

GAME THEORY AND INTERACTIVE LEARNING
COMPUTERS IN THE CLASSROOM

by

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Game theory is the sub-field of economics and mathematics that studies strategic decision-making behavior. Simple elements of game theory are taught in introductory microeconomics courses, typically in a lecture format. I developed software for playing economic (and other) games in a classroom setting using handheld computers. I call it EconGames, and it has been used successfully in several classrooms.

I describe and explain the basics of two games: the Ultimatum Game and the Prisoner's Dilemma. These two games complement and challenge many of the basic tenets of economics. They are not the only games I developed for EconGames, but serve as useful examples.

EconGames is written in the programming language Ruby and utilizes the Rails framework, also written (not by me) in the same language. The system also relies on FastCGI, Lighttpd and MySQL, though these technologies have alternatives that could easily substitute. I do not describe the actual programming in any detail.

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I would like to extend my thanks to several people who have been influential in my life and without whose help this project would not have happened.

To my Mom – because she rocks. But seriously, without her, where would I be today?¹

To Bill Harbaugh, my primary advisor and boss – for conceiving the project, keeping me working on it, and helping me deal with issues that came up. His comments on drafts of this thesis were very helpful.

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¹I wouldn't be anywhere, duh.

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1 Introduction

Game Theory is a field of economics. It is primarily concerned with modeling strategic decision-making behavior, that is, decision making behavior where outcomes depend on other people. The University of Oregon Department of Economics teaches simple elements of game theory as part of its introductory micro-economics courses (Economics 201) as well as in several upper-division classes. It has typically been taught by lecture.

Since we are talking about games, what could be more natural than to play some? Over the last year and a half I have developed a system for playing economic games in a classroom setting using handheld computers. The idea behind this thesis is one about the effectiveness of a more hands-on teaching approach. In the course of my work I have learned that such a system, when it is complete, will be enormous. I have developed several different types of games, each of which is quite customizable. I call the whole system EconGames.

I'm working on this project because I'm interested in several aspects of what I'm doing. I am interested in game theory, methods of teaching, and the process and challenge of programming such a system. I like the idea of bringing computers into classrooms, as long as it encourages learning.

In the remainder of the paper I will explain to you something about a couple of the games I have implemented, a little about the programming behind them, and a little bit about how we have used it in classrooms.

2 Basic Game Theory

Game theory focuses on situations where the results of a decision depend on other people's actions. In game theory, such a situation is called a game. There may only be one player, or there may be many. Game theorists are interested in how players play and think about games. Do people correctly anticipate the actions of others? Do they learn from their mistakes? Do people play as we think they "should?"

In the simplest case, a person is faced with several choices and they know with certainty

the outcomes that will result from those choices. Then it is simply a matter of choosing the best alternative. Often, however the situation is more complicated — the outcomes from each choice depend on the actions of others. Game theorists study these situations, developing decision-making models that explain and predict people’s decisions. The idea that a player’s choice depends on what other people do may be obvious, but an example can’t hurt.

Imagine a midterm examination in a course. Each student in the course has a choice of how much to prepare for the exam. Some students will learn the material more easily than others, so let’s just simplify things and say each student chooses their own preparation level. This choice will be reflected pretty well in the student’s score on the exam. Grades in university courses, however, are typically determined by applying some sort of curve. If that is the case, then the student’s grade depends both on his choice, reflected in his absolute score on the exam, and on the choices of others, reflected by his position and score relative to the other students’ scores. When students decide how much to prepare they are implicitly making a prediction about what they think the other students will do. They are maximizing their utility by balancing time spent studying with time spent doing other things, keeping in mind that everyone else will be doing the same thing. This example is actually fairly complicated as far as introductory game theory goes, but it is easy to understand intuitively.

2.1 Prisoner’s Dilemma

In introductory microeconomics courses, game theory is usually introduced using an example known as the Prisoner’s Dilemma. While our exam example had many players, the Prisoner’s Dilemma only has two. In that case a student could choose any of many preparedness levels, here each player only has two options.²

The story, invented by Merrill Flood [4] and Melvin Dresher [3] and formalized by Albert

²See Goeree, 2001 [7] for a brief history of the Prisoner’s Dilemma, or Holt, 2000 [11] for a detailed look at how Prisoner’s Dilemma games work in the classroom. The Wikipedia entry for Prisoner’s Dilemma [16] has a lot of information but may not be entirely reliable.

