Machine Vision and 21st Century AI – Our Responsibilities for The Planet

IEEM 2023
19.12.2023

Prof Saman K. Halgamuge
FIEEE, FIET, FAAIA, Dr.-Ing, Dipl.-Ing (TU Darmstadt, Germany), BSc.-Eng (Moratuwa, Sri Lanka), AI, Optimisation and Pattern Recognition lab
Department of Mechanical Engineering
School of Electrical, Mechanical and Infrastructure Engineering
The University of Melbourne, Australia
FAIR AI is an initiative by researchers in AI, Optimisation and Pattern Recognition Group.

Our location at University of Melbourne, Australia

Ranked 1st in Australia and within top 50 in the world.
• Machine Vision and 21st Century AI – What to expect?
  • Fakes and Real – how would we know the difference?
  • AI Applications changing the world

• FAIR AI: Socially Responsible AI

• Visualisation – a key aspect of FAIR AI

• Examples from Health, Automation
The planet will look very different in 100 years…..

“With climate change, overdue asteroid strikes, epidemics and population growth, our own planet is increasingly precarious,”

Stephen Hawking

- Climate change
  - Earth should not become a harsh environment for humans and other species
    - Clean water
    - Healthy oceans
    - Biodiversity
    - Weather and natural disasters
- Human made disasters: wars, refugees
- Extreme health emergencies

Would we have a livable world for humans in 2123?

The planet will look very different in 100 years.....

Imagine a world where every machine can see, process information, and communicate with other machines and humans.

a million ways machine vision and AI can help.....
but a million ways to make it worse too...

How can machine vision and AI positively interact with industrial Eng/Eng management to achieve this target?

Would we have a livable world for all species in 2123?
As an engineer, I love machines, but I love humans more!

**AI MUST BE REGULATED!**
What type of AI Future we do not want?

- AI that cannot explain its action
- AI that is secretive/not transparent
- AI that cannot learn continuously
- AI that can harm humans/world
- AI that can go out of control

ARE OUR ACTIONS SUPERIOR TO ANY PERCEIVED AI SINGULARITY?

Is there nothing? No imagination - no innovation than killing humans to resolve a conflict in 2023

[Image: why_momentum_works]
Generative Models

“What I cannot create, I do not understand.” — Richard Feynman

Generative models learn to approximate the sample generation process.

Generative models are widely used in AI for Engineering applications today.

In a future world can we recognize fake humans (humanoids) through such technology? Even if they are mixed with real humans?

Human faces generated by style generative adversarial nets [1]
Img src: https://thispersondoesnotexist.com/
Refresh this page, you’ll get a different face each time!

Vision Transformers
Diffusion Models
Generative Models

If probability density function $P_{\text{data}}(x)$ distribution CANNOT BE EXPLICITLY LEARNED what do we do?

Can we IMPLICITLY learn to sample from a $P_{\text{model}}(x)$?

Explicit means “clearly/directly expressed”
Implicit means “not directly expressed”

Without explicitly defining $P_{\text{model}}(x)$

https://learnopencv.com/generative-and-discriminative-models/

https://commons.wikimedia.org/wiki/File:Ambigram_Real_Fake_animated_%281%29.gif
Undercover Deepfakes: Detecting Fake Segments in Videos

Several members of my group are co-authors of this anonymous submission in collaboration with NUS – Singapore.

https://arxiv.org/abs/2305.06564
Our Contributions

Newly introduced benchmark dataset for temporal deepfake segment detection

• Simplified illustration of sample videos from the newly introduced benchmark dataset for temporal deepfake segment detection.
ANSAC: A deep learning framework for classifying breast cancer whole-slide images based on Tumor Infiltrating Lymphocytes and slide-level labels.

