
Teaching Report

Evolutionary Processes and Systems

Shantou University
May 6-10, 2013

Collaboration of
ALFA Group: AnyScale Learning for All
Shantou University

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1 Introduction

In this document we report on a 5 day module, entitled "Evolutionary Processes and Systems" which was taught to Shantou University students by Dr.'s Una-May O'Reilly and Erik Hemberg. The module was taught between Monday, May 6th and Friday, May 10, 2013. It results from a collaboration which is generously supported by the Li Ka Shing Foundation between Dr. O'Reilly's research group at Computer Science and Artificial Intelligence Lab, MIT and Shantou University.

Dr. O'Reilly is a technical specialist in evolutionary algorithms – algorithms which are inspired in design by biological evolution. Through the guidance of Provost Peihua Gu of Shantou University, Dr. O'Reilly, with the assistance of Dr. Hemberg, designed the module which showed Shantou University students new ways of learning while extending their understanding of evolutionary processes and systems. Driving the module's specific aims was a general, broad goal that students gain a clear, tangible, experience-based abstract understanding of evolution at a level above and beyond textbook biology. We wanted the students to abstractly understand evolutionary systems and processes broadly enough to naturally perceive them within man-made phenomena, social structures, history, culture and other domains. Attaining this powerful level of abstraction and then connecting it with programming, even in a high level manner, would allow any student, regardless of major, to understand how evolution can serve as powerful inspiration for computational intelligence. It would also prepare Computer Science majors for their later encounters with evolutionary algorithms in an advanced course.

2 Module Goals

The module had two teaching goals:

1. **To extend the students understanding of evolutionary processes and systems.**

   We assumed that our students had already learned the basics of evolutionary biology at a high school level. We wanted them to extend these textbook concepts toward the world in which they act and function. We called the teaching block within the module for this purpose "*Evolution in Action*".

   As one aim of *Evolution in Action* we wanted our students to start to recognize evolutionary processes and systems "right in front of them" (i.e. in the world around them) such as language, fashion, music or even operating systems like Linux. We expressed this ambition as one of developing a scientific, *evolutionary world view*.

   As another aim of *Evolution in Action*, we wanted to provide students with additional exposure to the *evolution of strategic behavior*. We wanted to show students how evolution was powerful enough to shape and guide the emergence of a set of cooperating strategies which allowed a group of individuals (e.g. society, collective, etc) to rise above a sub-optimal behavioral repertoire.

   As another aim of *Evolution in Action*, we wanted to demonstrate that evolution is a means of learning. We wanted students to recognize that adaptation in the Neo-Darwinian sense wherein population variation, parental selection and genetic inheritance are key mechanisms, is another way of problem solving or discovering efficient strategies which resolve complex situations. This is a challenging aspect of evolution to understand but it is key in understanding the fundamental nature of evolutionary computation and how it is a means of computational intelligence. Our goal was to make computation, inspired by evolution, another example of *evolution in action*.

   The purpose of our second teaching block, called "*Evolution in Nature and Biology*" was to widen our students' scientific knowledge of evolution. We wanted to expose them to short but explicit examples of evolution where the importance of the fossil record, genetic mechanisms, sexual selection or a field study was evident. Our goal was to ingrain the idea that, while evolution has no goal or intent, evolved populations have properties (such as diploid) which can serve them in a survival context. We also sought to ingrain the concepts of randomness, variation and diversity because of their importance in evolutionary processes. For this purpose, we led the students to look at sexual selection.

2. **To expose the students to new or non-conventional ways of learning, given their experience.**

   Provost Gu recounted to us that one part of the STU mission is to expand the Chinese teaching and learning experience by introducing its counterpart from the West and then, from the interaction, synthesizing a new,uniquely Chinese, educational methodology.

   Chinese students are often taught in large classrooms with limited opportunity to ask questions. Students have strong technical skills and work impressive hours. However, it has been noted that a strong emphasis on knowledge itself, rather than its acquisition, and on test performance, rather than knowledge application, may result in rote learning. Rote learning does not foster initiative, invention, motivation or confidence to solve problems.

   Recognizing we are not professional educators, albeit we have experience as teachers, we decided to aim to teach students in ways that likely would be new to them, in a setting that would be encouraging, safe and fun, so that they might discover new ways they effectively learn. We further decided to teach them in ways we would like to have learned the material, in a practical manner. We decided to focus upon:

   - making them aware of how they learn and to reflect on how to best learn
   - introducing them to self-assessment of current knowledge and reflection of what they have learned
   - proposing they consider themselves life-long learners, with learning occurring both inside and outside the classroom.

   Our goals included encouraging them to

   - learn because of curiosity. We invited questions and promoted being bold enough to make mistakes because it is possible to learn from mistakes
   - learn through conceptual exploration in a hands-on way via role playing
   - learn through “Active Learning” [Bonwell and Eison(1991)]
   - learn through programming, verbalizing, and writing
   - practice deep learning [Tagg(2003)]. Deep Learning by Tagg 2003, Indiana University Center for Post Secondary Research. discovery centered, project driven interactive. Not as extensive as CDIO. Apparatus of understanding in the embedded meanings that define us and that we define the world

3 How and What We Taught

3.1 Organization

We taught the module over 5 days for 2 hours a day according to the schedule in Table 1. Appendix A is the PowerPoint slides we presented each day. All class meetings and office hours were held in the Computer Systems Lab at STU.

3.2 Module Content Outline

Evolution In Action Evolution around us

Evolution in your world Evolution you observe

- Introduced the concept of a “world view” to students
- Linux example, students’ active learning

Evolution of Strategies (through role playing and programming)

- the Prisoner’s Dilemma: students learn about a Nash Equilibrium
- N player Iterated Prisoner’s Dilemma:students learn that there are more complex strategies when the game is N-player and iterated

Table 1: Teaching and Office Hour Schedule

Day	Time Slot	Type
Monday	8:00 -10:00	Lecture
	14:00 - 17:00	Office hours
	19:00 - 21:00	Office hours
Tuesday	19:00 - 21:00	Lab
	8:00 - 10:00	Office hours
Wednesday	8:00 -10:00	Lecture
	14:00 - 17:00	Office hours
	19:30 - 21:30	Office hours
Thursday	19:00 - 21:00	Lab
	18:00 - 19:00	Office hours
Friday	8:00 -11:00	Lecture and Feedback

- Evolutionary N player Iterated Prisoner's Dilemma

Evolutionary computation

Evolution in Nature/ Biology Evolution in the natural world

- Evolutionary Gems
- Inheritance with diploid" dominant/recessive gene expression
- Sexual selection: game
- Eye candy: diversity from sexual selection

3.3 Day 1

We started by setting an informal tone via self-introductions that were light hearted, enthusiastic and high energy. We emphasized that there were two important aspects to the course: considering how we learn and what we learn. We encouraged questions and being bold. We introduced Active Learning as a"think-pair-share" process, stating that discussion with a peer would be helpful in better understanding, it would provide practice articulating concepts in spoken English and it would enlarge the idea space.

