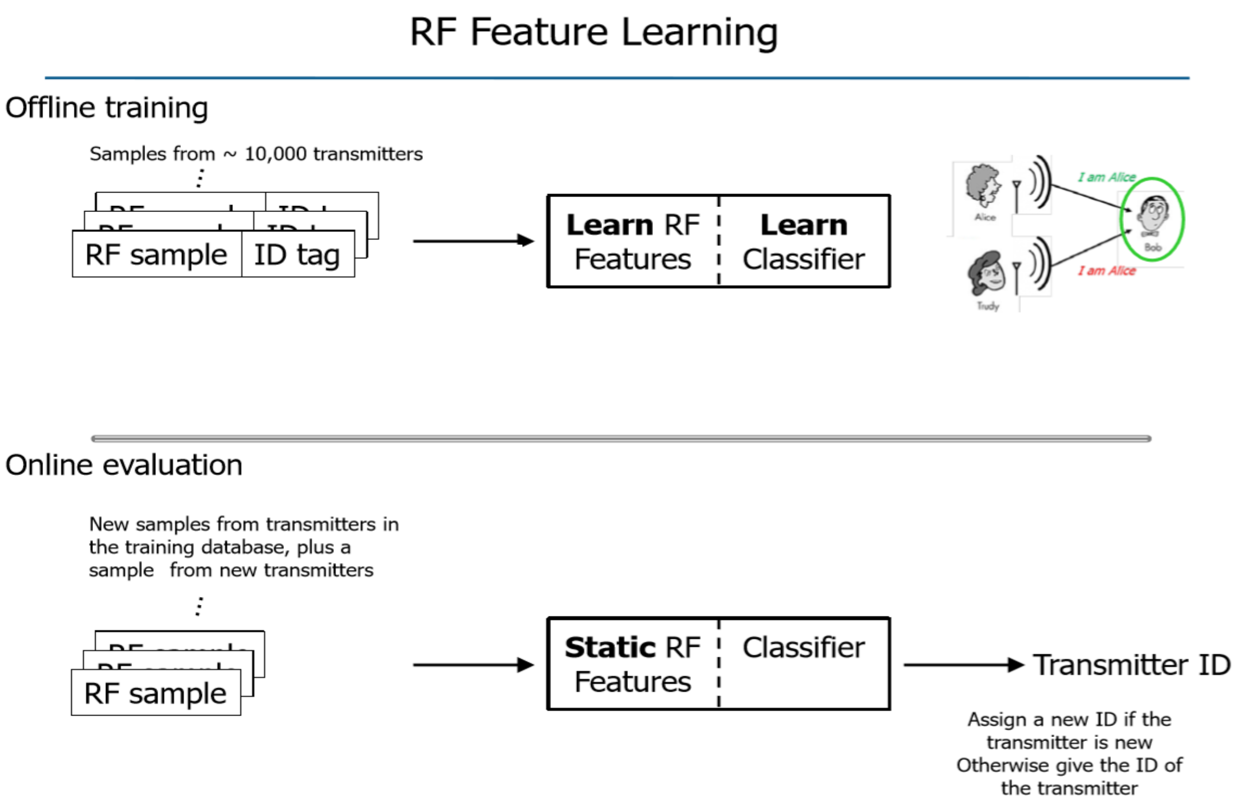


Figure: Objects in SAR Imagery

Reference: S. Scarborough, et. al. “A challenge problem for SAR-based GMTI in urban environments”Algorithms for Synthetic Aperture Radar Imagery XVI, edited by Edmund G. Zelnio, Frederick D. Garber, Proc. of SPIE Vol. 7337, 73370G

RF Signal Example:



Reference:

DARPA Public Release: RF Machine Learning Systems (RFMLS) Industry Day
https://www.darpa.mil/attachments/RFMLSIndustryDaypublicreleaseapproved.pdf

Previous Approach for SAR Object Classification: DARPA MSTAR Program (1998)

Template-based Matching Approach:

- The training/template formation process consists of registering and estimating the mean target signature over small aspect windows (10 deg)

$$(x_{opt}, y_{opt}) = \underset{x_s\, y_s}{\operatorname{argmin}}\left(\sum_{x=1}^{N}\sum_{y=1}^{N} |w(x,y)(M_k(x,y) - S(x-x_s, y-y_s))|\right)$$

where:

(x_s, y_s) = Translation Variable
$w(x,y)$ = Binary Mask
$S(x,y)$ = Chip Magnitude

and

$$M_k(x,y) = [(k-1)*M_{k-1}(k-1)/k + k*S(x-x_{opt}, y-y_{opt})]$$

($k = 1$ … Number Chips/Template)

- Classification Cost Measure: Data Processing, Storage, Collection

Reference:

Timothy D. Ross, Steven W. Worrell, Vincent J. Velten, John C. Mossing, Michael Lee Bryant, “ Standard SAR ATR evaluation experiments using the MSTAR public release data set," Proc. SPIE 3370, Algorithms for Synthetic Aperture Radar Imagery V, (15 September 1998); doi: 10.1117/12.321859

Previous Approach for SAR Object Classification: MSTAR

Results

Table _. Fractional Classification and Rejection Rates ($P_D = 0.9$)

	BMP2	BTR70	T72	Rejections	Confidence
BMP2-1	**0.8256**	0.0923	0	0.0821	+/- 0.020
BMP2-2	**0.7653**	0.1582	0	0.0765	+/- 0.020
BMP2-3*	**0.8929**	0.0408	0	0.0663	+/- 0.020
BTR70-1	0.0073	**0.9197**	0.0073	0.0657	+/- 0.017
BTR70-2*	0	**0.9890**	0	0.0110	+/- 0.017
BTR70-3	0.0182	**0.8869**	0.0036	0.0912	+/- 0.017
BTR70-4	0.0204	**0.8418**	0	0.1378	+/- 0.020
T72-1*	0.0051	0.0102	**0.9592**	0.0255	+/- 0.020
T72-2	0.0667	0.1795	**0.5744**	0.1795	+/- 0.020
T72-3	0.0419	0.1466	**0.6859**	0.1257	+/- 0.020

*: denotes trained object

Reference:

Timothy D. Ross, Steven W. Worrell, Vincent J. Velten, John C. Mossing, Michael Lee Bryant, " Standard SAR ATR evaluation experiments using the MSTAR public release data set," Proc. SPIE 3370, Algorithms for Synthetic Aperture Radar Imagery V, (15 September 1998); doi: 10.1117/12.321859

Current Deep Learning Approach for SAR Object Classification: DARPA TRACE Program (2016)

Public MSTAR

Ground Plane

REAL	Accuracy
BASELINE / Real network	**0.9961**

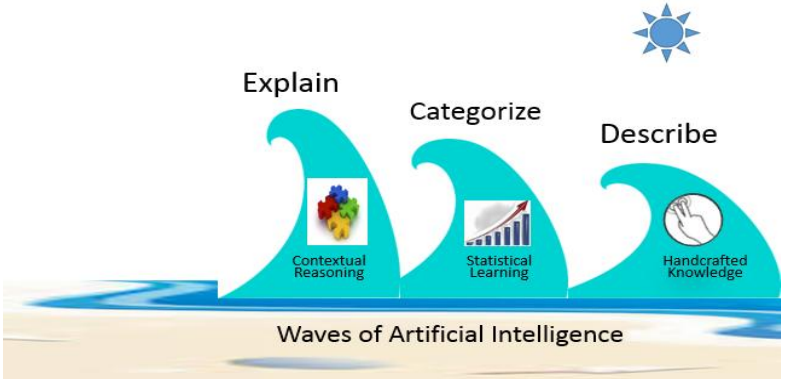
COMPLEX	Accuracy
Mag_64	0.9639
Hybrid_64	0.9961
Complex_64_5Z	0.9941
Complex_64	0.9939
Complex_128	**0.9971**
Hybrid_128***	0.9922

Results based on the public MSTAR CDs. 10% of data used for validation.
Obtained from https://www.sdms.afrl.af.mil/index.php?collection=mstar&page=targets

