

# Computer Science

This section presents the requirements for programs in:

- **M.C.S. Computer Science**
- **M.C.S. Computer Science with Specialization in Bioinformatics**
- **M.C.S. Computer Science with Specialization in Data Science**
- **Ph.D. Computer Science**

## Program Requirements

### M.C.S. Computer Science (5.0 credits)

#### Requirements - Thesis option (5.0 credits)

<b>1. 2.5 credits in</b> course work. Course work must include a minimum of 1.5 credits of OCICS courses in three different research areas (see OCICS course listing by research areas).	2.5
<b>2. 2.5 credits in:</b>	2.5
COMP 5905 [2.5] M.C.S. Thesis (Each candidate submitting a thesis will be required to undertake an oral defence of the thesis.)	
<b>Total Credits</b>	<b>5.0</b>

#### Requirements - Non-thesis option (5.0 credits)

<b>1. 4.0 credits in</b> course work. Course work must include a minimum of 1.5 credits of OCICS courses in three different research areas (see OCICS course listing by research areas).	4.0
<b>2. 1.0 credit in</b> Graduate project (Each candidate submitting a Project will be required to present a departmental seminar on their Project)	1.0
COMP 5903 [1.0] Intensive Graduate Project (M.C.S.)	
<b>Total Credits</b>	<b>5.0</b>

### M.C.S. Computer Science with Specialization in Bioinformatics (5.5 credits)

#### Requirements - Thesis Option (5.5 credits)

<b>1. 1.0 credit in:</b>	1.0
BIOL 5515 [0.5] Bioinformatics	
BIOL 5517 [0.5] Bioinformatics Seminar	
<b>2. 2.0 credits in</b> additional course work. Course work must include a minimum of 1.5 credits of OCICS courses in three different research areas (see OCICS course listing by research areas).	2.0
<b>3. 2.5 credits in:</b>	2.5
COMP 5905 [2.5] M.C.S. Thesis (Each candidate submitting a thesis will be required to undertake an oral defence of the thesis.)	
<b>Total Credits</b>	<b>5.5</b>

### M.C.S. Computer Science with Specialization in Data Science (5.0 credits)

#### Requirements - Thesis Option (5.0 credits)

<b>1. 0.5 credit in:</b>	0.5
DATA 5000 [0.5] Data Science Seminar	
<b>2. 1.0 credit from:</b>	1.0
COMP 5100 [0.5] Topics in Artificial Intelligence	

COMP 5101 [0.5]	Distributed Databases and Transaction Processing Systems	
COMP 5107 [0.5]	Statistical and Syntactic Pattern Recognition	
COMP 5108 [0.5]	Algorithms in Bioinformatics	
COMP 5111 [0.5]	Data Management for Business Intelligence	
COMP 5112 [0.5]	Algorithms for Data Science	
COMP 5204 [0.5]	Computational Aspects of Geographic Information Systems	
COMP 5209 [0.5]	Visual Analytics	
COMP 5305 [0.5]	Advanced Database Systems	
COMP 5306 [0.5]	Data Integration	
COMP 5307 [0.5]	Knowledge Representation	
COMP 5308 [0.5]	Topics in Medical Computing	
COMP 5401 [0.5]	Electronic Commerce Technologies	
COMP 5703 [0.5]	Algorithm Analysis and Design	
COMP 5704 [0.5]	Parallel Algorithms and Applications in Data Science	
<b>3. 1.0 credit in</b> course work		1.0
<b>4. 2.5 credits in:</b>		2.5
COMP 5905 [2.5]	M.C.S. Thesis	
<b>Total Credits</b>		<b>5.0</b>

#### Notes:

1. Course work must include a minimum of 1.5 credits of OCICS courses in three different research areas (see OCICS course listing by research areas).
2. M.C.S. Thesis must be in an area of Data Science and requires approval from the Institute of Data Science. Each candidate submitting a thesis will be required to undertake an oral defence of the thesis.