We then explained a world view as a an intellectual perspective on the world, narrowed our attention to science and then finally to evolution.

We collected self-assessment of programming skills (see Table 3). We confirmed that the class more or less split two ways. One group, mostly freshmen, were novice programmers with some experience using AppInventor. AppInventor is not sufficient to clearly express even the basic iterative, conditional logic of evolutionary algorithms. **Outcome:** This indicated we needed a programming exercise which would allow a student to program in a new language in some modest but insightful way. The second group had medium level experience programming in C. **Outcome:** For this slightly more advanced group, we prepared optional, more advanced programming exercises.

We explained how students would earn a course certificate. First, they had to attend and participate in class exercises. As well, they had to complete verbal, written and programming requirements. The verbal requirement would be a presentation of 1-2 minutes with a PowerPoint slide for accompaniment. The presentation would be based on material read by the students on a student selected "Evolutionary Gems". The written requirement would be a diary (a.k.a journal) composed of short, pithy entries each day reflecting upon what had been learned, what was challenging and/or what could have been taught better. The journal (which we would later have to clarify as a diary) was our means of teaching the students reflection. The programming requirement would be to add the conditional logic for all possible actions in a non-iterating 2 player Prisoner's Dilemma game.

We introduced office hours, front loading them to early in the week so we could provide extra programming support, address issues arising from language and/or reading challenges in interpreting and presenting the Evolutionary Gems. **Outcome:** These were not as well attended as we hoped. A small cadre of about 7 or 8 students did attend and use them. However, the majority either did not ask questions or they asked their questions at inappropriate times such as after a lecture or before class meeting. We referred to labs and lectures as different but, in practice, the material in a time slot did not differentiate in this way. In fact, on Day 1 (Monday) we went over lecture time by 30 minutes due to needing to adapt to feedback from the students.

Perhaps next time: Add an ice breaking activity to introduce students to each other and to encourage working together.

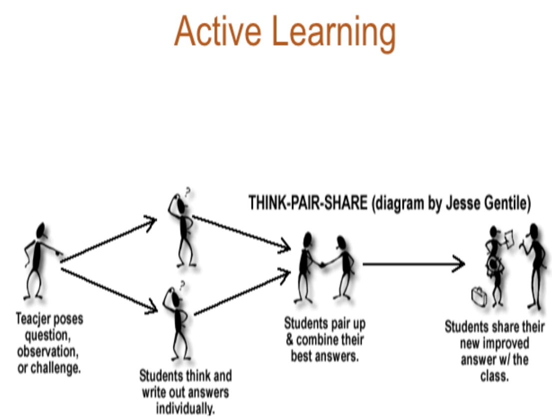

Figure 1: Day 1 module PowerPoint slides of active learning

We started the *Evolution in Action* block by reviewing the properties of an example evolutionary system then asking students to identify their own examples. The example we introduced was the Linux Operating System. Not everyone was equally familiar with computer science and its terminology (perhaps in English) so we reviewed to ensure the example was understood. We explained terns such as open-source, the difference between obtaining a binary and source for an application, the notion that Linux was an operating system like Mac OSX or Microsoft Windows. We showed a time line of the Linux distributions and we described the development of Linux distributions as an evolutionary process: it has a common ancestor in the original kernel, variants of distributions, inheritance from "parent" distribution, extinction of distributions which lose support and users, and speciation as incompatabilitiies between distributions.

As the first active learning exercise, we asked the students to individually identify their own examples of evolutionary processes. We asked them: what is evolving? How do the entities evolve? How to they compete? Why is this an evolutionary process? Then we asked the students to, in pairs, share their examples.

Due to time constraints we skipped putting the students into groups so that they could further share their examples. Instead, we immediately asked for 3 volunteers to present their examples to the class. The examples were: language, CAD software and mathematics. **Outcome:** This was our first opportunity to assess the students abstract understanding of evolution outside of evolutionary biology. We found they could intuit some simple examples but they lacked the ability to specifically link evolutionary properties to their examples and to non-superficially see what their examples lacked in terms of being completely evolutionary. We hypothesize that they were struggling either with the evolutionary vocabulary or concepts, such as *species*, *extinction*, and *inheritance*, etc. They did however emphasize competition and winning. This somewhat met our expectations, given they may not have renewed their knowledge of evolutionary biology recently. However, the Linux example had allowed us to review the properties so it pointed to a gap in communication between our spoken information and their comprehension of it. We would expect that a class of native English speakers would more readily be able to appraise their examples and find examples which differed more from the Linux example we presented. We used this feedback to slow down our verbal English. We also developed a team-teaching approach to presenting material, given our class of ESL students. First, one of us would present narratively to provide intuition and expose students to the complex use of English to convey an integrative, holistic meaning. Then, the other would review the other's narrative for its vocabulary and to re-synthesize the meaning, somewhat piecewise, by relating it to concepts we had previously introduced to the class.

We linked this exercise to the reflection component of the module. We asked the students to reflect upon their own examples or those of classmates in their journal entry for Day 1.

In the second part of the lecture, as another element of the *Evolution in Action* block, we introduced the Prisoner's Dilemma [Axelrod(1987)] which is a well-known example in social science that conveys the balance between cooperation and competition in social settings and some evolutionary systems (see Figures 2 and 3). We chose the Prisoner's Dilemma because it is simple to explain and can be role played. In a very short time, a pair of students can experiment with different actions (cooperate or defect) and learn for themselves that they should always defect in order to protect themselves from cooperating while being betrayed by their partner's defection. We asked the student to play the game (as one iteration) and explore strategies. **Outcome:** The students readily determined that defecting was better. We then discussed their experience and walked through the logic determining the choice to defect and then presenting them with the conundrum that they had found a stable strategy, but if both they and their partner had cooperated, both would have been better off. We provided them with the name of this sub-optimal competitive resolution to the situation: Nash Equilibrium.

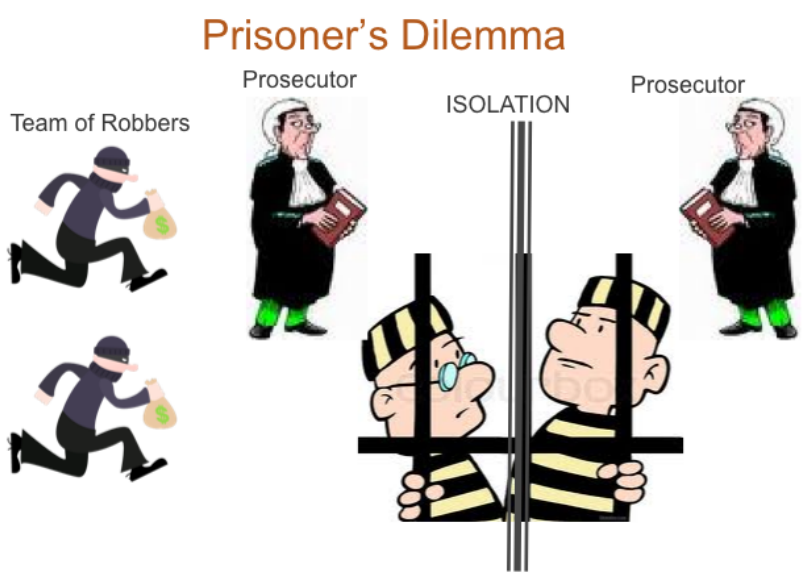

Figure 2: Figurative slide introducing the Prisoner's Dilemma.

