UMBC

AN HONORS UNIVERSITY IN MARYLAND

IS 709/809: Computational Methods for IS Research Fall 2021

Course Logistics

Nirmalya Roy

Department of Information Systems

University of Maryland Baltimore County

Welcome to IS 709/809

- Timings: Thursday; 7:10pm to 9:40pm
- Location: On-campus: Performing Arts and Humanities 107
  Online (Blackboard Collaborate)
- Instructor: Nirmalya Roy
  Faculty in IS from 2013
  MS in CSE: UT-Arlington, 2004
  PhD in CSE: UT-Arlington, 2008
  Postdoc in ECE: UT-Austin, 2010
  Research Interests: Mobile, Pervasive and Ubiquitous Computing (MPSC)
- Office hours: Thursday, 9:00am – 10 am or by appointment
  Email: nroy@umbc.edu
  Office: Online

Welcome to IS 709/809

- Course website
  - https://mpsc.umbc.edu/courses/computational-methods-in-is-research-fall-2021
  - Course related information will be posted on the website
  - Please check the course website frequently

- Prerequisite:
  - IS 698 (Smart Home Health Analytics) or IS 733 (Data Mining)

- Make up classes
  - If needed

Welcome to IS 709/809

- Grading:
  - Participation + Reflection + Presentation: 15%
  - Homework: 20%
  - 1 Exam: 30%
  - Research Project: 35%

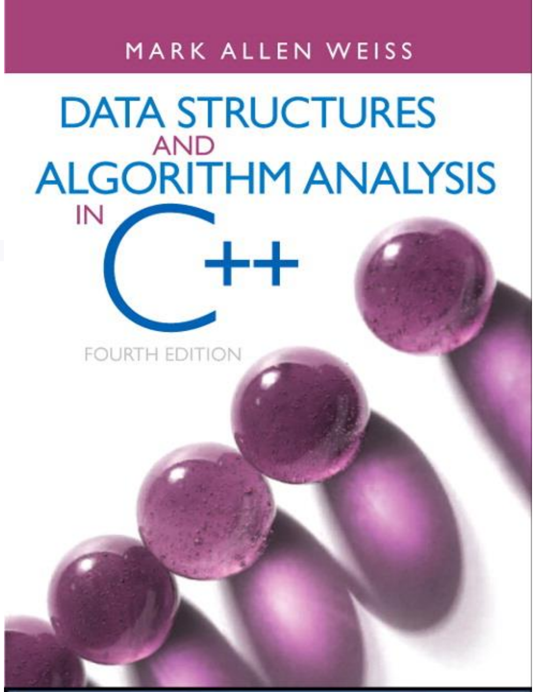
Course Expectations

- Attendance
  - You should attend class
  - Lecture notes will be made available, but they should not be considered a substitution for attending class
- Collaboration
  - Collaboration is encouraged in general but do not copy from each other

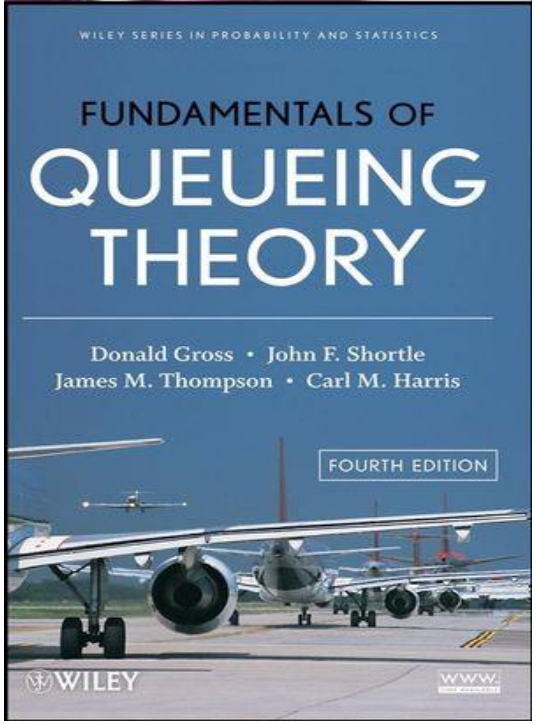
Course Information

- Course materials:
  - Textbooks (Optional):

