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Computational Thinking Across the Curriculum: A Conceptual Framework

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1   Introduction

The development of computer technologies and computer science has been largely motivated by a desire to support, extend and amplify the human intellect. The first general purpose computer, ENIAC, was built in 1946 to calculate artillery firing tables to support the task of artillery crews. At SRI in the mid-1960s, Doug Engelbart, in a project aptly entitled "Augmenting Human Intellect: A Conceptual Framework" [7], invented the mouse, the GUI (Graphic User Interface), hypertext (e.g. HTML), networked computers, and collaborative software tools such as tele- and video-conferencing. Today, the Internet, the WWW, a myriad of computer applications, and computational concepts and techniques are available for the purpose of augmenting a person's productivity, and more, in practically all human endeavors.

In order to make an effective use of computer applications and techniques in his/her field, a person needs to have certain skills. One skill is the ability to use basic computer applications such as an editor and a web or file-system browser; this skill is often described as computer literacy. Another skill is a high level understanding of the workings of a computer system, often defined as computer fluency. While computer literacy and fluency are certainly necessary, neither is sufficient for fully realizing the potential that computing can have in augmenting a person's productivity in their field. The third, critical, skill set is the intellectual and reasoning skills that a professional needs to master in order to apply computational techniques or computer applications to the problems and projects in their field, whether the field is in the arts, sciences, humanities, or social sciences.

This third skill was given the name computational thinking in a recent 2006 CACM article by Jeannette Wing [16]. Computational thinking is not new, however. Many of its elements are as old as mathematics itself (e.g. Euclid's 500 B.C Greatest Common Divisor algorithm). Computational thinking has been fleshed out and used by computer scientists in the context of computer application development for decades. Computational thinking has also been applied to fields other than computer science for years. For example, computer scientists,

psychologists, sociologists, anthropologists, and biologists have all contributed to applying computational concepts and processes to the field of cognitive science [9]. The application of computational thinking within computer science and related fields has been implicit, because it is the natural approach to problem solving in the field. The application of computational thinking to other fields has also usually been implicit, sometimes without an explicit recognition of the reasoning skills involved. What is different about the recent attention on computational thinking is the emphasis on explicitly defining what it is and explicitly using it to gain new insights into problems in fields outside of computer science. As Wing argues in her seminal article, "the ideas of abstraction, layering of abstractions, and automation, to name a few, are fundamental computer science concepts that have already yielded new insights in the natural sciences and hard social sciences such as economics" [16]. She argues that computational thinking is an emerging basic skill that should become an integral part of education:

> "Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability."

In this project we are developing a framework for implementing Wing's vision in the context of undergraduate education. More specifically, we focus on using liberal studies courses – part of the education of the vast majority of undergraduates – as a vehicle for the teaching of computational thinking. In order to achieve this, a broad consensus among faculty from diverse areas must be reached. In this project we worked toward achieving this consensus by developing a framework that faculty without formal training in information technology can use to understand and integrate computational thinking into their liberal studies courses.

2   A practical definition of computational thinking

Since Wing's article many, including Wing, have attempted to pin down a definition of computational thinking. Wing uses many examples from computer science and "hard sciences" to define the term in her article. Unfortunately, she does not give examples of computational thinking outside the "hard sciences". Wing's article is also not ideal for explaining computational thinking to professionals outside of computing. Part of the contribution of our project is to uncover examples of computational thinking more broadly and to explain computational thinking to faculty in all academic disciplines.

One way to decide whether some analytical process is computational thinking is if it is – or can be – described using computational thinking keywords and whether it can be categorized as employing a fundamental "computing principle". Using terminology defined in Appendix 8.1.2, we define the computing principles and keywords we will use.

2.1 Principles of computing and keywords

Computation is a broad term that encompasses different tasks, concepts and techniques. Similarly, computational thinking involves a broad set of approaches and skills. In this project we find it useful to define different categories of computational thinking. Using these categories we can understand computational thinking by distinguishing differences and finding similarities between specific examples in different fields.

In order to understand and organize computational thinking, we will use the categories defined by Denning in his "Great Principles of Computing" project [5]. The goal of Denning's project is to articulate the fundamental principles of computing. Of particular interest to us is one of Denning's motivations: "To establish a new relationship with people from other fields by offering computing principles in a language that shows them how to map the principles into their own fields." He claims that the "principles of computing can be organized into seven categories, each emphasizing a unique perspective on computation." The Great Principles of Computing, according to Denning, are: *computation, communication, coordination, recollection, automation, evaluation, and design.*

These seven "principles" form a foundation that is useful to recognize, organize, and categorize instances of computational thinking and build a framework that can translate computational thinking to contexts outside of computer science. The categories should be seen as a starting point, subject to modification as necessary. For example, abstraction is viewed by Denning as belonging to the design principle, when it could be argued that abstraction is a principle on its own. Below is our definition of each principle. Note that the definitions are somewhat different from Denning's because we are defining them in a context larger than computer science. For each principle, we also define a list of keywords typically used when expressing concepts or processes that the principle embodies.

- **Computation** is the execution of an algorithm, a process that starts from an initial state containing the algorithm and input data, and goes through a sequence of intermediate states until a final, goal state is reached.

  Keywords: *state and state transitions, algorithm, program, exhaustive search, backtracking, recursion and iteration, decision tree, randomization, problem complexity, computability.*

- **Communication** is the transmission of information from one process or object to another.

  Keywords: *information and its representations, messages, sender/receiver, communication protocol, message compression, message encryption, error correction, communication channel, encoder/decoder, noise, authentication.*

- **Coordination** is control (through communication, for example) of the timing of computation at participating processes in order to achieve a certain goal.

Keywords: *interacting processes/agents, inter-process protocols including communication protocols, synchronization, events and event handling, flow and sharing dependencies, concurrency.*

- **Recollection** is the encoding and organization of data in ways to make it efficient to search and perform other operations.

  Keywords: *storage media, data hierarchy and organization, data manipulations including data insertion/query/removal and their efficiencies, data locality and caching, virtual representations, naming system, relative and absolute references.*

- **Automation** is the mapping of computation to physical systems that perform them.

  Keywords: *mapping of algorithm to physical computing object, mechanization, applies to repetitive processes and provides error-free, consistent, fast, cost-efficient executions.*

- **Evaluation** is the statistical, numerical, or experimental analysis of data.

  Keywords: *visualization, data analysis, statistics, data mining, simulation, recommender system, computational experiment.*

- **Design** is the organization (using abstraction, modularization, aggregation, decomposition) of a system, process, object, etc.

  Keywords: *abstraction, layers of abstraction, modeling, modularity, information hiding, class, architecture, aggregation, pattern, underlying structure.*

2.2   What benefits does computational thinking bring?

When reaching out to people who do not work in the area of computing, it is important to emphasize the possible benefits of applying computational thinking. There is a tendency to be (justifiably) skeptical of applying new approaches, particularly when existing approaches have yielded satisfactory results and when the new approaches come from an area outside of one's expertise.

The impact of computing in the sciences has been recognized for a while now. Physics Nobel Laureate Ken Wilson recognized the role of computing in his work in Nobel lecture [15] he gave in 1982. Computing and computational thinking have been at the core of recent advances in molecular biology. Today complex physical processes, such as the behavior of a flock of birds [2], are often best understood as computational processes that are then amenable to analysis using algorithm and computational complexity tools.

Computational thinking has permeated the field of economics from computational finance to electronic trading. With more and more archival documents moving into databases, it is changing how social scientists research. Musicians and many artists have embraced computing as a way to enhance their creativity and productivity.

Overall, computational thinking:

1. Offers new ways of seeing physical, social, or other phenomena.

2. Presents new ways to solve problems [14].

3. Emphasizes creating knowledge rather than using information [14].

4. Enhances creativity and innovation.

We illustrate the benefits of computational thinking through several examples.

2.2.1 New views of physical, social, or other phenomena

The Human Genome Project: Interpreting DNA strands as data or code is the classic example of computational thinking that led to a revolution in molecular biology. Abstracting the complexity of organic chemistry to linear strings of 4 characters allowed researchers to view DNA as the encoding of information. DNA strands encode instructions to be used in the development of the organism and this encoding is an example of data organization (or recollection). Genetic mutations can be viewed as randomized computation and the cellular growth and interactions between cells may be viewed using the ideas of coordination and communication. By taking this new view of DNA, researchers have been able make dramatic advances in the area of molecular biology, such as the completion of the Human Genome Project in which the all the genes in human DNA were identified, the sequences making up human DNA were determined, and tools for analyzing the information were developed [10].

The evolution of the theory of evolution: Few people outside of the sciences understand that scientific discovery is often a distinctly non-linear process, where early ideas may be discarded or revised when new information is examined, understood, and integrated. Conveying this process to people who are not involved in scientific discovery can be difficult at best, yet it is one of the things that makes science appealing and interesting as a field. One of the most fascinating examples of this process can be seen in "On The Origin of Species" by Charles Darwin. Over the course of his lifetime, Darwin wrote six versions of the book, adding 40,000 words between the first and sixth editions. A project by Fry [8] examines the differences between the editions, tracking the changes in text in a visual way enabling a viewer to watch the revision and expansion of Darwin's seminal work. This is a clever use of visualization that produces new understanding about the development of an important scientific theory.

2.2.2 New approaches to problem solving

Origami structure: Origami, the Japanese art of paper folding, is something that has engaged artists, mathematicians, and computer scientists for many centuries. Recently the field of computational origami has arisen, in which algorithms and theory devoted to the solution of origami problems by mathematical means are developed [11]. In order to construct an origami representation of an object, the object's features may be abstracted using graph

theory. Once an abstract graph model is obtained, algorithms that construct the sequence of folding have been developed to construct the origami representation of the object. This in turn implies that the origami construction can be automated. By abstracting and automating this process, new and incredibly complex origami structures can be constructed [11]. The process of automating origami construction has also allowed people in the field to teach the underlying concepts of origami, with a particular focus on creating original origami designs [12].

2.2.3 Creating knowledge

Online purchase recommendations: Amazon.com has over its short existence amassed an enormous amount of data related to customer visits to their website and the purchases its customers make. A traditional, bookkeeping approach to leveraging this information could be to use it to keep track of customer interests and product inventory. The stored information, however, may contain data patterns that are impossible to detect visually or by hand. Knowledge is created when meaningful patterns hidden in the data are found and made explicit. Amazon.com has developed ways to mine the data to determine, for example, what books to recommend to a customer. This recommendation is based, for example, on the customer's past purchases and the behavior of other customers who made the same purchases. This rule, and many others, make up a system called a recommender system that is at the core of Amazon.com's business model, and also of many other online businesses as illustrated by the Netflix prize.

