SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4001 – Virtual and Augmented Reality

Academic Year	AY2022-2023	**Semester**	2			
Instructor(s)	Seah Hock Soon (ashsseah@ntu.edu.sg)					
Course Code	CE/CZ4001					
Course Title	Virtual and Augmented Reality					
Pre-requisites	CZ2003 Computer Graphics and Visualisation Study Year 3					
Pre-requisite for	NIL					
No of AUs	3					
Contact Hours	Lectures/TEL	24	Tutorials	12	Student Presentations	3

Course Aims

Virtual and augmented reality is becoming a powerful technology for engineers to design and implement applications ranging from manufacturing and medical to media and entertainment. Virtual reality refers to techniques that build imaginary worlds in computers. Augmented reality adds cues by overlaying computer-generated images onto the real world. An understanding of the hardware, software and algorithms for virtual and augmented reality allows engineers like you to push the limits of the technology and develop useful applications.

The prerequisite of this course is CZ2003 Computer Graphics and Visualisation, which covers fundamentals of 3D modelling and animation.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Explain what virtual and augmented reality is and how it can simulate and interact with the real-world.*
2. *Identify typical problems associated with virtual and augmented reality.*
3. *Describe some examples of real-world applications.*
4. *Design and implement a working system using available tools based on the concepts and mathematics learnt in this course.*

Overview of Course Content

	Topics
1	**Virtual Reality Platform** Project Window; Scene View; Hierarchy Window; Inspector Window; Game View
2	**Graphics** Primitive Shapes, Transforming Shapes; Controlling Appearance with Materials; Lighting, Camera; Shader, Texture; Particle System
3	**Physics** Rigidbody; Colliders; Joints; Character Controllers; Physics Debug Visualisation
4	**Animation** Workflow and Setup of Animations: Objects, Characters, Properties; Animation Clips; Humanoid Animation Retargeting
5	**Navigation** Inner Workings; Building NavMesh: Surface Modifier, Volume, Link; NavMesh Agent; NavMesh Obstacle; Creating Off-mesh Link; Building Hight Mesh, Navigation Area and Cost
6	**Particle System** Unified representation for rigid objects, deformable objects, liquid, gas, and cloth; Dynamics
7	**eLearning** Project Development
8	**Introduction to Augmented Reality** Definition and challenges; introduction to augmented reality engine; case study of a specific engine, e.g. ARToolKit
9	**Displays for Augmented Reality** History; augmented reality display technologies; head-mounted displays; hand-held displays; spatial displays; perceptual issues
10	**Tracking, Recognition and Registration** Tracking techniques: sensor-based, video-based, hybrid; recognition: feature detection and matching; calibration and registration: projection methods
11	**Rendering and Augmentation** Geometric model and transformations; rendering framework; augmentation; interaction
12	**Examples of Augmented Reality System** Example systems to link augmented reality concepts to real-world applications; challenges
13	**Project Presentation**

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. Project Written Report	20%	Team
3. Project Oral Presentation	20%	Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4013 – Distributed Systems

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Tang Xueyan (asxytang@ntu.edu.sg)			
Course Code	CE/CZ4013			
Course Title	Distributed Systems			
Pre-requisites	CE/CZ2005 Operating System CE3005 Computer Networks/CZ3006 Net-Centric Computing Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

This course aims to develop your understanding of the basic architectures, algorithms and design principles of distributed computing systems, and how they meet the demands of contemporary distributed applications.

This course provides an introductory but broad perspective of distributed systems, and is relevant for anyone pursuing a career in the IT/ICT industry – including those in product design and development, network/system administration, as well as, given the proliferation of IT in all walks of our lives, in executive roles across industries and government.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Explain the fundamental concepts and main features of distributed systems.*
2. *Describe the architectures of distributed systems.*
3. *Describe the functions of software components and common services to support distributed applications.*
4. *Analyse and apply the basic distributed algorithms.*
5. *Apply key design principles to an implementation of distributed system.*

Overview of Course Content

	Topics
1	**Characteristics of Distributed Systems and System Models** Fundamental characteristics of distributed systems, resource sharing, issues and problems in distributed systems, architecture models, fundamental models.
2	**Interprocess Communication** Transport services, external data representation, marshalling and unmarshalling, request-reply protocol over UDP, request-reply protocol over TCP.
3	**Distributed Objects and Remote Invocation** Distributed object model, architecture of remote method invocation, Java RMI.
4	**Distributed File Systems** Distributed file system requirements, Sun network file system, Andrew file system, Coda file system.
5	**Peer-to-Peer Systems** Introduction to P2P systems and applications, unstructured P2P file sharing, structured DHT systems.
6	**Name Services** Names, name services, Domain Name System.
7	**Time and Global States** Clock synchronisation algorithms, logical time, logical clocks, vector clocks, global states, distributed debugging.
8	**Coordination and Agreement** Distributed mutual exclusion algorithms, election algorithms, consensus problems.
9	**Replication and Consistency** Benefits of replication, requirements of replication, consistency models, consistency protocols.