### Ph.D. Computer Science (10.0 credits)

#### Requirements:

<b>1. 1.5 credits in</b> OCICS courses. Course work must include a minimum of 1.5 credits of OCICS courses in three different research areas (see OCICS course listing by research areas).	1.5
The admission committee and the student's advisory committee may impose additional program requirements according to the student's background and research topic.	
<b>2. Minimally, the student must make one presentation in the departmental seminar.</b>	
<b>3. 0.0 credit in:</b>	0.0
COMP 6907 [0.0] Doctoral Comprehensive (involving breadth and depth components, must be taken within the first 4 terms)	
<b>4. 0.0 credit in:</b>	0.0
COMP 6908 [0.0] Doctoral Proposal (defended at an oral examination)	
<b>5. 8.5 credits in:</b>	8.5
COMP 6909 [8.5] Ph.D. Thesis (defended at an oral examination)	
<b>Total Credits</b>	<b>10.0</b>

#### Guidelines for Completion of Doctoral Degree

The following completion times are estimates based on full-time study.

- During the first term, the student and his or her faculty adviser should select graduate courses related to their area(s) of research and interests. Approval from the Graduate Supervisor of the Institute is only required for courses not listed as valid OCICS courses.
- Subject to the approval of the Graduate Supervisor, Ph.D. students may take courses in other relevant disciplines. At least half of the course credits of a Ph.D. student must be valid OCICS courses.
- An advisory committee comprised of three to five faculty members must be established before the student registers in the comprehensive examination. The committee is responsible for the comprehensive examination, the thesis proposal, and for guiding the student's research. The advisory committee must include at least one representative from EECS at the University of Ottawa. The advisory committee must be approved by the director or associate director of the Institute.
- All course requirements must be completed within the first six (6) terms.
- Within the first eight (8) terms, the student must submit a written thesis proposal and defend it in an oral examination (see COMP 6908).
- The expected completion time for the Ph.D. program is approximately twelve terms depending on the type of thesis and the area of research.
- Before the completion of the program, the student is expected to present at least two seminars in the Ottawa-Carleton Institute for Computer Science seminar series.

### Graduate Courses

The following graduate courses are offered by the joint Ottawa-Carleton Institute for Computer Science (OCICS). The institute comprises the School of Electrical Engineering and Computer Science (EECS) at the University of Ottawa and the School of Computer Science (SCS) at Carleton University. Typically, the courses with COMP (CSI) designation are offered by SCS and the courses with CSI (COMP) designation are offer by EECS. Note that not all of the following courses are offered in a given year. For an up-to-date statement of course offerings or to determine the term of offering, consult [central.carleton.ca](http://central.carleton.ca). The courses are grouped according to research areas as follows:

#### Software Engineering

COMP 5001 (CSI 5113)	Foundations of Programming Languages
COMP 5104 (CSI 5314)	Object-Oriented Software Development
COMP 5110 (CSI 5140)	Computer Security and Usability
COMP 5209 (CSI 5140)	Visual Analytics
COMP 6104 (CSI 7314)	Advanced Topics in Object-Oriented Systems
COMP 6603 (CSI 7161,CSI 7561)	Advanced Topics in Programming Systems and Languages

CSI 5111 (COMP 5501)	Software Quality Engineering
CSI 5112 (COMP 5207)	Software Engineering
CSI 5115 (COMP 5503)	Database Analysis and Design
CSI 5118 (COMP 5302)	Automated Verification and Validation of Software
CSI 5122 (COMP 5301)	Software Usability
CSI 5134 (COMP 5004)	Fault Tolerance
SYSC 5101 (ELG 6111)	Design of High Performance Software
SYSC 5103 (ELG 6113)	Software Agents
SYSC 5105 (ELG 6115)	Software Quality Engineering and Management
SYSC 5709 (ELG 6179)	Advanced Topics in Software Engineering

#### Theory of Computing

COMP 5003 (CSI 5308)	Principles of Distributed Computing
COMP 5005 (CSI 5390)	Learning Systems for Random Environments
COMP 5008 (CSI 5164)	Computational Geometry
COMP 5107 (CSI 5185)	Statistical and Syntactic Pattern Recognition
COMP 5111 (CSI 5153)	Data Management for Business Intelligence
COMP 5112 (CSI 5154)	Algorithms for Data Science
COMP 5203 (CSI 5173)	Data Networks
COMP 5306 (CSI 5100)	Data Integration
COMP 5307 (CSI 5101)	Knowledge Representation
COMP 5308 (CSI 5102)	Topics in Medical Computing
COMP 5310 (CSI 5140)	Evolving Information Networks
COMP 5408 (CSI 5121)	Advanced Data Structures
COMP 5409 (CSI 5127)	Applied Computational Geometry
COMP 5703 (CSI 5163)	Algorithm Analysis and Design
COMP 6601 (CSI 7160)	Advanced Topics in the Theory of Computing
COMP 6602 (CSI 7170,CSI 7970)	Advanced Topics in Distributed Computing
CSI 5108 (COMP 5700)	Software Specification and Verification
CSI 5110 (COMP 5707)	Principles of Formal Software Development
CSI 5126 (COMP 5108)	Algorithms in Bioinformatics
CSI 5148 (COMP 5103)	Wireless Ad Hoc Networking