Our next step was to give the students a programming task related to the Prisoner's Dilemma. We provided them with a Python program for the Prisoner's Dilemma where the conditional logic which looked up the payoff matrix and reported the payoff according to a pair of actions was blank. Their task was to code this logic. We were prepared with the knowledge that none of the students had experience in Python. However we had decided that Python is sufficiently succinct and easy to learn that we could teach it on the students' base of knowledge of AppInventor and C. We had prepared material on basic statement syntax in Python, and had prepared the program which would link use of the statements to an example familiar to the students. **Outcome:** While we had intended to present this material fairly quickly, ESL issues and very rudimentary programming knowledge from the students who only had exposure

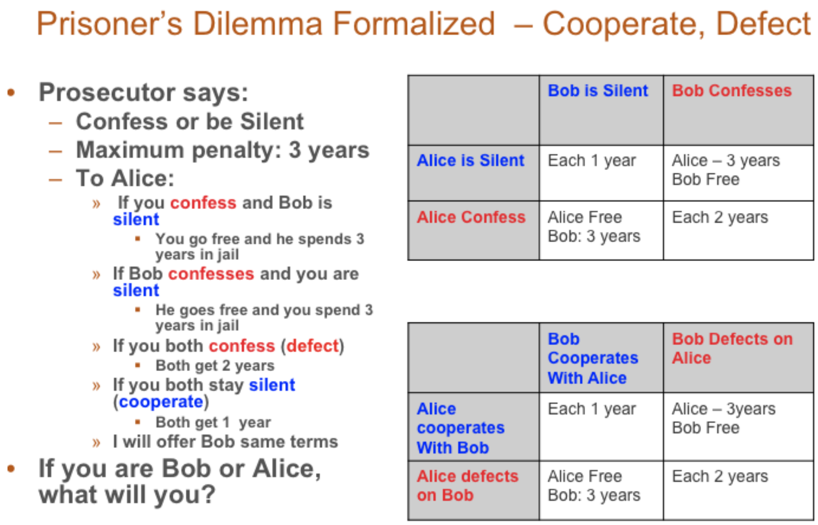

Figure 3: Text-based slide introducing the Prisoner's Dilemma.

to AppInventor forced us to slow down dramatically. We still rather swept through an introduction to Python but realized it was likely too fast and not well absorbed. We deferred teaching the students more to office hours and we also placed onus upon the students to start some self teaching of Python. We noted different levels of compliance to this edict. A majority of the students self-taught by bringing in Chinese Python manuals. A very few tried to help each other, and about 1/3 of the class showed us where they were stuck during office hours after we walked around asking their progress and making offers to assist them. We also gave students the option to work in pairs but no one did. The program was to be completed by the next start of Lab 1 on Tuesday night. There was confusion between the MIT practice and STU practice regarding completion. MIT wanted a demonstration of the program working, while the student expected to pass us code. We advocate demonstration to address grading time. We optionally provided additional program extensions for those who complete the basic programming easily. The extensions were to make the program accept moves as input from the keyboard, to iterate the game and accumulate the payoff of each player. A modest number of students (5-7) took advantage of this option.

Technical Issue: The computer lab did not have Python installed.

Technical Issue: Some students complained about a lack of PDF viewers installed on the computers. It was possible to use Chrome or online PDF viewers, but it was still a minor glitch.

Perhaps next time: We need to emphasize species and environment to help them with Darwinism and gems. The examples of evolving systems showed that they had no clear understanding of species. Sometimes the material was a repetition of high-school, so shorten and increase the level

Perhaps next time: They need a better example of evolution of languages and dialects. This might be better than the Linux example. Show Linux first, and then languages, since natural languages are more intuitive than computer.

3.4 Day 2

We started Day 2 by linking the cooperation and competition dilemma of the Prisoner's Dilemma game to evolutionary systems in biology. We gave the example of plant-rhizobium mutualism as one of evolved cooperation. In order to establish the means by which cooperative strategies can emerge and become stable, we emphasized that there were many plants, many rhizobium and that the interactions were numerous and unpredictable. We asked the students to ponder how these strategies come into existence and are developed, leading them to see evolution as the process from which cooperative and stable strategies emerge. We then used these concepts to motivate extending the Prisoner's Dilemma to N player Iterated Prisoner's Dilemma (NIPD), thence to evolving-NIPD. In NIPD players can have different strategies that become evolutionarily stable but not at sub-optimal equilibriums like that of the only-defect strategy of the Prisoner's Dilemma. Further, we linked evolving-NIPD as example of an evolutionary process to evolutionary computation. To do this, we introduced evolving-NIPD pseudocode with a generation loop and an adapting a population of organisms with mixed strategies. The pseudocode mirrored the role-playing game with respect to iterating a generation at a time, with competition directing selection. Each organism in the population plays the Prisoner's Dilemma over a fixed number of iterations with random opponents and records its total payoff. The organisms with higher payoff (fitness) have higher replication rate.

Figure 4: Slide introducing pseudocode of evolving-NIPD.

Once again, to ingrain the concept, we had the students role play evolving-NIPD. We started play by assigning each student an ID and one of nine anonymously named strategies, e.g. always-defect, tit-for-tat. In every "generation" they would play random partners for a random number of iterations. Each student, each generation, would record their ID and accumulated payoff. At the end of a generations, each student would enter their ID, strategy and and payoff (as "fitness") on the lab whiteboard. Then, collectively, we would step through randomly drawn tournaments (based on IDs) where the winner was the ID with the strategy that garnered the highest fitness. The winning strategy would be associated with a new ID for the next generation. This evolved the composition of strategies in the population proportionate to fitness. While we did not enact any "mutation" to a strategy after competition and replication, we allowed random strategies to be introduced into the next generation by random draw. We iterated for 3 generations then looked at the dynamics of the game in terms of emergence of a stable strategy, frequency of strategies and extinction of strategies.

Outcome: In our instance of the role-playing game, we observed population effects due to a small class and noisy fitness scores (see technical issue). The "Tit-for-tat" strategy quickly became extinct because it was infrequent in the initial population and each time must have encountered a strategy that did not allow it to accumulate high payoff. The all-defect or "hard majority" strategy dominated the population. This game outcome may not have illustrated the evolution of cooperation, however, this game itself still was extremely helpful in deeply conveying many core principles of evolution to the students. It helped them readily revise and abstract their conception of fitness proportional replication. It led them to a deeper understanding of the roles of inheritance, population, randomness and competition. They saw, in practice, the evolution of competition. With a clarification of the game, they saw how cooperation also could have evolved.

