# City University of Hong Kong Course Syllabus

# offered by College/School/Department of <u>Mathematics</u> with effect from Semester <u>B 2024 /25</u>

# Part I Course Overview

Course Title:	Reinforcement Learning and Its Applications in Finance
Course Code <sup>.</sup>	MA6634
course coue.	
Comment Descriptions	
Course Duration:	One Semester
Credit Units:	3 CUs
Level:	<u>P6</u>
Madium of	
Instruction:	English
Medium of Assessment	English
	- Singhon
Prerequisites:	
(Course Code and Title)	Nil
Precursors:	
(Course Code and Title)	Nil
Fauivalent Courses	
(Course Code and Title)	Nil
· /	
Exclusive Courses:	<b>N</b> 7'1
(Course Code and Title)	NII

#### **Course Details** Part II

#### 1. Abstract

This course introduces fundamental mathematical methods for reinforcement learning and its application in financial problems. It helps students to understand the basic concepts and programming tools in reinforcement learning models and develops students' ability to apply the technique to financial applications.

#### 2. **Course Intended Learning Outcomes (CILOs)**

(CILOs state what the student is expected to be able to do at the end of the course according to a given standard of *performance.*)

No.	CILOs	Weighting (if applicable)	Discov curricu learnin (please approp	very-enn Ilum rel goutco tick priate)	riched ated omes where
			A1	A2	A3
1.	Explain fundamental concepts and theories of reinforcement learning models include action space, state space, reward, value function, Finite Markov decision processes, policy, and Bellman equation.	30%	~	$\checkmark$	
2.	Apply classical dynamic programming and reinforcement learning algorithms, include policy iteration, Q learning, policy gradient methods, and deep Q learning.	25%	$\checkmark$	$\checkmark$	
3.	Program the reinforcement learning algorithms.	20%	$\checkmark$	$\checkmark$	$\checkmark$
4.	Implement the models in financial applications	25%	$\checkmark$	$\checkmark$	
		100%			

A1: Attitude

Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: Ability

Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to real-life problems.

A3: *Accomplishments* 

Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

# 3. Learning and Teaching Activities (LTAs)

(LTAs designed to facilitate students' achievement of the CILOs.)

LTA	Brief Description	CIL	O No.				Hours/week
	_	1	2	3	4		(if applicable)
Lectures	Students learn the primary knowledge through the lectures.	~	~	~	~		3 hours/week
Assignments	Students review the basic concepts and implement advanced theory for better understanding through take- home assignments.	~	<b>√</b>	~	~		after-class
Project	In the project, students apply reinforcement learning models to more complex financial problems and implement computing techniques introduced in this course.		~	~	~		after-class

### 4. Assessment Tasks/Activities (ATs)

(ATs are designed to assess how well the students achieve the CILOs.)

For a student to pass the course, at least 30% of the maximum mark for the examination must be obtained.

Assessment Tasks/Activities	CILO No.				Weighting	Remarks		
	1	2	3	4				
Continuous Assessment: 40%	Continuous Assessment: 40%							
Hand-in assignments	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$		20%		
Project		$\checkmark$	$\checkmark$	$\checkmark$		20%		
Examination: 60% (duration: 2 h	rs)							
Examination	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$		60%		
						100%		

# 5. Assessment Rubrics

(Grading of student achievements is based on student performance in assessment tasks/activities with the following rubrics.)