CSI 5149 (COMP 5007)	Graphical Models	CSI 5151 (COMP 5205)	Virtual Environments
CSI 5161 (COMP 5606)	Topics in System Simulation and Optimization	CSI 5168 (COMP 5309)	Digital Watermarking
CSI 5165 (COMP 5709)	Combinatorial Algorithms	CSI 5380 (COMP 5405)	Systems and Architectures for Electronic Commerce
CSI 5166 (COMP 5805)	Applications of Combinatorial Optimization	CSI 5386 (COMP 5505)	Natural Language Processing
CSI 5169 (COMP 5304)	Wireless Networks and Mobile Computing	CSI 5387 (COMP 5706)	Data Mining and Concept Learning
CSI 5174 (COMP 5604)	Validation Methods for Distributed Systems	CSI 5388 (COMP 5801)	Topics in Machine Learning
CSI 5510 (COMP 5707)	Principes de developpement formel de logiciels	CSI 5526 (COMP 5108)	Algorithmes en bioinformatique
CSI 5526 (COMP 5108)	Algorithmes en bioinformatique	CSI 5580 (COMP 5100)	Sujet en intelligence artificielle
CSI 5565 (COMP 5709)	Algorithmes combinatoires	CSI 5780 (COMP 5405)	Systemes et architectures des logiciels pour le commerce electronique
<b>Computer Applications</b>		CSI 5787 (COMP 5706)	Fouille des donnees et apprentissage des concepts
COMP 5002 (CSI 5128)	Swarm Intelligence	COMP 5220 (CSI 5175)	Mobile Commerce Technologies
COMP 5100 (CSI 5180,CSI 5580)	Topics in Artificial Intelligence	<b>Computer Systems</b>	
COMP 5110 (CSI 5140)	Computer Security and Usability	COMP 5003 (CSI 5308)	Principles of Distributed Computing
COMP 5111 (CSI 5153)	Data Management for Business Intelligence	COMP 5101 (CSI 5311)	Distributed Databases and Transaction Processing Systems
COMP 5112 (CSI 5154)	Algorithms for Data Science	COMP 5102 (CSI 5312)	Distributed Operating Systems
COMP 5204 (CSI 5124)	Computational Aspects of Geographic Information Systems	COMP 5107 (CSI 5185)	Statistical and Syntactic Pattern Recognition
COMP 5206 (CSI 5183)	Evolutionary Computation and Artificial Life	COMP 5203 (CSI 5173)	Data Networks
COMP 5209 (CSI 5140)	Visual Analytics	COMP 5305 (CSI 5129)	Advanced Database Systems
COMP 5210 (CSI 5140)	Human-Computer Interaction Models, Theories, and Frameworks	COMP 5401 (CSI 5389, CSI 5789)	Electronic Commerce Technologies
COMP 5305 (CSI 5129)	Advanced Database Systems	COMP 5402 (CSI 5142)	Protocols for Mobile and Wireless Networks
COMP 5306 (CSI 5100)	Data Integration	COMP 5406 (CSI 5105)	Network Security and Cryptography
COMP 5307 (CSI 5101)	Knowledge Representation	COMP 5407 (CSI 5116)	Authentication and Software Security
COMP 5308 (CSI 5102)	Topics in Medical Computing	COMP 5704 (CSI 5131)	Parallel Algorithms and Applications in Data Science
COMP 5310 (CSI 5140)	Evolving Information Networks	COMP 6100 (CSI 7131)	Advanced Parallel and Systolic Algorithms
COMP 5401 (CSI 5389, CSI 5789)	Electronic Commerce Technologies	COMP 6602 (CSI 7170,CSI 6970)	Advanced Topics in Distributed Computing
COMP 5406 (CSI 5105)	Network Security and Cryptography	COMP 6605 (CSI 7163)	Advanced Topics in Computer Systems
COMP 5407 (CSI 5116)	Authentication and Software Security	CSI 5134 (COMP 5004)	Fault Tolerance
COMP 6604 (CSI 7162)	Advanced Topics in Computer Applications	CSI 5147 (COMP 5201)	Computer Animation
CSI 5126 (COMP 5108)	Algorithms in Bioinformatics	CSI 5148 (COMP 5103)	Wireless Ad Hoc Networking
CSI 5146 (COMP 5202)	Computer Graphics	CSI 5161 (COMP 5606)	Principles of Distributed Simulation
CSI 5147 (COMP 5201)	Computer Animation		