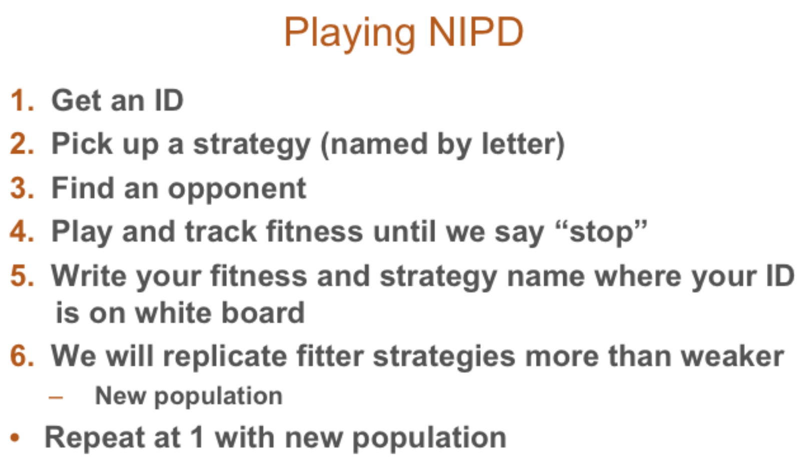

Figure 5: Slide introducing game of evolving-NIPD.

Technical Issue: We needed to clarify how many games should be played each generation and to declare how many iterations to play each game. We neglected to do this in the first generation and it resulted in very noisy payoffs being reported.

To cap off the block, we further linked evolution to programming and computational intelligence. For the novice programmers, we indicated where on the Internet they could find an NIPD game to play. We also provided a Python program of evolving-NIPD which they could run via a simple interface. We also introduced an optional programming assignment for the keen programmers. It involved providing some units of logic to the Python program of evolving-NIPD. **Outcome:** Very few students attempted this task, and not many of the ones who attempted it understood it. We recognized this was a difficult task but insisted on giving students something ambitious.

Perhaps next time: In retrospect, the increase in difficulty between the optional NIPD programming and changing the evolving-NIPD program might have been too steep. We should consider: a simpler version of evolving-NIPD, explicit office hours for delving into it for keen programmers, incrementally staged incomplete versions to be completed.

Perhaps next time: Emphasize that the Prisoner's Dilemma is an example of co-evolution and ask for other examples of co-evolution.

Perhaps next time: Speed up the tournament selection. E.g. ask students to write software to improve the game, now when they know where the bottle neck is. (They point is to clearly identify the problem for the students and point to tools which can be used for solving it)

Perhaps next time: Let students enter their own ID, strategy and fitness on the whiteboard after round 1. During the competition, let the competitors stand up, and then the loosers sit down.

The Day 2 reflective journal entry asked students to comment on evolution after playing evolving N player Iterated Prisoner's Dilemma and to reflect on whether they now saw evolution as more complex than on Day 1 when we explored the Linux OS and other examples.

3.5 Day 3

Our aim on Day 3, when we started the module's *Evolution in Nature and Biology* block, was to expand our students' understanding of the evolutionary process by circling back to biology which was their original learning context. We proposed to visit a few aspects of biological evolution in more detail while making connections to our *Evolution in Action* block. Our intention was that conceptual linkages would strengthen understanding and extend our students' abstract understanding of evolutionary processes and systems.

The lecture had 3 logical sections. First, we reviewed evolutionary biology using highly textual material couched in fairly scientific, dense English. We believe the material, as basic information on Natural Selection, was already known to the students. That is, the students would again see, variation, differential replication, and inheritance. However we believe the material also introduced more nuanced, detailed vocabulary and ideas central to Natural Selection, principally it as a theory explaining species, the tendency of species to exponentially increase in size, the limitation of resources imposing selectional variation, and the gradual emergence of new species.

As an example of the material's high comprehension complexity, we showed a complete definition of evolution from the Oxford English dictionary. A pertinent definition was shown nestled among other definitions which stretched the students' ability to use context for comprehension. The definition also included the word's Latin origin. We presented Darwin's theory of evolution as a text heavy list of descriptive transformations. While the concepts would now be familiar and easy to recall for our students, they would be challenged by the English presentation. After reviewing the information verbally, we presented an ensuing slide which pictorialized the concepts again. Verbally, we connected the concepts to our evolving-NIPD role-playing game. These two slides are shown side by side in , Figure 6.

Figure 6: Slides revisiting Natural Selection. Left: text heavy, Right: pictorial. We verbally linked this material to the evolutionary-NIPD game the class played the previous day.

We also included quotes from eminent biologists. From Theodosius Dobzhansky:

> Nothing in biology makes sense except in the light of evolution.

and from [Lewontin(1970)]:

> The individual struggle for existence has three principles:
>
> - Variation between "individuals"
> - Differential fitness, i.e different rates of survival and reproduction for different "individuals"
> - Heritability of fitness. No particular mechanism of inheritance needs to be specified, only a correlation in fitness between parent and offspring

and asked the students to consider their meaning.

Perhaps next time: An active learning exercise around these quotes and others emphasizing speciation and environment might call upon the students' verbal skills more and bring them into practice more readily.

In the second logical section of the day's material, as a specific aspect of evolutionary biology, we discussed inheritance of traits through diploidy. Our PowerPoint slide was, again, text heavy and discussed traits and heterozygosity, with a brief figure to help convey the concept. To communicate the idea that diploidy might confer a selective advantage to populations in dynamically changing environments we had the students go through a simple exercise, see Figure 7. **Perhaps next time:** We need to demo the exercise, it took some of the groups quite a while to understand the exercise

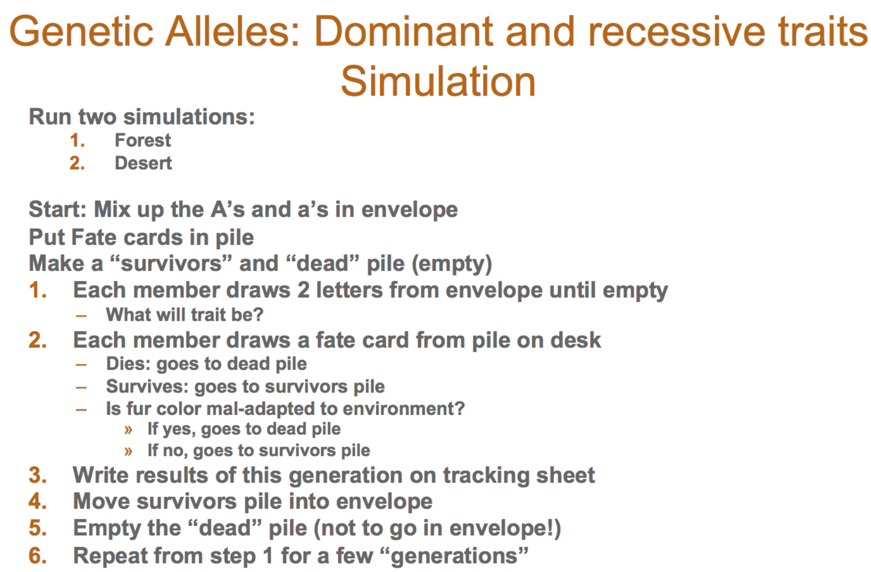

Figure 7: A simulation students ran to understand diploidy.

