A*STAR Scholarships – Graduate Studies
I²R's Projects

CATEGORIES	RESEARCH AREAS
Computing and Informational Science (CIS)	• AI and Data Science • Bioinformatics • Communications • Computational Engineering • Cybersecurity • Digital Health • Quantum Computing and Engineering
Engineering & Technology (E&T)	• Automation & Robotics • Communications • Green Urban Technologies • MedTech & HealthTech • Microelectronics & Semiconductors

Computing and Informational Science (CIS)
Research Area: AI and Data Science

- **Project Title: Deep Neural Network Transfer Learning and Analysis of EEG Datasets**
  I²R Supervisor: Ang Kai Keng, Group Leader (Signal Processing), Senior Scientist III

  We have an existing research project that aims to develop motor, cognitive, and affect Brain-Computer-Brain interface for multimodal feedback modules in integrated systems. One of the focal research works of this project entails applying machine learning on acquired EEG dataset, exploring state-of-the-art machine learning approaches such as deep learning using variants of convolutional neural network (CNN), long short-term memory (LSTM) and generative adversarial networks (GANs) on the data. Our group has developed novel Artificial Intelligence algorithms such as iterative cross-subject negative-unlabelled learning algorithm for detecting Fatigue from EEG [1], GAN-based data augmentation for EEG data [2]. This project is looking for a PhD student with a passion in understanding neural signal in the form of brain waves recorded as EEG signals across brain regions, in artificial neural network learning systems and also in MATLAB-Python coding.

- **Project Title: Label-Efficient Learning for Visual Recognition**
  I²R Supervisor: Cai Lile, Scientist II

  Deep learning is the state-of-the-art algorithm for visual recognition, the success of which relies on the availability of large-scale annotated datasets. Compiling large amounts of labels is time-consuming and can be prohibitively expensive, especially for dense prediction tasks like object detection and semantic segmentation. In this project, we will explore how label-efficient learning techniques, e.g., active learning, semi-supervised learning, and self-supervised learning, can be employed to ease the annotation burden in visual tasks.

- **Project Title: Multi-Task Modeling for Information Extraction Using Semi-Supervised Learning Techniques**
  I²R Supervisor: Chen Bin, Senior Scientist II

  Multi-task modeling has been successfully adopted in information extraction tasks such as relation extraction, event extraction, and slot filing, instead of pipeline approaches. We propose to explore multi-task modeling to incorporate information at the various pre-processing levels, including (cascaded) entity mention detection and coreference resolution, trigger word recognition, taking advantage of recent advances in neural architectures and pre-trained models.
  However, current deep learning approaches have a major limitation: they rely on the availability of a very large amount of tagged data to achieve better performance. These labeled data are often expensive, and sometimes impossible to collect for a given domain and language, while raw (i.e. unlabeled) data are generally easily accessible and in almost inexhaustible quantity. To overcome this issue, we propose to adopt unsupervised or semi-supervised learning techniques for multi-task modeling applied to information extraction tasks.

- **Project Title: Transfer Learning for Time Series Data Analytics**
  I²R Supervisor: Chen Zhenghua, Scientist III

  The current success of time series data analytics heavily relies on large amount of labelled data and the assumption of same data distributions for training and testing. However, in real world applications, e.g., activity recognition, sleep detection, machine health monitoring, etc., data annotation is expensive, and the distributions of training and testing data can be different due to environment changes, and device heterogenous. Existing domain adaptation methods are mainly developed for images. Very few works consider the challenging, but important time series domain adaptation which needs to simultaneously consider representation learning for time series sensory data with temporal dependency and domain shift problem. Thus, the objective of this project is to develop transfer learning for generalized time series data analytics.

- **Project Title: Incremental Knowledge Tracing**
  I²R Supervisor: Cheryl Wong Sze Yin, Scientist II

  Knowledge Tracing is the modelling of learner's knowledge over time. It is typically being done using data collected on e-learning platforms. Models could reflect the relative difficulty of questions and provide a personalised learning tool for students by providing student questions of suitable difficulty.

- **Project Title: Learning Based-Gripper Design, Grasping and Robot Manipulation**
  I²R Supervisor: Cihan Acar, Scientist II

  This project investigates the development of optimum gripper design, grasping control especially for soft objects, and learning manipulation skills using deep reinforcement learning (DRL) or evolutionary algorithms and generative deep learning models. The aim of the project is to learn grasping and manipulation skills such as picking objects like fruits or leafy vegetables, handling or harvesting mostly for indoor farming applications.

- **Project Title: Reinforcement Learning for Adapting in Collaborative Multi-Robot Missions**
  I²R Supervisor: Efe Camci, Scientist II

  Multi-robot teams are more efficient, resilient, and versatile as compared to single-robot systems. Yet, their autonomous collaboration is far from being trivial. Existing collaboration methods are either inefficient or inapplicable in real-world missions, which feature stochastically changing conditions and limited communication between robots. The overall objective of this project is to develop a novel, learning-based framework that will endow robots with the ability of adapting intelligently in collaborative multi-robot missions in real world. The proposed framework will eventually help a team of robots perform spatially separate tasks in urban solutions and manufacturing domains, e.g., cleaning in malls, surveillance in factories.

  The project will focus on collaboration of mobile robots, including ground and aerial robots. Case studies will be based on coverage problems, which feature the characteristics of many multi-robot missions such as mapping, surveillance, search and rescue, cleaning, and

inspection. Three key challenges in multi-robot coverage scenarios will be addressed by adapting to changes in:

- environmental map, as the map is explored on-the-fly,
- fleet size, as some robots can be added per need or some may fail during the mission,
- goal, as the mission itself may be altered after deployment.

To address these key challenges, the proposed approach will be developed and tested over software-in-the-loop simulations such as Gazebo, AirSim with Robot Operating System (ROS). The scenarios that bring the key challenges to the fore will be focused, such as ground and aerial robot teams exploring an emulated nature park with limited communication, changing team size, changing obstacle locations… Once the decent results are obtained in simulations, real world experiments will also be engaged.

- **Project Title: Learning with Less Data**
  I²R Supervisor: Foo Chuan Sheng, Assistant Department Head (Research), Senior Scientist I

  In this project, we aim to reduce data annotation and acquisition burdens when applying deep learning to applications in advanced manufacturing and engineering. Our goal is to develop methods that can achieve 95% of the performance of fully supervised approaches while using only 1-10% of the labels. We consider three representative applications: defect identification, predictive maintenance, and automated design, and focus on data types and learning tasks that arise from these. Specifically, we will develop deep learning methods that take multivariate time-series data, 2D/3D images and/or tabular data as inputs in order to perform classification, regression, image segmentation as well as anomaly detection tasks. We will build upon existing paradigms to address data scarcity – semi-supervised and unsupervised learning, techniques to incorporate external knowledge, transfer learning, and active learning – revisiting and updating them in the context of deep learning. We will further develop methods that integrate several paradigms in order to achieve our goal.

- **Project Title: Data-efficient Deep Learning**
  I²R Supervisor: Foo Chuan Sheng, Assistant Department Head (Research), Senior Scientist I

  We aim to develop deep learning algorithms that can learn with few labelled data examples by updating traditional paradigms such as semi-supervised learning, active learning, transfer learning and combining knowledge for deep learning. We will also algorithms combining these different paradigms for greater data efficiency.

- **Project Title: Graph Representation for Medical Image Analysis and Diagnosis**
  I²R Supervisor: Huang Weimin, Unit Leader (Medical Imaging), Principal Scientist I

  Graph is a suitable tool to represent knowledge and structure, for example, the conventional tree structure for classification, the brain network, the coronary artery tree. This PhD project aims to derive the graph representation automatically from the raw image data such as CT / MRI volumetric data. One specific area is the coronary artery tree extraction and

representation over low-to-middle quality CTCA images, with poor imaging quality and mixed plaque in stenosis. With the tree and image feature representation, the project is to develop methods to rectify the broken or missing coronary tree and provide a good semantic structure for clinical diagnostic report.

- **Project Title: Multi-Modal Math Question Generation and Answer Marking for Personalized Education**
  I²R Supervisor: Kim Jung-Jae, Group Leader (Explainable & Automatic AI), Senior Scientist I

  As online learning expands during the COVID-19 pandemic, AI-enabled personalized education has been promoted. One aspect of the personalized education is to provide questions personalized for individual students, rather than fixed questions for each topic, as students may have different strength/weakness. While text-only question generation and answer marking has been much studied, many math questions contain multi-modal context in forms of equation, table, graph, and image. Thus, there is a need to develop effective methods for generating multi-modal math questions and marking their answers.

  In this project, we will develop novel methods for multi-modal math question generation and answer marking and will semi-automatically construct a benchmark by collecting multi-modal questions and answers from the Web. We may extend the methods and the benchmark for other subjects like science.

- **Project Title: Deep Learning for CAD Document Translation**
  I²R Supervisor: Kim Jung-Jae, Group Leader (Explainable & Automatic AI), Senior Scientist I

  Intelligent manufacturing can only become a reality with the aid of standardized information-exchange formats. But traditional format translation is not capable of embodying valuable information of the source application into the destination. An example is the CAD document translation from one format to another, where typically only geometries are exported, voiding potentially useful information such as the design choices. Deep learning has been applied for CAD analytics applications like CAD document classification, but not for CAD document translation. Thus, there is a need to develop effective methods for information-preserving CAD document translation.

  In this project, we will develop novel deep learning methods for CAD document translation, including self-supervised learning of CAD documents, and encoding and decoding of CAD documents. We will work with a local institute for the project, who would provide labelled data of CAD document translation.

- **Project Title: Self-Supervised Learning of Multi-Modal Documents for Zero-/Few-Shot Applications**
  I²R Supervisor: Kim Jung-Jae, Group Leader (Explainable & Automatic AI), Senior Scientist I

  Self-supervised learning has made significant improvements in deep learning for text, image, and audio. While most of recent self-supervised learning methods target uni-modal data, however, real-world data are often multi-modal. For instance, Wikipedia pages are often used for text-based self-supervised learning, but their original Web pages have not only text but often also image, table and intra-/inter-document structure (e.g. section/sub-section, Web link). Thus, there is a need to develop effective self-supervised learning methods for multi-modal documents.

  In this project, we will develop novel methods of large-scale self-supervised learning for multi-modal documents and will evaluate them for multi-modal benchmarks (e.g. visual Q&A, table Q&A, multi-modal dialogue systems) as well as for uni-modal (text) benchmarks (e.g. GLUE, SuperGLUE).

- **Project Title: Algorithms and Systems for Protecting Privacy in Data Sharing and Analysis**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

  In the modern era of pervasive technological advancements, a huge amount of information has been collected through various channels such as personal smart devices, online surfing, or provided to companies when subscribing to their services. As a result, privacy preservation has taken a lead role in ensuring proper usage and confidentiality of data in every sector of our lives.

  As per the government regulations like PDPA and GDPR, privacy of data is crucial for every individual and enterprise, especially so in the context of collaborative learning within multi-enterprise federations. U.S. Commission on Evidence-Based Policymaking unanimously agreed that the country needed new strategies and supports for advancing privacy-preserving technologies. These innovative capabilities enable sharing of information in an increasingly protected manner - techniques such as multi-party computation, homomorphic encryption, and synthetic data. A wide array of data mining, cryptography and information hiding techniques have been applied to cater to different aspects of providing a risk-free collaborative work environment enabled by commercial and government clouds. At the most basic level, organisations rely on data anonymization techniques, which generally refer to the process of removing identifying information such that the remaining data does not identify any individual. Besides the process being lengthy and non-streamlined. Data anonymization was proven to be vulnerable to several attacks aiming at the re- identification of the anonymised data. Hence hindering the privacy of that data.