Violence outside the laboratory: Laboratory experiments in psychology find that media violence increases aggression in the short run [1]. Because of this effect, there exist a variety of restrictions on American children's ability to view violent movies and purchase violent games. Little understanding of the issue outside of the lab was known, however, until two researchers used crime statistics and movie databases to study the correlation between the release of a violent movie and actual violence on a given weekend. The researchers report "like the laboratory experiments, we find indirect evidence that movie violence increases violent crime; however, this effect is dominated by the reduction in crime induced by a substitution away from more dangerous activities" [4]. The attendance of violent people at violent movies results in less crime because violent people were engaged in activities that made it more difficult to engage in crime, namely watching a movie. Applying computational thinking techniques such as data analysis and searching allowed these researchers to gain new insight into the actual effects in the real world of a phenomenon observed in the laboratory.

2.2.4 Enhancing creativity and innovation

Music synthesis: Modern personal computers have sound hardware and software that make it possible to synthesize sound, process sound signals, and compose music. As pointed out by Roads in [17], "Any sound, from the simplest to the most complex, that can be produced through a loudspeaker can be synthesized with (the computer)", and "... powerful programs

have been developed for the purposes of editing and mixing ... sound". Through understanding the physical properties of sound and how to describe those properties in a format that can be stored in a computer, one can start thinking computationally about the process of synthesizing and processing sound, and composing music. With the computer as instrument, it is only natural to make a parallel between composing musing and programming a computer. In fact, powerful composing programming languages such as Nyquist [18] have been developed for exactly this purpose.

3   The *"Computational Thinking Across the Curriculum"* framework

The ultimate goal of this project is:

- A broad recognition that computational thinking is an essential skill for the next generation of workers and citizens, and

- The integration of computational thinking at all educational levels.

We propose here a framework of how to achieve the second goal in the context of higher education. The idea is to use courses in the general education (i.e. Liberal Studies) curriculum – part of the education of the vast majority of undergraduates – as a vehicle for the teaching of computational thinking. Computational thinking would thus join other core skills – such as critical reasoning, writing, and ethics – taught in the general education curriculum. Just like those other skills, it will be taught in context, i.e. within an application domain not directly related to computing.

In the sections that follow, we will describe many examples of how computational thinking can be and is taught in a variety of Liberal Studies courses at DePaul University. Those examples represent the proof-of-concept for our model in the case of DePaul's Liberal Studies Program. We emphasize that the model is not yet officially implemented or supported. Our project remains a research project and the current document only reports what the project participants have done in their courses. Also, the model is specific to DePaul University, but as will soon clear it is flexible enough to be implemented widely.

We briefly outline the *current* Liberal Studies program at DePaul University. The program consists of two parts. The first part is a Common Core which includes, among others, a first-year, two-course sequence in Mathematical and Technology Literacy, designed to teach "how to apply quantitative reasoning and quantitative information, and to critically evaluate real-world issues and problems using modern information technologies (e.g., spreadsheets, databases, statistical analysis software, search engines, programming algorithms)." [13] This sequence is the basis upon which we think the teaching of computational thinking in context can occur in other courses of the Liberal Studies Program. The second component of the Liberal Studies Program is made up of courses in six distinct learning domains:

- Arts and Literature,

- Philosophical Inquiry,

- Religious Dimensions,

- Scientific Inquiry,

- Self, Society, and the Modern World, and

- Understanding the Past.

Students are required to take 2-3 courses in each domain, but have a choice of several dozen courses for each domain.

There are some courses in many of the domains in which we think computational thinking can and should be explicitly taught. In the remainder of this document, we illustrate how exactly that is done in 19 courses across Liberal Studies domains. In Table 1 we list the examples of computational thinking brought explicitly in those 19 classes and we categorize those examples by Computing Principle.

4   Scientific Inquiry Liberal Studies Domain

4.1   CSC (Computer Science) 233: Codes and Ciphers

Catalog description: This course is an introduction to the science and history of secret writing (cryptography) and how codes and ciphers can be broken (cryptanalysis). In historical settings we will encounter the main ideas and methods devised to secure communication channels. Possible topics include: substitution ciphers, transposition ciphers, the Vigenere cipher, statistical methods in cryptanalysis, public-key cryptography, and quantum cryptography.

CT categories: Computation, Evaluation

Author: Marcus Schaefer, College of Computing, CDM

4.1.1   Cryptography and the Hardness of Computation

All modern cryptosystems are based on the assumption that certain mathematical problems are intractable, that is, hard to solve by a computer. While traditional systems use estimates on the size of the keyspace as a rough measure of complexity, the hardness of breaking modern systems can often be tied more closely to mathematical problems. For example, Diffie/Hellman is based on the assumption that a variant of the discrete logarithm problem is hard, and RSA is based on the hardness of factoring large numbers. So in modern cryptography computation is more than a tool, it has become a meta-tool: the very fact that some

Course Number	Course Title	Automation	Communication	Computation	Coordination	Design	Evaluation	Recollection
Scientific Inquiry								
CSC 233	Codes and Ciphers			4.1.1			4.1.2	
CSC 235	Problem Solving			4.2.1			4.2.2	
CSC 239	Personal Computing						4.3.1	
ECT 250	Internet, Commerce, and Society	4.4.1						
ENV 216	Earth System Science					4.5.1		
ENV 230	Global Climate Change						4.6.1	
ENV 340	Urban Ecology						4.7.1	4.7.1
GEO 241	Geographic Information Systems I					4.8.1		
HCI 201	Multimedia and the WWW					4.9.2		4.9.4
IT 130	The Internet and the Web		4.10.1			4.10.3		4.10.5
Arts and Literature								
ANI 201	Animation I	5.1.1						
ANI 230	3D Modeling	5.2.1		5.2.1		5.2.1	5.2.2	
DC 201	Introduction to Screenwriting					5.3.1		
GAM 224	Introduction to Game Design				5.4.2	5.4.1		
HAA 130	Principles of European Art					5.5.2	5.5.1	
Understanding the Past								
HST 221	Early Russia						6.1.1	
HST 250	Origins of the Second World War						6.2.1	
First Year Program								
LSP 112	Focal Point Seminar (The Moon)			7.1.2		7.1.1		
Honors Program								
HON 207	Introduction to Cognitive Science		8.1.1		8.1.2			

Table 1: Examples of Computational Thinking, in 19 courses across the DePaul curriculum, are categorized by Computing Principle; each example is described in detail in the indicated section.

task is computationally hard, can be exploited to build a feasible solution to another problem (public-key cryptography).

CT Learning Goal: Understand the role of computation, modular arithmetic, randomness and well-designed cryptographic protocols in modern cryptography. (CT Category: Computation.)

Public-Key Cryptography, case discussion: In public-key cryptography two parties (typically called Alice and Bob) can communicate securely over a public channel, even if they have never met before or exchanged any secret information: they can establish secure communication between them while other parties are listening (the third person is always known as Eve, the eavesdropper). Intuitively, this seems impossible: how could you exchange a secret with somebody you don't know over the phone, say, in the presence of other people listening in on your communication? However, public-key cryptography shows that this is indeed possible, and the mathematics involved for the easier systems is not very difficult and can be understood by the students.

Q1. Do an example of a Diffiee/Hellman key exchange. How does this make public-key cryptography possible?

Q2. Do an example of the three-way protocol. Why can this system not be broken using logarithms? What about discrete logarithms?

Q3. How can we calculate the average salary of everybody in the room without anybody learning anybody else's salary? Hint: the problem can be solved using a trusted third party (Trent), but what if we do not even allow that? We can assume that everybody is honest, but we do not want to share our salary information.

Q4. Do an example of bit-commitment using the hardness of the discrete log problem. How can we use bit-commitment to convince somebody that we have found a legal coloring of a graph?

Assessment: Students will set up a Diffiee/Hellman system for key-exchange and set up a secret-sharing theme requiring randomness.

4.1.2 The Substitution Cipher

In a substitution cipher each letter is replaced by some other (unique) letter of the alphabet. As such, a substitution cipher does not change the frequency distribution of the letters, it just disguises it by renaming the letters. This observation, with a little bit of statistical mathematics, can be used to automate the exhaustive breaking of the shift cipher, that is, the process can be done by a computer (or simulated by hand) without any human involvement. For the students to understand and recreate this process, they need to understand one of the most basic principles in computational thinking: when trying to understand a process (be it

a shift cipher, a sorting algorithm, or some other more complex procedure) it is difficult to argue about what changes; indeed, it is necessary to understand what a particular process does not change. In the case of the shift cipher, one such property is the frequency profile.

CT Learning Goal: Use statistical analysis and trial and error to break a monoalphabetic substitution cipher. (CT Category: Evaluation)

Breaking the Substitution Cipher, case discussion: Some (overly optimistic) texts claim that substitution ciphers are easily solved by frequency analysis; when trying this by hand, the students will quickly find out that this is at best a half-truth. Students realize that an approach can be heuristic, i.e. only lead to partial or suboptimal solutions which might not even be fully correct. The question then is how to improve results.

A form of exhaustive search, trial and error can be used but it quickly becomes painful for substitution ciphers; students realize that additional understanding of the syntactic nature of English text is required before this approach is meaningful. Indeed, a combination of frequency cliques, bigrams, and other information about English words leads to a collection of rules which together with frequency analysis can be used to solve substitution ciphers in which word separations have been maintained. The students will start by performing some substitution cipher encryptions and decryptions.

Q1. Can we try all possible keys to break the cipher? How many keys are there?

Q2. How long would it take to try all keys by hand? On a computer? How would we recognize English plaintext?

Q3. Does the frequency approach used for the shift cipher work?

Q4. Does the frequency approach lead to a mechanizable solution of substitution ciphers? How could it be extended to work?

Q5. What information about English words would be helpful in solving a substitution cipher by hand?

Assessment: The students will get a (individual) monoalphabetic substitution cipher to break.

4.2 CSC (Computer Science) 235: Problem Solving

Catalog description: How do you solve a problem? In this course we discuss different problem solving techniques and strategies such as modeling, establishing subgoals, and searching and pruning. The techniques will be presented as part of a theoretical framework, but there will be significant emphasis on solving problems in familiar domains such as games, newspaper articles, philosophy, and simple geometry and logic. At the end of the course,

students will have built a repertoire of problem solving tools that will allow them to make an informed choice of approach towards new problems.

CT categories: Computation, Evaluation

Author: Iyad Kanj, College of Computing, CDM

4.2.1 Defining Subgoals

Defining subgoals is a problem solving technique that breaks a problem into one or more problems, whose solution leads to a solution to the original problem.

CT Learning goal: The students should understand the defining subgoals technique, and they should be able to apply it. In particular, given an appropriate problem, they should be able to identify the subproblem within it whose solution leads to a solution of the original problem. They also need to illustrate the process of going from a solution of the subproblem to a solution for the original problem. (CT Category: Computation)

Towers of Hanoi, case discussion: The Tower of Hanoi problem has the following setup. Given are 3 pegs labeled A, B, C and n disks (of different sizes) placed on top of each other around peg A in a decreasing order of their size (largest at the bottom). The problem is to transfer the disks from peg A to peg C under the restriction that 1) only one disk can be moved at a time, 2) a picked up disk must be released around some peg before another disc is picked up, and 3) no disk can be placed on top of a smaller one.