Rashindrie D. Perera1,2, Peter Savas2,3, Damith A. Senanayake1, Roberto Salgado2,4, Heikki Joensuu5, Sandra O’Toole6, Jason Li1,2, Sherene Loi1,2,3, Saman K. Halgamuge1

1 School of Electrical, Mechanical and Infrastructure Engineering, University of Melbourne, Melbourne VIC 3010, Australia.
2 Division of Cancer Research, Peter MacCallum Cancer Centre, Melbourne VIC 3000, Australia.
3 Sir Peter MacCallum Department of Medical Oncology, University of Melbourne, Parkville VIC 3010, Australia.
4 Department of Pathology, GZA-ZNA Ziekenhuizen, Antwerp, Belgium
5 Helsinki University Hospital and University of Helsinki, Helsinki, Finland.
6 The Garvan Institute of Medical Research and The Kinghorn Cancer Centre, Sydney, NSW 2010, Australia.

*Corresponding authors, saman@unimelb.edu.au; sherene.loi@petermac.org

A socially responsible application of AI

Expert annotations of tumor (yellow border) and stroma (red border) regions
Common applications in manufacturing and automation

• Quality Control
• Packaging
• Assembly
• Resource management
• .....
Smart warehousing with a machine vision supported swarm of robots

• A “symphony” between humans and machines

With Semi-automation, they achieved what cannot be achieved with
  • full automation or
  • full manual operation

Courtesy: Amazon, US where my former PhD student and Mechatronic engineer Dr Ken Steer works
Machine Vision Applications ...

Machine Vision Applications ...

https://gifer.com/en/9kas
Is AI another tool or a disruptive technology (Computing ++)?

Common applications in manufacturing and automation

- Quality Control
- Packaging
- Assembly
- Resource management
- .....
Socially responsible AI or FAIR AI: Fair Accessible Interpretable and Reproducible AI

- Linguistic interpretation
- Partial semantic interpretation (visualisation)
- Statistical interpretation
- Domain specific (Physical/Science..) Model based interpretation

Understand - Low level

- Legal/Ethical compliance of AI
- Explainable AI (XAI)
- AI integrated with Mathematical models

Manually created Blackbox AI

Discovered AI through search

Discovered AI by generating

University of Melbourne
Visualisation - a form of XAI

**IDEAL**

- Y axis: an observation we can visualise
- A one-dimensional trajectory visualized in 2 dimensions

**REALITY...**

How do we visualize so many dimensions to separate the axis of continuity?

- X axis: some form of continuum (e.g. time)
SONG: Self Organizing Nebulous Growths (2021)


An algorithmic foundation for identifying hidden continuums in data with incremental visualization

A challenge posed by a completed NHMRC project led by Shalin Naik (WEHI)
SONG: Self Organizing Nebulous Growths (2021)

Homogenous Increments where the clusters are proportionally augmented

Heterogenous Increments where the clusters are vastly different from increment to increment
SONG: Self Organizing Nebulous Growths (2021)

- Based on Vector Quantization and Self-Organization
- **NEW**: outperforms all other dimensionality reduction methods when incorporating heterogeneous increments
- **BETTER**: Has Comparable/Better Visualization Quality to t-SNE / UMAP
- **FASTER**: Can act as a heuristic initialization for UMAP thus speeding up UMAP operation

Visualization of hand-written digits dataset (MNIST) when you add one class at a time
SONG: Application examples

1. Integrating large, high dimensional datasets into a single reference atlas (single cell transcriptomics)

Trick: Continuum here is not the time!

A completed NHMRC Project grant led by Shalin Nail at WEHI and a current ARC DP I hold.

2. Using SONG visualizations to track the developmental progression of brain organoids by visualizing their electrophysiological characteristics

Continuum here is indeed the time!

A completed Dementia Australia-Yuligbar Foundation grant led by Jagadish (ANU), MND grant and a current US DoD Biomedical Research grant – both led by Lezanne Ooi at UoW
SCEATLL: Application 1 of SONG

- Single-Cell biology has evolved a lot over the last decade, providing a high-resolution view into the cellular dynamics
- Laboratories from across the world produce single-cell data from various tissues/donors/species!
- Integrating them for better insights/confidence is computationally intractable…

Until now!