  In this project, Algorithms, and systems for protecting privacy in data sharing and analysis, we mainly target AI technologies with differential privacy and federated learning.

- **Project Title: Reinforcement Learning**
  I²R Supervisor: Li Xiaoli, Department Head, Adjunct Full Professor, Principal Scientist II

  Develop advanced reinforcement learning approach to tackle real-world decision-making tasks across healthcare, transportation, energy, and e-commerce domains.

  However, it still faces significant challenges in real world of multi-agent environments with complex settings for delayed and sparse reward and thus needs focused research. In this project, we will design novel dynamic and hierarchical multi-agent reinforcement learning method, targeting to address three key research problems: 1) how to reduce the time complexity based on hierarchical structure in a divide and conquer manner, 2) how to make our proposed approach more explainable to human beings to gain trust, and 3) how to solve the delayed reward issue effectively.

- **Project Title: AI for Data Management**
  I²R Supervisor: Li Xiaoli, Department Head, Adjunct Full Professor, Principal Scientist II

  Managing, querying, integrating data could be time-consuming and label intensive. This project will design advanced AI to help various data management tasks. In fact, the huge volume of big Data has made ML/DL indispensable for most organizations and thus we will develop critical AI tools which play a crucial role in enabling organizations to address their challenges in data management.

  Some key research problem statements include how to leverage deep learning for database indexing optimization, as well as trajectory similarity and search etc.

- **Project Title: Advanced Text Analytics**
  I²R Supervisor: Li Xiaoli, Department Head, Adjunct Full Professor, Principal Scientist II

  Rich text information is widely available at Web and social media. However, it is extremely challenging to analyse huge amount of unstructured text data. In addition, as labelling is time consuming and label intensive, we have to face the problem of unlabelled text data. In this project, we will design advanced deep learning techniques to analyse unstructured and unlabelled text data in the challenge of limited training data, including various text analytics tasks such as text summarization, Q&A, information extraction, document clustering, classification etc.

- **Project Title: Self-aware Continuously Learning Models**
  I²R Supervisor: Li Xiaoli, Department Head, Adjunct Full Professor, Principal Scientist II

  This project aims at developing Self-Aware Continuous Learning Models that continuously (1) are aware of the historical distributions they represent, (2) detect novel distributions that are unknown to them, (3) estimate the complexity of the unknown distributions (4) choose relevant data to represent the unknown distributions and (5) adapt themselves to represent these previously unknown distributions without catastrophically forgetting any previously learnt distribution. It is notable that labelling large volumes of data in the detected novel distributions

is labour-intensive. Hence, we propose to develop a spectrum of solutions, viz., self-awareness for unknown distribution detection, Self-supervised Contrastive and Unsupervised learning, depending on the availability of labelled data. We envision that such learning models become capable of comprehensive and robust representations of all the distributions they encounter. This enables them to improve their generalization through representational adaptations with new data. The project will potentially have broad impacts in facilitating the translation of continuous learning research in real-world deployments.

- **Project Title: Learning 3D Generative Models**
  I²R Supervisor: Liu Fayao, Scientist III

  3D generative modelling aims to learn models that can synthesize 3D objects or 3D scenes, which has wide applications in 3D recognition and 3D design (e.g., AR, VR). We aim to develop new 3D generative methods conditioning on images, sketches etc. to help improve 3D recognition tasks and help 3D design.

- **Project Title: Learning with Geometry Priors for Few-Shot Point Cloud Recognition**
  I²R Supervisor: Liu Fayao, Scientist III

  3D point cloud recognition is a crucial technique that has wide applications, e.g., autonomous vehicles, navigation, surveillance etc. Motivated by the fact that humans are very good at learning new concepts from just one or a few examples by inferring from past experiences, we here aim to learn 3D recognition models that can classify, or segment new classes given only a few labeled point clouds. We will design higher-order potential functions to exploit geometry priors in the graph modelling of limited examples, e.g., planes which involve a set of points, for label propagation.

- **Project Title: Learning with Geometry Priors for Few-Shot Point Cloud Recognition**
  I²R Supervisor: Liu Fayao, Scientist III

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- **Project Title: Exploiting Prior Knowledge for Predictive Maintenance**
  I²R Supervisor: Liu Fayao, Scientist III

  Currently most machine learning methods are purely data-driven, which require large amounts of (labeled) data and do not consider external knowledge, e.g., commonsense or domain knowledge.

This project aims to develop machine learning methods that can integrate prior knowledge, e.g., sensor relations in a smart system, for anomaly detection and remaining useful life prediction, which are very important for machine maintenance in many real-world systems. This is a time-serials prediction problem.

We will explore graph neural networks (GNN) including transformer models to improve the prediction accuracy.

- ❑ **Project Title: Incorporating Knowledge into Deep Learning Models**
  I²R Supervisor: Liu Fayao, Scientist III

Incorporating knowledge enables models to learn from limited labeled data and also enhances model capabilities. It can be done by either injecting explicit knowledge encoded by knowledge graphs or implicit knowledge learned offline or on-the-fly.

Main research topics include but not limited to:

1. Knowledge graph and graph neural networks to explicitly inject external knowledge, e.g., commonsense knowledge, domain knowledge.
2. Few-/zero- shot learning to learn from limited labeled data
3. Knowledge distillation to transfer knowledge learned by another network
4. Multi-task learning to facilitate current task learning by performing auxiliary self-supervised tasks

- ❑ **Project Title: Deep Learning for Educational Data Analytics**
  I²R Supervisor: Liu Guimei, Senior Scientist II

The rapid rise of online education platforms in recent years produces huge amount of data for educators to assess and understand teaching and learning in online environments. Deep learning technologies have demonstrated promising potentials for improving online learning and teaching. In this project, we will focus on using deep sequence models, graph neural networks and other deep learning methods to capture various relationships and patterns from multi-modal educational data. We will develop AI algorithms and tools for a number of educational data analytics tasks, including, but are not limited to, knowledge tracing, student profiling, learning material characterization and organization, detecting low-progress students, personalized learning path recommendation, and recommendation for instructors.

- ❑ **Project Title: Decision-Making in Local Path Planning / Footstep Planning by Prediction of Future Locomotion States in Quadrupeds with the Use of a Digital Twin / Shadow and a Real-to-Sim Environment Reconstruction**
  I²R Supervisor: Michael Chuah, Scientist II

Given the expanse of current works in simulation physics today, reliable, and accurate physics engine and simulators such as the Bullet, RaiSim, and MuJoCo are ubiquitous among the robotics community today. Most, if not all, developers use simulation physics as a testbed for their newly developed algorithms before deployment on actual robotic hardware to reduce occurrences of unforeseen circumstances.

Reactive quadrupedal locomotion has been largely explored amongst the robotics community hitherto, but the lookahead, otherwise the prediction of future locomotion states remains an area enigmatic to many. With the ability to lookahead and simulate multiple possibilities of the locomotion at high frequency with the current course of travel, a robot will be able to perform well-informed decision making in terms of local path planning or intervene a step further in the locomotion control - footstep planning.

To achieve this, the use of a Digital Twin (or Digital Shadow) with Real-to-Sim Environment Reconstruction will be explored. One such way in which the proposed idea may be used is as described – with the implementation of a digital twin of the quadruped, we will observe the exact state of the real robot in simulation, and at the same time, when the immediate real world environment in proximity is approximately reconstructed in simulation, the simulation may branch out and accelerate in search of future locomotion states within a certain specified time window. A quadrupedal mobile robot platform will be used in this research. An example where real-to-sim technique has been applied successfully is found here: Tactile Sim-to-Real Policy Transfer via Real-to-Sim Image Translation (2021).

https://openreview.net/pdf?id=2NcPgLa7yqD

- ❑ **Project Title: Autonomous Gait Switching for Obstacle Course and Terrain Adaptation with Trajectory-Optimized Closed-loop Locomotion Control for Perception-based Footstep Planner in Quadrupeds**
  I²R Supervisor: Michael Chuah, Scientist II

  Terrain adaptability has been largely explored in the field of quadrupedal locomotion in recent years. State of the art performance has been achieved with the help of reinforcement learning techniques in 'Learning robust perceptive locomotion for quadrupedal robots in the wild (2022)' in traversing varying terrains from uneven ground to staircases. Many recent research have focused on dynamic and reactive locomotion, some leveraging the use of Model Predictive Control and Whole-Body Control methods, while some built end-to-end neural network models to generate trajectories for legged locomotion.

  Exteroception-based locomotion with trajectory optimization algorithms and feedback system validating the quadrupedal footstep planner are areas in which further work may be explored. Much like how humans are able to lookahead, take a step and verify if they have a steady foothold, inducing visual feedback on top of proprioceptive awareness in a quadruped on its trajectories and foot positions will help in increasing the accuracy of reaching a desired planned footstep and have safe navigation in an obstacle filled environment.

  https://leggedrobotics.github.io/rl-perceptiveloco/assets/pdf/wild_anymal.pdf

- ❑ **Project Title: Multi-Axis Sensors for Human and Robot Locomotion**
  I²R Supervisor: Michael Chuah, Scientist II

  To explore the use of bimodal hemispherical sensors on legged robots as well as in wearables or prosthesis. The idea is that by having these force sensors at the end of the robot's feet, they

would be better equipped to understand their surroundings and perform agile motions. Similarly, having these force sensors in wearable smart shoes could aid in sports/rehabilitation analytics or in the future development of feet prosthesis for improved locomotion and gait. The latest in machine learning techniques for time series analysis such as GRUs and transformers would be employed to improve the sensor performance, especially with time-dependent properties such as stress relaxation. Alternative sensor geometries would be explored for different applications such as robotic grippers.

- **Project Title: Reasoning on Knowledge Graph for Recommendation**
  I²R Supervisor: Wu Min, Group Leader (Distributed & Adaptive Learning), Senior Scientist II

  Recommendation systems have been widely applied in different application scenarios in E-commerce platforms to help deliver products to the right customers. Therefore, the user experiences can be improved, and the revenue of the platform can be increased. With the rapid developments of deep learning techniques, various deep learning-based recommendation approaches have been proposed to improve the recommendation accuracy. One main drawback of these deep learning-based methods is that they lack reasonable explanations for the recommendation results. This motivates the recent research trend in recommendation system research, which is to develop explainable recommendation systems.

  Intuitively, the product knowledge graph including rich semantic information associated with different products can help explain the recommendation results. In this project, we will firstly apply different machine learning and natural language processing techniques to build the product knowledge graph considering various information, such as category, brand, and production place. To assist knowledge graph completion, graph neural networks taking advantage of both the underlying knowledge graph structure and different user behaviours will be developed. In addition, we are also interested in developing novel recommendation models that exploit the product knowledge graph to improve the recommendation accuracy. Reinforcement learning will be employed to perform reasoning on the product knowledge graph. Our objective is to find actual paths in the product knowledge graph to explain the recommendation results.

- **Project Title: Self-Supervised Machine Learning for Speech, Language, and Dialogue Processing**
  I²R Supervisor: Nancy F. Chen, Group Leader (Language Generation), Principal Scientist I

  Annotations for human language technology applications are particularly costly, time-consuming, and labor intensive. This project aims to develop unsupervised approaches to tackle this challenge for language technology tasks.