Q1. Demonstrate a solution to the Towers of Hanoi problem with 4 disks. How many steps does your solution take?

Q2. Your ultimate goal is to transfer the n disks from peg A to peg C. Define an appropriate subgoal.

Q1. Show how using the subgoal defined above you can achieve the ultimate goal of transferring the n disks from peg A to C.

Assessment: The student will, for example, be assigned the problem of constructing a straight-line passing through a given point and parallel to a given straight-line. They will be asked to describe how, using a compass and a straight-edge ruler, they can do this. They will be asked to define an appropriate subgoal, and show how achieving this subgoal leads to achieving the original goal.

4.2.2 Searching and Pruning

The "search and prune" technique uses heuristics and exhaustive search methods to arrive at a solution. It is usually used to solve problems that do not possess structure and easy

"solutions". For such problems, one may need to perform a systematic search to check all possible choices that may lead to a solution.

CT Learning goal: The student should learn how to apply systematic search procedures and understand how they can be automated. Given an appropriate problem, students should be able to illustrate how to apply the process of searching and pruning to arrive at a solution. (CT Category: Evaluation.)

Queens of Chess, case discussion: The problem asks to place 8 queens on a chessboard (or, in general, to place n queens on an nxn chess board) such that no two queens can attack each other.

Q1. Find a solution to the problem on an $8x8$ chessboard by trial and error.

Q2. Suppose that, in your search, you were able to place the i-th queen successfully on the board but you couldn't place the $i + 1$-st queen. How do you modify your search?

Q3. Can you devise a systematic method to list all solutions to the problem?

Assessment: The students will be given a maze and asked to answer the following:

1. Show how to model the maze using a graph. What are the vertices and edges?

2. Apply depth-first search to the graph to find a solution to the maze.

4.3 CSC (Computer Science) 239: Personal Computing

Catalog description: Students will learn how to develop Excel workbooks for computing elementary statistics and compute simple statistical inference (confidence intervals, hypothesis testing and linear regression models) using the data analysis toolkit. A variety of statistical, mathematical, logical, and text functions in Excel as well as the Excel Chart and Data features will be presented. Further, students will gain an introduction to web publishing, as the world wide web currently offers fast access to a huge audience for the presentation of research results.

CT Categories: Evaluation

Author: Jacob Furst, College of Computing, CDM

4.3.1 Constructing a Histogram

The construction of a histogram is an important first step in any statistical analysis. The visual appearance of the histogram can be used to determine if there are outliers and what the appropriate statistics are for reporting center and spread. For more complex statistical analysis, the shape of the histogram can be used to determine what analyses are appropriate

and which are not. However, the creation of a histogram is not a simple process; it is iterative and benefits greatly from automation.

CT Learning goal: Students can use a statistics package to generate multiple histograms from a single data set and choose the most meaningful visualization of the symmetry or skew of the data. (CT Category: Evaluation)

Histogram, case discussion: There are computer programs that completely automate the construction of a histogram. However, since the histogram is a visual statistic, it is best constructed using human input; in particular the choice of the number of bins is critical in generating a histogram that best provides visual information about the distribution of the underlying data. A histogram is critical in determining whether the mean and standard deviation or the mode and quartiles are better for summarizing the center and spread of the data.

Students are shown the algorithm for constructing a histogram:

1. Determine the minimum and maximum of the data

2. Create a number of bins for aggregating data

3. Create a distribution table for the data based on the bins

4. Graph the distribution table

Students will consider the following questions:

Q1. If the resulting histogram is too spiky, how do we improve it?

Q2. If the resulting histogram is too shapeless, what do we do?

Assessment: Students are given a data set and are asked to:

- Generate histogram bins that include all the data and are of equal width.

- Generate the "best" number of bins, i.e the one with the number of bins that best visualizes the data (i.e. patterns in the data set are made explicit and reasonable hypotheses can be made about the data set).

As this activity is done for many problem sets, the students have many opportunities to mean the objectives, and also to see different visualizations for different data sets (e.g. small data sets versus large ones; symmetric distributions versus skewed ones.)

4.4 ECT (E-Commerce Technologies) 250: Internet, Commerce and Society

Catalog description: ECT 250: An introduction of Internet technology, its application for commerce, and their social impact. This course surveys Internet technology, collaboration and commerce activities, digital media distribution, online communities, and social networking in the Internet environment.

CT categories: Automation

Author: Xiaowen Fang, College of Computing, CDM

4.4.1 Online Order Processing System

On a typical online retailing website, orders are taken through online forms, payment information is collected, inventories are updated, and products are made ready for shipping. The entire order fulfillment process is automatically handled by computers with minimum human intervention. Not every process can be automated however and deciding whether a process can or cannot be automated requires an understanding of the mapping between the algorithm underlying the process and the computing system potentially executing it.

CT Learning Goal: Students are able to analyze a process and argue whether it has the properties (e.g. can be described using a clear algorithm, exhibits repetitions, etc.) that make it amenable to automation; students understand, in context, the benefits (error-free, consistency, speed, low-cost) automation brings. (CT Category: Automation)

Order Processing System, case discussion: Dell is one of the top sellers of PC computers. In the first quarter of 2007, Dell shipped about 8 million units based on Gartner and IDC (International Data Corporation) reports. It is evident that the number of orders was huge. How did Dell process the orders? Let's look at Dell's order processing system at http://www.dell.com/.

Q1. What characteristics did you notice during the order process? (Answers: Standardized procedure, repetitive, etc.)

Q2. Did you perceive any human intervention during this process? Are humans good at processing this type of orders? Why? (Benefits of human information processing?) Why not? (Limits of human information processing)

Q3. Who actually handled all the orders? (Answer: Computers). Define the term "automation" in computational thinking.

Q4. What are the benefits of automation (Answer: Consistent, error free, fast, efficient, cost-effective, etc.)

Q5. Can you think of some other examples of automation?

Q6. What characteristics of order processing make automation helpful? (Answer: Large number of orders, standardized procedure, repetitive, etc.)

Assessment: The following question will be added to an assignment. The registrar's office at a community college is short of people handling course registrations due to the recent surge of student enrollment. This results in students waiting in a line for hours and employees working for long hours. They decide to develop a Web-based course registration system to automate this process. Please answer the following questions: 1) Please use a flow chart and your own language to describe a common registration process. 2) What characteristics of the registration process make it suitable for automation? 3) What are the benefits of using automation?

4.5   ENV (Environmental Sciences) 216: Earth System Science

Catalog Description: This course uses a systems approach, to investigate the fundamental structure of functions, processes and changes within, and dynamic interactions (cycling) among Earth's living and non-living systems. This course is designed for students with fundamental grounding in biology, chemistry, ecology, and mathematics.

CT categories: Design (abstraction and modeling)

Author: Mark Potosnak, Environmental Sciences, LA&S

4.5.1   Global Climate Models

Earth system science is the integrated study of living and non-living systems and how those systems create a meta-stable environment that is conducive to continuing life on our planet. Typically, earth system science focuses on exchanges of matter and energy between the four great Earth spheres: the biosphere, atmosphere, hydrosphere and lithosphere. With antecedents in a variety of fields, earth system science has flourished in the era of computers. Often driven by a need to understand human impacts on the environment, Global Climate Models (GCMs) are the tools for integrating detailed understanding of particular processes into a broader context in a quantitative manner.

CT Learning goal: Students will appreciate how computational thinking is used to guide efforts to model the Earth's climate system and in particular how modeling and abstraction are critical tools for this endeavor. Considering the question of 'how much is enough,' students will understand how GCMs are built from the understanding gleaned from individual studies (theoretical and empirical). But they will balance the need to capture important processes with the reality that models can become too large, too complex and therefore unusable. The students also will explore how these models reveal complexities (e.g., emergent properties) that

arise when non-linear systems are coupled. While keeping the discussion at a broad level and avoiding technicalities associated with implementation, students will appreciate that GCMs are the result of critical decisions based on the principles of computational thinking. (CT Category: Design.)

Global Climate Models, case discussion: Using a GCM built for classroom use (EdGCM, provided by NASA's Goddard Institute for Space Studies), students will explore how simulations of climate depend on different model subcomponent choices. In particular, the coupling of the ocean to the atmosphere has been an intense focus of research, and EdGCM provides a number of different options for this. Students will explore how the choice of model subcomponent affects future climate change predictions.

Q1. How much is enough? When modeling and abstracting the climate system, how do scientists determine which processes are essential and which must be neglected for computational efficiency?

Q2. Given the complexity of the earth system and the difficulty of developing algorithms to model this complexity, can we gain confidence in climate predictions using ensemble model results that average across variations in model implementation?

Q3. Earth system scientists, like all scientists, employ the scientific method to validate their results. Since there is only one Earth, how do scientists use GCMs to conduct experiments? What are the limitations on this approach?

Assessment: Students groups will be assigned to teams that support different implementations of the ocean-atmosphere coupling scheme. During a class period, the students will hold a mini-conference where the groups support their implementations and associated model results. As an end product, the teams will negotiate a joint statement that expresses their confidence in a single set of predictions with associated error estimations.

4.6 ENV (Environmental Sciences) 230: Global Climate Change

Catalog description: This course introduces the student to the general principles of climate changes and how it affects weather, agriculture, ocean levels, etc. In recent years, the problem of global climate change became one of the most important issues in science and politics. This course will cover topics like natural and human made climate changes, the handling of proxy data and data methods, and social behavior.

CT categories: Evaluation (simulation)

author: Mark Potosnak, Environmental Sciences, LA&S

4.6.1 Predicting climate change from human activities

In the global warming debate, global climate models (GCMs) have played a central role. Although crude, back-of-the-envelope calculations can give some insight on the link between increasing carbon dioxide concentrations and global temperature increases, for the past 20 years scientists have employed increasingly sophisticated computer simulations. The basic science behind the GCMs remains unchanged, but massive increases in computing power have allowed for finer temporal and spatial resolution, more comprehensive algorithms describing existing physical processes and the addition of algorithms corresponding to new processes. Along with the solution to vexing earlier problems (e.g., coupling the ocean and the atmosphere), these advances have lead most climate scientists to accept the hypothesis that fossil-fuel emissions have caused global temperatures to increase. But the public often is swayed by arguments from a small minority of scientists and other skeptics that the models are uncertain and global warming is a myth. This misconception is perpetuated by the lack of understanding of how such computationally intensive predictions are actually made. This project introduces students to an educational GCM (EdGCM, provided by NASA's Goddard Institute for Space Studies) in an attempt to dispel the misunderstanding.