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. Course Project	40%	Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4015 – Simulation and Modelling

Academic Year	AY2022-2023	**Semester**	2			
Instructor(s)	Huang Shell Ying (assyhuang@ntu.edu.sg)					
Course Code	CE/CZ4015					
Course Title	Simulation and Modelling					
Pre-requisites	CE/CZ1007 Data Structures CE/CZ1011 Engineering Maths I Study Year 3					
Pre-requisite for	NIL					
No of AUs	3					
Contact Hours	Lectures/TEL	26	Tutorials	13	Lab	8

Course Aims

Modelling and Simulation (M&S) course aims to equip you with one of the most important techniques to study real-time complex systems. M&S is an essential tool in many areas of science and engineering and has many applications, ranging from system analysis, decision support, to virtual environments. Thus, this course will introduce some fundamental techniques in M&S and build an understanding of the systems and tools of this field.

This course provides an introduction to system simulation and modelling techniques for complex dynamic systems. While the focus of this course is on how to analyse complex systems using computer simulation, some basic mathematical techniques will also be discussed. Various modelling, simulation and performance analysis techniques of complex systems will be discussed in this course with the emphasis on discrete event systems.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Determine the properties of different types of physical systems and different types of simulations that are suitable to analyse their behaviours.*
2. *Analyse data collected from real world and build input models for simulation studies.*
3. *Conduct various simulation studies to investigate the behaviours of complex systems.*
4. *Conduct statistical analysis of the simulation outputs.*
5. *Analyse discrete event systems through the competent use of computer simulation methods and mathematical modelling techniques.*

Overview of Course Content

	Topics
1	**Introduction** Nature of simulation, The concept of systems, models and simulation, Steps in a good simulation study
2	**Different Types of Simulation** Monte Carlo simulation, Continuous system simulation, Discrete event simulation, Simulation clock, Time advance mechanisms
3	**Simulation World View and Simulation Software** Event-scheduling world view, Process-interaction world view, General purpose programming language vs simulation software
4	**Basic Probability and Statistical Models for Simulation** Random variable, PDF, Mean, Variance, Correlation, The Law of large numbers, Central Limit Theorem, Sampling, Confidence interval, Statistical tests
5	**Random Numbers and Random Variate Generation** Middle-square method, LCG, Inverse Transform, Convolution, Composition, Acceptance-rejection
6	**Input Modelling** Data collection, Identifying the distribution with data, MLE, Goodness-of-fit tests (Chi-Square Test, Kolmogorov-Smirnov test), Arrival process
7	**Verification and Validation of Simulation Models** Basic concepts, Verification techniques, Calibration and validation of models
8	**Output Analysis** Output analysis for terminating simulations, Output analysis for steady-state simulations, Variance Reduction Technique - Antithetic variates
9	**Comparison of Alternative Designs** Pair-t approach, Multiple comparison problem, Variance Reduction Technique - Common random numbers
10	**Queueing Models** Basic properties, Performance measures, Kendall notation, Little's Law, Analysis of M/M/1 system

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. Practical Lab Assignment	25%	Individual
3. Written Assignment	10%	Individual
4. Presentations/Discussions	5%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4031 – Database System Principles

Academic Year	AY2022-2023	**Semester**	1 & 2	
Instructor(s)	Long Cheng (c.long@ntu.edu.sg) Sourav S Bhowmick (ASSourav@ntu.edu.sg)			
Course Code	CZ4031			
Course Title	Database System Principles			
Pre-requisites	CZ2007: Introduction to Databases Study Year 3			
Pre-requisite for	CZ4033: Advanced Data Management			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

Database management systems (DBMS) are designed to manage large and complex data sets. The fundamentals of the implementation of database management systems must be understood by all Computer Science students. This will help students to develop and design software systems utilising databases, and equip students with the knowledge of managing data of large scale. Moreover, this should be understood by current and future business leaders so that they can offer strategic guidance based on an informed understanding of database business capabilities. This course provides the basis for achieving this goal.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Discuss the importance of, and uses for, databases within organisations.*
2. *Explain how a relational database is implemented.*
3. *Describe the principles behind commercial databases and how to manage a relational database system.*
4. *Communicate knowledgeably about data management using professional language.*