- **Project Title: Causal Machine Learning for Language and Visual Understanding**
  I²R Supervisor: Nancy F. Chen, Group Leader (Language Generation), Principal Scientist I

  Current machine learning models only consider correlations and not causal reasoning, therefore leading state-of-the-art deep learning models that lack factual consistency and

hallucinations. This project investigates computational models for casual learning and reasoning and the application to computer vision and natural language processing tasks.

- **Project Title: Interpretable and Robust Neural Language Generation**
  I²R Supervisor: Nancy F. Chen, Group Leader (Language Generation), Principal Scientist I

  Neural modeling techniques from deep learning has propelled avid research in neural language generation recently. However, the blackbox nature of neural models make it difficult to understand the innerworkings and ensure factual correctness and causal reasoning. This project aims to derive algorithms that take advantage of the practical advantages of neural models while addressing the limitations of factual inconsistency. Possible applications of this research include summarization, machine translation, dialogue response generation and data-to-text generation.

- **Project Title: Multimodal Fake News Detection**
  I²R Supervisor: Nancy F. Chen, Group Leader (Language Generation), Principal Scientist I

  Video and language generation technology is also advancing at a paramount rate, accelerating the spread and prevalence of misinformation. This project investigates to jointly model audio, video, and textual features in a computationally resourceful way to adeptly detect dynamically evolving disinformation sources.

- **Project Title: Self-supervised, Semi-supervised, and Unsupervised Training for Speech Recognition**
  I²R Supervisor: Nancy F. Chen, Group Leader (Language Generation), Principal Scientist I

  While much progress has been made in speech recognition with more commercially available technology, the standard training approaches still rely heavily on supervised learning with high investment in data preparation of linguistic resources. This project explores resourceful unsupervised neural approaches in tackling challenges arising from data/annotation sparsity.

- **Project Title: Active, Distributed, Remote Perception**
  I²R Supervisor: Ng Lai Xing, Scientist II

  Drones, or machines in general, have a multitude of sensors that provide information about the surroundings. Existing works on drone perception often use image-based sensors, such as RGB cameras and depth cameras. Image-based sensors are susceptible to motion blur as well as variation in illumination and thus do not work well when the drone is fast-moving. For teleoperated drones, the human operator can only rely on the live video feed of a single camera and the restricted field-of-view affects the human understanding of the drone's environment. In this project, the aim is to utilize the available sensors and provide a human operator a perspective of being at the drone's location. Selected candidate will work on developing novel approaches on how distributed sensors can communicate, collaborate (including changing what they sense) and process the signals in an energy-efficient way to extract meaningful information from the scene, in response to existing knowledge models

(long term memory) and real-time interaction and decisions from humans, and send back the information to humans for visualization. Research tasks include:

- Process different types of sensory signals (e.g. data collected from event-based cameras, synchronous cameras, and other sensors) for scene understanding (e.g. object detection and localization) using neuromorphic systems embedded on a single or multiple drones.
- Extract meaningful information (3D layout of the scene, objects of interest, threats, etc.) and combine with existing knowledge models.
- Provide meaningful multimodal feedback to the user based on a wearable device (e.g. smart glasses) that should provide remote (augmented) perception.

- ❑ **Project Title: Semi-Supervised and Continual Learning for 3D Semantic Segmentation**
  I²R Supervisor: Ramanpreet Singh Pahwa, Scientist III

  High Resolution 3D X-ray scans are used in various fields like medical-imaging and semiconductor manufacturing for identifying tumors and anomalies in 3D regions. Traditional approaches involve locating these anomalies by spending months labelling data and training fully supervised models. Additionally, previously trained models perform poorly on new datasets consisting of new chip designs or using different scanners for biomedical data. We aim to develop fundamental 3D Semi-Supervised Segmentation algorithms that will leverage on unlabelled voxelized data, novel augmentation techniques, and explore incremental continual learning to achieve similar performance with fractional labelled data.

- ❑ **Project Title: Network Architecture Design and Selection in Deep Learning**
  I²R Supervisor: Ramon Sagarna Almandoz, Scientist II

  Transfer Learning methods are being increasingly adopted in practice to learn a model when data is scarce (e.g. few images have been labeled due to annotation cost). In deep learning, Domain Adaptation (DA) is a major Transfer Learning strategy which is not fully understood as yet. While a good amount of research efforts has been devoted to the design of loss functions, much less attention has been paid to the design of DA architectures that can deliver a successful transfer model. A suitable network design is especially important for widely used deep DA approaches which rely on the interactions of several modules (for example, domain-invariant methods). This project will investigate the impact of DA architecture selection on the transfer performance of the models and based on the achieved insights, develop methods for the generation of suitable networks.

- ❑ **Project Title: Multi-Agent Reinforcement Learning from a Game-Theoretical Perspective**
  I²R Supervisor: Senthilnath Jayavelu, Scientist III

  A*STAR and NTU are building new research capabilities that integrate multi-agent reinforcement learning (MARL), and multi-agent system modelling where multiple agents learn simultaneously. This is an interdisciplinary domain, which includes machine learning, game theory, and optimization. Although MARL has achieved considerable empirical success in solving gaming environments using virtual agents, there is a need for the game-theoretical

foundations in MARL to address uncertainties and adversarial attacks on multiple agents. We are inviting PhD candidate applicants to work on investigating MARL from the game-theoretical perspective that covers both the fundamentals and the real-world implementation as a research frontier.

University supervisor: Prof Bo An, NTU
A*STAR supervisor: J. Senthilnath, I^{2}R

- **Project Title: Deep Representations of Words and Knowledge Graphs for Information Extraction**
  I^{2}R Supervisor: Su Jian, Group Leader (Natural Language Processing), Principal Scientist I

  (This is a resubmission of a PhD project proposal to elaborate the project and more co-supervision context)

  Natural Language Processing has made continuous progress towards identifying elements of meaning in text in the framework of information extraction: extracting specific types of information and knowledge conveyed by texts and using them to expand knowledge graphs.

  Representing words or knowledge graphs as vectors (embeddings) in continuous, multidimensional spaces is a very active area of recent research both in Natural Language Processing and in the Semantic Web. Word embeddings learnt from large text corpora have helped to extract information from texts and build knowledge graphs. Conversely, continuous representations learnt from knowledge graphs have helped knowledge graph completion and recommendation tasks. The potential of joint word and knowledge graph embedding has been explored less so far.

  This PhD project aims to investigate how word embeddings and knowledge graph embeddings can cooperate to improve information extraction and lead to more accurate and comprehensive knowledge graph construction. It will look into the interaction between word representation, information extraction and knowledge graphs, investigating the respective merits of methods such as incorporating knowledge graphs into word representation, mapping from word representation space to knowledge graph representation space, and joint construction of distinct or shared word and knowledge graph representations. The underlying fundamental issue is that of the link between words and utterances in language and concepts and knowledge graphs in knowledge representations.

  This is an international collaboration research project in IPAL, joint lab between CNRS, France, A*STAR and NUS on Artificial Intelligence. The co-supervision includes Pierre Zweigenbaum from CNRS, LIMSI / LISN as well.

- **Project Title: Hate Speech Detection in Online Conversations**
  I^{2}R Supervisor: Su Jian, Group Leader (Natural Language Processing), Principal Scientist I

  Hate Speech (HS) and harassment are particularly widespread in online communication, especially due to users' freedom and anonymity and the lack of regulation provided by social media platforms. This phenomenon has determined a growing interest in using artificial

intelligence and Natural Language Processing techniques to address social and ethical issues. An extensive body of work has been proposed to automatically detect HS relying on a variety of deep learning methods (Founta and Nunes, 2018; Schmidt and Wiegand, 2017). Most research focus on HS as expressed in texts without taking into account the contexts in which they have been uttered. This PhD aims to bridge the gap by investigating for the first time how HS are expressed and detected in multi-party dialogues. We will propose new dialogue datasets for HS detection as well as new context-based deep learning methods that leverage the conversation thread to account for hateful contents and how they evolve as the dialogue proceeds.

References

Paula Fortuna, Sérgio Nunes:A Survey on Automatic Detection of Hate Speech in Text. ACM Comput. Surv. 51(4): 85:1-85:30 (2018)

Anna Schmidt, Michael Wiegand: A Survey on Hate Speech Detection using Natural Language Processing. SocialNLP@EACL 2017: 1-10

This project is part of DesCartes program, https://www.cnrsatcreate.cnrs.fr/descartes/, with co-supervisor, Professor Farah Benamara from University of Toulouse III – Paul Sabatier (UPS) as well.

- **Project Title: Visual Explanation Generation for Video Question Answering**
  I²R Supervisor: Sun Ying, Group Leader (Visual Learning & Reasoning), Senior Scientist II

Video Question Answering (VideoQA) is a recent emerging challenging task which requires a deep understanding of video data to answer questions asked in natural language. As real-world visual information is increasingly available in the form of videos, the task of VideoQA plays an essential role in supporting interaction between machines and humans with the aim to improve cognitive performance. For example, in video surveillance applications, the question-answer process can help direct human attention to keyframes or events in a timely manner, and to facilitate decision making.

Although promising performance has been achieved for VideoQA by deep learning-based methods, it remains a challenge for humans to truly understand model decisions. Therefore, beyond generating a short answer to each question, it is desirable to also provide the corresponding visual explanation to elucidate the QA pairs, e.g., instance grounding, temporal localization, and future frame prediction. Hence, the objective of this project is to develop new and powerful algorithms that can generate visual explanation of answers in VideoQA tasks. This requires the investigation of not only spatio-temporal analysis of video data and multimodal reasoning, but also generative models such as conditional generative adversarial networks and diffusion models.

- **Project Title: Privacy-Preserving Data Sharing for the Future Economy**
  I²R Supervisor: Tan Hong Meng Benjamin, Scientist II

Data analytics, machine and deep learning are set to power the future data-driven economy. These methods make intensive use of data to draw insights on the problem at hand. However,

this necessitates collection of large amounts of data and thus brings concern about the privacy of the people who are the targets of the data collection exercise. For example, existing guidelines for research involving people restrict data collected in any study to only being for the approved research questions put forth in the study. Such data cannot be used for any other purposes without the expressed consent of the study participants. Besides that, there is a trend towards greater collaboration between companies and organizations and pooling together everyone's data to enable more powerful machine learning is one aspect that is gaining traction. Presently, concerns about the security and privacy of the data held within each organization is a big roadblock towards enabling such deep collaboration.

Data anonymization is one way to transform data to remove the ability to identify individuals from it. Such anonymized data, with no ability to re-identify individuals, can be used for use in any application without any restrictions. Yet, there are gaps with existing approaches to data anonymization. The main metrics for anonymization such as k-anonymity and its generalizations only comment about the similarity among the resulting data and does not consider potential use of data from other sources for re-identification attacks.

This project aims to study privacy-preserving methods for generating synthetic data that offer a differential privacy guarantee. Differential privacy quantifies the likelihood that the result of some computation is due to one of its inputs without any restrictions on the knowledge of any attacker. Furthermore, synthetic data generated with differential privacy guarantees can be used for any task without affecting the privacy guarantees.

- **Project Title: Auditable Federated Learning**
  I²R Supervisor: Teo Sin Gee, Senior Scientist I

  Federated Learning (FL), a learning paradigm that enables collaborative training of machine learning models in which data reside in data silos and are not shared during the training process, can help AI thrive in the privacy-focused regulatory environment. As FL allows self-interested data owners to collaboratively train machine learning models, end-users can become co-creators of AI solutions. In this project, the student will explore how to design FL learning frameworks that allows insightful third-party audits on the desirable properties of an FL algorithm (e.g., model bias, fairness, robustness), while preserving important private information from the auditors (e.g. test cases) as well as the model owners (e.g., the FL model which could be proprietary).