Applicable to students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter

Assessment	Criterion	Excellent	Good	Fair	Marginal	Failure
Task		(A+, A, A-)	(B+, B, B-)	(C+, C, C-)	(D)	(F)
1. Hand-in	1.1 Comprehensive understanding of the	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
assignments	processes and reinforcement learning.	demonstrates a	demonstrates an	some	limited	understanding of
	r	thorough	understanding of	understanding of	understanding	the Markov
		understanding	the Markov	the Markov	of the Markov	decision processes
		of the Markov	decision processes	decision processes	decision	and reinforcement
		decision	and reinforcement	and reinforcement	processes and	learning and is
		processes and	learning and has	learning and has	reinforcement	unable to solve
		reinforcement	ability to solve	some ability to	learning and	relevant problems
		learning and	complex problems	solve simple	has limited	
		has strong		problems	ability to solve	
		ability to solve			simple	
		complex			problems	
		problems				
	1.2 Ability to apply appropriate	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
	problems.	demonstrates a	demonstrates an	some	limited	understanding of
		thorough	understanding of	understanding of	understanding	reinforcement
		understanding	reinforcement	reinforcement	of	learning and is
		of	learning and has	learning and has	reinforcement	unable to solve
		reinforcement	ability to solve	some ability to	learning and	MDP control
		learning and	MDP control	solve MDP	has limited	problems
		has strong	problems	control problems	ability to solve	

		ability to solve			MDP control	
		MDP control			problems	
		problems			problems	
	1.3 Ability to relate reinforcement	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
	learning to financial applications.	demonstrates a	demonstrates an	some	limited	understanding of
		thorough	understanding of	understanding of	understanding	reinforcement
		understanding	reinforcement	reinforcement	of	learning and is
		of	learning and has	learning and has	reinforcement	unable to solve
		reinforcement	ability to solve	some ability to	learning and	financial problems
		learning and	financial problems	solve financial	has limited	
		has strong		problems	ability to solve	
		ability to solve			financial	
		financial			problems	
		problems				
2. Project	2.1 Ability to apply the reinforcement	Demonstrates	Adequately	Demonstrates	Demonstrates	Inappropriately or
	in financial applications.	а	demonstrates an	some	some	unable to apply
		comprehensive	understanding of	understanding of	understanding	reinforcement
		understanding	reinforcement	reinforcement	of	learning
		of	learning algorithms	learning	reinforcement	algorithms to
		reinforcement	and ability in	algorithms and	learning	solve problems by
		learning	applying program	little ability in	algorithms but	programming
		algorithms and	language to solve	applying program	cannot apply	
		strong ability	financial problems	language to solve	program	
		in applying		financial problems	language to	
		program			solve financial	
		language to			problems	
		solve financial				

	problems				
2.2 Ability to program and train a simple	Demonstrates	Adequately	Demonstrates	Demonstrates	Inappropriately or
reinforcement learning model.	а	demonstrates an	some	some	unable to apply
	comprehensive	understanding of	understanding of	understanding	reinforcement
	understanding	reinforcement	reinforcement	of	learning model to
	of	learning algorithms	learning	reinforcement	solve problems by
	reinforcement	and ability in	algorithms and	learning	programming
	learning	applying program	little ability in	algorithms but	
	algorithms and	language to solve	applying program	cannot apply	
	strong ability	financial problems	language to solve	program	
	in applying		financial problems	language to	
	program			solve financial	
	language to			problems	
	solve financial				
	problems				
2.3 Ability to discuss and validate the	Demonstrates	Adequately	Demonstrates	Demonstrates	Inappropriately or
results with data.	а	demonstrates an	some	limited	unable to evaluate
	comprehensive	understanding of	understanding of	understanding	and validate the
	understanding	reinforcement	reinforcement	of	results with data
	of	learning algorithms	learning	reinforcement	
	reinforcement	and ability to	algorithms and	learning	
	learning	evaluate and	some ability to	algorithms and	
	algorithms and	validate the results	evaluate and	limited ability	
	strong ability	with data	validate the results	to evaluate and	
	to evaluate and		with data	validate the	
	validate the			results with	