    Data Structures and Algorithm Analysis in C++, 4th Edition by Mark Allen Weiss, 2013

    Fundamentals of Queueing Theory, 4th Ed., by Donald Gross & John F. Shortle & James M. Thompson & Carl M. Harris. John Wiley & Sons, Inc, 2008

Course Information

- Class notes/slides

- Supplementary reading materials
  - Research Papers

What is this course about?

- Graduate level course in computational methods
  - MS and PhD students

- Learn principles of algorithm analysis
- Learn fundamentals of computational complexity
- Learn performance metrics of system
- Information systems performance & evaluation as case study
- Basic techniques of systems performance modeling
- Learn how to find an interesting IS research problem
- Learn about Robotics, Cyber-Physical Systems, Smart Service Systems, Future of Work, Smart City and Smart & Connected Communities

Course Offerings

- At the end of the course
  - You understand variety of concepts ……………
  - Designing efficient algorithms
  - Mathematical modeling and analyzing a system
  - Statistical methods and their computational implementation
  - Computational system performance evaluation
  - Exploratory and objective data analysis methods
  - Building/Simulating real systems
  - Tackling a research problem
  - …

Course Expectations

- What will you do in this course?

Course Participation + **Research Reflection** + **Individual Paper Presentation**	15%
4 Homework	20%
1 Exam	30%
Research Project + Final Project Report	35%

Research Reflection

Research Reflection

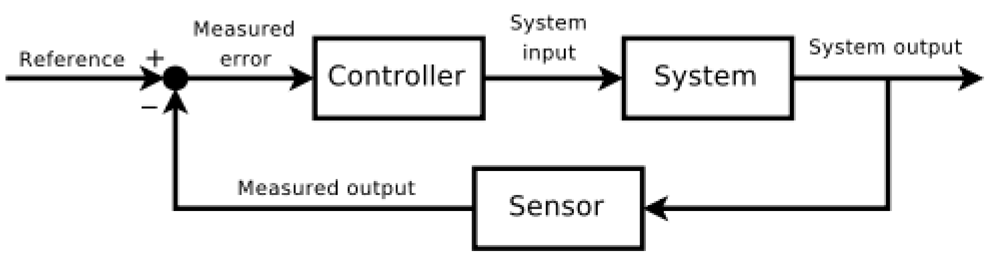
- Cyber-Physical Systems
  - engineered systems that are built from, and depend upon, the seamless integration of *computational algorithms* and physical components
  - enable capability, adaptability, scalability, resiliency, safety, security, and usability
    - exceed the simple embedded systems of today
  - transform the way people interact with engineered systems
    - Internet has transformed the way people interact with information
  - drive innovation and competition in multiple smart sectors
    - agriculture, energy, transportation, building design and automation, healthcare, and manufacturing
    - water, ecology, supply-chains, medical and assistive technology

CPS Computational Techniques

- control and/or optimization of CPS
- machine learning, data mining/analytics for CPS
- game theory applied to CPS
- model-based design and verification of CPS
- mobile and cloud computing for CPS
- signal processing for CPS
- human-in-the-loop shared or supervisory control of CPS
- ....

Example of CPS

- The Internet of Things (IoT)
  - integrates many CPS technologies that may well transform our lives
  - creates an ecosystem with tens of billions of devices
  - harnessing the power of the IoT requires
    - to identify foundational technologies that will foster an "Internet of Dependable and Controllable Things"
    - provide control algorithms that can transform IoT sensor data into action



Smart Service Systems

- Smart Service Systems
  - A **"smart" service system** is a system that amplifies or augments human capabilities to identify, learn, adapt, monitor and make decisions
  - The system utilizes data received, transmitted, or processed in a timely manner, thus improving its response to future situations
  - These capabilities are the result of the incorporation of technologies for sensing, actuation, coordination, communication, control, etc.