- **Project Title: Explainable Federated Learning**
  I²R Supervisor: Teo Sin Gee, Senior Scientist I

  Federated Learning (FL), a learning paradigm that enables collaborative training of machine learning models in which data reside in data silos and are not shared during the training process, can help AI thrive in the privacy-focused regulatory environment. As FL allows self-interested data owners to collaboratively train machine learning models, end-users can become co-creators of AI solutions. In this project, the student will work on a dissertation to develop AI explainability techniques for FL. The key challenge is that existing XAI approaches generally require direct access to the test data, while such data could be deemed private under FL settings. New XAI mechanisms that can produce verifiable explanations while complying

with data privacy protection requirements are needed. The formats of explanation suitable for various stakeholders involved in FL can also be a topic of study.

- **Project Title: Multi-language Code-Switch Automatic Speech Recognition**
  I²R Supervisor: Tran Huy Dat, Deputy Department Head, Group Leader (Audio Analytics & Speech Recognition), Senior Scientist III

  In this project we develop a novel multi-language code-switch automatic speech recognition engine which can take spoken audio input from Southeast Asian (SEA)languages, including those with code-switched speaking (mixed in sentences level) with English. The candidate will be working on an industry-oriented research environments and learn to handle a very big data training and modelling with sophisticated joint optimization algorithms on audio, text, and linguistic domains.

- **Project Title: Satellite VHF voice communication digitalization & analysis**
  I²R Supervisor: Tran Huy Dat, Deputy Department Head, Group Leader (Audio Analytics & Speech Recognition), Senior Scientist III

  In this project we develop AI-driven speech processing, recognition, and emotion analysis of satellite VHF communications between controllers and pilots. The satellite VHF signals are characterized with scintillation effects which are changing unpredictably and introduces high level of noises and distortions. Secondly, the transmission introduces data loss which also results in bad signal quality. The team will work on developing of speech recognition and emotion recognition engines from voice communication under those challenging conditions.

- **Project Title: Object-Aware Domain Adaptation for Object Detection in Rain**
  I²R Supervisor: Wang Jiangang, Senior Scientist II

  In the context of autonomous vehicles, object detection from image is important to ensure the AV can move safely by responding to the environmental changes. Although impressive progress has been achieved by using deep learning, object detection in bad weather from an in-car camera is still challenging when much of the object information has been lost due to the rain on the road as well as the raindrop on the frontal windshield. Most of the data, used to train object detector are collected on sunny day, is very different from the actual rainy data. All of these factors make the object detection accuracy degraded significantly in rain. The application of autonomous vehicles is consequently limited because fail to keep away from objects could cause fatal accidents.

  In this project, a novel deep learning approach is proposed to enhance/detect object from rain images. The images that are captured on clear and rainy weather conditions respectively are considered as images come from two different domains. The object enhancement and detection are formulated as domain adaptation problem: convert image from one domain to another domain in order that the object detection rate can be improved in rain. Different from existing de-rain approaches which aim to improve the image visual quality, we aim at lane detection. An object-aware domain adaptation is proposed in this project to enhance object awareness in rain conditions. The methods proposed in this project can also be extended to other weather conditions (e.g. hazy).

- **Project Title: Multimodal Robot Perception and Skills Learning**
  I²R Supervisor: Wu Yan, Deputy Department Head, Group Leader (Manipulation & Human-Robot Collaboration), Senior Scientist II

  Since infancy, humans make use of the rich multisensory streams that they experience to perceive the world and shape their learning. For robots to really make sense of the world and to be of assistance to our daily tasks, it is important to learn the cross-modal experiences and build a multimodal representation through active interaction with the world especially through the coordination of the sense of touch, vision, and audition. This area of research investigates the construction of a representation model for the multiple sensory information that a robot is equipped to learn its perception of the world as well as the skills that it can build through the interaction and sensory feedback. Apart from specific topics in existing projects, interested candidates can also propose other project within this scope.

- **Project Title: Sparse Representation-based Deep Learning for Image Processing and Analysis**
  I²R Supervisor: Xie Shoulie, Senior Scientist I

  Sparse representation has attracted great attention in the past decades because it can represent the characteristics of data in a low-dimensional space and save computational resources significantly. It is also a well-established theory and can provide problem-specific interpretability with a profound impact on the fields of signal and image processing.

  With the advance of sensor technologies, a volume of data is available and becomes more diverse and complex. The intrinsic structure of data is hardly revealed with the classical representation approaches. Recently, deep learning has been successfully addressed this issue due to its stronger representation learning ability. However deep neural network is a black-box model and lack of interpretability.

  This motivates us to bridge the recently developed deep learning techniques with the sparse representation theory to explore efficient deep learning models with reasonable mathematical interpretation.

  This PhD project is to develop new interpretable deep learning algorithms to solve some practical problems in image processing and analysis by exploiting sparse representation theory and deep learning techniques.

- **Project Title: AI-Powered Holographic Display for 3D Communication**
  I²R Supervisor: Xu Yichao, Scientist I

  The deep neural network can help speed up the computer-generated hologram. Novel 3D communication method with holographic display will be investigated.

- **Project Title: Deep Learning for Image Anomaly Detection without Labeling**
  I²R Supervisor: Yang Xulei, Senior Scientist I

  Anomaly detection has attracted extensive attentions from both academic research and industrial applications in the past years. Image anomaly detection is one of the main categories, aiming to identify the image samples or instances that deviate from a dataset's normal behavior. Comparing to the classic approaches, the recent advance in deep learning enables more flexible feature representation, which has become increasingly popular for image anomaly detection. However, most of the deep image anomaly detection schemes require certain level of supervision, i.e., either annotation of the anomalies, or a corpus of purely normal data, which may not be practicable in real application scenarios.

  In this project, we make efforts to conduct comprehensive study on unsupervised / semi-supervised / self-supervised / weakly supervised deep learning approaches and compare their performance with standard supervised learning approach for image anomaly detection on several public benchmarks. Specifically, we will focus on how to develop a self-supervised deep learning scheme based on adversarial learning for image anomaly detection without any labelling. The proposed scheme should be directly trained over a mixture of normal and abnormal image data, while still able to distinguish and automatically label the anomaly without supervision. The project will also explore the transfer learning to enhance the generalization capability and representation learning of the proposed scheme, to handle the feature diversity cross various benchmarks.

- **Project Title: Towards Realistic Deep Learning for 3D Vision**
  I²R Supervisor: Yang Xulei, Senior Scientist I

  Deep learning with 3D data is vital for a wide range of emerging applications such as autonomous driving, robot perception, VR/AR, UAV inspection, and 3D metrology. However, due to the unique characteristics of 3D data, as well as the strict constraints from real-world applications, the research and adoption of 3D deep learning are still at early stage, currently facing many technical challenges, such as costly annotations and multiple modalities. In this project, we aim to explore essential research works to build 3D deep learning capabilities, to tackle all the aspects of technical challenges occurred in current 3D deep learning. In such a way, to make 3D deep learning more realistic for real-world applications.

  Specifically, we will focus on two research directions: label-efficient 3D and heterogenous 3D. The first one is to build 3D deep learning models with limited labelled data but maintain the satisfiable performance, with several research topics on: leveraging unlabelled 3D data, distillation from 2D data & models, augmentation by generative model, and unsupervised / semi-supervised / weakly supervised for 3D representation learning. The second one is for fine-grained representation learning across various modalities of heterogeneous & multi-view 3D data to boost the performance of 3D model, with several research topics include: 3D multi-task & multi-modality learning, 3D construction & mapping, 3D joint representation learning, and 3D transfer learning.

  At the end of this project, we will demonstrate the efficiency of the proposed research works on benchmark datasets, as well as real-world application use cases.

- **Project Title: Self-Supervised Representation Learning for Cross-Domain Trajectories**
  I²R Supervisor: Yin Yifang, Scientist III

  A raw trajectory is a sequence of fine-grained location indicators such as latitude and longitude, which are difficult to be effectively utilized in geo-aware applications. In this project, we propose to learn deep trajectory representations via a self-supervised pre-training scheme. Once the network is trained, it can be used as a pre-trained model for feature extraction from trajectories world-wide. Our proposed method will benefit a wide range of cross-domain and cross-modal downstream applications such as trajectory classification and forecasting based on transfer learning.

- **Project Title: Machine intelligence of human cognitive-neuromuscular performance and intention for human-robot physical interaction**
  I²R Supervisor: Zhang Haihong, Unit Leader (Neural and Biomedical Technologies), Senior Scientist I

  Along with increasing autonomy in the robots, machine intelligence of human cognition-neuromuscular performance and intention will be a key factor in creating a safe, friendly, and efficient physical interaction between human and machine so as to maximize the overall performance and safety of the human-robot system.

  Inspired by recent developments in physiological and psychological research into cognitive-neuromuscular activities, this project aims to investigate humans' cognition-neuromuscular processes associated with interactions with assistive robots, and to develop machine learning methods that will enable real-time decoding of human's motion and control intention and perform automated analysis of human performance for apt decision making by the robot control.

  This PhD research will be associated with existing and potential research projects -- such as Intelligent Human-Robot-Interface for Assistive Robot funded by National Robotics Programme. The research will take advantage of the capabilities and resources of the Neural-Biomedical Technology Laboratory at I²R. The student will be learning the basics of human cognition-neuromuscular processes, as well as related techniques for data processing, analysis and machine learning, and is expected to create impactful research outcomes in terms of new understanding of the neuro-physiological processes in human's interaction with assistive robots, and/or advanced machine learning techniques for real-time decoding of human's motion and control intention.

- **Project Title: Machine Learning for Early and Adaptive Prediction of Motion Intentions from Neurophysiology Signals**
  I²R Supervisor: Zhang Haihong, Unit Leader (Neural and Biomedical Technologies), Senior Scientist I

  Understanding and predicting human motions and intentions is of high importance in advancing multiple disciplines ranging from neuro-muscular physiology to human-machine interactions. It remains an open question as to how to model the complex, articulated human body motion processes with subject-dependent cognitive and neuromuscular functions. This project aims to design and study appropriate deep-learning techniques based on in-depth

analysis of human motion data (including electroencephalogram, electromyogram, inertial measurements, motion tracking data, etc.) collected by the neural and biomedical technology laboratory of I^2R (A*STAR) and/or collaborators. The research will also conduct interactive experiments involving human subjects and robotics/computer to study human-machine co-adaptation with human-motion-intention intelligence.

- **Project Title: Mobile Computational Photography by Fusing Model-driven and Data-driven Approaches**
  I^2R Supervisor: Li Zhengguo, Senior Scientist III

  Computational photography techniques enhance or extend the capabilities of digital photography in which the output is an ordinary photograph, but one that could not have been taken by a traditional camera. In this project, new computational photography frameworks will be developed by fusing model-driven and data-driven approaches. The model driven approach is benefited from the data driven one for enhanced representation capability. The data driven approach is benefited from the model-driven one for fast convergence speed and learning with few training samples.

  The proposed frameworks are scalable from the complexity point of view. It is attractive for "capturing the moment" via cloud computational photography in the 5G era. The model-driven method can be adopted to produce an image for previewing on the mobile device. The set of captured images will be simultaneously sent to the cloud and an image with a higher quality will be synthesized immediately. The synthesized image in the cloud will be sent back to the mobile device instantly due to the low latency of the 5G. If the photographer does not like the synthesized image, she/he can capture another set of images immediately.