The final logical section of the lecture was devoted to introducing a set of "Evolutionary Gems" to students. Evolutionary gems is a resource collection of 15 readings (or articles) assembled by 3 Nature editors in 2009 [Gee et al.(2009)Gee, Howlett, and Campbell], see Appendix F of this report. They were compiled to communicate how "evolution by natural selection is an empirically validated principle", i.e. it is a well founded theory based upon fact and supported by scientific evidence collected with rigorous scientific methodology. The collection is divided in 3 ways: gems from the fossil record, gems from habitat studies and gems from molecular processes. Each article briefly presents a scientific question of evolution then explains a scientific research finding which resolves it. It also provides references and resources for further information while introducing scientific vocabulary. The question and finding range from having simpler to more complicated descriptions and complexity. For example, one article, ([Thewissen et al.(2007)Thewissen, Cooper, Clementz, Bajpai, and Tiwari]) considers how whales, as mammals, came to be aquatic. It explains how the fossil record provides evidence of the land-living creatures from which whales eventually evolved demonstrating its value in identifying transitional forms. Another gem [McKinnon et al.(2004)McKinnon, Mori, Blackman, David, Kingsley, Jamieson, Chou, and Schluter], from habitat study, addresses how speciation is driven by divergent natural selection. It links the buildup of reproductive isolation in sticklebacks to the adaptation of body size because of stream living and ocean spawning.

We asked students to each choose one specific evolutionary gem and study it in depth. We asked them to subsequently pair up and discuss with a partner the information in their gem. They had to do this outside of class. **Outcome:** We did not formally ask, but our best guess is that students did not follow up and engage pairwise discussion, with a formal structure. They were accustomed to working independently or informally in groups so, to some degree, an informal version of this engagement may have occurred. Finally, they were to prepare one PowerPoint slide, with less than 20 words and an oral presentation of 1-2 minutes on the information in their gem. The presentation would be given to the rest of the class on Day 5. We encouraged the students to use figures (hand written or sourced from the Internet, with attribution) because of how that helps other learns and because it guides students into a process of sketching meaning - yet another way of casting information to learn it more deeply. We kept other parameters of the assignment flexible and non-explicit. We answered any questions that arose but, for example, didn't say either way what to do with the article's pointers to supplementary material. To help with selecting a gem, we reviewed 9 of them in class.

3.6 Day 4

On day 4 we continued the block on *Evolution in Nature and Biology* with a deeper dive into sexual selection. Students at STU assume a lab means they sit facing a computer waiting for a programming assignment. When we discovered this, we acted to change that assumption. We entered the computing lab with an assortment of 5 kinds of candies which we had purchased from the STU student canteen. We offered each student two and asked them to hold off enjoying them. Then we polled the class, with a student scribing, to characterize the "traits" of each kind of candy and its popularity. We then explained to the students that the selected candies represented desirable traits and each student was"role playing" a female selecting a mate. Those left in the bowl represented male individuals of a species not selected by "sexual selection. Preferential selection which is not based on genetic value (which is drives adaptation) is an activity in higher level organisms. The candy activity serves as a model for biology because more attractive male individuals in a species, or in this case treats, are often selected by female individuals in that species. That selection gives those individuals a greater likelihood of reproducing and thus passing their genes along. As this "attractive" trait becomes more and more common, evolution is occurring. This was a fun, simple, fast exercise which segued to the day's topic of sexual selection by emphasizing the role of preference and its variational influence on selective diversity.

We next shortly introduced sexual selection with a more formal PowerPoint presentation that offered biological examples, see Figure 8. We pointed out to the students that explaining non-genetic selection was a problem for Darwin. We lectured on the nuances of the problem and explained how secondary sexual traits are used for battle or merely for showmanship. We went over vocabulary necessary for understanding, including *impregnate*, *brood*, *fecundity*, *litter*. To help the students deeply understand the nuances of the topic, we then engaged them in a role playing game we called "*The Mating Game*".

In *The Mating Game*, it is mating season and there are two roles for breeding organisms: females and males. Females and males both have a hidden genetic value. Males have some number of teeth which allows them to battle for females (the male with more teeth wins). Males also have a kind of attraction (.e.g clapping, singing, snapping, stamping) to use to "woo" a female. Females have a fecundity (i.e. number of eggs) and some of them have the ability to see the genetic value of a suitor (this is done by asking the male). We called this ability "X-Ray vision".

Males want to meet as many females as possible and make them pregnant in order to pass on their genes. Females can only mate twice in the season. They get to pick their mates. The game is played by by males and females meeting each other and trying to decide who to mate with. When a couple decides to mate, they "high five" and the female reveals her number of eggs, while the male shares his genetic value.

Then, the female of the mating pair goes to a government birth official to register how many of their offspring survive until adulthood. This quantity is calculated by this formula:

number of offspring = (number of eggs) (male genetic value + female genetic value)

While a female is registering the birth, she may not be courted. The mating season is over when all females have had their maximum 2 pregnancies or it is called to a stop by the instructors. The role-playing game allows many important aspects of sexual selection to be deeply learned because it brings out the importance of courtship, the scarcity of females, the hidden aspect of genetic value and the battleship role of secondary sexual characteristics. It shows directly how sexual selection has an impact on population traits. We analyzed a number of prototype males and females and observed how their traits and behaviors resulted in different offspring frequency.