SCSE MPEs courses for AY22-23 Semester 2

Overview of Course Content

	Topics
1	**Overview of Database Management Systems (DBMS)** DBMS Architecture, Relational DBMS
2	**Storage of Relational Data** Memory Hierarchy, Disks, Representing Relations in Disks, Using Secondary Storage Effectively, How to Move Data to Memory
3	**Indexing Techniques** Indexes on Sequential Files, Secondary Indexes, B-Trees, Hashing, Multi-dimensional Indexes (R-Trees, kD Trees)
4	**Query Processing** One-Pass Algorithms, Nested-Loop Joins, Two-Pass Algorithms based on Sorting and Hashing, Index-Based Algorithms, Algebraic Laws
5	**Query Optimisation** Introduction to Physical Query Plan Operators, Logical Query Plans, Physical Query Plans, Join Ordering
6	**Failure Recovery** Modelling Resilient Operations, Undo/Redo Logging, Checkpoint, Recoverability, Recovery process
7	**Transaction Management and Concurrency Control** Transactions, Serial and Serialisable Schedules, Conflict-Serialisability, Locking, Resolving Deadlocks

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	50%	Individual
2. Quizzes	20%	Individual
3. Assignments	30%	Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4034 – Information Retrieval

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Erik Cambria (cambria@ntu.edu.sg)			
Course Code	CZ4034			
Course Title	Information Retrieval			
Pre-requisites	CZ2001 or CZ2101 Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	23	Tutorials	8

Course Aims

This course aims to involve students in a technical way to understand and build information retrieval systems. They were expected to master the basic concepts and building blocks for information retrieval systems. In addition, applications in artificial intelligence were also introduced to get students acquainted with state of the arts.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *List and explain each of the modules information retrieval system.*
2. *Code with necessary packages to build a preliminary search engine.*
3. *Describe and distinguish various retrieval systems.*
4. *Apply fundamental clustering, classification and web search techniques to solve problems, such as computations and designs.*

SCSE MPEs courses for AY22-23 Semester 2

Overview of Course Content

	Topics
1	**Introduction to Information System** Course details and schedule. General introduction to definition and application to information system.
2	**Boolean Retrieval and Tolerant Retrieval** Term-document incidence; Inverted index; Boolean query; Optimisation; Tokenisation; Linguistic analysis; Query.
3	**Ranked Retrieval** Term-document count matrix; tf-idf; Vector space ranking.
4	**Efficient Retrieval** Efficient vector space representation; Efficient cosine ranking; Computing the K largest cosine values; Parametric and zone indexes; Tiered indexes.
5	**Enhancing Retrieval** Evaluation, calculating F-measure; Options for improving results using global and local methods.
6	**Classification** Text classification; Techniques; Feature selection.
7	**Clustering** Document clustering; Clustering algorithms.
8	**Web search and IR applications** Web search; Link analysis.

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	50%	Individual
2. Assignment	35%	Team
3. Quiz	15%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4041 – Machine Learning

Academic Year	AY2022-2023	**Semester**	2			
Instructor(s)	Li Boyang (boyang.li@ntu.edu.sg) Sinno Jialin Pan (sinnopan@ntu.edu.sg)					
Course Code	CE/CZ4041					
Course Title	Machine Learning					
Pre-requisites	CE/CZ1011 or CE/CZ1004 & CE/CZ2100 CE/CZ1007 Study Year 3					
Pre-requisite for	NIL					
No of AUs	3					
Contact Hours	Lectures/TEL	22	Tutorials	10	Student Presentations	6

Course Aims

This course provides an introductory but broad perspective of machine learning fundamental algorithms, and is relevant for anyone pursuing a career in AI or Data Science. It aims to provide you with the essential concepts and principles of algorithms in machine learning so that you can use various machine learning techniques to solve real-world application problems.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Explain the motivations and principles behind various machine learning algorithms.*
2. *Apply or even design specific machine learning algorithms to solve real-world application problems.*
3. *Identify some state-of-the-art machine learning techniques.*
4. *Conduct research on machine learning.*

Overview of Course Content

	Topics
1	**Introduction to Machine Learning** Overview of machine learning, supervised learning, unsupervised and applications
2	**Bayesian Classifiers** Bayesian decision theory, Naïve Bayes, Bayesian Brief Networks
3	**Decision Tree** Tree induction, prediction-based trees, generalisation errors
4	**Artificial Neural Networks** Perceptron, Multi-layer perceptron, backpropagation algorithm
5	**Support Vector Machines (SVMs)** Induction of SVMs, linear SVMs, Kernelised SVMs
6	**Regression Models** Linear regression, Kernelised regression
7	**K-Nearest Neighbor Classifiers (KNN)** KNN with majority voting, KNN with distance-weighted voting
8	**Ensemble Learning** Boosting, bootstrapping, model average
9	**Clustering** K-means clustering, hierarchical clustering, performance evaluation for clustering, applications
10	**Density Estimation** Parametric and non-parametric density estimation approaches
11	**Dimension Reduction** Principal component analysis (PCA), linear discriminant analysis (LDA)
12	**Application and Advanced Research Topics** Through course project on a predefined list of applications or research topics