- **Project Title: Commonsense Reasoning for Natural Language Understanding**
  I^2R Supervisor: Zou Bowei, Scientist III

  Commonsense reasoning is important for the success of many Artificial Intelligence (AI) systems. With the ability to make logical inferences from commonsense knowledge, AI systems can be more robust and adaptive when dealing with the unknown. This project looks into three open challenges of commonsense reasoning that are important in delivering human-level AI. (1) Commonsense Knowledge Acquisition: to identify and formalize commonsense knowledge automatically for a specific task; (2) Commonsense Knowledge Representation: to represent commonsense knowledge in neural approaches; (3) Commonsense Reasoning Integration: to integrate commonsense reasoning with downstream NLP tasks and investigate the performance evaluation of such systems.

- **Project Title: Long-Text Machine Reading Comprehension**
  I^2R Supervisor: Zou Bowei, Scientist III

  Long-text machine reading comprehension requires QA systems to answer questions based on a lengthy text. Despite transformer-based models achieve promising results, most of them are incapable of dealing with long sequences for their time-consuming. In general, a proper solution by sliding window splits the passage into equally spaced fragments, then predicts the

answer based on each fragment separately without considering other contextual fragments. However, this approach suffers from the lack of long-distance dependency, which severely damages the performance. This project aims to address these challenges by a retriever-reader architecture, to compress long texts into pieces of key memories instead of simplifying self-attention ways, then figure out the correct answer.

- **Project Title: Detection and Recognition of Fine-Grained Actions via Action Synthesis**
  I²R Supervisor: Lim Joo Hwee, Department Head, Principal Scientist II

  Fine-grained actions often convey very useful messages about the attention, emotion, and intention of the speaker. Automated detection and recognition of actions such as facial expressions and human behaviors have recently achieved rapid progress with the advance of deep neural networks (DNNs) and availability of large-scale training data. However, most existing work focuses on apparent actions with obvious movements but largely neglects fine-grained actions with imperceptible movements such as micro facial expressions, subtle body movement, etc. This is largely due to the lack of relevant training data that are very challenging to collect and label.

  In this project, we will investigate novel video synthesis techniques that can generate fine-grained actions that are realistic, self-annotated and have sufficient fidelity for training deep detection and recognition networks. Innovative neural radiance fields (NeRF) will be designed for 3D novel view generation with superior multi-view consistency and detail preservation. In the end, we will develop novel action synthesis techniques that can generate high-fidelity fine-grained action videos that can be directly applied to train fine-grained action detection and recognition networks effectively.

- **Project Title: Data-Efficient Image Generation via Regularization and Transfer**
  I²R Supervisor: Lim Joo Hwee, Department Head, Principal Scientist II

  Generative adversarial networks (GANs) usually require a large amount of training images for training for generating realistic yet diverse images. The recent 3D generation with neural radiance fields (NeRF) also requires a good number of training samples, plus the camera pose of each training sample that is often complicated to collect. Data-efficient image generation aims to develop new generative learning techniques that allow to train robust and high-quality image generation models with a small amount of training samples only (e.g., 1% of training data in conventional setups).

  In this project, we will investigate innovative generative learning techniques that allow to train data-efficient image generation models effectively. Two approaches will be studied: 1) regularization approach that designs certain self-supervision and consistency for effective learning from small data; 2) transfer approach that aims to distil features and knowledge from certain pre-trained mega models. In the end, we will develop novel data-efficient learning techniques that allow to train high-quality generation models with a small amount of training images.

- **Project Title: Open-World Continuous Learning with Mega Vision-and-Language Models**
  I²R Supervisor: Lim Joo Hwee, Department Head, Principal Scientist II

  Most existing visual learning algorithms assume a close-world setup with a fixed set of predefined objects or events of known categories. It has very limited scalability and sustainability while facing open-world scenarios that are rich in many unseen objects or events that fall out of the predefined object or event categories. Machine learning models trained under the close-world setup will simply ignore those unseen objects or events no matter whether they are relevant to the actual situations or not. The open-world continuous learning aims to address this issue by enabling machine to learn and understand various objects or events of new categories on the fly without requiring laborious collection and annotation of large amounts of training samples of new categories.

  In this project, we will investigate open-world continuous learning by leveraging mega vision-and-language models such as CLIP that stores a huge amount of pre-learnt knowledge about images, texts, and their relations. In the end, we will develop a set of open-world learning techniques that allow to detect and recognize various undefined new objects/events with the inputs of their text description only (e.g., object names, text description of an action, etc.).

Computing and Information Science (CIS)
Research Area: Bioinformatics

- **Project Title: Privacy Preserving Technology for Human Genetics Research**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

  To develop privacy-preserving frameworks which allow for genetic analyses to be conducted without access to highly sensitive individual-level genomic data in unencrypted form.

Computing and Informational Science (CIS)
Research Area: Communications

- **Project Title: RF, Antenna System, 5G beyond, 6G, mmWave**
  I²R Supervisor: Chia Yan Wah, Department Head, Principal Scientist II

  New cellular communication systems for 5G beyond and 6G require highly complex RF and Antenna structures to meet their high-performance specifications. Research into new RF system and Antenna architectures with the support of AI signal processing can help to tackle challenges for future complex 5G beyond and 6G.

- **Project Title: Phasea Array Metantenna Technology for Satellite Systems**
  I²R Supervisor: Qing Xianming, Group Leader (RF), Principal Scientist I

  The antenna is one of the most critical components for satellite-on-the-move communications (SOTM) systems. In particular, for low earth orbit (LEO) based SOTM systems, the antenna, which is equipped on the moving platforms such as cars, airplanes, ships, and trains, needs to

frequently conduct the beam alignment with the fast-moving LEO satellites. Electronically steered antenna (ESA) is considered as one of the most promising techniques.

Another important requirement for SOTM antennas is the capability to produce circular polarization (CP) in the far-field zone. The CP capability for both sides of the SOTM minimizes the effort to physically align the polarization of the antennas so that the polarization loss can be reduced.

A number of fundamental challenges when developing an ESA at higher frequencies such as Ka-band of 30 GHz are of significance for further research.

1. **Mutual coupling for Active ESA**
   As frequency goes up, the wavelength of the electromagnetic wave shrinks. Even with a low-profile planar antenna, surface wave can propagate within the substrate and increases the inter-element coupling. A strong inter-element coupling affects the ESA performance significantly with degraded active impedance matching during scanning, distorted radiation pattern, lowered beam-pointing accuracy, caused scanning blindness, and so on. Furthermore, for CP antennas, the mutual coupling severely affects the polarization purity especially in broadband designs.

2. **Wide-angle scanning with controlled scan loss**
   The practical applications require the EAS offers wide scan angle up to 85□ even 90□ in elevation plane, which causes large scan loss considering the shape of the antenna element pattern and conventional array factor distribution.

3. **Dual-beam or multi-beam function**
   The new LEO satellite constellations bring challenges related to satellites handovers and increased Doppler effect, requiring multiple satellite tracking and thus the ESA to feature the dual-beam or multi-beam capability.

- **Project Title: Joint Sensing, Communications and Control in 6G**
  I²R Supervisor: Sun Sumei, Distinguished Institute Fellow

Machine is envisioned as primary users in 6G networks, calling for embedded and native intelligence on machines. This will request for enhanced sensing, edge computing and intelligence, to be jointly designed with communications and control for machine users. While there have already some researches on joint communication and control design in the wireless networked control using, for example, age of information, age of loop, many questions remain open, calling for systematic framework of joint sensing, communications and control design.

- **Project Title: Multiple Access for Massive URLLC in 6G**
  I²R Supervisor: Sun Sumei, Distinguished Institute Fellow

Machines will be primary users in 6G networks. Seamless and real-time connection and interaction among the physical, digital, and human worlds will be enabled by 6G. Unit-area user capacity with ultra-reliability and low latency communications will be further increased than 5G, calling for renewed design of multiple access technologies. In this project, multiple

access schemes will be studied to support massive URLLC in co-existence with other quality-of-service users. Orthogonal and non-orthogonal, random, and deterministic, multiple access schemes will be analyzed in the 6G network architecture, and new schemes will be proposed to meet key performance indicators, including network synchronization accuracy, end-to-end delay, reliability, user capacity, spectrum, and energy efficiency.

- **Project Title: Semantic Communications**
  I²R Supervisor: Sun Sumei, Distinguished Institute Fellow

  Semantic communication, regarded as the breakthrough beyond Shannon paradigm, aims at the successful transmission of semantic information conveyed by the source rather than the accurate reception of each single symbol or bit regardless of its meaning. Semantic communications are especially relevant for intelligent and autonomous unmanned machines operations. On the other hand, human intervention and validation will still be an important and critical part in semantic communication-enabled operations. Hence, joint design of semantic communications and traditional source communications will be required to achieve both purposes, forming the focus of this proposed project.

- **Project Title: Integrated Sensing and Communication for Connected Intelligence**
  I²R Supervisor: Zeng Yonghong, Senior Scientist III

  Sensing and communication are crucial in many applications like automatic driving, VR/AR, industrial automation, and internet of things. Sensing and communication have a lot of similarities in hardware and software. However, currently dedicated spectrum, hardware, and software are used separately for them. This separation has caused huge spectrum, hardware, and energy waste. With the increasing usage of software-defined radio and digital signal processing, the hardware and RF front-end for sensing and communication tends to be similar. Thus, in recent years there is a trend to integrate sensing and wireless communication as one of the key technologies in future wireless systems.

  This project studies joint sensing and communication in the same platform. It tries to solve the following key issues:

  1. Radar detection algorithms based on standard communication waveforms.
  2. System design for shared use of hardware and software for joint sensing and communication.
  3. Self-interference cancellation in joint radar and communication.
  4. Optimized waveform for future (6G) sensing and communication at millimetre/terahertz band.
  5. Artificial intelligence for joint sensing and communication.

- **Project Title: Joint Radar and Communications**
  I²R Supervisor: Zeng Yonghong, Senior Scientist III

  Radar sensing and communication are crucial in many applications like automatic driving, VR/AR, industrial automation, and internet of things. Both radar and communication use RF

signals and have a lot of similarities in hardware and software. However, currently dedicated spectrum, hardware, and software are used separately for them. This separation has caused huge spectrum, hardware, and energy waste. With the increasing usage of software defined radio and digital signal processing, the hardware and RF front-end for radar and communication tends to be similar. Thus, in recent years there is a trend to integrate radar sensing and wireless communication as one of the key technologies in future wireless systems. This project studies joint radar and communication (JRC), which uses the same RF signal and hardware platform for both radar sensing and communication. It tries to solve the key issues in JRC with the latest technologies in communications, network, signal processing, and artificial intelligence.

Computing and Informational Science (CIS)
Research Area: Computational Engineering

- **Project Title: Towards Practical Homomorphic Encryption for Deep Learning**
  I²R Supervisor: Tan Hong Meng Benjamin, Scientist II

The use of data-driven methods in the industry is set to increase but these methods require users to release their data to reap their benefits. With greater focus on data protection, it is important to develop methods for preserving privacy of users while still getting the benefits from machine learning. Especially with the advent of Machine Learning as a Service (MLaaS), user data may be sent by companies and organizations to external parties for analysis and may face challenges managing customer privacy. Homomorphic encryption is one such privacy-preserving technology. It is a method for encrypting data but still allow the encrypted data to be processed obliviously. Unfortunately, it introduces heavy overhead compared to computation on unencrypted data. With deep learning, a lot of the computation involved at the inference stage can be parallelized and distributed across many nodes to obtain large gains, but there is still a lot of room for improvement. In RIE 2025, a great emphasis will be put on developing trust technologies for various sectors such as healthcare, finance, manufacturing, and defence under the FIDES programme at I²R, of which this project will be a key component for pushing homomorphic encryption towards commercialization.