CT Learning goal: In addition to limitations imposed by imperfect models, predictions of future climate are constrained by inadequate data sources for initializing model runs and uncertainty of future drivers (e.g., greenhouse gas emissions from fossil fuel combustion). The CT learning goal will be to understand how uncertainties in inputs produce uncertainties in results and how ensemble averaging of different realistic input scenarios can reduce this uncertainty. Students will appreciate how GCMs can reliably predict future climate conditions from different assumptions about how carbon dioxide and other greenhouse gases (GHGs) will change. (CT Category: Evaluation)

Climate Change Prediction, case discussion: Students will do research on how carbon dioxide concentrations and other GHGs have changed in the past using peer-reviewed literature. In the next step, the students will decide how these concentrations will change in the future based on a business-as-usual scenario and how different control strategies could reduce emissions to lower levels. These scenarios will be built by considering separately the emissions from major countries (e.g., the United States and China) or geographical regions (e.g., Africa) using the IPAT framework (impact = population $\times$ affluence $\times$ technology) and demography projections. Next, students will work backwards: starting with a maximum allowable global temperature change, students will run successive model iterations to find maximum allowable GHG scenarios.

Q1. How can ensemble averaging over reasonable input scenarios increase the confidence of model results?

Q2. The scenarios developed for reducing GHG emissions involve sacrificing some economic growth for a sustainable future. How difficult will it be for scientists to sell the necessity for these sacrifices, given that complex computer simulations were used for their

development?

Assessment: Currently, a big sticking point in reaching consensus in the U.S. senate on a climate change bill is the action that developing countries will be required to take. Playing the role of legislative interns, students will write a one-page policy brief for a legislator based on the following scenario: When projecting future GHG concentrations, the role of China, India and Brazil is crucial; reductions by the United States and Europe can be readily offset by growth in these three countries. Can the spatial output of the GCM be used to convince these countries that global warming will affect them also? What issues of fairness and equity are raised, since currently the United States has far greater per capita emissions than these nations?

4.7 ENV (Environmental Sciences) 340: Urban Ecology

Catalog Description: There is a growing awareness of the functional importance of trees contributing to improved air quality, minimizing noise pollution, protecting rivers from nutrient pollutant runoff, and in maintaining biodiversity. This course will discuss this broad spectrum of notions concerning urban forestry.

CT categories: Recollection, Evaluation (data analysis and visualization)

author: Liam Heneghan, Environmental Sciences, LA&S

4.7.1 DeepMapping Lincoln Park

Municipal programs lack some basic vital statistics on the health of the urban forest—for instance, what trees do well and under what environmental circumstances? Having accurate and site specific information addressing such questions could assist in planning plantings, save considerable resources, and ensure a maximum return on municipal investment in the urban forest. This class will contribute to the design of an evaluative program for the distribution, health, and analysis of the diversity of trees in a large urban park. In addition, we will also work on a parallel process of soliciting narratives from the community about their perception, memories, and associations with the park. The aggregated information will then be visually presented using mapping software. We refer to this combination of qualitative assessment of resources and the integration of narrative approaches to human responses to these resources *DeepMapping*. Through work on this project, students will learn how to efficiently store, retrieve, analyze, interpret and communication the results of a complex project.

CT Learning Goal 1: The collected data will be stored in a certain way and then analyzed using tools such as Excel or SAS. Student learn how to store the data is a structured way to allow for easy and efficient access to the data by the analysis tools. (CT Category: Recollection.)

CT Learning Goal 2: Students learn how meaning can be extracted from a large data set using statistics, statistical tools and/or data mining. Students understand that the meanings/ aggregated information from a data set can best be represented using visualization; students learn to represent aggregated data visually using mapping software. (CT Category: Evaluation—data analysis and visualization)

DeepMapping Lincoln Park, case discussion: Students will gather information on park trees using handheld Garmin Geographical Positioning System (GPS) units. Data collected in the field on GPS handheld and backed-up and supplemented with field notes are downloaded into a Geographical Information System [GIS] and analyzed by a variety of tools, including EXCEL and SAS. The ultimate output will be a map, summary statistics and plots of relative frequency. One of the goals of the activity will be to develop a meaningful integration of the narrative and quantitative components. This will be done through mapping technology which allow the embedding of pictures and wav files into a single map of the park. Throughout, students will be taught techniques for data collection, storage, retrieval, analysis, and visualization.

Assessment: To be done.

4.8   GEO (Geography) 241: Geographic Information Systems I

Catalogue description: An introduction to the fundamentals of geospatial information processing. Special topics include spatial data types, map design, and animation. Instruction is accomplished through lectures and hands-on computer lab exercises.

CT categories: Design (abstraction)

author: Julie Hwang, Geography, LA&S

4.8.1   Representing land, water and other geographic features in a GIS

GEO241 introduces basic concepts and methods that underlie information systems designed to deal with geographically referenced data. Students will get to understand characteristics of geographic data, and learn to apply GIS methods and tools to display and analyze geographic data. Two types of data models are used to represent spatial entities in GIS: vector and raster. A vector model represents spatial entities based on a set of points (or vertices). A raster model represent spatial entities based on a set of regular grid cells.

CT Learning Goals: Students will be able to understand different ways in which spatial entities are abstracted into data (that is spatial data modeling) and comprehend technical and conceptual challenges with and the utility of spatial data modeling. (CT category: Design)

Geograhical Features Representations, case discussion: Imagine you're flying over the State of New York. Let's focus on two natural landmarks: the Adirondack Mountains and

Lake Ontario. Given your understanding of GIS data models reviewed earlier, consider what data model would be suited to representing spatial properties of the Adirondack Mountains, and Lake Ontario. Spatial properties can be generalized into characteristics specific to point, line, area, and volume in terms of geometry type: location, length, direction, area, shape, and concentration. Sketch the vector and raster view that represents the boundary of Lake Ontario.

Q1. Take a close look at your sketch of the vector view. In what way would a vector model be limited in representing the boundary of Lake Ontario? Is there any merit that a vector model offers in representing the boundary of Lake Ontario?

Q2. Take a close look at your sketch of the raster view. In what way would a raster model be limited in representing the boundary of Lake Ontario? Is there any merit that a raster model offers in representing the boundary of Lake Ontario?

Sketch the vector and raster view that represents the elevation of the Adirondack Mountains.

Q3. Take a close look at your sketch of vector view. In what way would a vector model be limited in representing the elevation of the Adirondack Mountains? Is there any merit that a vector model offers in representing the elevation of the Adirondack Mountains?

Q4. Take a close look at your sketch of raster view. In what way would a raster model be limited in representing the elevation of the Adirondack Mountains? Is there any merit that a raster model offers in representing the elevation of the Adirondack Mountains?

Assessment: The students' job is to estimate the fraction taken by green spaces in Chicago using two sets of data – DLG (Digital Line Graphs) and DOQ (Digital Orthophoto Quadrangles) – that cover the City of Chicago. DLG is vector data and DOQ is raster data. The fraction of green spaces from DLG will be calculated as the sum of vector areas that constitute green spaces divided by the total land area of Chicago. The fraction of green spaces from DOQ will be calculated as the sum of raster areas that constitute green spaces divided by the total land area of Chicago. Vector areas are the sum of trapezia marked as green spaces. Raster areas are the sum of pixels marked as green spaces. The students will answer the following questions:

- Suppose that it turns out that results (that is the fraction of green spaces from DLG and the fraction of green spaces from DOQ) are quite different. What would explain the difference? (This question tests whether students understand the concept of abstraction, more specifically building blocks of the respective data model and its consequences on estimation results.)

- What data model do you think yields better estimation results? Why do you think so? Be sure to link the respective data model to characteristics of geographic phenomena

measured. (Through this question, students show their understanding about the relative strengths and weaknesses of the respective data model for representing spatial properties of different geographic phenomena.)

- Do you think that getting the estimate of the fraction of green spaces from digital data is any better than alternative methods like a field survey? If so, in what way? If not, in what way? You should answer both questions (that is, why better and worse). (This question evaluates students' understanding of why abstraction is used, and what limitations abstraction would pose.)

4.9 HCI (Human-Computer Interaction) 201: Multimedia and the WWW

Catalog description: An introduction to the World Wide Web and web development for non-technical majors. Students will create web pages using a WYSIWYG editor. Students will evaluate web sites using a variety of analytical and empirical methods. Students will conduct technology-related experiments following the principles of the scientific method and use technology to analyze their results. Topics include web-based technology, creating content for distribution on the web, and design principles for web sites.

CT categories: Communication, Design, Recollection

Author: Craig Miller and Ljubomir Perković, College of Computing, CDM

4.9.1 Communication protocols

See 4.10.1.

4.9.2 Class Membership

A class is the abstraction of key properties of objects and patterns. It is used to hide less relevant or variable properties of the object or pattern and to provide a way to create multiple instances (of objects or patterns) sharing the same properties.

CT Learning goal: Students can identify a group of (e.g. visual) elements that should all have the same property and abstract them into a class; they should then be able to specify class-wide (e.g. visual) properties that achieves the desired uniformity of the visual elements. (CT category: Design)

Style classes, case discussion: A style rule (using CSS) may specify visual formatting properties for a class. These formatting properties are then applied to all HTML tags that have the same class name as the style rule.

Q1. How does the use of a style class promote a consistent design across multiple web pages?

Q2. Can the class name by any sequence of characters? What are the advantages of giving it a meaningful name?

Assessment: The students will write a CSS rule that will format all HTML tags of a specific class so that their content appears in a particular color.

4.9.3 Relative vs. Absolute References

See 4.10.3.

4.9.4 Tree Structure

Trees are used as a structure for hierarchical data organization. The big idea is: organize large amounts of items into groups and continue partitioning each group into subgroups, recursively. A tree data structure allows efficient insertion and search. Understanding and using a tree data structure is a computational thinking instance that belongs in the Recollection category.

CT Learning Goal: Students recognize the application of a tree structure to organize data; they are able to take advantage of the structure to efficiently locate/reference data in the tree. (CT category: Recollection)

File System Structure and URLs, case discussion: URLs consist, basically, of a hostname and a pathname. The pathname is just the file system (relative) pathname of the file with the content identified by the URL. The file system pathname uses the hierarchical terminology to reference a file on a computer.

Q1. Do you know anyone with 50 files on their desktop? How easy is it to find a file with this organization?

Q2. How are folders useful for organizing and finding files?

Q3. What's a good number of folders? If we have a large number of files, then we might end up with too many folders? How do we continue organizing the folders?

Q4. If I have 1000 files and 5 folders at each level. How many levels do I need?

Q5. How do we search for a file in a file system?

Q6. How can we represent a file location as text? How do URLs do this?

Site Maps, case discussion: A web site is often organized as a tree. Web sites exist to offer content that can be partitioned into groups and, recursively, into subgroups. This organization is to help users find the content they are looking for.

Q1. How does a tree structure aid users in finding needed content on a web site?

Q2. How are web site categories organized within a tree?

Q3. How is navigating through a web site like searching through a tree?

Q4. Examine the web site for your college or university. Discuss how pages and links match a link structure? Are there links that do not match a tree structure?

Domain Name Servers, case discussion: The Domain Name System is a computer application that connects many servers around the globe to provide the following service: translating a hostname to an IP address. (The destination host IP addresses is required to send information to it.) Domain name system is hierarchically organized to allow for efficient search of the DNS server that can provide a current IP number for a given a hostname.