CSI 5168 (COMP 5309)	Digital Watermarking
CSI 5169 (COMP 5304)	Wireless Networks and Mobile Computing
CSI 5174 (COMP 5604)	Validation Methods for Distributed Systems
CSI 5380 (COMP 5405)	Systems and Architectures for Electronic Commerce
CSI 5780 (COMP 5405)	Systemes et architectures des logiciels pour le commerce electronique
COMP 5220 (CSI 5175)	Mobile Commerce Technologies

#### Others

COMP 5900 (CSI 5140)	Selected Topics in Computer Science
COMP 5901 (CSI 5901)	Directed Studies (M.C.S.)
COMP 5903 (CSI 6900)	Intensive Graduate Project (M.C.S.)
COMP 5905 (CSI 7999)	M.C.S. Thesis
COMP 5913	Master's Co-operative Workterm
COMP 6901 (CSI 7901)	Directed Studies (Ph.D.)
COMP 6902 (CSI 7900)	Graduate Project (Ph.D.)
COMP 6907 (CSI 9998)	Doctoral Comprehensive
COMP 6908 (CSI 9997)	Doctoral Proposal
COMP 6909 (CSI 9999)	Ph.D. Thesis

### Admission

#### M.C.S., M.C.S. Bioinformatics and M.C.S. Data Science

See the General Regulations section of this Calendar for detailed admission requirements. Applicants should have an honours bachelor's degree in computer science or the equivalent. By equivalent is meant an honours degree in a program that includes at least twelve computer science half-credits, two of which must be at the 4000-level, and eight half-credits in mathematics, one of which must be at the 3000- or 4000-level.

Applicants who have a general (3-year) bachelor's degree, or who otherwise lack the required undergraduate preparation, may be admitted to a qualifying-year program. Refer to the General Regulations section of this Calendar for regulations governing the qualifying year.

#### Accelerated Pathway

The accelerated pathway in the M.C.S. Computer Science is a flexible and individualized plan of graduate study. Students in their final year of a Carleton B.C.S.(Hons.) degree with demonstrated academic excellence and aptitude for research may qualify for this option.

Students in their third-year of study in the B.C.S.(Hons.) degree should consult with both their Undergraduate Program Coordinator and the Director for Graduate

Studies to determine if the accelerated pathway is appropriate for them and to confirm their selection of courses for their final year of undergraduate studies.

#### Accelerated Pathway Requirements

1. At least one OCICS courses at the 5000-level with a grade of B+ or higher.
2. Minimum overall and Major CGPA of A-.

Students may receive advanced standing of up to 1.0 credit which can reduce their time to completion.

#### Admission

See the General Regulations section of this Calendar for detailed admission requirements. Admission to the Ph.D. in Computer Science requires a Masters in Computer Science with thesis, or equivalent including demonstrated significant research ability.

In exceptional cases, students who are currently in the M.C.S. program and who have completed all course requirements with a grade of no less than A in each course may be permitted to transfer into the Ph.D. program.

#### Co-operative Option

A co-operative option is also available to full-time students in the Masters of Computer Science. Co-operative education is based on the principle that academic studies combined with work experience are desirable for effective professional preparation.

In addition to all other requirements for the degree, students admitted to the co-operative option must satisfactorily complete two work terms placements with a suitable employer in order to graduate with a co-op designation on their transcripts and diplomas. It is desirable that the work placements be related to the student's research. Placements are subject to the approval of the Supervisor of Graduate Studies and of the student's research supervisor. These work terms are four months in duration and students will conduct job searches through the university's co-op office. During a work term, students will register in COMP 5913. While on a work term, students in this option are limited to taking one additional 0.5-credit course, or registering in their thesis.