This project aims to improve the performance of privacy-preserving applications developed with homomorphic encryption in a distributed and possibly heterogeneous computing environment. Key challenges include the transfer of huge amounts of encrypted data across compute nodes, which are themselves typically several megabytes large and maintaining high utilization of the resources on each node with limited amounts of memory. HE-encrypted data are often several megabytes large and deep learning operations may require many thousand ciphertexts and thus have intense memory requirements that far exceed the RAM equipped on commodity hardware that is typically used in the cloud.

- **Project Title: Computational Holographic Display for AR/VR Applications**
  I²R Supervisor: Xu Yichao, Scientist I

The computer-generated hologram is a computationally expensive task. The project target is to reduce the computational cost and increase the generation speed while maintaining good image quality, which can be suitable for AR/VR applications.

Computing and Informational Science (CIS)
Research Area: Cybersecurity

- **Project Title: Research on Quantum Computing Error Correction Codes**
  I²R Supervisor: Jin Chao, Senior Scientist I

  Quantum computing plays a vital and disruptive role in modern cybersecurity, as it can easily break most cryptography techniques currently in use. However, what is possible in quantum computing is still far from what can be implemented, this is because 1)a quantum bit (qubit) is not just two possible state 0/1 as in classical systems, but can be in many states between 0 and 1, and 2)quantum state is extremely fragile, the error rates of qubits are very high due to many types of errors such as bit flip error, phase flip error, rotation error, and decoherence. Therefore, complex quantum computation is impossible without the ability to recover from errors.

  Designing Quantum Error Correction Codes is different and more difficult than designing classical Error Correction Codes, mostly due to the following reasons.

  1. Non-cloning theorem: No device to copy an unknown qubit state, repetition ECC is not possible.
  2. Non-measurable: any measurement to the quantum state will destroy the state permanently.
  3. Many error types: besides bit flip errors like classical ECC, many other more complicated errors.

  The research directions along the line of quantum error correction codes could possibly include:

  1. Redundancy, not repetition: encode quantum state into multiple qubits through entanglement.
  2. Measure the error, not the data: for instance, for the two-bits error syndrome of the three-way repetition code, 1st bit of error syndrome says whether the first two bits of the state are the same or different, and 2nd bit of error syndrome says whether the second two bits of the state are the same or different.
  3. Designing codes to correct different types of errors: for instance, of the classical nine-qubit codes, repetition of 000, 111 corrects a bit flip error, while repetition of phase +++, --- corrects a phase error.

- **Project Title: Trust and Privacy in the Post-Quantum Blockchain**
  I²R Supervisor: Tan Hong Meng Benjamin, Scientist II

  Existing systems for authentication and verification such as the ECDSA algorithm are based on traditional cryptography using the RSA and discrete logarithm problems to underpin their security. However, since Shor's algorithm was proposed, the security of these systems have become a ticking time bomb with the ever-increasing capabilities of quantum computers. A key new technology, blockchain, is becoming increasing popular for enabling decentralization and data immutability, which enhances the security and transparency of systems built from it. One important aspect of blockchain technology is the signatures that are used to provide integrity

and non-repudiation for blockchain. Once quantum computers become powerful enough to run Shor's algorithm on the algorithms used, all these guarantees would no longer apply and severely impact the systems based on it.

This project aims to design algorithms with quantum-resistance properties that can replace or enhance existing uses of signatures, within the blockchain ecosystem and beyond. Besides basic digital signatures that provide the foundation of trust in modern systems, we will also consider other privacy-preserving primitives such as verifiable credentials that enable authentication and establishing trust without exposing any private and sensitive information that would be needed in the authentication process.

- **Project Title: Secure Sharing of Data via Privacy-Preserving collaborative Learning Framework**
  I²R Supervisor: Teo Sin Gee, Senior Scientist I

  Different people can own various kinds of data that can be combined to discover new trends with deep learning algorithms. However, many data contain private and confidential information that is not allowed to be shared due to valuable information, laws protection, etc. Therefore, many solutions use different privacy-preserving machine learning algorithms to enable sharing and collaborative Learning of the combined data (Federated Learning and Split Learning). However, there are still multiple challenges to be addressed:

  i. Dynamic data from distributed data sources usually exhibits non-IID (IID stands for independent and identical distribution) properties. Many existing collaborative learning solutions cannot perform well with non-IID data, especially under rigorous privacy-preserving constraints.
  ii. Many existing privacy-preserving collaborative learning solutions suffer severe white-box attacks that need to be addressed by the research community.
  iii. Privacy-preserving technologies impose large performance overheads on collaborative learning solutions, which also need to be optimized for practical applications.

  We will propose a secure collaborative learning framework to solve the issues as discussed. The proposed framework consists of Federated and Split Learnings, which uses differential privacy (DP) and Secure Multi-Party Computation (SMC) to compute different outputs from dynamic data shareable among various parties without privacy violation. Our proposed framework needs to ensure the following:

  i. Each data owner learns nothing from other party data. Even the servers know nothing from the owner data.
  ii. The framework provides light-weighted protocols that allow efficient and effective computation (time and communication costs). Besides, all the protocols need to be proven secure against malicious (or covert) attacks.
  iii. The framework needs to ensure the fairness and correctness of computation on data. In the correctness computation, each party is guaranteed to receive the correct output. For fairness, malicious parties only receive their output if and only if the honest parties do.

- **Project Title: Reliable and Robust Linux Malware Detection Research based on Artificial Intelligence Technologies**
  I²R Supervisor: Teo Sin Gee, Senior Scientist I

  In recent years, malware attacks and vulnerability exploitations have become severe security threats to various devices, including PCs, servers, and even IoT devices, which has led to massive losses, including data leakage and usability destruction. The increasing volume of malware poses challenges to traditional malware detection methods.

  Traditional malware detection methods can be roughly categorized into two types: the signature-based detection method and behavior-based detection. Traditional signature-based detection methods can achieve high accuracy but cannot detect new emerging malware. On the other hand, conventional behavior-based detection methods can detect new emerging malware but have a high rate of false positives.

  Some AI-based techniques have been proposed to solve these problems and have achieved great results (higher accuracy and lower false positives). Machine learning and deep learning are two of the most typical AI-based techniques. Machine learning algorithms such as SVM, Random Forest, and ensemble learning have been widely applied to detect malware. Deep learning algorithms such as CNN, RNN, and LSTM have been leveraged to classify malware. The two methods are used in both research and practice. However, these AI-based methods have recently been found to have some flaws, as follows:

  i. The aging problem of machine learning classifier due to malware evolution
  ii. Adversarial malware generation to evade detection, and
  iii. Poisoning attack by polluting dataset source to misguide classifier. Under this situation, it is of great significance to enhance AI-based detection methods by study the robustness of dataset construction, feature selection, and model building in machine learning. For example, we take Linux malware analysis to clarify some challenges: complicated architectures such as MIPS, ARM, and x86, the compatibility problem due to the discrepancy between different versions of the operating system and shared library, and the combination of cybersecurity and artificial intelligence domain knowledge.

Computing and Informational Science (CIS)
Research Area: Digital Health

- **Project Title: Multimodal EEG and NIRS BCI for stroke**
  I²R Supervisor: Ang Kai Keng, Group Leader (Signal Processing), Senior Scientist III

Although the clinical studies had demonstrated clinical effectiveness of BCI for stroke rehabilitation, study had shown that only 103 out of 125 stroke patients (82%) can use EEG-based BCI, and only 75 of them (60%) performed well with accuracies above 70% [1]. Thus, one of the biggest challenges in BCI research is to understand and solve this "BCI Illiteracy" problem, of which was estimated to comprise 15-30% portion of users [2]. Current clinical practice includes a BCI screening process [3] to determine if stroke patients are able to perform motor imagery and use EEG-based BCI for stroke rehabilitation.

Fundamentally, the BCI screening process [3] and the computation of a subject-specific calibration model for the stroke patients [4] is highly dependent on the performance of the algorithm in decoding motor imagery from EEG, and the ability of the stroke patient in performing motor imagery. The first dependency can be easily addressed, but the second dependency is harder because unlike motor execution that is observable, motor imagery is an endogenous mental process that cannot be observed for compliance [4]. However, there is currently no effective method to know that the subject is compliant in the performance of motor imagery at certain instance during EEG data collection process.Other than EEG, Near-Infrared Spectroscopy (NIRS) is another non-invasive optical measurement of brain activity based on variation of hemoglobin oxygenation and deoxygenation in cerebral blood [5]. The simultaneous acquisition of NIRS and EEG can potentially provide two different sources of brain signals, electrical and hemodynamic responses, and hence has several advantages. In this proposal, a Multimodal BCI system is proposed to address the challenges of multimodal BCI and the issue of unobservable motor imagery performed by the stroke patient by concomitant monitoring the activation of the motor cortex using NIRS and EEG.

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- **Project Title: Brain-Computer-Brain Interface with real-time monitoring using EEG and NIBS**
  I²R Supervisor: Ang Kai Keng, Group Leader (Signal Processing), Senior Scientist III

  Currently, very little is known about how neural circuits produced oscillations are linked to motor and cognition. In past studies, evidence on the relationship between Electroencephalogram (EEG) oscillations and cognition have been correlative in nature [1]. Recent research in non-invasive brain stimulation (NIBS) has showed that it allows direct manipulation of ongoing brain oscillations for neural entrainment that outlasts the stimulation, which suggests that plasticity effects that can be utilized for therapy [2]. However, this research is still in its infancy. Facilitating the effects of non-invasive brain stimulation has been observed for stroke [3-5], but this was not a one-size-fits-all treatment with highly variable responses from patients [6]. Thus, the long-term vision of this project is focused on developing the computer-brain interface that delivers NIBS for direct effective brain oscillation entrainment towards recovery in stroke. The specific goals are: (1) To develop algorithms to remove artefacts of various non-invasive stimulation on EEG due to the stimulation. (2) To study the entrainment effects in EEG to develop Brain-Computer-Brain algorithm that identifies effective subject-specific stimulation parameters.

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- **Project Title: Developing Privacy Enhancing Digital Health Machine Learning**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

  The main objective of this project is to study and develop advanced Privacy Enhancing Technologies for digital health data sharing and analytics. Machine learning is extremely pervasive today, especially in the health data domain where highly privacy sensitive user data is used. For example, genomic data of users are extremely sensitive and unique per user, which makes users uniquely identifiable through their genomic data. In addition, health data generated by the users' wearables is rich of data that leaks information about users' lifestyle and whereabouts. Furthermore, user clinical data must be strictly protected. The objective of this study is to protect user privacy while crosslinking the aforementioned three sensitive data types (genomic, wearable and clinical) for effective learning. The project will advance the state-

of-the-art machine learning techniques by developing advanced privacy enhancing technologies utilising the properties of AI and privacy enhancing technologies.

- **Project Title: Privacy Enhancing Digital Health**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

  To study and develop Privacy Enhancing Technologies for digital health data sharing and analytics.