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. Course Project Presentation	10%	Team
3. Course Project Report	30%	Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4046 – Intelligent Agents

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Bo An (boan@ntu.edu.sg) Zhang Jie (zhangj@ntu.edu.sg)			
Course Code	CE/CZ4046			
Course Title	Intelligent Agents			
Pre-requisites	Study year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

Intelligent agents are a new paradigm for developing software applications and the focus of intense interest as a sub-field of Computer Science and Artificial Intelligence. Multi-agent systems arise when these agents co-exist, interact and cooperate with each other. Agents and multi-agent systems are being used in an increasingly wide variety of applications, such as personal assistants, e-commerce, traffic control, workflow and business process management systems, etc. This course will equip you with the skills and knowledge on the design and implementation of intelligent agents and multi-agent systems to solve large-scale, complex, and dynamic real-world problems.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Describe the variety of connotations that agent-based computation implies and describe how the field fits into Artificial Intelligence and more broadly, Computer Science.*
2. *Identify the typical problems associated with intelligent agents and multi-agent systems.*
3. *Describe and debate the ways for solving problems related to intelligent agents and multi-agent systems.*
4. *Analyse real world and (possibly) new problems related to intelligent agents and multi-agent systems, and propose and evaluate possible mitigations.*

SCSE MPEs courses for AY22-23 Semester 2

Overview of Course Content

	Topics
1	**Introduction to Intelligent Agents** What is an agent; Principles of autonomy and agency; Views of the field from different aspects: Software engineering/simulation/AI; Relationship with AI/distributed systems/game theory/social science
2	**Deductive Reasoning Agents** Symbolic research agents; Planning systems; Planning agents
3	**Practical Reasoning Agents** Intentions and practical reasoning; Means-end reasoning; A Procedural reasoning system
4	**Reactive and Hybrid Architectures** Reactive vs hybrid; Brooks subsumption architecture; Limitations and hybrid architectures
5	**Introduction to Multi-Agent Systems and Applications** Definition of multi-agent systems; Applications of intelligent agents and multi-agent systems; Some demos
6	**Working Together** Benevolent agents; Cooperative distributed problem solving; Contract Net; Task sharing and result sharing; Coordination
7	**Multi-Agent Interaction** Utilities and preferences, Payoff matrices; Solution concepts, Game Theory; Nash equilibrium; Prisoners Dilemma
8	**Allocating Scarce Resources – Auctions** Definition of auctions; Categorisation of auctions; English auction; Dutch auction; First-price sealed bid auction; Vickrey auctions; Combinatorial auctions; Bidding languages; The VCG Mechanism; Some examples
9	**Making Group Decisions** Social Choice; Preference aggregation; Social Welfare; Voting procedures
10	**Forming Coalitions** Cooperative games; Computational and representational issues; Modular representations; Coalition games with goals; Coalition structure formation

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. Course Project	40%	Individual/Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4052 – Cloud Computing

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Tan Chee Wei <cheewei.tan@ntu.edu.sg>			
Course Code	CE/CZ4052			
Course Title	Cloud Computing			
Pre-requisites	CE/CZ1004 or CE/CZ1104 (Linear Algebra for Computing) Study year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

Cloud computing refers to both the applications delivered as services over the Internet and the modern applications powered by these services, collectively known as Software as a Service (SaaS), IaaS (Infrastructure as a Service) and PaaS (Platform as a Service). This course introduces the students to the basic concepts and theory behind cloud computing. Techniques and algorithms in distributed computing that leverages artificial intelligence, machine learning and blockchains, topics that forms an integral part of modern cloud computing and edge/fog computing, will also be covered, along with industrial perspectives. Upon completion, students will be able to understand cloud computing applications that use software frameworks, e.g., MapReduce/Spark, distributed computing services—including database, networking, software, analytics, and intelligence over the Internet to offer faster innovation, flexible resources, and economies of scale.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Describe the variety of connotations that agent-based computation implies and describe how the field fits into Artificial Intelligence and more broadly, Computer Science.*
2. *Identify the typical problems associated with intelligent agents and multi-agent systems.*
3. *Describe and debate the ways for solving problems related to intelligent agents and multi-agent systems.*
4. *Analyse real world and (possibly) new problems related to intelligent agents and multi-agent systems, and propose and evaluate possible mitigations.*