		results with			data	
		data				
3.	3.1 Understanding of the fundamental	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
Examinations	scenarios.	demonstrates a	demonstrates an	some	limited	understanding of
		thorough	understanding of	understanding of	understanding	the concepts,
		understanding	the concepts,	the concepts,	of the	principles, and
		of the	principles, and	principles, and	concepts,	applications of
		concepts,	applications of	applications of	principles, and	reinforcement
		principles, and	reinforcement	reinforcement	applications of	learning
		applications of	learning	learning	reinforcement	
		reinforcement			learning	
		learning				
	3.2 Ability to implement the dynamic	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
	algorithms covered in the course.	demonstrates a	demonstrates an	some	limited	understanding of
		thorough	understanding of	understanding of	understanding	dynamic
		understanding	dynamic	dynamic	of dynamic	programming and
		of dynamic	programming and	programming and	programming	reinforcement
		programming	reinforcement	reinforcement	and	learning
		and	learning algorithms	learning	reinforcement	algorithms and is
		reinforcement	and has ability to	algorithms and has	learning	unable to solve
		learning	solve complex	some ability to	algorithms and	relevant problems
		algorithms and	problems	solve simple	has limited	
		has strong		problems	ability to solve	
		ability to solve			simple	
		complex			problems	
		problems				

3.3 Comprehensive problem-solving	Consistently	Adequately	Demonstrates	Demonstrates	Demonstrates little
dynamic programming and reinforcement	demonstrates a	demonstrates an	some	limited	understanding of
learning model.	thorough	understanding of	understanding of	understanding	dynamic
	understanding	dynamic	dynamic	of dynamic	programming and
	of dynamic	programming and	programming and	programming	reinforcement
	programming	reinforcement	reinforcement	and	learning model
	and	learning model and	learning model	reinforcement	and can rarely or
	reinforcement	can usually apply	and can	learning model	never apply them
	learning model	them to solve	sometimes apply	and can seldom	to solve relevant
	and can	financial problems	them to solve	apply them to	problems
	always apply		simple financial	solve simple	
	them to solve		problems	financial	
	financial			problems	
	problems				

Assessment	Criterion	Excellent	Good	Marginal	Failure
Task		(A+, A, A-)	(B+, B)	(B-, C+, C)	(F)
1. Hand-in	1.1 Comprehensive understanding of the	Consistently	Adequately	Demonstrates some	Demonstrates little
assignments	processes and reinforcement learning.	demonstrates a	demonstrates an	understanding of	understanding of
		thorough	understanding of the	the Markov	the Markov
		understanding of	Markov decision	decision processes	decision processes
		the Markov	processes and	and reinforcement	and reinforcement
		decision processes	reinforcement	learning and has	learning and is
		and reinforcement	learning and has	limited ability to	unable to solve
		learning and has	ability to solve	solve simple	relevant problems
		strong ability to	complex problems	problems	
		solve complex			
		problems			
	1.2 Ability to apply appropriate algorithms to	Consistently	Adequately	Demonstrates some	Demonstrates little
	solve MDP control problems.	demonstrates a	demonstrates an	understanding of	understanding of
		thorough	understanding of	reinforcement	reinforcement
		understanding of	reinforcement	learning and has	learning and is
		reinforcement	learning and has	limited ability to	unable to solve
		learning and has	ability to solve MDP	solve MDP control	MDP control
		strong ability to	control problems	problems	problems
		solve MDP control			
		problems			
	1.3 Ability to relate reinforcement learning to	Consistently	Adequately	Demonstrates some	Demonstrates little
	financial applications.	demonstrates a	demonstrates an	understanding of	understanding of
		thorough	understanding of	reinforcement	reinforcement
		understanding of	reinforcement	learning and has	learning and is