Students in the co-op option normally apply for admission to the co-operative option during their first academic term. This option requires an initial study period of two academic terms, typically followed by two work terms and a final academic period to complete the remaining requirements of the degree. The student must submit a work term report upon the completion of each work placement, and receive a grade of Satisfactory in order to meet the requirements for the successful completion of that work term's requirement.

#### Regulations

See the General Regulations section of this Calendar.

## **Computer Science (COMP) Courses**

### **COMP 5001 [0.5 credit] (CSI 5113)**

#### **Foundations of Programming Languages**

Advanced study of programming paradigms from a practical perspective. Paradigms may include functional, imperative, concurrent, distributed, generative, aspect- and object-oriented, and logic programming. Emphasis on underlying principles. Topics may include: types, modules, inheritance, semantics, continuations, abstraction and reflection.

### **COMP 5002 [0.5 credit] (CSI 5128)**

#### **Swarm Intelligence**

Collective computation, collective action, and principles of self-organization in social agent systems. Algorithms for combinatorial optimization problems, division of labour, task allocation, task switching, and task sequencing with applications in security, routing, wireless and ad hoc networks and distributed manufacturing.

### **COMP 5003 [0.5 credit] (CSI 5308)**

#### **Principles of Distributed Computing**

Formal models; semantics of distributed computations; theoretical issues in design of distributed algorithms; computational complexity; reducibility and equivalence of distributed problems. Related topics: systolic systems and computations, oligarchical systems and control mechanisms.

### **COMP 5004 [0.5 credit] (CSI 5134)**

#### **Fault Tolerance**

### **COMP 5005 [0.5 credit] (CSI 5390)**

#### **Learning Systems for Random Environments**

Computerized adaptive learning for random environments and its applications. Topics include a mathematical review, learning automata which are deterministic/stochastic, with fixed/variable structures, of continuous/discretized design, with ergodic/absorbing properties and of estimator families.

Prerequisite(s): SYSC 5503 or equivalent.

### **COMP 5007 [0.5 credit] (CSI 5149)**

#### **Graphic Models**

### **COMP 5008 [0.5 credit] (CSI 5164)**

#### **Computational Geometry**

Study of design and analysis of algorithms to solve geometric problems; emphasis on applications such as robotics, graphics, and pattern recognition. Topics include: visibility problems, hidden line and surface removal, path planning amidst obstacles, convex hulls, polygon triangulation, point location.

### **COMP 5100 [0.5 credit] (CSI 5180, CSI 5580)**

#### **Topics in Artificial Intelligence**

Areas in knowledge-based systems including recent approaches to machine learning and data mining, inference methods, knowledge-based and fuzzy systems, heuristic search, and natural language processing.

Precludes additional credit for COMP 4106.

### **COMP 5101 [0.5 credit] (CSI 5311)**

#### **Distributed Databases and Transaction Processing Systems**

Principles in the design and implementation of distributed databases and distributed transaction processing systems. Topics include: distributed computing concepts, computing networks, distributed and multi-database system architectures and models, atomicity, synchronization and distributed concurrency control algorithms, data replication, recovery techniques, reliability in distributed databases.

Precludes additional credit for COMP 4101.

### **COMP 5102 [0.5 credit] (CSI 5312)**

#### **Distributed Operating Systems**

Design issues of advanced multiprocessor distributed operating systems: multiprocessor system architectures; process and object models; synchronization and message passing primitives; memory architectures and management; distributed file systems; protection and security; distributed concurrency control; deadlock; recovery; remote tasking; dynamic reconfiguration; performance measurement, modeling, and system tuning.

### **COMP 5103 [0.5 credit] (CSI 5148)**

#### **Wireless Ad Hoc Networking**

### **COMP 5104 [0.5 credit] (CSI 5314)**

#### **Object-Oriented Software Development**

Issues in modeling and verifying quality and variability in object-oriented systems. Testable models in model-driven and test-driven approaches. System family engineering. Functional conformance: scenario modeling and verification, design by contract. Conformance to non functional requirements: goals, forces and tradeoffs, metrics.