Computing and Informational Science (CIS)
Research Area: Quantum Computing & Engineering

- **Project Title: Private Quantum Computing**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

1. To address serious security threats posed by quantum adversaries which are not only greater but are also qualitatively different from those posed by classical ones
2. To build new wave of quantum encryption technologies capabilities in dynamic thread landscape
3. To build private quantum computing capabilities and disruptive innovation

- **Project Title: Quantum Computing In (i) Computational Molecular Biology/ Biological Sciences and (ii) Climatology/ Climate Change**
  I²R Supervisor: Khin Mi Mi Aung, Group Leader (Data Security), Principal Scientist I

In quantum computing, what is possible in theory is very far from what can be implemented. Currently, we are interested in four main problems:

1. "Short" vectors in high dimension lattices,
2. Decoding error correcting codes,
3. Solving systems of multi-variate quadratic equations and
4. Isogeny graphs of elliptic curves. Theoretically quantum error correcting codes are available but quantum computing systems that can work with many qubits in super-position for long timespans are not ready yet.

Quantum Error-correcting codes could enable quantum computers to function indefinitely, and we are keen to work in the area of Quantum Computing in (i) computational molecular biology/ biological sciences and (ii) climatology/ climate change.

Engineering & Technology (E&T)
Research Area: Automation & Robotics

- **Project Title: Quadruped Robot Task Oriented Control and Navigation**
  I²R Supervisor: Albertus Hendrawan Adiwahono, Group Leader (Mobility), Senior Scientist II

  In this PhD topic, the student will research novel robotics solutions to address the research gap of quadruped deployment in unstructured and uncertain real environment. The deployment terrains expected for quadrupeds may include urban environments, industrial plants, built environment, and unstructured uneven terrain. Despite advancements of recent technologies, the robot's ability to navigate successfully on these areas with uncertainties such people, undulating terrains, thick vegetation, debris, and collapsible ground in these unstructured environments remain to be limited. The solution may include, but not limited to, development of quadruped control framework, advancement in machine learning, terrain analysis, and bio-inspired control heuristics that flexibly adjust to the obstacle faced by the robot.

- **Project Title: Learning to Adapt in Collaborative Multi-Robot Missions by Reinforcement Learning**
  I²R Supervisor: Efe Camci, Scientist II

  Multi-robot teams are more efficient, resilient, and versatile as compared to single-robot systems. Yet, their autonomous collaboration is far from being trivial. Existing collaboration methods are either inefficient or inapplicable in real-world missions, which feature stochastically changing conditions and limited communication between robots. The overall objective of this project is to develop a novel, learning-based framework that will endow robots with the ability of adapting intelligently in collaborative multi-robot missions in real world. The proposed framework will eventually help a team of robots perform spatially separate tasks in urban solutions and manufacturing domains, e.g., cleaning in malls, surveillance in factories.

  The project will focus on collaboration of mobile robots, including ground and aerial robots. Case studies will be based on coverage problems, which feature the characteristics of many multi-robot missions such as mapping, surveillance, search and rescue, cleaning, and inspection. Three key challenges in multi-robot coverage scenarios will be addressed by adapting to changes in:

  - Environmental map, as the map is explored on-the-fly,
  - Fleet size, as some robots can be added per need or some may fail during the mission,
  - Goal, as the mission itself may be altered after deployment.

  To address these key challenges, the proposed approach will be developed and tested over software-in-the-loop simulations such as Gazebo, AirSim with Robot Operating System (ROS). The scenarios that bring the key challenges to the fore will be focused, such as ground and aerial robot teams exploring an emulated nature park with limited communication, changing

team size, changing obstacle locations. Once the decent results are obtained in simulations, real world experiments will also be engaged.

- **Project Title: Dexterous Manipulation through Sense of Touch**
  I²R Supervisor: Liang Wenyu, Scientist II

  This project is to develop algorithms and framework for robot motion planning and control with the sophisticated tactile-based decision that enables robots to perform fast closed-loop manipulation tasks in occluded and/or vision-denied environments and on deformable objects.

- **Project Title: Exploration of Efficient Gait Using Compliant Material for Energy Storage and Restitution During the Gait**
  I²R Supervisor: Michael Chuah, Scientist II

  The rapid evolution of leg robotics led to commercially available platforms (Unitree, Boston Dynamics, ANYmal and others), mostly using electric actuators. Other solutions involve hydraulic systems for an increased available power. The use of compliant joints is beneficial for reliability, as it reduces the constraints on the mechanical parts [1]. Later, higher density power motor allowed to reduce the gearing ratio and reproduce this compliancy through torque control [2]. However, this solution is not energy efficient as no energy is recovered. Indeed, elastic joints have long been envisioned to perform energy storage and during locomotion and thus improving efficiency [3]. Recent studies include bio inspired solution to add elasticity in the limb which showed improvements in energy efficient locomotion [4]. Research has been made toward energy efficient gait controller with reinforcement learning [5]. In this PhD, the aim is to investigate the use of reinforcement learning in addition with compliant joint of legs to achieve efficient locomotion. Part of the research would be to integrate such compliant models in the training environment to perform custom training and demonstrate the energy saving of the controller on a real robot.

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- **Project Title: Development of Agile Locomotion System for Legged Robots**
  I²R Supervisor: Michael Chuah, Scientist II

  This project involves the simulation and control of a legged robotic platform, and the implementation of algorithms for parameter optimization, localization, and navigation.

  Student will learn about advanced robot kinematics and dynamics and their relevant applications. Student will explore the latest in legged locomotion and have the opportunity to apply their findings on a quadrupedal robotic system.

  Student will be responsible for understanding the current control framework of the legged robot using ROS, and the design and testing of various algorithms.

- **Project Title: Efficient Feature Detection in Point Cloud Data**
  I²R Supervisor: Saurab Verma, Scientist II

  The rise of lidar (Light Detection and Ranging) sensors in the recent decades has created several applications. All lidars essentially output point cloud i.e. a (typically) huge collection of space geometric points, representing distance to the near-by objects in various directions.

  In the context of AV and robotic navigation technologies, the lidars significantly assist in preventing accidents by rapid and reliable detection of potential obstacles. Further, lidars have also become predominantly useful for localization, map generation, autonomous navigation and traversability analysis via latest algorithm developments.

  The robotic algorithms intensively rely on suitable feature detection in the point cloud. Although, the current algorithms can detect only a handful of useful features, such as poles and roadside curb for localization. Furthermore, accurate and reliable detection of such features is still very computationally expensive and exceedingly dependent on lidar design and environmental complexity. Some latest algorithms have tried to address the problem by leveraging complementary sensors such as vision cameras. Albeit vision algorithms are typically even more computationally expensive (especially for battery-powered robots) and practically restricted to ideal-lighting conditions. In this project, the candidate will examine enhancement of accuracy and robustness of feature detection from point cloud data. The objective is to first train learning functions to understand the basic context of feature detection from current analytical algorithms and thereafter, assist in several robotic tasks in challenging environment with continual performance enhancement via self-competition and life-long learning.

  The enhanced feature detection algorithms will thereby directly bolster several applications including point cloud map cleaning, robust feature detection for high accuracy robot localization, stable features encoding into the point cloud maps for long-term robust localization of robots and traversibility analysis for mobile robots. These system level

enhancements will eventually lead to easy and reliable adoption of robotic technologies for mundane societal activities.

- **Project Title: Maplite Localization in Outdoor Environment**
  I²R Supervisor: Saurab Verma, Scientist II

  Typical state-of-the-art localization technology needs generation of a prior 3D map. This approach significantly restricts the deployment of mobile robots because generation of prior 3D map can be time and manpower intensive, or impractical due to time-limitation or security reasons. Further, maintaining the 3D map up to date in dynamic environments can be very challenging. Therefore, in this PhD study, the candidate will research on novel approaches for estimating accurate localization pose of the mobile platforms without the need for generation of prior 3D maps. The solution may include, but not limited to, multi-sensor data fusion, leveraging 2D floor or open-street maps, or bio-inspired topological/semantic maps using advanced machine learning approaches.

- **Project Title: Neural Behavior Embeddings for Visual Navigation**
  I²R Supervisor: Wan Kong Wah, Group Leader (Perception), Senior Scientist II

  We focus on the learning of control strategies for robots to navigate in complex dynamic environment with RGB cameras. Due to the high dimensionality of the visual input, a key issue faced by most learning algorithms, such as Reinforcement Learning (RL), is that they require long training time over large amounts of labelled training data. To alleviate this, we aim at deriving suitable representations for the state, action, and policy space, in the following areas:

  1. Transfer Learning -- using embeddings whose dimensionality remain fixed even when other environment variables change, hence allowing few-shot transfer across domains, and also from simulation to real.
  2. Auxiliary Learning -- using rewards from lower dimensional features (but expensive) that are available during training, and hence expediting convergence of training on higher dimensional data (cheaper) needed for test time.

  We demonstrate the utility of our method to enable a robot to auto-configure the parametric weightage of its sensor suite (e.g an expensive LiDAR and a cheap RGB camera) for navigation. This will then allow a robot fleet operator to amortize its sensors.

- **Project Title: Human-robot Interaction**
  I2R Supervisor: Wu Yan, Deputy Department Head, Group Leader (Manipulation & Human-Robot Collaboration), Senior Scientist II

  As robotics technologies mature, robots are expected to work in a team and collaborating with other people, not only in a factory setup as a cobot but also increasing in our living spaces.

Focusing on the use of learning techniques, multiple sensory and interaction modalities, this area of research seeks to investigate on methods for safe interactions, compliant and collaborative interactions and/or coordinated actions to improve the quality of task completion. Apart from specific topics in existing projects, interested candidates can also propose other project within this scope.

- **Project Title: Dexterous Robot Manipulation, Control, and Interaction**
  I2R Supervisor: Wu Yan, Deputy Department Head, Group Leader (Manipulation & Human-Robot Collaboration), Senior Scientist II

  Robots are increasing expected to perform ever complex manipulation tasks in the real-world environment. Coupling with the improved data quality of existing and emerging sensory modalities and actuation techniques, dexterity has becoming ever more possible for robot to acquire and execute. This area of research investigates the motion planning, control and learning research using multimodal sensory feedbacks for dexterous manipulation and interaction with the environment. Apart from specific topics in existing projects, interested candidates can also propose other project within this scope.

Engineering & Technology (E&T)
Research Area: Communications

- **Project Title: Transmission Technologies for 6G**
  I²R Supervisor: Sun Sumei, Distinguished Institute Fellow

  The fifth generation (5G) network, envisioned to provide enhanced mobile broadband (eMBB), mission-critical internet of things (IoT), and massive IoT, aims to be the digital transformation enabler in our all-industry sectors. While the 5G network is being deployed worldwide, it is timely to start looking at the megatrends moving to 2030, analyzing the needs for communications and networks and gaps from 5G, and developing enabling technologies for 6G to bridge the gaps. Internet of things, artificial intelligence of things, digital transformation consistently appear in the top list of megatrend 2030. The number of connected devices will continue to grow, connected living, industry 5.0, zero-latency world, etc., will be the driving force of 6G technology advancement, and also pushing for integrated and joint design of secure communications with computing and control, convergence of information technology and operational technology. We are looking for self-motivated PhD students with a strong bachelor or master's degree in electrical and computer engineering, computer science, applied mathematics, for research in advanced technologies for 6G. The topics include but are not limited to massive ultra-reliability low-latency communications (M-URLLC), intelligent and agile aggregation of licensed and unlicensed spectrums, joint sensing, and communication (JSAC), integrated security-communications design, and software-defined artificial intelligence-supported re-configurability in system, network, and radio environment.