Q1. Why have IP addresses? Why have hostnames?

Q2. How does the domain name system find an IP number?

Q3. How does the hierarchical structure of the Domain Name System reduce the number of DNS queries for finding an IP number?

Q4. How does this hierarchical structure allow for distributed managing of the hostname/IP address pairs?

Assessment: Students will be given a visual representation of a simple file system tree and will answer several questions:

- Give the absolute pathname of file X

- Give the pathname of file Z relative to ancestor folder Y

- If moving folder D into folder C, list the files that will move as well.

4.9.5   Caching

See 4.10.5.

4.10   IT (Information Technology) 130: The Internet and the Web

Catalog description: An introduction to the Internet, the World Wide Web, and web development for students with a strong interest in technology. Students will create interactive web pages by writing HTML and CSS and by programming in JavaScript. Topics include the origins of the web, the roles and operations of web browsers and web servers, interacting with

web applications through forms, and using style sheets to separate document structure and document formatting.

CT categories: Communication, Design, Recollection

Authors: Craig Miller and Ljubomir Perković, College of Computing, CDM

4.10.1   Communication protocols

When two entities communicate, and particularly if they do so in an automated way, they follow a protocol that specifies, at any given step, the state of each entity (and, in particular, who is listening/receiving and who is talking/sending a message), messages that can be received/sent, and a state transition function that maps (state, received message) pairs to (new state, sent message) pairs. A student who understand how to break down the structure of communication protocols will be a more effective user of them.

CT Learning Goal: Students understand that automated communication requires a precise communication protocol, including a specification of the set of states the communicating entities can be in and, for each state, the set of messages the entities can receive/send. (CT category: Communication)

TCP/IP protocols, case discussion: The Internet provides two fundamental communication protocols: TCP for connection-oriented reliable communication and IP for best-effort connection-less communication. Sending an IP message is like sending a letter through the mail: the USPS will do its best to deliver it, without guarantees. TCP uses IP for message transport but augments it with the requirement that the receipt of every message must be acknowledged (using an IP ACK message) to the sender. An unacknowledged message will be resent.

Q1. What states/messages are required for the IP protocol? What is the advantage of the IP protocol? What is the disadvantage?

Q2. What state/message types are needed, at a minimum, for the TCP protocol?

Q3. What state transitions can you describe?

Q4. What is the advantage of TCP? What is its cost?

HTTP protocol, case discussion: Web browsers and web servers communicate using the HTTP protocol. The web server is waiting for client requests in a listening state. A click of a hyperlink in a client-side browser will create a TCP connection between client and server. This connection will be used by the client browser to send a HTTP "GET" message to the server along with the url of the requested resource. The server will respond with a reply code and, if the request was successful, the requested content.

Q1. What happens when we click on a hyperlink? How does the browser connect to the web server hosting the resource? Should this be a reliable or unreliable connection?

Q2. What information should the request message contain?

Q3. What information should the reply message contain? How are errors handled?

Assessment: Web browsers cache recently visited content. Future requests for the same content can be served from the cache. How long should the browser be doing this? Well, it depends on the content and the content owner (web server) determines this. How can you augment the HTTP protocol to let the web content server inform the web browser how long should the cached content be considered fresh?

4.10.2 Class Membership

See 4.9.2.

4.10.3 Relative vs. Absolute References

A setting or a location can be specified relative to a current state or in terms of an absolute specification. For example, a location of a building can be specified relative to a current location (e.g. 3 blocks north of here) or by an absolute location (e.g. 25 S. Elm St.,). The concept of relative and absolute references are commonly used in IT applications and include file name references, cell references in a spreadsheet and configuration settings, such as those used in page formatting. Being able to understand and use absolute and relative references is an example of computational thinking.

CT Learning goal: Students can find the relative reference given an absolute reference and state; vice versa, they can reconstruct an absolute reference based on a state and a relative reference. (CT category: Design)

Referencing URL/File location, case discussion: Items in a tree structure can be referenced through an absolute pathname, i.e. the sequence of groups containing the item, from largest to smallest. In many cases, these structures can be iterated through and a relative pathname to an item is defined from the current group (containing the item).

Q1. Given a web page and a hyperlink to another web page at the same web site, describe absolute and relative references

Q2. Why use relative references? How is a relative hyperlink reference useful if you transfer your files to a web server? What if you had used an absolute reference and then moved your files?

Q3. Consider a file finder application: which user actions would make use of absolute references?

Q4. Consider a file finder application: Which are relative to current location?

Style Property Settings, case discussion: Many style properties can be specified by an absolute setting or relative to the current setting. For example, a margin setting may be given in terms of an absolute amount (1 inch margins) or relative to the current setting (increase current margin setting by 5em).

Q1. When is it useful to specify a relative setting?

Q2. When is it more useful to specify an absolute setting?

Assessment: Students will be given a visual representation of a simple file system tree and will answer several questions:

- Give the absolute pathname of file X

- Give the pathname of file Z relative to ancestor folder Y

- If moving folder D into folder C, list the files that will move as well.

4.10.4   Tree Structure

See 4.9.4.

4.10.5   Caching

Caching replicates data originating from a remote resource locally, so it is close to the consumer of the data. The goal of caching is to improve data access latencies. What data is cached will depend on assumptions about future data accesses which are usually not deterministic. Understanding the usefulness of caching and the ability to reason about what data to cache is example of computational thinking that belongs in the Recollection category.

CT Learning Goal: Students understand the purpose of caching; they understand the issue of limited cache capacity and usability, and that the choice of what to cache is based on assumptions about future data access; they understand that cached data may be stale and will need to be re-synched with the original data. (CT category: Recollection)

Web Browser Caching, case discussion: Web browsers cache recently visited web pages to improve response times. The assumption is that future web page request will match recent web pages requests.

Q1. What web sites do you get back to quite often?

Q2. Do you mind waiting for a web page to load?

Q3. How can you minimize waiting for web pages you visit often?

Q4. Your solution raises issues of cache consistency. How do we deal with it?

DNS caching, case discussion: DNS servers cache recently obtained <hostname, IP address> pairs to improve response times. The assumption is that future DNS requests will match recent ones.

Q1. How many DNS servers need to be queried in order to obtain an IP address for a web host in Sweden?

Q2. What penalty do we pay when we move from web page to web page on this Swedish host?

Q3. How do we using the caching concept to shorten the latency of web page downloads from this web site?

Assessment: Student will be given the example of phone number caching on cell phones and will be asked the following questions:

- Why do cell phones cache recently dialed or received numbers?

- Why not cache every number ever seen? What limits the cache capacity? Is it just memory capacity or other factors?

- Give a reasonable argument for what numbers should be cached. Most recent? Dialed most often? Both?

- Is there an issue of cached data staleness in this example?

5   Arts and Literature Liberal Studies Domain

5.1   ANI (Animation) 201: Animation I

Catalog description: Course introduces a variety of basic animation techniques for cinema and gaming, such as hand-drawn, cutout, stop-motion and (very basic) 3D, with an emphasis on the use of computer technology. Examples of diverse animation genres and styles (experimental, cartoon, anime, special effects, computer games) from different cultures will be screened and discussed. Students will explore the unique qualities of the medium through a series of hands-on projects that can be adapted to their own personal interests. They will

learn about professional animation process (storyboard and animatic) during the production of a final project that encourages them to consider the role and potential of animation in our society.

CT categories: Automation

Author: Scott Roberts, School of Cinema and Interactive Media, CDM

5.1.1 Scripting for hand-drawn animation

If digital video is analyzed at the level of the frame, it can be abstracted into large amounts of discrete, incrementally changing data. Using scripts in applications such as Photoshop, After Effects and Maya, manipulations of one frame can be automated and applied to any number of other frames; the automation of changes enables freer creative experimentation with an efficient feedback process. A student who recognizes the way that these processes can be separated and adapted to multiple uses and software will be able to work faster and with more creative control.

In ANI 201 Animation I students are introduced to hand-drawn animation, an art form that appears far removed from computation. Since its discovery in the late 1800's, however, technological innovation has been critical for the practical and economical production of hand-drawn animation due to the large number of drawings required (from 8-24 drawings per second). One aspect of the process, the cleaning up and resizing of the scanned drawings, can be made simpler by using Photoshop's Action and Batch Processing tools.

CT Learning Goal: Students should understand the pragmatic value of automation for digital media manipulation. They should be able to apply the principles of automation to a variable set of objectives in a production environment. (CT category: Automation)

Automating animation, case discussion: After completing approximately 60 drawings for the project, students input the drawings into Photoshop using a flatbed scanner that has been adapted to 3-pin registration (a method that allows accurate registration between successive drawings).

Q1. What are the limitations of the Adobe batch processing system? What can't it do?

Q2. How does the creation of a batch processing script differ from creating a computer program?

Q3. How could the ideas of batch processing be applied to other animation/video software, such as Flash, After Effects, Maya or Final Cut?

Q4. Show and discuss a simple example of using the scripting system in After Effects.

Assessment: Students will adapt the script created in class to other situations and they

will be assessed on whether they effectively apply it to enable flexibility, experimentation, and creativity. For example:

- Students will choose a step in the automated process and batch process the same group of files using different settings. Possibilities include: resizing the target frame, changing the levels settings, applying a sharpen filter, cutting a section of the image that contains an unwanted scanning artifact, etc.

- Students will be asked to figure out how to best tackle a production problem using batch processing. For example:

  You have a set of 100 high resolution images that are to be processed for use on a website. You are asked to create one set of the images resized to 600 pixels wide with high quality JPEG compression, and another set resized to 300 pixels wide with medium quality compression. Describe the steps you would take to accomplish the tasks efficiently using batch processing.

5.2 ANI (Animation) 230: 3-D Modeling

Catalog description: This course covers introductory modeling and texturing techniques required to construct 3D objects and scenes to be used for animation and gaming. Topics to be covered include: scene composition, modeling 3D objects with polygons and smooth surfaces, surface materials and texturing, cameras, lighting and rendering.

Categories: Design, Automation, Computation (randomization)

Author: Joshua Jones, School of Cinema and Interactive Media, CDM

5.2.1 Modularization in complex 3D modeling

Because most 3D model are inspired by or have a foundation in the world we are familiar with, there is an inherent complexity in what a 3D modeler is expected to achieve in order to give their models an accepted level of believability. On the other hand, the production time and the computer processing of 3D models require them to be simple, not complex. Techniques such as abstraction, modularization, automation, and randomization are necessary to create realistic models that can be efficiently designed and processed.