### **COMP 5107 [0.5 credit] (CSI 5185)**

#### **Statistical and Syntactic Pattern Recognition**

Topics include a mathematical review, Bayes decision theory, maximum likelihood and Bayesian learning for parametric pattern recognition, non-parametric methods including nearest neighbor and linear discriminants. Syntactic recognition of strings, substrings, subsequences and tree structures. Applications include speech, shape and character recognition.

### **COMP 5108 [0.5 credit] (CSI 5126)**

#### **Algorithms in Bioinformatics**

### **COMP 5110 [0.5 credit] (CSI 5140)**

#### **Computer Security and Usability**

This course focuses on designing and evaluating security and privacy software with particular attention to human factors and how interaction design impacts security. Topics include current approaches to usable security, methodologies for empirical analysis, and design principles for usable security and privacy.

**COMP 5111 [0.5 credit] (CSI 5153)****Data Management for Business Intelligence**

Application of computational techniques to support business such as decision making, business understanding, data analysis, business process automation, learning from data, producing and using business models, data integration, data quality assessment and cleaning, use of contextual data, etc. Also offered at the undergraduate level, with different requirements, as COMP 4111, for which additional credit is precluded.

**COMP 5112 [0.5 credit] (CSI 5154)****Algorithms for Data Science**

Algorithmic techniques to handle (massive/big) data arising from, for example, social media, mobile devices, sensors financial transactions. Algorithmic techniques may include locality-sensitive hashing, dimensionality reduction, streaming, clustering, VC-dimensions, external memory, core sets, link analysis and recommendation systems.

**COMP 5201 [0.5 credit] (CSI 5147)****Computer Animation****COMP 5202 [0.5 credit] (CSI 5146)****Computer Graphics****COMP 5203 [0.5 credit] (CSI 5173)****Data Networks**

Mathematical and practical aspects of design and analysis of communication networks. Topics include: basic concepts, layering, delay models, multi-access communication, queuing theory, routing, fault-tolerance, and advanced topics on high-speed networks, ATM, mobile wireless networks, and optical networks.

**COMP 5204 [0.5 credit] (CSI 5124)****Computational Aspects of Geographic Information Systems**

Through recent advances in navigation systems, mobile devices, and new software such as Mapquest and Google Earth, GIS is becoming increasingly important and exciting from a CS perspective. This course lays the algorithmic foundations to understand, use and further this technology. Also offered at the undergraduate level, with different requirements, as COMP 4202, for which additional credit is precluded.

**COMP 5205 [0.5 credit] (CSI 5151)****Virtual Environments****COMP 5206 [0.5 credit] (CSI 5183)****Evolutionary Computation and Artificial Life**

Study of algorithms based upon biological theories of evolution, applications to machine learning and optimization problems. Possible topics: Genetic Algorithms, Classifier Systems, and Genetic Programming. Recent work in the fields of Artificial Life (swarm intelligence, distributed agents, behavior-based AI) and of connectionism.

Precludes additional credit for COMP 4107.

**COMP 5207 [0.5 credit] (CSI 5112)****Software Engineering****COMP 5209 [0.5 credit] (CSI 5140)****Visual Analytics**

Principles, techniques, technology and applications of information visualization for data analysis. Topics include human visual perception, cognitive processes, static and dynamic models of image semantics, interaction paradigms, big data visual analysis case studies.

**COMP 5210 [0.5 credit] (CSI 5140)****Human-Computer Interaction Models, Theories, and Frameworks**

Emphasis on the application of theory to user interface design. Review of main theories of human behaviour relevant to HCI, including especially cognitive dimensions of notations framework, mental models, distributed cognition, and activity theory, and their application to design and development of interactive systems. Lecture

**COMP 5220 [0.5 credit] (CSI 5175)****Mobile Commerce Technologies**

Wireless networks support for m-commerce; m-commerce architectures and applications; mobile payment support systems; business models; mobile devices and their operating systems; mobile content presentation; security issues and solutions; relevant cross layer standards and protocols; case studies.

**COMP 5301 [0.5 credit]****Software Usability****COMP 5302 [0.5 credit] (CSI 5118)****Automated Verification & Validation of Software****COMP 5304 [0.5 credit] (CSI 5169)****Wireless Networks and Mobile Computing****COMP 5305 [0.5 credit] (CSI 5129)****Advanced Database Systems**

In-depth study on developments in database systems shaping the future of information systems, including complex object, object-oriented, object-relational, and semi-structured databases. Data structures, query languages, implementation and applications.