Outcome: We were getting the hang of how to introduce games. Judging by the complexity of the Mating Game and

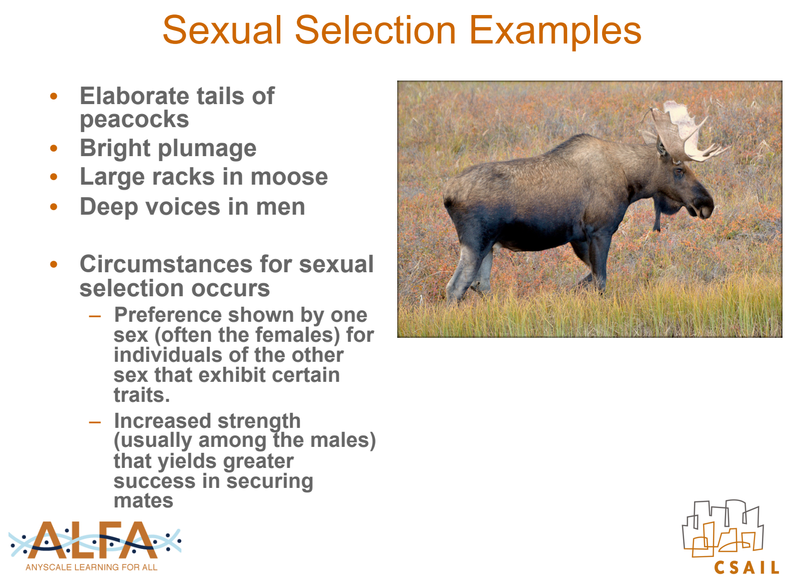

Figure 8: Slide showing sexual selection examples

students' confusion with the Diploidy exercise the previous day, we completely rehearsed a demonstration which we added to very explicit description of the game. This was very successful because, we saw very little confusion about the game when we asked the students to start playing it. This was the role playing game that really loosened students up, let their personalities emerge and that got them joking and relaxed. It is also one where they deeply connected to the material.

We then circled back to make some more connections obvious and explicit to the students. We recognized they might be wondering why we, as Computer Scientists, were so interested in evolution. We answered this question by explaining how computational intelligence can be achieved by developing programs with evolution-based logic.

We used the example of evolving an antenna for a NASA satellite to demonstrate why computer scientists are interested in evolution and that evolution also is a powerful engineering tool. **Outcome:** We got two very good questions. The first question was: evolution does not find the best solution since it is not optimizing, so why use it? A correct observation to which our answer was that evolution will adapt and improve on previous solutions, this is a useful property when the optimum is constantly changing. The second question was: why not write a the problem in mathematical equations and solve it? Not everything can be can be expressed in closed form solutions.

We circled once more back to Day 1 now that we had completed presenting all course subject material. We asked our students to repeat the Day 1 exercise and use their updated knowledge of evolution in their analyzes. With them we self-observed that they were better informed about evolution and how this helped them analyze their example.Three students shared excellent examples of evolutionary systems with us: Chinese characters, Chinese language and dialects of English.

Perhaps next time: Make this reflection a think-pair-share, whereas we just had a think then share sequence.

For the day's journal entry we asked our students to reflect on how their understanding of evolutionary processes and systems had expanded.

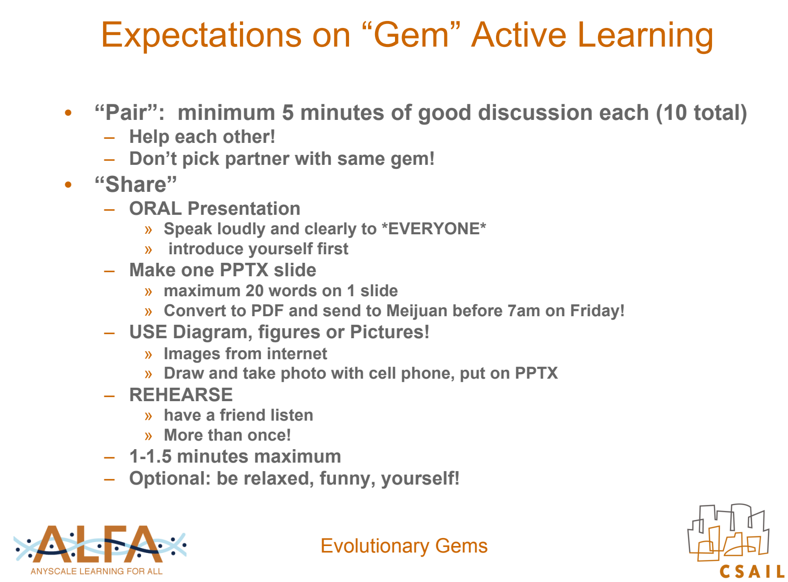

Figure 9: Slide showing the Evolutionary Gems presentation instructions

3.7 Day 5

On the final day we started with collecting paper copies the students' journals, see Appendix H. **Outcome:** The diaries showed that many students had acquired a more evolutionary world view as the course progressed. In addition, it was a great feed back for the different parts of the course from the students perspective.

Perhaps next time: We asked for the output of the students PD program. We should improve the collection of results from assignments next time.

While we were aggregating the students' PPTX slides, Dr. O'Reilly gave a retrospective view of the course. We emphasized why there was less programming in the course than expected by some students. The argument was that it is not possible to write a good algorithm without understanding the underlying process properly. We then moved onto the student presentations.

Perhaps next time: It took almost 20 min to merge all the power point presentations to a single slide. We should get the students to hand in the presentations earlier so that a TA can do this before the lecture.

The presentation requires an organization of thoughts, small to large knowledge acquisition, then inversely, picking the most important thing to say. It also requires creative, effective slide preparation – good use of visuals and relating to other concepts audience may know. The Evolutionary Gems PPT slide we used is shown in Figure 9. We introduced a word limit to avoid reading off the slide, encourage a more direct use of verbal discourse and transform the written words in gem into an oral presentation and then verbalize it. The order of the students was picked randomly. We had a watch to time the presentations and we were a little soft on time, though we used a gong.

Perhaps next time: Instead of telling students what not to do in the presentation, we should phrase what is necessary and optional.

Outcome: The first presentation did not follow any of the presentation rules: there were too many slides, too many words and it was not properly practiced. Luckily, the quality of the presentations improved indicating that that the first was an outlier. There was only one student who talked for so long that we had to stop the presentation. After

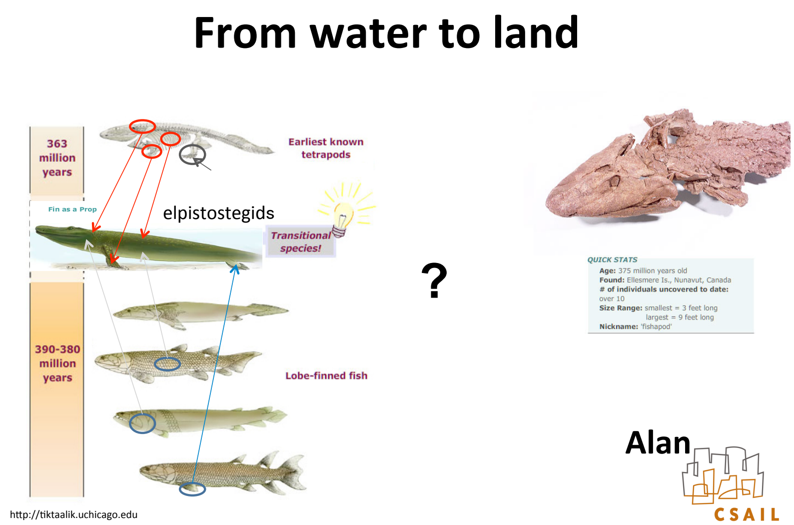

Figure 10: Slide from the best presentation. The slide used animations to allow a gradual introduction of information

each presentation, anyone could ask a question. There was only one presenter who was asked a question by a student. Not all presentations met all criteria. Some lacked the investment of effort toward deeply understanding the articles. Others did not try to convey its subtleties. Some students clearly thrived with the presentation challenge, whereas others underestimated it.