CT Learning Goals: Students are able to identify visual patterns in a complex environment or object in order to break it into groups of repetitive modular components. They are then able to use automation and randomization to efficiently design a realistic reconstruction of the environment or model in 3D space. (CT categories: Design – abstraction, Automation, Computation – randomization)

Environment Modeling, case discussion: When one considers the problem a modeler faces when she is required to create a field of grass, it quickly becomes apparent that modeling

each individual blade, texturing it, and placing each in a scene would be a completely inefficient use of time and even then may not result in a usable finished model. Using modularization and automation, a 3D modeler would instead create a single blade of grass which would then be duplicated to fill the required area. The organic" seeming placement, rotation, scale, and relative color of individual blades can then be achieved either by a simple randomization script or (more often than not) some random clicks of the mouse.

Students are required to model an interior warehouse environment out of simple polygon primitives. Along with modeling a simple I-beam skeleton, they must create a believable space by modeling three different kinds of inventory and then by arranging them appropriately within the warehouse.

Q1. What challenges are presented when trying to fill the warehouse space with inventory?

Q2. Describe some ways in which those challenges can be met? What are the advantages and disadvantages to each solution?

Q3. Do the solutions change depending on whether the warehouse is modeled for a film as opposed to a video game?

Q4. What issues arise from duplicating model groups? How can these issues be addressed?

Q5. What types of model attributes can randomness be applied to? Which ones give desirable results?

Q6. Does using an automated script for randomness offer any benefits over creating it by hand? Are there benefits to doing it by hand?

Assessment: Students will be required to turn in both 3D models and rendered images of a finished warehouse space. Both images and model will be evaluated for the student's ability to:

- Assemble efficient groups of modular components.

- Create the illusion of a complex space through the duplication of modular components.

- Break the patterns of repetition of warehouse inventory with randomization.

5.2.2   2-D Filters and Procedural Texturing

3D texture artists and modelers can use image filter to create textures from brushed metal to rotting wood. They can also be used to alter existing textures to create a stylized look for their piece. Image filters like the ones commonly available in programs like Adobe Photoshop have completely changed the approach an artist can take to creating digital images from one that uses hand-eye coordination and a mouse, to one that uses computational thinking. Instead of

hand painting all the detail in a texture, an artist will decide on a filter or a series of filters they believe will produce the effect they are looking for. They will then play with various parameters of the filter to achieve the desired effect. In Photoshop, the number of parameters a filter can have generally varies between 2 and 6, and each parameter can have a range of a single digit whole number to a floating point value that goes to 100. The total possible combinations of all these parameters can easily number in the millions. As there is no way for an artist to know the exact combination of parameters that will create the look they are going for, they must be able to first identify the different patterns within the desired texture. Once patterns have been identified, the artist can then begin layering the filter algorithms and evaluating the massive amount of visual data for the best possible solution. While many seasoned Photoshop professionals will of course have a favorite few filters with set parameters, all of them will be well versed in using them as a kind of exploratory paintbrush.

CT Learning Goal: Students are able to identify visual patterns within a given texture and then experiment with a selection of filter algorithms to recreate or exaggerate the original texture. Students can evaluate the texture at all stages of creation in order to select the next layer of filters and/or filter parameters that will result in a more convincing texture. (CT category: Evaluation)

Image Filters in Bitmapped Texturing, case description: Students use a series of Photoshop filters to create a texture that gives the impression of brushed metal complete with dirt, dents, and scratches. When complete, the texture will be applied to a 3D model. Students will first have to look at a photograph of the brushed metal they are trying to reproduce in order to determine what filters might be used to recreate it. Once likely candidates have been chosen, they will then begin applying the filters and adjusting parameters to create the final product.

Q1. How does making a texture with a filter change the way you think about creating?

Q2. What advantages or disadvantages does using a filter to achieve an effect have over doing it by hand?

Q3. How can a filter be used as exploratory tool?

Q4. In what ways can a filter be limiting? Advantageous?

Q5. What role does the base image play when creating textures with filters? How does changing the base image affect the final result?

Q6. How does using multiple filters on one image change our ability to create?

Q7. Is there a more efficient or effective method of image modification/creation?

Assessment: Using filters, students will be required to recreate a realistic texture that is given to them in class. The rendered images will be evaluated for the student's ability to:

- Recognize the different visual patterns within the original texture.

- Use abstraction to choose appropriate filters for recreating patterns.

- Evaluate the combinations of filter parameters to find the ones that provide the most convincing recreation of the original texture.

5.3 DC (Digital Cinema) 201: Introduction to Screenwriting

Catalog description: This course is an introduction to and overview of the elements of theme, plot, character, and dialogue in dramatic writing for cinema. Emphasis is placed on telling a story in terms of action and the reality of characters. The difference between the literary and visual medium is explored through individual writing projects and group analysis. Development of synopsis and treatment for a short theatrical screen play: theme, plot, character, mise-en-scene and utilization of cinematic elements.

CT categories: Design

Author: Matthew Irvine, School of Cinema and Interactive Media, CDM

5.3.1 Screenplay structure

Narrative motion pictures follow the same general structure that consists of five key plot points and six stages. These stages and plot points have the same narrative purpose for every script and occur, generally, at the same point in time as the stories unfold.

PLOT POINT #1: *Inciting Incident*

Usually five to ten minutes into a feature film or five to ten percent in, an event must occur that spins the plot into motion. The event changes the hero's path and presents them with a new, very visible desire, which starts them on their journey.

PLOT POINT #2: *Leaving Port*

At this stage of the film, thirty minutes for a feature or one-fourth of the way in, something must happen to the hero that clarifies their goal and solidifies their need to obtain it. It is where the hero leaves port on the main voyage of their journey toward their goal. This point spins the action into a new direction and moves the story into the main conflict of Act II.

PLOT POINT #3: *Crossing the Rubicon*

At the midpoint of the screenplay, the hero must be tempted to turn back only to realize they are far too deep in on their journey. They have crossed the Rubicon and can never return home or to their lives before the journey took place. They must be fully committed to achieving their goal at this point.

PLOT POINT #4: *Hits Bottom*

>   Around page seventy-five or so, the hero must be confronted with a major setback in their quest. The audience must believe there is little hope for success in our hero's quest. The hero should also come to terms that there is only one option for them in their pursuit of their goal and this knowledge must spin them into a final push toward the climax.

PLOT POINT #5: *Climax*

>   Here is where the hero makes a stand and confronts the antagonist or major obstacle preventing them from obtaining their goal. It is the final struggle to win. Our hero or heroine succeeds, fails, lives or dies.

CT Learning Goal: Students should demonstrate competency in abstracting the structure of a narrative screenplay by breaking down the three-act structure and five plot points to motion pictures. (CT category: Design)

The Feature, case discussion: The structure of the three-act narrative creates the feature-length script's spine, which the student can then flesh out in any way he or she is so inclined to do so. These rules of structure also provide students an opportunity to use abstraction when thinking of major turning points or plot points within the screenplay. Knowing that the inciting incident or turning point #1 must occur at page 15 to 18 (10% into the script) means a student has a very limited amount of time to set up the three basic components of the script: character, desire and conflict.

Understanding the stages and turning points provides screenwriting students with a powerful tool for developing and writing their feature screenplay. Having these basic sets of rules in place, allows a student greater freedom to explore more personal and creative elements of their screenplay.

Q1. Is there an inciting incident?

Q2. Is the story concept defined at the one-quarter mark?

Q3. Have they fully introduced the hero before presenting him/her with an opportunity around page 10?

Q4. Is there a turning point at the end of Act I?

Q5. Does the hero hit "bottom" at the end of Act II?

Q6. Does she/he suffer a major setback 75% of the way into the script?

Assessment: Students will compare Flops and Blockbusters to Reveal Structure:

- Students will take the screenplays to three successful motion pictures (100 million dollars or more at the box office) and three box office flops all of the same genres and break them down using the THREE ACT STRUCTURE as well as the FIVE PLOT POINTS.

- Students will then compare the six scripts and plot them out using the structure formula outlined in class. They will then draw some conclusions on the theme, metaphor, premise, moral and hero's journey from their script comparisons.

- Through this breakdown and comparison students will discover which screenplays follow the three-act structure and five plot points and which ones do not. In comparing the different plot points, paying close attention to the inciting incident, for comedies and dramas students will use Abstraction in determining why some motion pictures are successful (box office hits) while others are not despite being from similar genres.

- This assessment is intended to allow students to show that they have a clear understanding of the stages, turning points and overall structure of narrative cinema.

5.4 GAM (Gaming) 224: Introduction to Game Design

Catalog Description: This course approaches the study of computer games from three directions angles: first, as examples of media that can be analyzed and critiqued for their thematic elements, formal structure, plot and interactive appreciation; second, as complex software artifacts subject to technological constraints and the product of a labor-intensive design and implementation process; and three as a cultural artifact with behaviors and associations comparable in import to other popular art forms. Student will study the principles of game design and use them both to analyze existing games and to develop their own original game ideas. Students will also learn about the process of game development, starting from the game's narrative concept and moving to consideration of a game's components: the representation of the player, of artifacts, the virtual world that contains them and the interaction between them and the player.

CT categories: Coordination, Design

Author: Amber Settle, School of Computing, CDM

5.4.1 Representation of Game Rules

Game rules can be categorized into three types: constitutive, operational, and implicit. Operational rules are the guidelines players require in order to play, such as the rules printed on the box of a board game. Constitutive rules are the underlying logical and mathematical structures in the game. Implicit rules are the unwritten" rules of the game, such as rules about decorum. Important here are the first two types of rules: constitutive and operational. Two games are considered to be the same if there is a 1-1 relationship between the constitutive rules of the two games, so that if you can find a winning strategy in one game you can use

the mapping to find a winning strategy in the other game. At the same time, the operational rules for two structurally identical games can vary significantly. While the operational rules are what make a game enjoyable to play, the constituative rules are the ones that more experienced players are using when they find winning strategies.

Abstracting game rules in different ways is an example of computational thinking; it allows students to see the relationship between different abstractions of rules, the modeling of game behavior, and the underlying structure of a game.

CT Learning Goals: Students will be able to abstract the operational rules of a simple board game to find the underlying constituative rules for the game and use the constituative rules to comment on strategies that may exist for the game. (CT category: Design)

Tic-Tac-Toe and 3-to-15, case discussion: Students will consider the well-known rules of Tic-Tac-Toe as well as the rules of 3-to-15 described as follows:

1. Two players alternate turns

2. On your turn, pick a number from 1 to 9. You may not pick a number that has already been picked by either player.

3. The first person to obtain a set of exactly 3 numbers that sum to 15 wins the game

4. If all numbers between 1 and 9 have been chosen and no player has a subset that sums to 15, the game ends in a draw

Q1. What strategies exist for Tic-Tac-Toe? Include both strategies for winning and for preventing the other player from winning.

Q2. What strategies exist for 3-to-15? Include both strategies for winning and for preventing the other player from winning.

Q3. Are the two games the same? Why?

Q5. Translate a strategy for Tic-Tac-Toe into a strategy for 3-to-15. For example, describe a blocking strategy for 3-to-15 derived from a blocking strategy for Tic-Tac-Toe.

Q6. Which game is easier to play using its operational rules? Why?