Figure 1: Payoff matrix for a typical Prisoners Dilemma game

		B	
		Defect	Cooperate
A	Defect	-2 , -2	0 , -10
	Cooperate	-10 , 0	-5 , -5

W. Tucker, goes like this:

Two suspects, A and B, are arrested by the police. The police have insufficient evidence for a conviction, and, having separated both prisoners, visit each of them to offer the same deal: if one testifies for the prosecution against the other and the other remains silent, the betrayer goes free and the silent accomplice receives the full 10-year sentence. If both stay silent, the police can sentence both prisoners to only six months in jail for a minor charge. If each betrays the other, each will receive a two-year sentence. Each prisoner must make the choice of whether to betray the other or to remain silent. However, neither prisoner knows for sure what choice the other prisoner will make. So the question this dilemma poses is: What will happen? How will the prisoners act? [16]

Each cell in the payoff matrix (Figure 1) represents a set of choices by the two players. Here I have generalized “confess” and “deny” to “defect” and “cooperate.” Within each cell there are two payoffs. The first player (A) receives the first payoff, and the second player (B) receives the second one. So the second number in the top right cell is the payoff (-10) that player B receives if she chooses to cooperate but player A chooses to defect.

What does game theory predict will happen? The game theory that we apply to games like this is based on the assumption that people are self-interested. What economists mean by self-interested is that people make decisions attempting to increase their own happiness or well-being. Different people will have different ways of increasing their own happiness: one person likes to drink nice wine, while another likes to give food to homeless people. In the Prisoner’s Dilemma we assume that the players are only interested in how much jail

time they will have to serve — it does not bother them to play deceitfully nor do they have any sympathy for each other.

Game theory predicts behavior in the Prisoner's Dilemma as follows: first, we choose one of the players and consider the options available to him. This game is symmetric, having the same payoffs for each player, so it doesn't matter which player we choose. Consider player A: he doesn't know what B is going to do, so he must consider all possibilities. If B defects, then A can choose to cooperate and receive -10 or defect and receive -2. Since -2 is greater than -10, A should choose to defect. If B cooperates, then A can choose to cooperate and receive -5 or to defect and receive 0. Since 0 is greater than -5, A will choose to defect. Combining these conclusions, we predict that player A should choose to defect no matter what B does. Since the game is symmetric, we predict the same for player B.

Therefore, the outcome we expect to see is that both players defect, receiving two years of jail time each. We call this outcome an equilibrium because it is stable — neither player A nor B will want to unilaterally change their choice to cooperate. It is clear, however, that both the players would much prefer the cooperative outcome where they each receive only six months of jail time. We call this outcome the social optimum because it maximizes the sum of the payoffs to all the players.

Clearly, this Prisoner's Dilemma leads to the situation where the social optimum is not the same as the equilibrium outcome. If the players work together, then they will both cooperate and receive a total prison sentence of one year. This is the social optimum. However, we assume that each player is self-interested. Each player only cares about her own prison sentence, so no matter what the other does she should defect in order to minimize her own sentence. This point is key — the social optimum is *not* an equilibrium because at that point, both players have incentives to change their strategies. Each individual could do better.

Now that is what rational, self-interested people “should” do. What happens when this game is actually played? When we play this game using EconGames the system randomly pairs people up, changing the pairings each round. Moreover, we don't tell the players

who their partners are. All this in an attempt to eliminate the effects of any preexisting friendships between players. Even when they are paired anonymously and randomly, it turns out that people cooperate a small, but non-zero portion of the time. So the prediction made by game theory does not perfectly explain people's behavior.

There are several possible explanations for this divergence between what game theory predicts and what happens in the real world. One is that perhaps the players simply didn't understand what was going on. If they were playing randomly it could certainly lead to cooperative outcomes. This is possible, but, especially after multiple explanations, it is likely that most of the players understand the game. Another, more likely, explanation is that people are optimistic and trusting. They are attempting to reach the social optimum, even though it puts them at risk.