# Applicable to students admitted from Semester A 2022/23 to Summer Term 2024

		reinforcement	learning and has	limited ability to	unable to solve
		learning and has	ability to solve	solve financial	financial problems
		strong ability to	financial problems	problems	
		solve financial			
		problems			
2. Project	2.1 Ability to apply the reinforcement learning	Demonstrates a	Adequately	Demonstrates some	Inappropriately or
	algorithms covered in the course in financial	comprehensive	demonstrates an	understanding of	unable to apply
	applications.	understanding of	understanding of	reinforcement	reinforcement
		reinforcement	reinforcement	learning algorithms	learning algorithms
		learning algorithms	learning algorithms	and little ability in	to solve problems
		and strong ability in	and ability in	applying program	by programming
		applying program	applying program	language to solve	
		language to solve	language to solve	financial problems	
		financial problems	financial problems		
	2.2 Ability to program and train a simple	Demonstrates a	Adequately	Demonstrates some	Inappropriately or
	reinforcement learning model.	comprehensive	demonstrates an	understanding of	unable to apply
		understanding of	understanding of	reinforcement	reinforcement
		reinforcement	reinforcement	learning algorithms	learning model to
		learning algorithms	learning algorithms	and little ability in	solve problems by
		and strong ability in	and ability in	applying program	programming
		applying program	applying program	language to solve	
		language to solve	language to solve	financial problems	
		financial problems	financial problems		
	2.3 Ability to discuss and validate the results	Demonstrates a	Adequately	Demonstrates some	Inappropriately or
	with data.	comprehensive	demonstrates an	understanding of	unable to evaluate
		understanding of	understanding of	reinforcement	and validate the
		reinforcement	reinforcement	learning algorithms	results with data

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		learning algorithms	learning algorithms	and limited ability	
		and strong ability to	and ability to	to evaluate and	
		evaluate and	evaluate and validate	validate the results	
		validate the results	the results with data	with data	
		with data			
3. Examinations	3.1 Understanding of the fundamental	Consistently	Adequately	Demonstrates some	Demonstrates little
	concepts, principles, and their application scenarios.	demonstrates a	demonstrates an	understanding of	understanding of
		thorough	understanding of the	the concepts,	the concepts,
		understanding of	concepts, principles,	principles, and	principles, and
		the concepts,	and applications of	applications of	applications of
		principles, and	reinforcement	reinforcement	reinforcement
		applications of	learning	learning	learning
		reinforcement			
		learning			
	3.2 Ability to implement the dynamic	Consistently	Adequately	Demonstrates some	Demonstrates little
	algorithms covered in the course.	demonstrates a	demonstrates an	understanding of	understanding of
		thorough	understanding of	dynamic	dynamic
		understanding of	dynamic	programming and	programming and
		dynamic	programming and	reinforcement	reinforcement
		programming and	reinforcement	learning algorithms	learning algorithms
		reinforcement	learning algorithms	and has limited	and is unable to
		learning algorithms	and has ability to	ability to solve	solve relevant
		and has strong	solve complex	simple problems	problems
		ability to solve	problems		
		complex problems			
	3.3 Comprehensive problem-solving skills in	Consistently	Adequately	Demonstrates some	Demonstrates little
	programming and reinforcement learning	demonstrates a	demonstrates an	understanding of	understanding of

model.	thorough	understanding of	dynamic	dynamic
	understanding of	dynamic	programming and	programming and
	dynamic	programming and	reinforcement	reinforcement
	programming and	reinforcement	learning model and	learning model and
	reinforcement	learning model and	can sometimes	can rarely or never
	learning model and	can usually apply	apply them to solve	apply them to solve
	can always apply	them to solve	simple financial	relevant problems
	them to solve	financial problems	problems	
	financial problems			

Part III Other Information (more details can be provided separately in the teaching plan)

### 1. Keyword Syllabus

(An indication of the key topics of the course.)

Markov Decision Processes. Bellman equation. Dynamic Programming. Q learning and Deep Q learning, Policy gradient methods. Dynamic Asset-Allocation. Optimal Exercise of American Options

### 2. Reading List

#### 2.1 Compulsory Readings

(Compulsory readings can include books, book chapters, or journal/magazine articles. There are also collections of e-books, e-journals available from the CityU Library.)

1.	Course materials provided
2.	
3.	

#### 2.2 Additional Readings

(Additional references for students to learn to expand their knowledge about the subject.)

1.	Reinforcement Learning : An Introduction, Sutton & Barto 1 <sup>st</sup> Edition
2.	Foundations of Reinforcement Learning with Applications in Finance, Ashwin Rao & Tikhon
	Jelvis 1 <sup>st</sup> Edition
3.	