Future of Work at the Human-Technology Frontier: Advancing Cognitive and Physical Capabilities

- Future of Work
  - To respond to challenges and opportunities in the changing landscape of jobs and work by supporting convergent research to
    - Understand and advance the human-technology partnership
    - Promote new technologies to augment human performance
    - Illuminate the emerging socio-technological landscape and understand the risks and benefits of new technologies
    - Foster lifelong and pervasive learning with technology

Robotics

- Robotics
  - robotic systems exhibit significant levels of both computational capability and physical complexity
  - a robot is defined as intelligence embodied in an engineered construct, with the ability to process information, sense, and move within or substantially alter its working environment
    - enable a robot to solve problems or make contextually appropriate decisions
  - Promote integration of robots to the benefit of humans including human safety and human independence
    - The NRI-3.0 program is supported by multiple agencies of the federal government including the National Science Foundation (NSF), the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA), the Department of Transportation (DOT), the National Institutes of Health (NIH), and the National Institute for Occupational Safety and Health (NIOSH).

Robotics

- Robotics Applications
  - Configurable Multi-Agent Teams. Examples include the following areas:
    - High-level task planning, execution, and control systems for spatially distributed autonomous or semi-autonomous robots that operate in concert with co-workers, either human, robotic, or other devices/systems
    - Innovative use of intelligently coupled robot drones and unmanned ground vehicles (UGVs) to improve crop and animal management
    - Communication protocols and standards for inter-agent coordination (including natural language) and for unsupervised collaboration
    - Distributed intelligence, fault tolerance, and "failure with grace" that will allow high-level task completion despite failure of one or more agents (or teams) or temporary loss of human attention

Robotics

- Robotics Applications
  - Scalable Robotic Technologies. Examples include the following areas:
    - Automated and mechanized intelligent systems that focus on labor-intensive tasks in production and distribution of crops
    - Automated systems for planting, scouting, spraying, culturing, irrigating, and harvesting plant crops (including forests) to decrease costs, improve efficiency, or reduce inputs of water, fertilizer, or chemicals
    - Automated systems for inspection, sorting, processing, or handling of animal or plant products (including forest products) in post-harvest, processing, or meat Processing, or product distribution environments
    - Multi-modal and rapid sensing systems for detecting defects, ripeness, physical damage, microbial contamination, size, shape, and other quality attributes of plant or animal products (including forest products), or for monitoring air or water quality

Research Reflection

- NSF/NIH/DARPA/ARL/Industry funded research projects
  - Applications
  - Computational techniques
  - System performance
    - reliability, resilience, high-confidence, trustworthiness…….
    - dependability, security, safety, and privacy
    - timeliness, response time, delay

Research Reflection

- Federal Research Agencies
  - Department of Homeland Security (DHS), Science & Technology Directorate
  - U.S. Department of Transportation, Federal Highway Administration (FHA)
  - National Aeronautics and Space Administration (NASA)
  - National Institutes of Health (NIH)
    - National Institute of Biomedical Imaging and Bioengineering
    - National Cancer Institute
  - National Center for Advancing Translational Sciences
  - U.S. Dept. of Agriculture
  - National Institute of Food and Agriculture

Research Paper Presentation

Paper Presentation

- Class presentation
  - Choose a paper related to your tentative research project
  - You present one paper (20 minutes)
    - Deadline for selecting a paper is October 1, 2021
  - Research reflection and research paper presentations are individual and separate class assignment

- Email me the title of the paper, authors list and the venue where it has been published
  - Do not worry about not knowing the topic
    - Read the paper and you will understand the main concepts eventually!