Trick: Continuum here is not the time!
IL-VIS: Application 2 of SONG

- IL-VIS (Incrementally-Learned Visualization) (2022, bioRxive)
- **Brain organoid**-based longitudinal study
- Brain organoids (mini brains) are tiny tissue cultures
  - Derived from human stem cells
  - Mimics the functionality of the brain
- Many neurological diseases, including **Alzheimer’s disease (AD)**, are being studied using brain organoids to test the effects of potential drugs.
- **Electrophysiological properties** of these organoids can be studied using **Multi-Electrode Arrays (MEA)**
- MEAs contain multiple electrodes that record the extracellular activities of the neurons in the organoid

---

1. [https://www.popularmechanics.com/science/health/a42916548/are-brain-organoids-conscious](https://www.popularmechanics.com/science/health/a42916548/are-brain-organoids-conscious)
IL-VIS

- MEA recordings are obtained from an organoid over a period of time at different sampling time points
  - $t_1, t_2 \ldots t_n$
- We hypothesize that the progression of the electrophysiological properties of an organoid could be represented as a **trajectory** embedded in the **high-dimensional MEA data**
- Our goal is to **visualize this trajectory in a 2D space** while keeping the complex relationships between electrodes and organoids (when modeling multiple organoids) intact
IL-VIS: Approach

- We propose **IL-VIS** (*Incrementally Learned Visualizer*), a machine-learning pipeline that visualizes the longitudinal progression of the electrophysiological properties of an organoid.

A schematic diagram of IL-VIS
The dataset contains MEA data obtained from brain organoids derived from:

- two AD patients (AD1 and AD2)
- two healthy controls (CN1 and CN2)

Four organoids are derived from each cell line exposed to one of the following four treatments:

1. Untreated
2. Quinolinic Acid (QUIN) : a metabolite known to play a role in many neuroinflammatory diseases including AD
3. Quinolinic Acid Antibody (QUIN Ab) : a blocking antibody of QUIN
4. Both QUIN and QUIN Ab added.
IL-VIS: Findings on Experimental Data

- We test the ability of QUIN Ab to reduce the harmful effects of QUIN

<table>
<thead>
<tr>
<th>Organoid age</th>
<th>Treatment time (t)</th>
<th>CN1</th>
<th>CN2</th>
<th>AD1</th>
<th>AD2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 months</td>
<td></td>
<td>$I_1$</td>
<td></td>
<td>$I_1$</td>
<td></td>
</tr>
<tr>
<td>6 months (Drugs added)</td>
<td>t=0</td>
<td>$I_2$</td>
<td>$I_1$</td>
<td>$I_2$</td>
<td>$I_1$</td>
</tr>
<tr>
<td>6 months &amp; 1 Day</td>
<td>t=1 day</td>
<td>$I_3$</td>
<td>$I_2$</td>
<td>$I_3$</td>
<td></td>
</tr>
<tr>
<td>6 months &amp; 1 Week</td>
<td>t=1 week</td>
<td>$I_4$</td>
<td>$I_3$</td>
<td>$I_4$</td>
<td>$I_2$</td>
</tr>
<tr>
<td>6 months &amp; 1 Month</td>
<td>t=1 month</td>
<td>$I_5$</td>
<td>$I_4$</td>
<td>$I_5$</td>
<td>$I_3$</td>
</tr>
<tr>
<td>6 months &amp; 3 Months</td>
<td>t=3 months</td>
<td>$I_6$</td>
<td>$I_5$</td>
<td>$I_6$</td>
<td>$I_4$</td>
</tr>
</tbody>
</table>
IL-VIS: Findings on Experimental Data

- **QUIN Ab-treated** organoid trajectory deviates from the other three conditions in all four cell lines.

- Our findings support the evidence of QUIN Ab’s capability in reducing the harmful effect of QUIN which is of greater importance to the field of neurobiology.
Will Bedowes (PhD student)

- **Kenya** - 71.4% Electrification
- **Uganda** - 41.5% Electrification

**Co-supervisors:**
Dr Elizabeth Ratnam (ANU)
Dr Julian de Hoog

**Funding:**
Australian Research council
Leveraging Artificial Intelligence for Enhancing Renewable Energy Adoption in Developing Countries: An Industry Focused Review

A comprehensive review of challenges facing developing countries and suggestion for future research. To appear:

Accepted:

Sustainable/Renewable Energy Reports
Rural electrification, one STEP at a time.