Overview of Course Content

	Topics
1	**Cloud Computing Basics** Scalable computing over Internet, Classification of clouds as public clouds, private clouds, enterprise clouds, federated clouds. Types of cloud computing applications: Software-as-a-Service (SaaS), Infrastructure-as-a-Service (IaaS) and Platform-as-a-Service (PaaS)
2	**Network Virtualization** Virtualization techniques: Models for dynamic provisioning of resources, Algorithms for computation decentralization, load-balancing, security and privacy preserving, trust management. Analysis to abstract and synthesis network resources in hardware and software using network virtualization
3	**Virtual Machines** Classifications and features of virtual machines (VM): system VM, process VM, hypervisor, security, attack and threat models, hyperjacking, resource allocation and management. VM techniques to combine multiple physical networks to one virtual, software-based network or divide one physical network into separate, independent virtual networks
4	**Distributed Computing** Parallel and distributed computing of big data. Scalable software: MapReduce, Hadoop, Spark, Examples
5	**Cloud Economics** Economics of scale: Cloud pricing models like Pay-as-you-go on-demand pricing, usage-based pricing, spot pricing model, auction-based pricing, cloud virtual service provider pricing, Algorithms for cloud pricing and bidding
6	**Edge and Fog Computing** Edge-cloud by mobile computing: Edge-cloud offloading, Cloudlets, Architectural issues, Live VM Migration, Mobile communication congestions issues, Trust, security and privacy issues at cloud edge, Fog computing for 5g/6G wireless networks and IoT
7	**Cloud Computing with Artificial Intelligence and Machine Learning** Relation between cloud computing and Artificial Intelligence (AI) Cognitive computing in cloud: machine learning in cloud, Robotic Process Automation, Tactical cloud, federated learning. Applications of cloud AI, Examples and case studies in industry
8	**Cloud Computing with Blockchains** Relation between cloud computing and blockchains, Blockchain-as-a-Service (BaaS) and Web 3.0 technologies in cloud. Applications of BaaS to decentralized finance, NFT (Non-fungible token) tokenized digital economy and distributed online social networks, Examples and case studies in industry

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Quizzes	30%	Individual
2. Project	30%	Individual
3. Exam	40%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4055 – Cyber Physical System Security

Academic Year	AY2022-2023	**Semester**	2			
Instructor(s)	Anupam Chattopadhyay (anupam@ntu.edu.sg)					
Course Code	CE/CZ4055					
Course Title	Cyber Physical System Security					
Pre-requisites	CE/CZ1006: Computer Organisation and Architecture Study Year 3					
Pre-requisite for	NIL					
No of AUs	3					
Contact Hours	Lectures/TEL	26	Tutorials	12	Lab	3

Course Aims

Cyber physical systems are typically designed as a network of interacting elements with physical input and output, and are characterised by the interaction between the physical world (sensors, user inputs, actuators) and the cyber world (processing, decision making). Cyber physical systems are the driving force behind modern civilisation, being integral part of technologies, such as additive manufacturing, smartcard-based payment, power delivery systems, drone-based operations, and smart home automation. Cyber physical systems are characterised by stringent performance requirements, such as, extremely low energy budget, small area footprint and often hard real-time constraints. Due to the pervasive nature of the cyber physical systems in our everyday lives, it also runs the risk of huge security hazards.

In this course, we will learn about the basics of cyber physical systems, including the design principles and methodologies. Further, there will be a detailed treatment of the security challenges for cyber physical systems, which vary in practice due to the diverse nature of the application environment of cyber physical systems. These different forms of security breaches, observed across diverse cyber physical systems, will be put in a well-characterised taxonomy, to be systematically identified as attack surfaces. The techniques to handle these attacks will be described in a generic manner, including key management and wireless/RFID communication. The attack surfaces and protection/mitigation principles will then be elaborated with practical case studies, from the representative cyber physical systems such as automotive, smart card systems and smart grid.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Describe the basic concepts of cryptography are used for ensuring security of cyber-physical systems.*
2. *Describe the basic design, architecture and design principles of cyber physical systems.*
3. *Identify the sources of vulnerability in a cyber physical system systematically via attack surfaces.*
4. *Determine how security is incorporated at different abstractions and at different components of cyber physical systems.*
5. *Articulate the principles behind the detection and mitigation of attacks for different attack surfaces of a cyber-physical system.*
6. *Compare and contrast practical cyber physical system security such as for smart grid, smart vehicle, and smart card systems.*
7. *Determine the performance overheads to consider for incorporating security in a cyber-physical system.*