Selecting the Papers

- Select a paper from a top Computing, Robotics or Cyber-Physical Systems conference (pervasive, ubiquitous, mobile computing)
- Name of the good conferences and workshops in broad area of computing and CPS:
  - IEEE ICRA
  - IEEE/ACM CPS week
  - IEEE ICDM, ICDE, ICML, KDD
  - ACM Ubicomp, MobiSys, CHI, PerCom
  - ACM SenSys, IPSN, ICCPS, BuildSys
  - International Symposium on Wearable Computers (ISWC)

Course Research Project

TED Talk by Prof. Vijay Kumar

- Autonomous Agile Aerial Robots
  - In his lab at Penn, Prof. Vijay Kumar and his team build flying quadrotors, small, agile robots that swarm, sense each other, and form ad hoc teams -- for construction, surveying disasters and far more.

Lex Fridman Podcast #97

- Sertac Karaman: [Robots That Fly and Robots That Drive]
  - 0:00 - Introduction
  - 1:44 - Autonomous flying vs autonomous driving
  - 6:37 - Flying cars
  - 10:27 - Role of simulation in robotics
  - 17:35 - Game theory and robotics
  - 24:30 - Autonomous vehicle company strategies
  - 29:46 - Optimus Ride
  - 47:08 - Waymo, Tesla, Optimus Ride timelines
  - 53:22 - Achieving the impossible
  - 53:50 - Iterative learning
  - 58:39 - Is Lidar is a crutch?
  - 1:03:21 - Fast autonomous flight
  - 1:18:06 - Most beautiful idea in robotics
  - Sertac Karaman is a professor at MIT, co-founder of the autonomous vehicle company Optimus Ride, including robots that drive and robots that fly

Recent Research in Robotics

- [ICRA21 Autonomous Racing Talk] - Sertac Karaman (MIT) - On Fast and Agile Autonomous Super-Vehicles

- OPPORTUNITIES AND CHALLENGES WITH AUTONOMOUS RACING
  - 2021 ICRA Full-Day Workshop 31 May 2021

Examples

- FlightGoggles
  - FlightGoggles is envisioned to be development environment that allows the design, implementation, testing and validation of autonomous super-vehicles
  - Provides exteroceptive sensor simulation based on the Unity3D engine as well as vehicle dynamics and inertial sensor simulation capabilities
  - https://flightgoggles.mit.edu/learn

Possible Research Projects

- **16.30 Feedback Control Systems**
  - An MIT Feedback Control Systems Class that Teaches with Palm-size Drones
  - http://fast.scripts.mit.edu/dronecontrol/

Possible Research Projects

- Matlab Toolbox for Parrot Rolling Spider
  - A Matlab/Simulink toolbox for the Parrot Rolling Spider. The toolbox allows designing, simulating, and implementing estimation and control algorithms on the palm-size Parrot Rolling Spider drone. The toolbox is open source, and can be found here:
  - https://github.com/Parrot-Developers/RollingSpiderEdu

Devices

- Parrot Rolling Spider Drones: Linux-based and MATLAB/Simulink codes
- DJI Tello
- Parrot Mambo Fly
- Crazyflie

Ground Bots

- Raspberry Pi Mouse V3
- ROSbot 2.0
- GoPiGo3 (needs assembly, out of stock)

Simulation Toolkits

- Unity
  - https://unity.com/
- Gazebo
  - http://gazebosim.org/
- Robotic Operating Systems (ROS)
  - http://wiki.ros.org/ROS/Tutorials
- ARL Autonomy Stack
  - Scalable, Adaptive, and Resilient Autonomy (SARA)
  - https://www.arl.army.mil/business/collaborative-alliances/current-cras/sara-cra/sara-overview/

Course Research Projects

- Project consists of 3 parts:
  - Choosing an interesting topic
    - Identifying what new you can do
  - Proposing your novel ideas
    - Designing or modeling the solution
  - Performance evaluation
    - Data collection/selection
    - Implementation
    - Evaluating your proposed methodology

Your take on Development Project

- Check with me
- Finalize the research idea and then look for the datasets you need to do a great development project!
- Development project pitch
  - Identify the devices
  - Let the class know what you are proposing, why you need those devices, how you will integrate all and deploy to get data, and what are the final results you are expecting
- Be proud of your development idea related with the dataset
- Use this dataset for your research project

Let's get back to our business!!