Chutes and Ladders, case discussion: The Chutes and Ladders children's board game will be considered. The goal of this activity is to find the set of constituative rules of Chutes and Ladders.

Q1. How can you represent the spinner? How can you represent the player's movement on the board without using a board? How will the chutes" be represented? Explicitly list all of the constituative rules that must be included for the chutes" in the game. How

will the ladders" be represented? Explicitly list all of the constitutative rules that must be included for the ladders" in the game.

Q2. How do you handle the winning condition using this model?

Q3. Does the purely constituative version of Chutes and Ladders have the same feel as the original game?

Q4. Are there any strategies that the constituative rules make clear to you?

Assessment: Consider the board game Candyland. Develop a set of constituative rules for Candyland by:

1. Constructing a table that represents the positions on the board for each of the color blocks and picture cards. The table should include a representation for the two shortcuts (gumdrop pass and rainbow trail).

2. Describing a way to randomly produce each of the card combinations from the deck.

3. Describing how each of the 3 penalty spaces (gooey gumdrops, lost in the lollypop woods, and stuck in the molasses swamp) will be handled in your rules.

4. Describing the winning condition for the game.

After you have constructed the constituative rules, describe any strategies that the rules make clear. If there are no strategies that your constituative rules illuminate, explain why that is. Is it a property of your representation? Or is it a property of the game?

5.4.2   Classifying feedback loops

While discrete models can be used to understand simple games (like Tic-Tac-Toe), complex games such as modern computer games are better modeled as cybernetic systems. In a cybernetic system, the "encouragement" of movement in a certain direction is called a positive feedback loop. A positive feedback loop has the effect of creating exponential growth or decline in some aspect of the system. On the other hand, the "discouragement" of movement in a certain direction is called a negative feedback loop, and its effect is to stabilize a system or maintain equilibrium. In order to create a game that is balanced, students must understand how the alteration of the game state through positive and negative feedback loops affects the player's perception of the fairness and competitiveness of the game. It requires students to model and understand the internal state of a game system, the mechanisms detecting the game state, and the mechanisms altering the game state. Students would in these case use coordination and evaluation computational thinking skills.

CT Learning Goals: Students will be able to describe what a negative or positive feedback loop is, how such a feedback loop can be incorporated into an existing game, and how that

feedback loop impacts the experience of both winning and losing players in the game. (CT category: Coordination)

Feedback Loops, case discussion: A cybernetic system is one in which the behavior of the system is controlled by a negative feedback loop, a positive feedback loop, or in some cases, several of each. A negative feedback loop acts to move the state of the system in the direction of its previous state. A positive feedback loop acts to move the state of the system in the direction it is currently moving.

Students will consider game rules found in common board games and be consider the following questions for each rule:

Q1. Classify each rule as a positive feedback loop, negative feedback loop, or neither.

Q2. If positive, indicate what direction the game state is moving in and how the rule aids the movement of the state of the system.

Q3. If negative, indicate what state the rule is trying to preserve and how the rule keeps the game in that state.

Q4. If neither, indicate why.

Q5. If negative or positive, describe the impact that the rule has on a player who is winning and the impact that the rule has on a player who is losing. How would each type of player perceive the rule?

Game rules that may be considered are:

1. You must reach the final/winning square (square 100) in Chutes and Ladders with an exact roll. For example, if you are on square 96 and you roll a 6, you do not advance but instead lose your turn.

2. In Checkers, if a piece reaches the far end of the board, then it becomes a king". A king" is allowed to move and jump diagonally backward and forward, unlike ordinary pieces which may only move and jump diagonally forward.

3. In Candyland, penalty spaces on the board cause players to remain stuck in a certain position until they draw a specific card that frees them from the space.

4. Players landing on properties owned by another player in Monopoly must pay rent. A player who owns an entire color group of properties may charge double the rent for any unimproved property in that color group.

Case description: Describing feedback loops

Pick one example of a positive feedback loop and one example of a negative feedback loop in a computer game you have played. For each of the positive and negative feedback loop examples you describe:

Q1. Describe the direction that the game state is moving when the positive feedback loop begins, and how the positive feedback loop enhances that game state.

Q2. Describe the state that the situation or rule is trying to preserve, and how the negative feedback loop causes the game state to be stabilized.

Q3. Describe how the positive feedback loop enhances the game play. Be specific about how the positive feedback loop modifies game play, paying special attention to its impact on both the winning and losing players.

Q4. Describe how the negative feedback loop enhances the game play. Be specific about how the negative feedback loop modifies game play, playing special attention to its impact on both the winning and losing players.

Assessment: Consider an existing board, card, or computer game. Modify the game to include a positive or negative feedback loop not already present in the game. In doing so, describe:

- Precisely where in the game (under what circumstances and when) you are introducing the negative or positive feedback loop

- How the negative or positive feedback loop works, and what game state it is either enhancing (in the case of a positive feedback loop) or stabilizing (in the case of a negative feedback loop)

- How your change to the game makes it more fun. What balance issues is the change to the game addressing? How will the change to the game affect winning and losing players? Do you anticipate any potential problems that your change could introduce?

5.5 HAA (History of Art and Architecture) 130: Principles of European art

Catalog Description: An introduction to the art historical methods and their application to a broadly chronological and select survey of the European world from pre-history to the 20th century. Field trips to Chicago art institutions extend the visual traditions and critical methods taught in class lectures and discussions.

CT categories: Evaluation, Design

Author: Elena Boeck, History of Art and Architecture, LA&S

5.5.1 Categorizing Subjects of Art

Worldly and religious authorities have often been the main subject of art across time and across European cultures. By studying a sample of art objects from a particular culture,

analyzing the subject of the art sample, and categorizing the art objects by what type of authority they represent, if any, one can learn the role art had in the culture, and also about the culture itself.

CT learning goal: Use data gathering and simple data analysis to find the distribution of the data into several categories. (CT category: Evaluation)

Categorizing subjects of art, case discussion

We will consider three separate cultures in three different periods covered in three course textbook chapters.

Q1. Establish the proportional relationship between images of individuals of worldly authority (such as rulers, generals, etc.) and religious authority (such as divine figures, gods, saints, priests, etc.) in each chapter, also noting in a separate category any images that overlap (i.e. that represent a ruler together with a divine figure, such as Augustus of Primaporta)

Q2. Establish the proportion of images in each of the three chapters that represent architecture (including architectural sculpture.) (The category of architecture includes buildings, building plans, architectural sculpture, windows, or other features that cannot be detached from a structure.) Identify those that serve primarily non-religious purposes (private houses, museums, etc.) and those that serve primarily religious purposes (temples, altars, etc.), also noting those that overlap in function.

Q3. Establish the similarities and differences in the images as compared across chapters.

Assessment: Has the student used collected and categorized the data correctly? Are the students arguments backed up by a reasonable quantitative analysis of the data? Student will also explore how the textbook presents different cultures based on the selection of images (focusing on the concept of authority). They will analyze and attempt to explain patterns of selection and distribution of images in the textbook.

5.5.2   Symbols of Authority

In art whose subject is worldly or religious authority, there are cues/iconographic features that communicate that authority. Sometimes the same cues of authority appear across time or cultures.

CT learning goal: Students learn to abstract away symbols of authority that keep being used across time and cultures. (CT category: Design)

Symbols of Authority, case discussion: We will consider three separate cultures in three different periods covered in three course textbook chapters. After having identified images of authority in each chapter (in the above example):

Q1. Analyze the most important iconographic features that communicate authority in these images in each individual chapter (such as the figures height, direct eye-contact, open gesture, expensive material, particular symbols, etc.).

Q2. Consider the role of architecture in construction of authority. Are there similarities and differences in the ways that architectural monuments (in the three chapters) communicate authority or reinforce secular or religious power?

Q3. Compare the similarities and differences BETWEEN images of authority in the three chapters that you selected. What kinds of patterns emerge? Are there consistent features of authority among the three chapters or are the iconographic features of authority restricted to particular cultures/periods? If there are no images of authority or a very limited number in one of your chapters, attempt to explain this in terms of changing functions of art during that period. Compare the similarities and differences in the concept of authority among the three chapters that you selected.

Assessment: Have the students successfully picked up the iconographic features determining authority? Have they been able to abstract them away to find common patterns of authority representation across time and cultures? Student will also explore how the textbook presents different cultures based on the selection of images (focusing on the concept of authority). They will analyze and attempt to explain patterns of selection and distribution of images in the textbook.

6 Understanding the Past Liberal Studies Domain

6.1 HST (History) 221: Early Russia

Catalog Description: This course examines political, economic, social, and cultural developments in Russia from the emergence of the Kievan state in the ninth century to the reign of Peter the Great in the early eighteenth century. Topics include the rise and fall of Kiev; the Mongol invasion and rule by the "Golden Horde;" the rise of Moscow and unification of Great Russia; the consolidation of tsarist authority and the reign of Ivan the Terrible; the Time of Troubles; and the early Romanov dynasty.

CT categories: Evaluation

Author: Brian Boeck, Department of History, LA&S

6.1.1 Quantitative analysis of Early Russia textbook representations

At its core computational thinking involves finding creative ways to both see and solve existing problems. In our case, the problem is how textbooks and surveys represent the history of

Russia from 1650-1750. Cracking the code means uncovering patterns of emphasis, selection and bias that shape the process of allocating space.

Our data set consists of comparative histories that discuss (however briefly) early modern Russia from 1650-1750. Collectively, we will also be contributing to a database of information on how early modern Russia is represented.

CT Learning Goal: Apply data gathering, and pattern and quantitative analysis tools to obtain insights. (CT category: Evaluation)

History textbook analysis, case discussion: Our first task is to evaluate our (Early Russia) textbook, in order to abstract/pull out important properties and to generalize relationships between them. This is like cracking a code because these relationships are not immediately evident. Often they are systematic, but implicit or even below the surface. First, we will gather the data, then look for patterns in this data. Next, we will put this raw numerical data into words.

Our second task is to do the same with a book of your choice, Text II. This outside book must meet the following criteria: 1) It must be a single book that covers three or more centuries; 2) It will be a survey of either world/global history or European history, but NOT a history of Russia; 3) It must include a discussion of Russia from 1650-1750.

Q1. Determine approximately how much space is allocated to Russia from 1650-1750. Count pages and which rulers are mentioned, and how often. Determine approximately the number of sentences allocated to Russia in the reign of Peter I (1682-1725). What percentage of the text is devoted to this period compared to the periods 1650-1682 and 1725-1750?

Q2. Determine the number of sentences in which Collective Actors are the main subject of the sentence. (Examples: the army, the nation, the population of Russia, the opposition, the church, etc.; characterized by pronouns such as they.) Determine the number of sentences that discuss negative aspects of the period such as forced labor, government corruption, or deaths of tens of thousands of ordinary Russians.

Q3. Roughly establish the total number of sentences allocated to EACH of the following specific categories: Warfare, Westernization of Culture, Peters Personality, Petersburg, and Opposition/Resistance.