**COMP 5306 [0.5 credit] (CSI 5100)****Data Integration**

Materialized and virtual approaches to integration of heterogeneous and independent data sources. Emphasis on data models, architectures, logic-based techniques for query processing, metadata and consistency management, the role of XML and ontologies in data integration; connections to schema mapping, data exchange, and P2P systems.

**COMP 5307 [0.5 credit] (CSI 5101)****Knowledge Representation**

KR is concerned with representing knowledge and using it in computers. Emphasis on logic-based languages for KR, and automated reasoning techniques and systems; important applications of this traditional area of AI to ontologies and semantic web.

**COMP 5308 [0.5 credit] (CSI 5102)****Topics in Medical Computing**

Introductory course on data structures, algorithms, techniques, and software development related to medical computing (in particular spatial modeling). Topics may include: computational geometry algorithms for cancer treatment, medical imaging, spatial data compression algorithms, dynamic programming for DNA analysis. Precludes additional credit for COMP 5900 section 'Y' offered 2001-2002 to 2005-2006 inclusive.

**COMP 5309 [5.0 credits] (CSI 5168)****Digital Watermarking****COMP 5310 [0.5 credit] (CSI 5140)****Evolving Information Networks**

Convergence of social and technological networks with WWW. Interplay between information content, entities creating it and technologies supporting it. Structure and analysis of such networks, models abstracting their properties, link analysis, search, mechanism design, power laws, cascading, clustering and connections with work in social sciences.

**COMP 5401 [0.5 credit] (CSI 5389, CSI 5789)****Electronic Commerce Technologies**

Introduction to business models and technologies. Search engines. Cryptography. Web services and agents. Secure electronic transactions. Value added e-commerce technologies. Advanced research questions.

**COMP 5402 [0.5 credit] (CSI 5142)****Protocols for Mobile and Wireless Networks**

Link and network layer protocols of wireless networks; applications of wireless networks may be discussed. Topics may include: protocol implementation, mobile IP, resource discovery, wireless LANs/PANs, and Spreadpectrum. Precludes additional credit for SYSC 5306.

**COMP 5405 [0.5 credit] (CSI 5380)****Systems and Architectures for Electronic Commerce****COMP 5406 [0.5 credit] (CSI 5105)****Network Security and Cryptography**

Advanced methodologies selected from symmetric and public key cryptography, network security protocols and infrastructure, identification, secret-sharing, anonymity, intrusion detection, firewalls, defending network attacks and performance in communication networks. Prerequisite(s): COMP 3203 and COMP 4109, or equivalent, or permission of the instructor.

**COMP 5407 [0.5 credit] (CSI 5116)****Authentication and Software Security**

Specialized topics in security including advanced authentication techniques, user interface aspects, electronic and digital signatures, security infrastructures and protocols, software vulnerabilities affecting security, untrusted software and hosts, protecting software and digital content.

**COMP 5408 [0.5 credit] (CSI 5121)****Advanced Data Structures**

Simple methods of data structure design and analysis that lead to efficient data structures for several problems. Topics include randomized binary search trees, persistence, fractional cascading, self-adjusting data structures, van Emde Boas trees, tries, randomized heaps, and lowest common ancestor queries.

**COMP 5409 [0.5 credit] (CSI 5127)****Applied Computational Geometry**

Computer-based representation and manipulation of geometric objects. Design and analysis of efficient algorithms for solving geometric problems in applied fields such as Computer-Aided Design and Manufacturing, Cartography, Materials Science, and Geometric Network Design.

**COMP 5501 [0.5 credit] (CSI 5111)****Software Quality Engineering****COMP 5503 [0.5 credit] (CSI 5115)****Database Analysis & Design****COMP 5505 [0.5 credit] (CSI 5386)****Natural Language Processing****COMP 5604 [0.5 credit] (CSI 5174)****Validation Methods for Distributed Systems****COMP 5606 [0.5 credit] (CSI 5161)****Topics in Simulation and Optimization****COMP 5703 [0.5 credit] (CSI 5163)****Algorithm Analysis and Design**

Topics of current interest in the analysis and design of sequential and parallel algorithms for non-numerical, algebraic and graph computations. Lower bounds on efficiency of algorithms. Complexity classes.