SCSE MPEs courses for AY22-23 Semester 2

Overview of Course Content

	Topics
1	**Basics of Cyber Physical System (CPS)** Examples of CPS (Avionics, Health, Grid, etc.), Design Principles, and Characteristics: Robustness, Real Time Constraints, Distributed Control, Human Intervention. Deployment: Wireless Sensor Nodes, Internet-of-Things (IoT), Practical Examples. Security Aspects.
2	**Basics of Security** Confidentiality, Integrity, Availability, Authenticity. Basics of Cryptography - symmetric-key algorithm, message authentication code, mode of operations, key diversification, Public Key Infrastructure (PKI) and Certificate Authority (CA), hash function and signature, authentication, fingerprint, certification, secured messaging, security token principle of the operation. Security challenges in cyber physical systems. Risk Assessment. CPS Security Characteristics.
3	**Attack Surfaces of Cyber Physical Systems** Attack surfaces based on network, distributed control, distributed storage, real-time constraints. Attack surfaces based on computing and communication. Hierarchy of vulnerabilities.
4	**Device-Level Security** CPS Platforms. Security by Design. Microprocessor Security, Security Accelerators.
5	**Key Management in Cyber Physical Systems** Key generation system, key injection system, key management in distributed cyber physical systems, smart device personalisation system with biometric security.
6	**Secure Communication in Cyber Physical Systems** Communication standards and performance requirements. Vulnerability issues in prominent communication protocols, Ethernet, SCADA, NFC.
7	**Cyber Physical System Security: Smart Cards** Smart cards (contact, contactless): Attack Surfaces, Attack Example: Side-channel Attack, Privacy Intrusion, Mifare RFID hack. Attack Detection and Mitigation.
8	**Cyber Physical System Security: Smart Grid** Smart grid overview: Attack Surfaces, Attack Example: GPS Spoofing, False Data Injection, and Deadline Violation. Attack Detection and Mitigation.
9	**Cyber Physical System Security: Smart Vehicle** Automotive systems overview: Attack Surfaces, Attack Example: LIDAR spoofing, Keeloq attack, Malware injection. Attack Detection and Mitigation.

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	50%	Individual
2. Two Quizzes	20%	Individual
3. Project	20%	Team
4. Assignment	10%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4062 – Computer Security

Academic Year	AY2022-2023	**Semester**	1 & 2	
Instructor(s)	Tay Kian Boon (kianboon.tay@ntu.edu.sg) Zhang Tianwei (tianwei.zhang@ntu.edu.sg)			
Course Code	CE/CZ4062			
Course Title	Computer Security			
Pre-requisites	CE/CZ2005 (Operating Systems) Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

This course aims to equip you with foundational knowledge on many important security issues and techniques required for cyber security.

You will have the knowledge of different security policies and security models, and have the ability to recognise security features and discover pitfalls in computing systems, including the operating system and software.

Intended Learning Outcomes (ILO)

On successful completion of the course, the student should be able to:

1. *Understand security mechanisms in modern computer systems, its role, and its importance;*
2. *Understand techniques for implementing security policies;*
3. *Use and operate access-control mechanisms;*
4. *Understand vulnerabilities associated with computer systems, and how they can be mitigated.*

Overview of Course Content

	Topics
1	Overview of computer security
2	Software Security
3	OS Security
4	Network Security
5	Passwords: Authentication & Authorisation
6	Mobile Security: Intro-Android & IOS
7	Real World Case Studies
8	Cryptography: Overview, public and private cryptosystem
9	Project development, discussion and presentation

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Quizzes(two)	70	Individual
2. One project	30%	Team and individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4067 – Software Security

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Li Yi (yi_li@ntu.edu.sg)			
Course Code	CE/CZ4067			
Course Title	Software Security			
Pre-requisites	CZ/CE2002: Object Oriented Design & Programming CZ/CE2005: Operating Systems Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

This course aims to develop skills in software security. It focuses on security attacks launched by supplying specially crafted inputs to software components that modify the intended behaviours of those components, and the secure coding techniques (defences). The modified behaviours of the software components become security critical in a connected world where application systems are constructed from a collection of software components. Software developers who are not familiar with software security are likely to omit suitable defences out of ignorance.

As such, this course will equip you with the deep knowledge about software security attack and defence techniques, a skill necessary to become IT security experts or professional software developers.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Describe the causes for common software vulnerabilities.*
2. *Include basic defences in their code.*
3. *Make use of software security tools.*
4. *Describe the importance and the recommended phases of a software development process geared towards writing secure code.*

Overview of Course Content

	Topics
1	**Introduction to Secure Software Development** Definitions. Why software security? Secure development lifecycle approach; Software threat modelling, risk analysis, and impact analysis. Defensive programming concepts and principles.
2	**Buffer Overrun Attacks** Buffer overruns; the call stack and stack frames; classes of stack overrun attacks; defences: canaries, DEP, ASLR; integer overflows; safe integer arithmetic; refined attacks: return-oriented programming, jump-oriented programming; overrun attacks on the heap
3	**Targeted Overwrite Attacks** Format string attacks; memory allocation and deallocation; double-free attacks; attack targets; defences
4	**Input Security** Sources of input: Environment variables; object reuse and storage residues; uninitialised memory corruption attacks
5	**Type Safety and Race Conditions** Type-safe languages; type confusion attacks; race conditions
6	**Character and Integer Representations** Meta characters; UTF-8 encoding of Unicode characters and the challenges posed to filtering input; input filtering: Regular expressions; wrappers; HTML encoding
7	**Data Access Security** HTTP parameter pollution attacks; SQL injection attacks: Principles of SQL injection attacks; defences: escaping, filtering, bound parameters
8	**Generation and Handling of Cryptographic Material** Session security; cross-site request forgery attacks; use of cryptographic mechanisms, and security protocols in software; software key generation and handling; code signing and verification of loadable modules
9	**Code Review, Software Testing and Taint Analysis** Static and dynamic taint analysis; data flow and information flow analysis; fuzzing; regression testing; black/white box testing; data mutation