Q4 Determine approximately the selection of images in sections allocated to Russia from 1650-1750, and categorize them as above.

Q5. Carefully scrutinize the results of your analysis. Have any clear patterns emerged from your investigation? Which events or actors seem to get a disproportional amount of attention?

Q6. Now repeat the same analysis for text II.

Assessment: The assessment will be performed on the students' interpretation of the data collected. They will be asked to answer the following questions:

- Are the overall patterns of allocation similar or different in both texts? Do both texts devote roughly the same overall proportion of the larger text to Russia from 1650-1750?

- Are there patterns of prioritizing either individual actors or collective actors that you can discern in both texts?

- Are there patterns in the ways that the authors discuss or do not discuss negative aspects of this period?

- Are there patterns in how both texts talk about rulers other than Peter I?

- Are there patterns in how both texts talk about Peter I?

- Which events seem to get a disproportional amount of attention in both texts?

- Are the image selections similar or different?

- What major points do BOTH texts agree on?

- What major points do BOTH disagree about?

- For each question above, how would you explain the patterns that you have observed?

6.2   HST (History) 250: Origins of the Second World War

Catalog Description: Examines the European (and world) state system in the aftermath of the First World War and the Russian Revolution; the attempts to forge a new international equilibrium at the Paris Peace Conference and after; the rise of Hitler and Nazism; appeasement; the immediate origins of the Second World War in Europe; and the rise of militarism and advent of war in East Asia.

CT categories: Evaluation

Author: Eugene Beiriger, Department of History, LA&S

6.2.1   Relative and absolute industrial growth in Germany, France, and Britain

CT Learning Goal: Understand the ways in which the data can be interpreted using absolute and relative analyses; understand the kinds of questions which need to be asked of the data and the limits of the answers provided; develop visualization techniques to present the data in order to assess specific variables..

Pre-WWII re-armament, case discussion: German re-armament programs in the 1930s eventually prompted re-armament programs in both France and Britain. These three re-armament programs were qualitatively and quantitatively different in kind and scope. And, these programs – part of each country's strategic and defense policies – were not all successfully coordinated with each country's foreign policies. By examining the output of key industrial and armament production sectors of Germany, France and Britain, we can draw some conclusions regarding their absolute and relative outputs, as well as the implications of these outputs, to gain some insights into absolute and relative advantages of each country in the period leading up to the second world war.

Q1. How do figures in industrial (e.g., iron, steel, engines, chemicals) and arms (e.g., small arms, machine guns, artillery guns, tanks, motor vehicles, ammunition, etc.) production compare *within* each country – Germany, France and Britain – in 1931 and 1939? How do we use these figures to articulate the concept of "absolute" growth?

Q2. How do figures in industrial (e.g., iron, steel, engines, chemicals) and arms (e.g., small arms, machine guns, artillery guns, tanks, motor vehicles, ammunition, etc.) production compare *between* the three countries, Germany, France and Britain, in 1931 and 1939? How do we use these figures to articulate the concept of "relative" growth?

Q3. What differences exist within production types that could allow for further analysis? In particular, for example, what arms are of a defensive nature (e.g., stationary artillery pieces, fighter planes, coastal patrol ships and destroyers) and what are of an offensive nature (e.g., tanks, bombers, submarines and capital ships)? At what levels are they being produced? How do they compare in relative term with each country?

Q4. Develop a visualization strategy (incorporating graphing software to generate comparative statistical models) which allow for us to discern more detailed differences in production categories. For instance, what differences exist within production types that could allow for further analysis? In particular, for example, what arms are of a defensive nature (e.g., stationary artillery pieces, fighter planes, coastal patrol ships and destroyers) and what are of an offensive nature (e.g., tanks, bombers, submarines, and capital ships)? At what levels are they being produced? How do they compare in relative term with each country? What implications can be derived by these visualization and modeling techniques?

Q5. In what ways do quantitative data assist us in understanding defense and foreign policy analysis? In what ways do computational data assist us to explain – in part, at least – how events played out in 1939-40?

Assessment: The following short assignment will be the main assessment tool used. Discuss the assertion that the events at the beginning of the second world war (the German invasion of Poland through the Battle of Britain) were largely shaped by the success or failure of coordinating industrial, defense and foreign policies. In answering this question, you should

be sure to incorporate your computational analyses with the readings to offer additional context to the readings, as well as to provide evidence to support your conclusions.

7 Liberal Studies First Year Program

7.1 LSP (Liberal Studies Program) 112: Focal Point Seminar (Theme: The Moon)

Catalog description: The moon has been earth's companion for billions of years and humanity's companion for thousands of years. This course will trace the influence of the moon on human culture and science from the dawn of civilization through the space race and into the present. It will touch on the moon's influence on human religion, art, science, and politics. An important theme of the course will be how humanity's perception of the moon has changed over time. Other topics will include: the moon's orbits and its effects through tides, phases, eclipses and calendars; the invention of the telescope and the first detailed maps of the moon; and modern theories of the moon's origin and evolution.

CT categories: Design (abstraction), Computation

author: Chris Goedde, Department of Physics, LA&S

7.1.1 Models for satellite and planet motion

For centuries humans have attempted to predict the occurrence of solar or lunar eclipses with varying degrees of success. The earliest models and algorithms for planetary and satellite motion were based solely on observations of the most obvious relevant celestial cycles, the lunar month and the solar year. In the 17th century, Isaac Newton's theory of gravity led to an accurate algorithm for predicting the motion of the moon, the sun, and the planets.

CT Learning goal: Modeling and abstracting the motion of planets and satellites. Students should understand that a model is built from limited information (whether by lack of information or by choice - for algorithm execution speed reasons, for example) and is an abstraction/simplification of the system that is amenable to science/simulations. (CT category: Design)

Models of planetary motion, case discussion:

We will look at different historical periods and analyze the model cultures of the period used to describe planetary motion in order to predict eclipses. For each culture we will ask the following:

Q1. What are the the basic concepts that constitute the model, including any simplifications or idealizations?

Q2. How did the model translate into an iterative algorithm for eclipse prediction?

Assessment: See Assessment in 7.1.2.

7.1.2 Eclipse prediction

CT Learning goal: The nature of iterative numerical computation. In particular, students will be able to 1) Identify the presence of an iterative algorithm, 2) Identify the appropriate initial value(s) for the algorithm, 3) Identify the fundamental transformation that comprises the algorithm, 4) Relate the transformation to the underlying physical theory (or lack thereof), 5) Repeatedly apply the transformation to the initial value(s) to obtain the desired final state, 6) Assess the validity of the algorithm by comparing its predictions to the actual behavior of the physical system.

Eclipse prediction, case discussion:

For a particular culture at a certain point in time, we will consider the eclipse prediction algorithm used, and do the following:

Q1. Describe the algorithm used to predict eclipses, including the appropriate input values for the algorithm.

Q2. Using the most recent eclipse of the sun or moon as a starting point, use the algorithm to predict the dates of the next five solar or lunar eclipses.

Q3. Describe the reliability and limitations of this algorithm, if any.

Assessment: After discussing the ancient algorithms for predicting eclipses, students will complete a homework assignment where the answer the same discussion questions for the algorithm that uses Newton's law of gravity to predict the moon's orbit.

8 Honors Program

8.1 HON (Honors Program) 207: Introduction to Cognitive Science

Catalogue description: HON (Honors Program) 207: Working under the assumption that processes of human thinking can be understood in computational terms, this course is designed to introduce students to the interdisciplinary field of cognitive science by constructing and evaluating process-oriented theories of how people think and reason. Prerequisite: Completion of Honors Data Analysis and Statistics (non-science majors); or, completion of one course in a required Math sequence (Commerce, CDM, or science majors).

CT Categories: Communication, Coordination

Author: Robert Rotenberg, Department of Anthropology, LA&S

8.1.1 Conversation protocols

In human conversation, the communication protocol involves four rules. The first rule (turn-taking) is that each speaker takes the attention of the group solely for the purpose of starting or completing a pragmatic frame, provides a clear transition point for giving that attention up to others, and in some cases, selecting the next speaker. The second rule (pragmatic frame) is that a first speakers comment opens up a direct request for others to respond to that comment. Thus, an assessment requests agreement, a question requests an answer, or a compliment requests an acknowledgment. The first speakers request specifically implies that some responses are preferred over others and that a few responses are dis-preferred. The third rule is that the turn-taking system can only be suspended for the purpose of narration (storytelling) if all the participants agree. This is known as warranting. The narrator must permit the participant to re-warrant the narration periodically. The fourth rule is that members of a conversation form a closed, ratified group. Simultaneous conversations between ratified participants are allowed, but must be brief, non-disruptive and acknowledge that the main conversation takes precedence. Conversations between ratified and non-ratified participants, like narration, must be warranted and re-warranted.

CT Learning Goals: Students will learn the rules guiding communication in a conversation: turn-taking, frame of reference, adjacency pairs, preferred response, dis-preferred response, narration, warranting of narration, ratified participants etc.

8.1.2 Conversation coordination

Coordination is achieved in human conversation through the turn-taking system, while changes in the context (person, space and time) are accomplished by specialized shifters.

CT Learning Goals: Students will learn the accepted rules, like turn-taking, shifters, and anchors, that are used by participants to coordinate a conversation.

Assessment: The class project that will occupy the class for the term will be used, in part, for the assessment of CT learning. Students will create, select, transcribe, and analyze a conversation. They will first record a conversation on tape, i.e. create their data set. Then they will transcribe the conversation: the transcription is to conversational analysis what a data table is to statistical analysis. Finally, the students will analyze the conversation. They will indicate, in the transcript, the indexes (pointers, shifters and anchors), the various adjacency pairs, framed responses, etc. Students will discuss how the communication rules and the conversation coordination can be modeled precisely using computational protocols.

References

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Appendix A

- **Algorithm** (or procedure, function): An algorithm is a set of rules that describe how to do something, or how to solve a problem. An algorithm may be described as a program, pseudo-code, or a less formal step-by-step explanation (even a recipe).

- **Data** (or variable, database, queue): Data is the information that is part of the problem/question, as well how the information is organized and how it is accessed. Distances between neighboring cities is the data for the problem of computing distances between cities, for example.

- **Abstraction** (or conceptualization, modularization): Abstraction is the pulling out of important properties and the generalization of relationships.

- **Iteration** (or loops, recursion): Iterations involve the repetition of a procedure until a desired goal is reached. In math, iterations occur in long division. In science, it occurs in repeating a step of an experiment, until the desired condition is achieved. In game design and development, it happens in the construction of game versions, from initial prototype to the beta.

- **Object**: An entity that has certain properties and can perform certain actions. A human being, a car, or a calculator software application are all objects.

- **Process**: The execution of an explicit or implicit algorithm. A process could be a human being, a community, or a virus performing some actions. It can also be an actual running program or computer application.

- **System**: A system is a group of processes or objects that interact. A system could be computer network, a flock of birds, a social group including a virtual community, as well as larger entities like economies and biological systems.