Engineering & Technology (E&T)
Research Area: Green Urban Technologies

- **Project Title: AI-assisted Ultrasensitive Fiber Distributed Acoustic Sensing for Smart Nation**
  I²R Supervisor: Hu JuanJuan Dora, Division Head (Sustainable Built Environment Division), Senior Scientist I

  Acoustic detection technology offers the most promising way for the insight into the application scenarios of smart nation, such as transportation system, building health monitoring, and environmental monitoring. In terms of the complicated environments, large-coverage areas and varieties of acoustic/vibration sources, traditional point-to-point acoustic sensors or detectors meet great challenges of the response bandwidth and the sensor networking. The recent development of fiber-based DAS technology possesses the intrinsic advantages of high sensitivity, immune to electromagnetic interference, resistant to harsh environment, underwater passive sensing, compact size, light weight, easy to be compatible to large-capacity networking, etc. Despite the myriad of available fiber-based technologies, fundamental challenges such as strong low-frequency noise and limited response bandwidth still exist, which have significantly restricted their further applications.

  An advanced technology for highly-sensitive, long-distance and broadband fiber-optic distributed acoustic detection is therefore proposed here. More importantly, our intention is to actively apply self-correcting recurrent neural network to analyze the collected irregularly sampled time-series sensing data, while acting as a generator to predict and forecast the future sensing data, which will provide insightful information offered by infrasound waves in a real-time monitoring and prevention manner. This work will essentially address the following challenges:

  1. To enhance the backscattered sensing signals and expand the detection frequency bandwidth,
  2. To achieve highly coherent and chirp-controlled pulse generation for broadband acoustic sensing, and
  3. To achieve technology integration and proof-of-concept experimental demonstration for AI-assisted broadband acoustic detection in smart nation applications.

- **Project Title: Physics-Informed Machine Learning for Battery State Estimation and Forecasting**
  I²R Supervisor: Edwin Khoo, Unit Leader (Sustainable Energy), Scientist II

  Because of the urgent need to decarbonize and electrify society and industry, we are compelled to deploy batteries on a large scale that serve as an effective energy storage solution to store electricity generated by intermittent renewable energy sources such as solar and wind power. To ensure that batteries operate optimally with minimal degradation, accurate estimation and forecasting of their states is critical. In this project, we propose to use physics-informed machine learning, which integrates physics-based modeling with machine learning, to develop battery models that provide accurate estimation and forecasting of battery states while keeping computational costs manageable.

Engineering & Technology (E&T)
Research Area: MedTech & HealthTech

- **Project Title: MHz Spectral Domain Optical Coherence Tomography (SD-OCT)**
  I²R Supervisor: Hu JuanJuan Dora, Division Head (Sustainable Built Environment Division), Senior Scientist I

  SD-OCT is the main form of ophthalmic and dermatologic OCT devices due to its advantages in spatial resolution, phase stability and the potential to lower the device cost. The current global device market is over 10B euros with annual growth of over 10%. The major drawback of SD-OCT is the low imaging speed due to the fundamental limitation in the line rate of the line scan camera. The fastest OCT line scan camera can provide a line rate of 250kHz, which is far below the clinical needs. A MHz SD-OCT as the next generation OCT technology is urgently needed to provide both unprecedented scanning speed and spatial resolutions.

  To address the issue of speed limitation, we will take a spectral division parallel acquisition approach. Specifically, we will use a single spectrometer to detect the interference signals from 4 interferometers of distinct spectral bands. The key device to implement such as approach is a multi-core fiber that can deliver the OCT signal to one spectrometer with optimal efficiency. The total scanning speed will reach up to 1MHz which will be the highest in the world. In this project, aim 1 will be design and development of a novel multi-core fiber for signal mode transmission of OCT signals; aim 2 will be development of a MHz SD-OCT system and performance testing; aim 3 will be validate the speed and resolution advantages over the state-of-the-art technologies in animal and human subjects in vivo. At the same time, the cost of the device will be controlled so that it is significantly lower than the current MHz solutions (swept source OCT). A clinical prototype will be developed for clinical trials and commercialization.

- **Project Title: Explainable Feature Clustering and Representation for Medical Image Interpretation**
  I²R Supervisor: Huang Weimin, Unit Leader (Medical Imaging), Principal Scientist I

  Explainable AI for medical image analysis is still a challenging task due to the following issues. Firstly, it is difficult to quantitatively measure the correctness of the explainable heat-map such as Grad-CAM. Second the saliency maps may display inconsistent results compared with the inspection of clinicians. And it lacks intermediate or middle level representation. To tackle this issue, a knowledge-aware system that integrates some clinical prior information into the learning process can be explored and a general feature library that may be beneficial to improve the generalization ability of the deep framework on different medical image analysis tasks. Thirdly, the number of medical images with labels is usually insufficient to train a powerful explainable deep network because of the difficulty of annotation. Here, we will investigate to develop an explainable deep network with limited annotated medical data. A semi-supervised learning process is designed to generate the feature-clusters. By iteratively mapping the feature clusters to the domain-associated features, we can generate the desired feature library. The final AI disease models are to be built by incorporating the explainable generic features and tuned by the specific disease model.

- **Project Title: Medical Image Analysis Using Advanced Machine Learning Approaches**
  I²R Supervisor: Huang Weimin, Unit Leader (Medical Imaging), Principal Scientist I

  In this project, the student will explore the state-of-the-art deep neural networks in computer vision tasks, especially tasks that are related to medical image analysis for health care. However, the big data assumption for training, which is key for deep learning applications, is not always realistic. Particularly, in enterprise or healthcare scenarios, labelling samples is often very expensive or even impossible. In order to build powerful models in these problematic situations, we will examine few-shot learning algorithms which have been proved to be a promising tool in scenarios for small data set or big data set with limit labels.

- **Project Title: Assistive systems using multi physiological signal for motor disabled users**
  I²R Supervisor: Yang Tao, Scientist II

  Patients with motor disabilities suffer from dramatic deterioration of life quality. They are unable to perform their daily activities as normal due to the broken linkage between their intention and executive mechanism. There is a need for these patients to control and interact with their surrounding environment.

  Electroencephalogram (EEG) and Near-infrared spectroscopy (NIRS), Electromyography (EMG) each possess opportunities allowing the user to express his intention via a decoding mechanism. However, each of these physiological signs has its own pros and cons in a real application, such as accuracy of decoding, time delay from onset of event and physiological signal, signal stability. In this project, we plan to investigate the use of EEG, NIRS, and EMG signal to build an assistive system with non-invasive method that allows motor disabled patients to achieve control and communication purpose, such as motor imagery-based brain-computer interface using EEG, with verification motor imagery using NIRS and EMG signal.

  Challenges of the project include addressing the stability of EEG signal over time; understanding of the source of EEG signal during motor imagery; improve the motor imagery-based EEG decoding accuracy and information transfer rate (ITR) in control and communication application.

  Although many research works had been conducted in the field of EEG decoding, the application of these methods in controlling purposes still facing limitations. Further researches are required to improve the ITR and accuracy of decoding. It could be tackled by using deep learning techniques, such as convolutional neural network (CNN), long-short term memory (LSTM) could be applied in interpretation of EEG signals. NIRS which measures the changes in haemoglobin could be used in investigating the stability and localization of EEG which is an electrical signal.

- **Project Title: Super Modals for Medical Imaging by Transfer Learning and Self-supervised Learning**
  I²R Supervisor: Yang Xulei, Senior Scientist I

  Though artificial intelligence techniques, especially deep neural networks, have achieved outstanding performance in medical image analysis in recent years, there are still many challenges limit their translational applications. Firstly, the success of deep neural networks greatly counts on a large amount of annotated data, however, it is expensive to acquire such amount of medical images and label the image accordingly. Secondly, there is lack of deep neural networks for general medical image analysis cross various imaging modalities, as well as various body regions. A common practice to handle these bottlenecks is to do transfer learning through pre-trained models on large amount of various image resources. However, the current popular pre-trained models are basically trained on the data from non-medical domains, which may lead to performance degradation on medical images.

  This project aims to develop super pre-trained models for general medical image analysis based on small amount of labelled data. Specifically, the study will focus on exploring three related topics:

  1. Benchmark dataset - consolidate multiple medical images sets publicly available, to form the benchmark dataset for model training and performance verification.
  2. Development platform - enhance the representation learning through self-supervised mechanisms by leveraging up the unlabelled data from multiple imaging, as well as to enhance the generalization of deep learning modals cross various modalities and regions through modality adaption.
  3. Performance verification - conduct the performance comparisons between models trained from scratch, models finetuned by existing pre-trained models, and models defined by our pre-trained models. We believe, the study in this project will greatly speed up the transformation of the achievements of deep learning from computer vision domain to medial imaging research.

- **Project Title: Video-based AI for Cardiac Function Analysis**
  I²R Supervisor: Yang Xulei, Senior Scientist I

  Cardiovascular disease is a major health care burden. Cardiac function assessment and its underlying etiology is paramount. Doctors use diverse imaging tests - echocardiography, nuclear scintigraphy, and magnetic resonance imaging (MRI) for diagnosis and prognostication. MRI is frequently recommended for patients at intermediate risk of CVD to triage them for medication or invasive aggressive treatment.

  However, conventional interpretation of CMR images requires expert manipulation, is often operator-dependent, not easily amenable to computational evaluation, and reports only ventricular volume and ejection fraction. However, current techniques fail to exploit the full potential of the rich image dataset and also rely on expert inputs extensively (2-4 hours per report). Frequently, there is a lack of agreement between modalities. All heart imaging modalities can be presented in a video format (beat-to-beat). We proposed video-based AI for cardiac function analysis that is physiologically meaningful, reproducible, and validated.

In this project, we will develop a video-based AI for cardiac function analysis (VACFA). Our solution will provide the following function:

1. Point tracking;
2. Line tracking; and
3. Wall motion tracking beat-to-beat.

From point tracking, we will generate myocardial velocities for both LV and RV. From line tracking, we will generate myocardial strain and strain for LA, LV, RA and RV. From wall motion tracking, we will generate wall motion scores for LA, LV, RA and RV. From all above, we will report LV diastolic function/dysfunction (0, normal diastolic function; 1, diastolic dysfunction), systolic function/dysfunction (0, normal systolic function; 1, systolic dysfunction), wall motion (0, normal; 1, mild or moderate hypokinesia; 2, severe hypokinesia; 3, akinesia; and 4, dyskinesia), ischemia state (0, non-ischemia; 1, ischemia) to meet the clinical needs.

Engineering and Technology (E&T)
Research Area: Microelectronics & Semiconductors

- **Project Title: Multi-Level Machine-Learning Models for Fault Detection in The Digital Twin of Advanced Semiconductor Technology**
  I²R Supervisor: Senthilnath Jayavelu, Scientist III

  A*STAR and NUS are building new research programs that integrate machine learning analytics and advanced electronic device modelling. The aim is to develop techniques for defect prediction and diagnostic. With microelectronics moving deep into sub-5nm technologies and multi-chip heterogeneous integration, defect detection in state-of-the-art microchips has become extremely challenging, even with advanced metrology, imaging, and electrical testing capabilities. We are inviting PhD candidate applicants to work on investigating multi-level machine-learning models for predictive fault detection and building a digital twin of advanced semiconductor technology.

  University supervisor: Prof Aaron Voon-Yew Thean, NUS
  A*STAR supervisor: J. Senthilnath, I²R