**COMP 5704 [0.5 credit] (CSI 5131)**  
**Parallel Algorithms and Applications in Data Science**  
Multiprocessor architectures from an application programmer's perspective: programming models, processor clusters, multi-core processors, GPU's, algorithmic paradigms, efficient parallel problem solving, scalability and portability. Projects on high performance computing in Data Science, incl. data analytics, bioinformatics, simulations. Programming experience on parallel processing equipment.

**COMP 5706 [0.5 credit] (CSI 5387)**  
**Data Mining & Concept Learning**

**COMP 5707 [0.5 credit] (CSI 5707)**  
**Principles of Formal Software Development**

**COMP 5709 [0.5 credit] (CSI 5565)**  
**Combinatorial Algorithms**

**COMP 5801 [0.5 credit] (CSI 5388)**  
**Topics in Machine Learning**

**COMP 5805 [0.5 credit] (CSI 5166)**  
**Applications of Combinatorial Optimization**

**COMP 5900 [0.5 credit] (CSI 5140)**  
**Selected Topics in Computer Science**  
Selected topics, not covered by other graduate courses. Details will be available from the School at the time of registration.

**COMP 5901 [0.5 credit] (CSI 5901)**  
**Directed Studies (M.C.S.)**  
A course of independent study under the supervision of a member of the School of Computer Science.

**COMP 5903 [1.0 credit] (CSI 6900)**  
**Intensive Graduate Project (M.C.S.)**  
A one- or two-session course. For M.C.S. non-thesis option students only. Not to be combined for credit with COMP 5902.

**COMP 5905 [2.5 credits] (CSI 7999)**  
**M.C.S. Thesis**

**COMP 5913 [0.0 credit]**  
**Master's Co-operative Workterm**

**COMP 6100 [0.5 credit] (CSI 7131)**  
**Advanced Parallel and Systolic Algorithms**  
Continuation of COMP 5704.

**COMP 6104 [0.5 credit] (CSI 7314)**  
**Advanced Topics in Object-Oriented Systems**  
Advanced object-oriented software engineering, in particular the issues of reuse and testing. Sample topics include: interaction modeling; class and cluster testing; traceability; design patterns and testing; the C++ standard template library. Students will carry out research.

**COMP 6601 [0.5 credit] (CSI 7160)**  
**Advanced Topics in the Theory of Computing**

**COMP 6602 [0.5 credit] (CSI 7170, CSI 6970)**  
**Advanced Topics in Distributed Computing**

**COMP 6603 [0.5 credit] (CSI 7161, CSI 7561)**  
**Advanced Topics in Programming Systems and Languages**

**COMP 6604 [0.5 credit] (CSI 7162)**  
**Advanced Topics in Computer Applications**

**COMP 6605 [0.5 credit] (CSI 7163)**  
**Advanced Topics in Computer Systems**

**COMP 6901 [0.5 credit] (CSI 7900)**  
**Directed Studies (Ph.D.)**

**COMP 6902 [0.5 credit] (CSI 7900)**  
**Graduate Project (Ph.D.)**

**COMP 6907 [0.0 credit] (CSI 9998)**  
**Doctoral Comprehensive**  
A committee must be assembled and approve at least 3 topics for written examination: typically, a major and two minor areas. An oral examination occurs if the written exam is passed. Both elements must take place within the first 4 terms following initial registration in the program. The comprehensive may be failed, passed conditionally (i.e., with extra course requirements) or passed unconditionally. If failed this course may be retaken at most one time.

**COMP 6908 [0.0 credit] (CSI 9997)**  
**Doctoral Proposal**  
Within 8 terms following initial registration in the program, a document generally defining the problem addressed, relating it to the literature, and outlining the hypotheses, goals, research methodology, initial results and validation approach must be submitted to an examination committee and successfully defended.

**COMP 6909 [8.5 credits] (CSI 9999)**  
**Ph.D. Thesis**

**Summer session:** some of the courses listed in this Calendar are offered during the summer. Hours and scheduling for summer session courses will differ significantly from those reported in the fall/winter Calendar. To determine the scheduling and hours for summer session classes, consult the class schedule at [central.carleton.ca](http://central.carleton.ca)

Not all courses listed are offered in a given year. For an up-to-date statement of course offerings for the current session and to determine the term of offering, consult the class schedule at [central.carleton.ca](http://central.carleton.ca)