Social
- Education
- Awareness
- Adoption

Technical
- Resources
- Knowledge
- Applications

Economic
- Financing
- Investment
- Poverty

Political
- Policy
- Incentives
- Corruption

Leveraging Artificial Intelligence for Enhancing Renewable Energy Adoption in Developing Countries: An Industry Focused Review

PhD student Will Bedowes in Uganda
Power Quality of Existing mini grids in DRC

Significant and sustained overvoltage can cause sensitive equipment to malfunction.

Sustained voltage sags reduce device lifetimes

Frequent outages, both long and short duration

Image Source: nLine Power Watch Sensors
Non Intrusive Load Monitoring (NILM)

NILM uses classifiers including AI models to desegregate different loads based on electrical signal.

NILM AI Models:
- LTST-RL
- CNN
- SVM
- Random Forest
- CALM
- DNN
- HMM

Applying AI to improving electrification rates

Biofuel cooking is the leading cause of carbon emission in developing Africa.

Biofuel based cooking contributes 2% of all global greenhouse gasses and causes nearly 500,000 deaths annually, impacting women and children disproportionately. In Uganda, 92% of the population does not have access to cleaner cooking.

Image Source: Acumen.org
New project....

**Objective:** To increase payback of microgrids and rural electrification by
• introducing electric cooking, and
• validating its use for carbon credit payback.

**Industry backing:** Energrow, StemaCo
Role of Deep Learning/ Optimisation in Solar Power Forecasting

On going work (more information will be available on Arxiv in mid 2023):

- Deep learning for cloud movement forecasting
- Forecasting regional solar generation using deep learning techniques

Published work (available online):

- Residential solar power forecasting across multiple time resolutions and horizons
- Estimating and forecasting regional distributed solar generation
- Improving solar power forecasting using seasonality models

How can accurate solar power forecasts help?

- Grid operators can better plan and manage the energy supply - forecasts can help reduce the uncertainty associated with energy supply.
- Consumers can manage their energy storage systems and better plan their energy demand.

PhD thesis submitted by Maneesha Perera
All you need to know are in clouds?

Optimal Operation of Energy Storage Systems Considering Forecasts and Battery Degradation

Authors: Khalid Abdulla, Julian De Hoog, Valentin Muenzel, Frank Suits, Kent Steer, Andrew Wirth, Saman Halgamuge

Publication date: 2018

Journal: IEEE Transactions on Smart Grid

Publisher: IEEE

Description: Energy storage systems have the potential to deliver value in multiple ways, and these must be traded off against one another. An operational strategy that aims to maximize the returned value of such a system can often be significantly improved with the use of forecasting - of demand, generation, and pricing - but consideration of battery degradation is important too. This paper proposes a stochastic dynamic programming approach to optimally operate an energy storage system across a receding horizon. The method operates an energy storage asset to deliver maximal lifetime value, by using available forecasts and by applying a multi-factor battery degradation model that takes into account operational impacts on system degradation. Applying the method to a dataset of a residential Australian customer base demonstrates that an optimally operated system returns a lifetime value which is 160% more, on average ...

Total citations: Cited by 192

Scholar articles:

Optimal operation of energy storage systems considering forecasts and battery degradation
K Abdulla, J De Hoog, V Muenzel, F Suits, K Steer... - IEEE Transactions on Smart Grid, 2016

Cited by 192 Related articles All 3 versions
How to write a great survey paper and WHY?