Outcome: We observed overall that student comportment while giving the presentation followed a Gaussian distribution with a right shifted mean, implying the average was strong while there was the usual tail behavior. The exercise, from its introduction through to solo reading, independent further investigation, presentation preparation, rehearsal and presentation was productive and worth repeating.

Perhaps next time: Ask the students to prepare questions to ask. One random student asks a question per presentation by assignment.

In the introduction we said that there would be two awards, one from the teachers, and one from the students. The students were given a shortlist of three presentations that we deemed interesting, and that had not been nominated for the best award by the teachers. The presentations we picked followed the presentation rules, clearly visualized the Evolutionary Gem chosen and showed that the presenter had read and understood the paper, and gained a deeper understanding of the subject and evolutionary processes. Sadly, there were numerous presentations which these criteria did not apply.

Perhaps next time: Spend more time explaining presentations and give feed back to presentations. In addition, spend more time discussing Evolutionary Gems with students after they have been read, even pushing them to related resources. Further, spend more time giving individual feedback to the students after their presentation. Finally, force more variety in the choice of articles by having a sign up sheet for articles, first-come-first-serve.

The best presentation (shown in Figure 10) made good use of graphics and clearly presented the subject. The student had, during the office hours, discussed the subject with us. His interaction with the teachers during the course convinced us to break the tie in his favor since the other two nominations also provided good graphics and elaboration on evolutionary process and systems.

The presentations for the students' choice were either clearly structured presentation of an Evolutionary Gem that many had struggled to explain or original in their examples, as showing Disney princesses and mermaids. The students' choice gave positive feedback from both teachers and peers. It was a recognition of a job well done.

4 Student Cohort

At the beginning of the first lecture we asked the students to hand in a note with their English name, major (see Table 2) as well as programming language and skill level (see Table 3). Not everyone specified their programming knowledge. Not all students were present to hand in the initial survey. Some students listed multiple languages.

We are not certain of the student selection criteria. We believe students were chosen for: strong English and completion of an AppInventor course or for average C programming ability with slightly less emphasis on English.

Table 2: Student background. Not all students were present to hand in the initial survey

Major	Number
Physics	2
Mechanical Engineering	3
Mechatronics Engineering	1
Telecommunication	3
Civil Engineering	2
Math	2
Computer Science	2
English	1

Table 3: Student background. Not everyone specified their programming knowledge. Not all students were present to hand in the initial survey. Some students listed multiple languages.

Language	Level	Number
AppInventor		9
	Beginner	6
	Average	2
Matlab Lingo		2
	Beginner	1
C		7
	Beginner	1
	Average	5

The full class, including teachers, is shown in Figure 11

5 Course Evaluation

5.1 Student Course Feedback

At the end of the course we asked the students to write a note answering the question "Would you recommend this course to a friend?". There were 22 responses, 21 were yes and 1 was a qualified yes saying that it would not meet the expectations and desires of a software engineer. The students were also asked to write comments on the note. The free text comments are condensed in Table 4. All the replies are in Section G

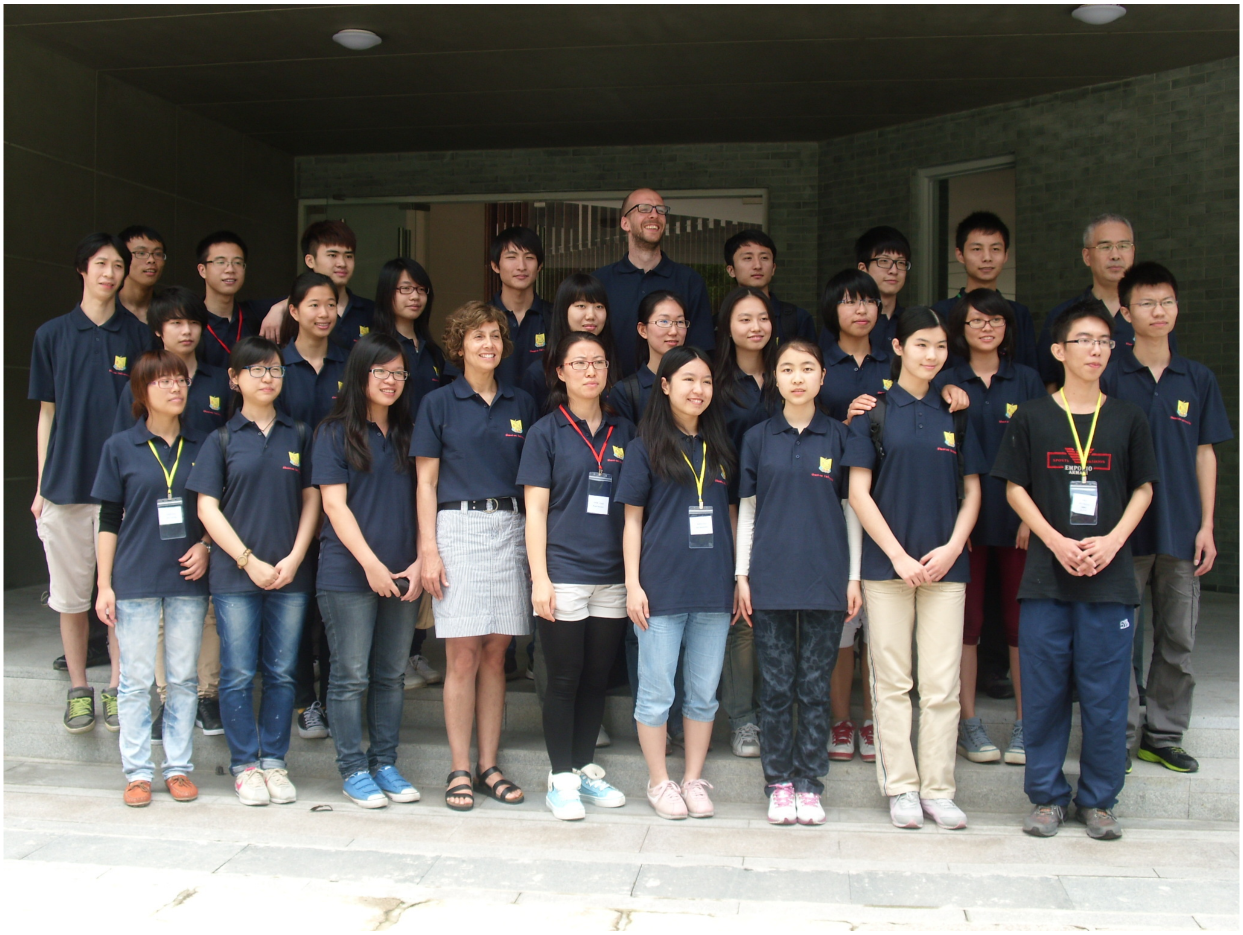

Figure 11: The full class, including teachers

Table 4: Classification of free text feedback.