Computational Methods

Computational Methods

Introduction to Algorithm Analysis

AND

Introduction to System Modeling

Algorithms

- Computational Complexity
- Runtime computation of several sorting algorithms
- Graph Algorithms
  - Shortest paths; Network flow; Minimum spanning tree etc.

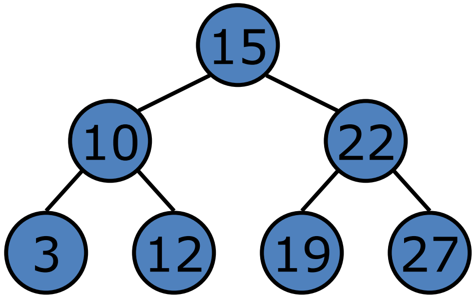
Why do we need Algorithms and Data Structures?

- "Why not just use a big array?"
- Example problem
  - Search for a number k in a set of N numbers
- Solution # 1: Linear Search
  - Store numbers in an array of size N
  - Iterate through array until find k
  - Number of checks
    - Best case: 1 (k=15)
    - Worst case: N (k=27)
    - Average case: N/2

15	10	22	3	12	19	27

Data Structures

- Solution # 2: Binary Search Tree (BST)
  - Store numbers in a binary search tree
    - Requires: Elements to be sorted
  - Properties:
    - The left subtree of a node contains only nodes with keys less than the node's key
    - The right subtree of a node contains only nodes with keys greater than the node's key
    - Both the left and right subtrees must also be binary search trees
  - Search tree until find k
  - Number of checks
    - Best case: 1 (k=15)
    - Worst case: $\log_2 N$ (k=27)
    - Average case: $(\log_2 N) / 2$



Example

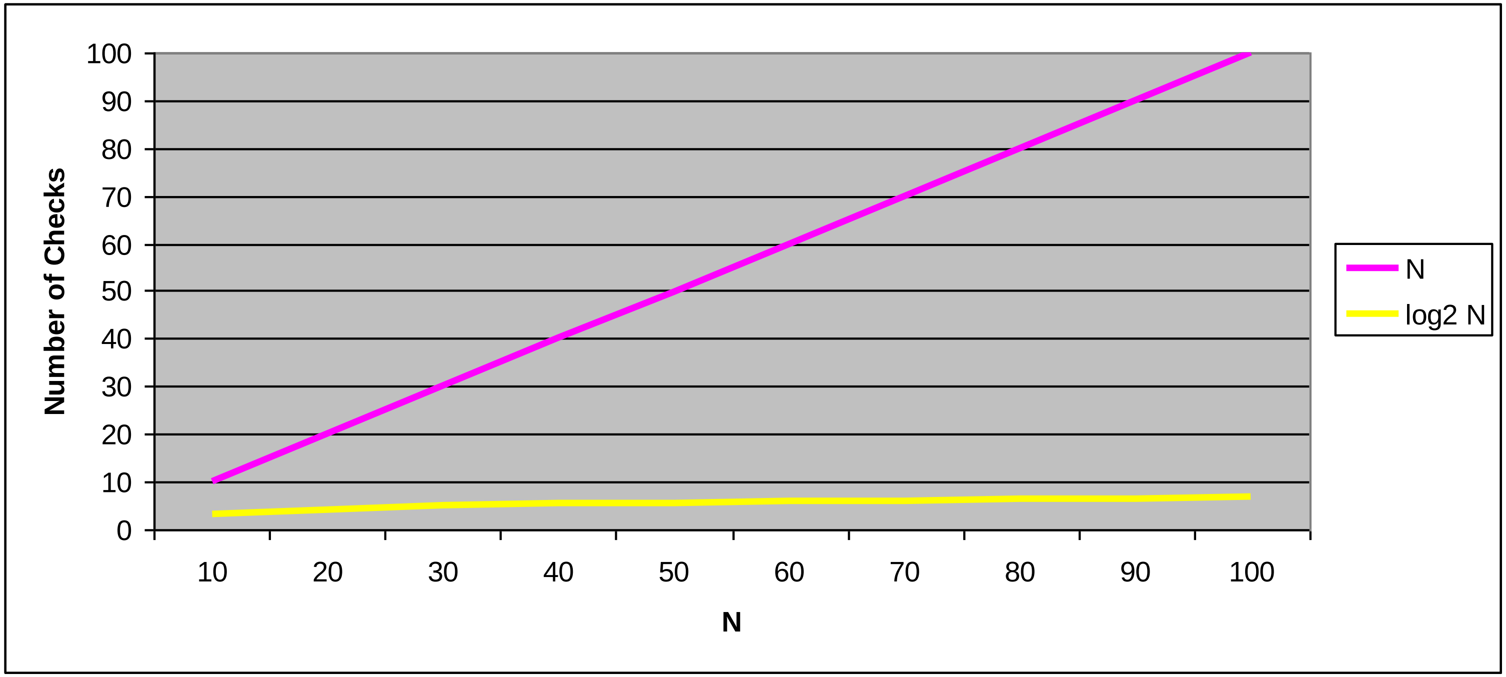
- Does it matter?
- Problem Artifacts
  - N = 1,000,000,000
    - 1 billion (Walmart transactions in 100 days)
  - 1 Ghz processor = 10^9 cycles per second