Nanduni – a former PhD student and a graduate from Sri Lanka wrote this paper in her first year of PhD in 2020.
Social Optimisation – a new cool idea

Chathurika – a former postdoc and a graduate from Sri Lanka wrote this paper with Marnie – a former postdoc and a graduate of University of Melbourne in 2020

An Incentive-compatible Energy Trading Framework for Neighborhood Area Networks with Shared Energy Storage

Authors: Chathurika Prasadini Mediwaththe, Marnie Shaw, Saman Halgamuge, David Smith, Paul Scott
Publication date: 2020/1
Journal: IEEE Transactions on Sustainable Energy
Volume: 11
Issue: 1
Publisher: IEEE

Description: Here, a novel energy trading system is proposed for demand-side management of a neighborhood area network (NAN) consisting of a shared energy storage (SES) provider, users with non-dispatchable energy generation, and an electricity retailer. In a leader-follower Stackelberg game, the SES provider first maximizes their revenue by setting a price signal and trading energy with the grid. Then, by following the SES provider’s actions, the retailer minimizes social cost for the users, i.e., the sum of the total users’ cost when they interact with the SES and the total cost for supplying grid energy to the users. A pricing strategy, which incorporates mechanism design, is proposed to make the system incentive-compatible by rewarding users who disclose true energy usage information. A unique Stackelberg equilibrium is achieved where the SES provider’s revenue is maximized and the user-level social cost is minimized ...

Total citations: Cited by 97
Customer benefits in getting the charging and discharging property right...

Nanduni, Chathurika and young staff member Elizabeth 2020 publish this work in 2021...
Continuous Learning

Similar to humans, artificial neural networks suffer from “catastrophic” forgetting of old knowledge as they acquire new knowledge.

Continual learning aims to develop mechanisms to overcome forgetting.

CAN WE CREATE methods that can continually gain new knowledge without storing or reusing old data?

NAPA-VQ: Neighborhood-Aware Prototype Augmentation with Vector Quantization for Continual Learning
Accepted by International Conference on Computer Vision (ICCV 2023) Anonymous ICCV submission

Abstract

Catastrophic forgetting: the loss of old knowledge upon acquiring new knowledge, is a pitfall faced by deep neural networks in real-world applications. Many prevailing solutions to this problem rely on storing exemplars (previously encountered data), which may not be feasible in applications with memory limitations or privacy constraints. Therefore, the recent focus has been on Non-Exemplar based Class Incremental Learning (NECIL) where a model incrementally learns about new classes without using any past exemplars. However, due to the lack of old data, NECIL methods struggle to discriminate between old and new classes causing their feature representations to overlap. We propose NAPA-VQ, Neighborhood Aware Prototype Augmentation with Vector Quantization, a framework that reduces this class overlap in NECIL. We draw inspiration from Neural Gas to learn the topological relationships in the feature space, identifying the neighboring classes that are most likely to get confused with each other. This neighborhood information is utilized to enforce strong separation between the neighboring classes as well as to generate old class representative prototypes that can better aid in obtaining a discriminative decision boundary between old and new classes. Our comprehensive experiments on CIFAR-100, TinyImageNet, and ImageNet Subset demonstrate that NAPA-VQ outperforms the State-of-the-art NECIL methods by an average improvement of 5%, 2% and 4% in accuracy and 10%, 3% and 9% in forgetting respectively. Our code will be made available.
Acknowledgement

Funding:
**Australian Government**: 19 ARC and 3 NHMRC grants, Australia Indonesia Centre
**Philanthropy/Foundations**: Yuligbar Foundation, Rowden White Foundation, MND Foundation
**Industry**: Your Gene BioSciences (UK), Google (USA), IBM (Australia), Robert Bosch (Germany), POSCO (South Korea), US Department of Defence (Biomedical Research Program)
**University of Melbourne**: 50 PhD scholarships, Internal grants
**Australian National University**: Internal grants
**Data 61**: PhD scholarships

**External collaboration**: Howard Florey Institute, Peter Mac Cancer Centre, WEHI, Tongji and Hebei Universities (China), Academia Sinica (Taipei), CUHK (HK), Oxford (UK), Uni Southampton (UK), Uni Wollongong (Aus), NTU and NUS Singapore, Tutte Institute (Canada), Cambridge (UK)
Contact: saman@unimelb.edu.au

Thank you