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Final Examination	60%	Individual
2. One Quiz	20%	Individual
3. Project/Assignment	20%	Team
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE4123/CZ4123 – Big Data Management

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Luo Siqiang (siqiang.luo@ntu.edu.sg)			
Course Code	CE4123/CZ4123			
Course Title	Big Data Management			
Pre-requisites	CE/CZ4031 Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	13

Course Aims

We are in the "Big Data" era – an extremely large amount of data is created every day. The world of data management has dramatically changed in the "Big Data" era. This is primarily driven by multiple factors including cheaper storage costs, increasing availability of sensors, smart devices, social software, and availability of cloud computing infrastructure, and cheaper processing cost of large volumes of data due to dramatic advances in modern hardware (e.g., solid state disk, multicore CPUs, large memory). This seismic impact of big data has led to increasing demand in building scalable data infrastructures toward supporting real-world applications. This course aims to provide a broad understanding of big data and current technologies in managing and processing them. Key topics covered in this course include general principles of designing big data systems, distributed storage of big data, programming models in big data, big data analytics techniques, key-value stores, and big data analytics. Upon completion of this course, you will learn to evaluate issues associated with big data management and business data analytics, learn how the data is stored in a distributed file system and how queries and analytics run in parallel.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Explain and describe the fundamental properties of big data, and basic operations of big data systems.*
2. *Discuss and explain the construction of big data systems based on different storage models and data models.*
3. *Analyse and describe the advantages of using different categories of data systems in certain real-world applications.*
4. *Describe and explain the data analytics procedures and techniques in big data applications industry.*
5. *Design and process big data using standard programming models and open APIs.*

Overview of Course Content

	Topics
1	**Introduction to Big Data Management** The overall context of the big data era; Big data 5V's; Terminology: data volume, data velocity, data variety, data veracity, data value, data format, data structure; Histories and developments of big data systems
2	**Data Models and Query Languages** Relational models, schema, primary keys, foreign keys; Key-value models; Graph models; Query languages
3	**Designing Big Data Systems—General Principles** Concept of data system design; Storage hierarchy; Cache Mechanism; Cache-Conscious Design
4	**Architecture of Data Systems** Internals of Data Systems; logical plan, optimiser, physical plan; Query lifecycle
5	**Row Store and Column Store** Concept of row/column store; Advantages of row/column stores; Lazy tuple reconstruction; Vectorisation; Zone map; Query plans and cost analysis
6	**Distributed Systems and MapReduce** Distributed file system; Distributed computing; Programming models of MapReduce; Hadoop and Spark; Cloud computing
7	**NoSQL and Key-Value Stores** CAP theorem; Differences between Relational DB and NoSQL; Concept of key-value indexes; LSM-trees
8	**Big Data Analytics** Graph-based applications; Data mining in big data; Data warehousing

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Quiz	30%	Individual
2. Project	30%	Team and Individual
3. Final Examination	40%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE/CZ4171 – Internet of Things: Communications and Networking

Academic Year	AY2022-2023	**Semester**	2	
Instructor(s)	Tan Rui (tanrui@ntu.edu.sg) Dusit Niyato (dniyato@ntu.edu.sg)			
Course Code	CE/CZ4171			
Course Title	Internet of Things: Communications and Networking			
Pre-requisites	CE3005/CZ3006/CE2108/CZ2108 Study Year 3			
Pre-requisite for	NIL			
No of AUs	3			
Contact Hours	Lectures/TEL	26	Tutorials	10