Reference:
SPIE DSS 2016: Public Release, Approved by DARPA

History of Learning

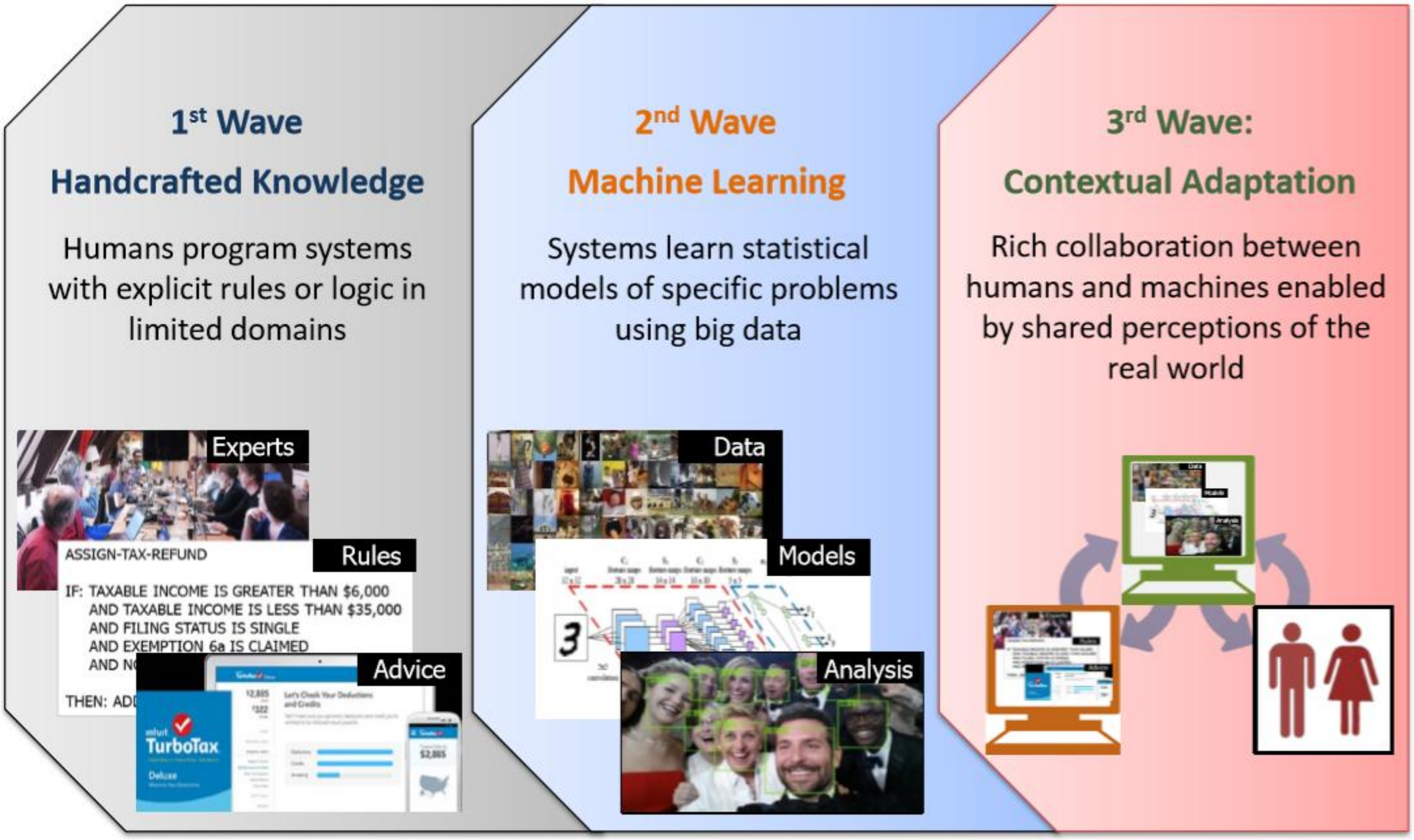
- **AI – Machines** to think/behave/react - ANN
- **ML – Data** for (Machines) to learn - RL, BN, ILP
- **DL – Brain-Inspired** NN for robust methods – CNN, RNN
    - (mostly supervised from labeled data)



AI: Artificial Intelligence
ANN: Artificial Neural Networks
RL: Reinforcement Learning
BN: Bayesian Networks
ILP: Inductive Logic Programming
CNN: Convolutional Neural Networks
RNN: Recurrent Neural Networks

Reference: Andrew Fogg, A histroy of Deep Learning, (import.io)

Three Waves of Artificial Intelligence



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Summary

- ✓ We provided an overview of RF ATR
  - **Past**: Template Based Approach
  - **Present**: Deep Learning Approach
  - **Future**: Reinforcement Learning / More Autonomous Decision Making, Explainable ATR, Secure and Trusted ATR, Quantum Neural Networks, Real-time on-board ATR