- Solution #1 (assume 10 cycles per check)
  - Worst case: 1 billion checks = 10 seconds

- Solution #2 (assume 10 cycles per check)
  - Worst case: 30 checks = 0.0000003 seconds

Computational Complexity & Analysis

- Does it matter?
  - N vs. ($\log_2$ N)



Insights

- Moral
  - Appropriate data structures and algorithms ease design and improve performance
- Challenge
  - Design appropriate data structure and associated algorithms for a problem
  - Analyze to show improved performance

Why do we need Math for algorithm analysis?

- Analyzing data structures and algorithms
  - Deriving formulae for time and memory requirements
  - Will the solution scale?
- Proving algorithm correctness

Computational Methods (contd.)

Cyber-physical systems (CPS)

+

Smart service systems (SSS)

+

Future of Work at the Human-Technology Frontier

+

Smart and Connected Communities (SCC)

+

Robotics

……………………..

Performance Measurements

Systems

- Performance evaluation and modeling
- Concepts and techniques needed to plan the capacity of computer/information systems
  - predict their future performance under different configurations
  - design new applications that meet performance requirements
  - analytic queuing network models of computer systems
  - study the performance of centralized, distributed, parallel, client/server systems, web server, and e-commerce site performance
- Database systems, mobile systems, robotics system, networked systems, CPS, Smart service systems, Future of Work, SCC
  - Telecommunication network design ....

Queueing Theory

- Waiting in lines
  - In the grocery store, on the telephone, at the airport, on the road
- Queueing theory is the mathematical study of lines
  - What are the stochastic characteristics of delay?
  - For example, what is the average delay?
  - What is the probability that delay exceeds some threshold?
  - What fraction of customers are turned away?
  - What system capacity (e.g., what number of servers) is needed to achieve a specified quality of service?
- Provide decision makers a way to efficiently allocate resources to reduce delay

Applications of Queueing Theory

- Applications to operations research, cyber-physical systems, smart service systems, future of work, management science and industrial engineering
- Examples are
  - Traffic flow (vehicle, aircraft, people communication)
  - Scheduling (patients in hospital, jobs on machines, programs on a computer)
- Facility design
  - Banks, post offices, amusement parks, fast-food restaurants

Applications of Queueing Theory

- Applications to Networks
- Study of the performance of systems composed of
  - Waiting lines
  - Processing units
- Allows to estimate
  - Time spent in waiting
  - Expected number of waiting requests
  - Probability of being in certain states
- Useful for the design of systems such as telecommunication networks
  - Delay, blocking probability, links, bandwidth, number of processors, buffers size

In this course

- Survey the quantitative models used to analyze queueing systems

- Focus will be both on mathematical analyses of such models as well as practical issues in using such models to represent real CPS, SSS, FW, SCC, Robotics problems

Questions

?