Count	Classification
7	Appreciated teaching method/way of thinking/learning
7	Expanding understanding of evolution and taking it as a world view
1	General benefit
5	Enjoyable
1	Needs good English
1	Time schedule could be better
1	Limit time of games
4	Too short
2	More evolutionary computation
1	More python
1	Give me course goals ahead of time
1	New experience vs Chinese
1	Not cramming
1	Combine Evolution with Programming (which we did)
1	More course content before

5.2 Instructor Reflections

These were great students to work with. It was truly a pleasure to meet and teach them. They were prompt, attentive, fairly committed, friendly and polite.

In our estimation, students liked the new way of learning and they embraced the goals of the course - the "how to learn" as much as the "what to learn". The new way of learning was active, based on questions and understanding. The new way of learning was also less lecturing from the teacher, rote learning and passive listening.

We hoped the students would ask more questions and feel free to do so. However they students did not ask enough questions even when they did not understand, let alone be urged on by curiosity. We will try to improve this by having lectures with components based on questions which are enforced by the teacher. E.g. quizzes where each student needs to ask questions. We think the reasons stem from the distinct language barrier, fear of admitting confusion in front of peers and some impatience in wanting instructors to proceed with the course contents. The students waited until they really needed the information and then even lapsed to expecting us to help on the spot in reaction to their inaction or confusion. This wastes time when they should be role playing or participating in the pair part of a think-pair-share exercise.

Most students did not use office hours. Only a core group of 7-10 students camped in the lab to be able to intermittently ask us questions or receive help as we roamed around asking about progress. Only 6-8 decided to approach us. Moreover, many wanted to ask questions after class, instead of during class or office hours. We might try assigning personal question time for students as an alternative. Each student would get something like 5 minutes to talk to a teacher during the office hours.

We noticed that the students were very obedient, but not very good at self organization. We couldn't ask them to do something as a group without our leadership, but perhaps some of this was language related. Time could be saved by having TA's who knew the students and who could help organize and explain.

6 Future Plans: 2014

The section discusses how to revise and extend the current course content for 2014 and expand the number of students. In general, we would like to increase the Biology and Computer Science elements of the course, in order to retain its interdisciplinary nature. The increase in material would bring the course closer to a sophomore/junior level evolutionary computation course. However, we still want to maintain the diversity of student backgrounds. The mix of students from 2013 worked well and we believe it will work even better when we expand the content.

We would also like to test teaching some of the course material in a larger and an online setting. It will result in a so-called "blended" course.

Expand duration Provide online lectures and assignments after teachers and students meet face to face during an introductory week in China. This will allow more in depth programming assignments without the teachers waiting in China while students work on them. We estimate somewhere between 3 to 6 weeks for the online instruction and assignments completion, one programming assignment per week. Then we propose to return to China for one week of final teaching where we work with the students to integrate their programming assignments into a class project addressing a challenge.

Expand students Have 100 students, this requires (see Section **??**):

- **Facilities** Physical and virtual environments are needed
  - **Physical** A room with 10 tables with 10 students each at them. Students must be able to see the "black board". "Clickers" for quick questions to students.
  - **Virtual** Online learning platform, e.g. EDx. Students must be able to access the platform from STU.
- **Teachers** There is need to increase the teaching staff

- 5 TA's, preferably Meijuan and the 4 best students from 2013 at STU.
- 2 teachers for pair-teaching

Expand material Hold a mini course in Evolutionary Computation

- Extend with material from Section 6.1 (2 more lectures)
- Extend with material from Section 6.2 (7 more lectures)

6.1 Extend STU 2013

Look at UPOP and use tables, teams and feedback in group. Then break outs and take up with one table as example or, solicit a comment from each table.

Teaching Methods The methods need to be revised

- Need to physically group and identify students, need a clicker
- Poster session for students, before presentation
- A form for writing down presentation feed back
- Students should write diary every day and report

Content Review all the **Perhaps next time:** in the previous sections

- molecular biology
- population genomics
- mathematical formulations of evolution
- evolution of mutation ratio (self-adaptation)
- punctuated equilibrium vs gradual change
- genetic drift
- epigenetics
- cultural evolution

6.2 Extend Evolutionary Computation

Start with N player Iterated Prisoner's Dilemma and build on it to program EA.

- Build on existing the Prisoner's Dilemma, Iterated Prisoner's Dilemma and N player Iterated Prisoner's Dilemma content.
- Add possibility to mutate and crossover strategies in the source.
- Tournament of human and computer strategies.
- Ask students to implement the class room N player Iterated Prisoner's Dilemma exercise in software to improve the execution and exploration.
- Have students read a technical paper on N player Iterated Prisoner's Dilemma, e.g. Axelrod [Axelrod(1987), Nowak(2006)]

Program a system with a distributed system design: master-slave, island. The goal would be an interactive evolutionary algorithm with client-server communication on cell phones and laptops.

Develop co-evolving system, e.g. game-player strategy like TRON, see Funes & Polack [Funes and Pollack(2000)].

There are more EC methods that can be introduced as well:

- Generic Genetic Algorithm for discrete optimization. Examples could be combinatorial optimization with scheduling, routing, bin packing and grid based wind turbine layout.
- Genetic Programming
- Evolutionary Strategies for continious optimization
- Particle Swarm Optimization

6.3 Selection of the 2014 Class

We want to increase the biology and computer science parts, in order to retain the interdisciplinary nature of the course. The increase in material would bring the course closer to require a higher competency in programming. We still want to maintain the mix of students and subjects from 2013, which worked well, and we believe it will work even better when we expand the content.

More evolutionary computation material would require stronger programming skills. As a consequence the English could be weaker, fewer freshmen and less interdepartmental collaboration. Moreover, the mindset might be less open in regards to evolutionary processes and systems, knowledge learning and active learning. These are things we want to avoid.

7 Summary

Teaching a module on Evolutionary Processes was a great experience. The feedback gathered from the students appears to echo our feelings of excitement and success. We introduced new methods and new material to the students at STU. We learned a lot while during our first experience teaching in China. This has re-energized our commitment and we look forward to returning in 2014 with a bigger and better module. It will have evolved.

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Appendices

Please download or request all appendices since they are quite large files.

A Day 1

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/day1.pdf

B Day 2

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/day2.pdf

C Day 3

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/day3.pdf

D Day 4

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/day4.pdf

E Day 5

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/day5.pdf

F Evolutionary Gems

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/gems.pdf

G Student feedback

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/student_feedback/student_feedback.pdf

H Student Journals

http://groups.csail.mit.edu/EVO-DesignOpt/STU_2013_Report/student_journals/student_journals.pdf