Course Aims

The objective of this course is to introduce Internet of Things (IoT) technologies with the focus on data communications and networking. The course consists of two complementary components, i.e., wireless communications and wireless networking to support IoT applications and systems. The wireless communications part includes the basics and concepts of wireless transmission technologies such as frequency, power consumption, wireless performance, mobility, wireless standards, medium access control protocols including fixed assignment and random access techniques. The wireless networking part includes the introduction and basics of wireless ad hoc routing, and cellular networks such as cellular system architecture, frequency reuse concept, hexagon geometry, co-channel interference, capacity expansion techniques. In addition to these two major components, the course will also discuss the IoT network architecture, IoT devices and IoT application use cases to provide comprehensive understandings of the entire IoT ecosystem. After attending this course, the students will be able to address the various technical challenges associated with wireless communications and networking to support IoT applications by solving such challenges using the principles learned. In addition, the students will be able to design and evaluate wireless communications and networking systems to support specific IoT applications. The concepts covered in this course are particularly important for those working in fields such as IoT network development, wireless IoT apps implementations, and mobile IoT services.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Design data communications and networking systems to support IoT applications.*
2. *Analyse, evaluate and assess performances of the data communications and networking systems to support IoT applications.*
3. *Conduct performance optimization of the data communications and networking systems to support IoT applications.*
4. *Review new technologies and perform literature review related to IoT.*
5. *Develop an IoT application (a course project) by using IoT technologies, and give a demo and presentation about the project.*

Overview of Course Content

	Topics
1	**Introduction to Internet of Things, IoT (1 hours)** Explain background of IoT, motivations, needs and requirements from different sectors for smart objects and systems, discuss design goals of IoT and some success stories such as smart healthcare, smart manufacturing, and smart city.
2	**Introduction to IoT Network Architecture and Design** Explain new requirements for network architecture for IoT, comparison among different IoT network architecture, and some introduction about IoT network architecture.
3	**IoT Devices** Explain the concepts of smart and connected objects including sensors and actuator, discussing sensors networks.
4	**IoT Wireless Communications** Explain the basics and concepts of wireless transmission technologies such as frequency, power consumption, wireless performance, mobility, wireless standards, medium access control protocols including fixed assignment and random access techniques.
5	**IoT Networking** Explain the introduction and basics of wireless ad hoc routing, and cellular networks such as cellular system architecture, frequency reuse concept, hexagon geometry, co-channel interference, capacity expansion techniques.
6	**IoT Application Use Cases** Discussing IoT systems used in manufacturing, healthcare, utilities, smart city, transportation, logistics, and public safety.

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Assignment	20%	Individual
2. Term Paper	40%	Individual
3. Course Project	40%	Individual
Total	100%	

SCSE MPEs courses for AY22-23 Semester 2

CE4172/SC4172 – Internet of Things: Tiny Machine Learning

Academic Year	AY2022-2023	**Semester**	2			
Instructor(s)	Nicholas Vun (ASCHVUN@ntu.edu.sg)					
Course Code	CE4172/SC4172					
Course Title	Internet of Things: Tiny Machine Learning					
Pre-requisites	CE2107/SC2107: Microprocessor System Design and Development Study Year 3					
Pre-requisite for	NIL					
No of AUs	3					
Contact Hours	Lectures/TEL	26	Tutorials	8	Student Presentations	10

Course Aims

In this Tiny Machine Learning (TinyML) course, students will learn the techniques to implement machine learning on resource constrained devices that are to be deployed as smart IoT devices that form the crucial end components in Edge computing.

TinyML enables very low power (mW range and below) IoT device (typically a microcontroller) to perform the ML inference on the device in real time, which enable on-device data analytics and improved response time as well as reduces power consumption since the data does not need to be forward to the Cloud for further processing.

After attending this course, the students will know the steps required to develop deep learning based applications running TensorFlow Lite for microcontroller. Students will also learn the techniques to optimise performance parameters such as latency, energy, and code size for the implementation of smart IoT devices.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, students shall be able to:

1. *Build deep learning based models for IoT applications.*
2. *Train the model and deploy inference engine on Microcontroller.*
3. *Analyse, evaluate and conduct performance optimisation to support highly efficient smart IoT implementations.*
4. *Develop smart IoT devices based applications.*

SCSE MPEs courses for AY22-23 Semester 2

Overview of Course Content

	Topics
1	**Basics of Machine Learning for TinyML Development** The Deep Learning workflow – goal setting, dataset collection, Training Model, Running Inference. TensorFlow and TensorFlow Lite for Microcontroller. Development platform requirements.
2	**Developing a Basic TinyML Application** Building a simple model (Sine Predictor), Generating the dataset, Training the model, Porting to TensorFlow Lite C file, Building the application, Deploying on Microcontroller.
3	**Developing a Keyword Spotting Application** Application architecture and walking through the tests (Audio Provider Feature Provider, Command Recogniser and Responder, Listening for Wake Words), Training the model, building an application and deploying to Microcontroller.
4	**Design Considerations of TinyML Applications** Optimising Latency, Optimising Energy Usage,Optimising Model, Optimising Code Size
5	**Project Presentation and Discussion**

Assessment (includes both continuous and summative assessment)

Component	Weightage	Team/Individual
1. Exam (1-hr)	30%	Individual
2. Quiz	20%	Individual
3.Course Project	50%	Individual
Total	100%	