There are many examples of this sort of situation in real life. The Prisoner's Dilemma entry in Wikipedia outlines several such examples, one of which I have included here:

Another interesting example concerns a well-known concept in cycling races, for instance in the Tour de France. Consider two cyclists halfway in a race, with the peloton (larger group) at great distance behind them. The two cyclists often work together (mutual cooperation) by sharing the tough load of the front position, where there is no shelter from the wind. If neither of the cyclists makes an effort to stay ahead, the peloton will soon catch up (mutual defection). An often-seen scenario is one cyclist doing the hard work alone (cooperating), keeping the two ahead of the peloton. In the end, this will likely lead to a victory for the second cyclist (defecting) who has an easy ride in the first cyclist's slipstream. [16]

In the Tour de France, the same cyclists may find themselves playing this game stage after stage. When we examine a single stage of the race we conclude that if they are rational and self-interested then they will choose to defect. If there is more than a single stage then the game is quite different. Players know that there will be repercussions next stage if they defect in the current stage, so we might expect to see some cooperation.

What about the final stage of the race? There is no "next stage" at that point, so we expect that the players will defect. Knowing that their rational opponent will defect in the final stage, what should a rational rider choose to do in the next-to-last stage? He should

defect, of course, since there is no future benefit from cooperating. By repeating this logic the whole repeated game unravels and we are left with the same conclusion: that a rational self-interested player will defect in each period of the game.

If, however, there were an infinite or unknown number of periods in the game, then we would expect to see cooperation between players. There have been contests to program the most successful prisoner’s dilemma player in very large repeated games. Many strategies have been tried, but the most successful is one of the most simple. It is called Tit for Tat and is played by simply doing each round what the other player did last round. This way you reward cooperation and punish defection. This strategy is not so different from what we see in many trust relations between humans.

Experimental data show that Experiments involving repeated games do usually have a higher cooperation rate.

The Prisoner’s Dilemma is just one game among many.³ I have described it here as an illustration of what game theory is about. As a cornerstone of game theory, it serves the purpose well. Not incidentally, it is the first game I developed for EconGames.

I should not conclude this section without mentioning Frank, Gilovich and Regan, 1993 [5] and 1996 [6], in which the authors discuss the potential negative ramifications for society of teaching people game theory. It is an interesting idea, and certainly worth considering. I believe, however, that the benefits from well-developed logic and practiced critical-thinking skills outweigh the possible costs incurred when students develop an unhealthy “cynicism about the altruism of others.” [6, p. 191]

2.2 Ultimatum Game

The second game I developed for EconGames is known as the ultimatum game. Again, this is a game involving only two players. The Prisoner’s Dilemma was a simultaneous game — both players moved at the same time. This game is sequential. The first player must

³Though I do not describe many other games here, there are many references available, both online and in print. See Wikipedia’s article on game theory [15] or Dixit and Skeath’s *Games of Strategy* [2] for more information

propose how to divide a certain sum of money between the two players. The second player is told the proposed division; they then choose whether to reject the division, in which case neither party receives anything, or to accept it.

Suppose the first player has \$10.00 to divide up and that he offers a split of \$9.99 for himself and \$0.01 for the second player. If we believe that the players are only attempting to maximize their monetary gain then we would expect the second player to accept even this very uneven proposal because one cent is greater than zero — something is better than nothing. Experimental results indicate overwhelmingly that people do not play this way. [1, p. 209]

Table 1: Move and Payoff Structure in a Classroom Ultimatum Game

Offer ^a	# Offered	# Accepted
1	10 (7%)	0 (0%)
2	18 (13%)	10 (56%)
3	37 (27%)	22 (59%)
4	39 (29%)	37 (95%)
5	18 (13%)	18 (100%)
6	8 (6%)	8 (100%)
7	4 (3%)	4 (100%)
8	0 (0%)	0 (N/A%)
9	1 (1%)	1 (100%)
10	0 (0%)	0 (N/A%)
Total	135 ^b	100 (74%)

^aThe first mover was given 10 to allocate

^b135 = 27 groups * 5 rounds

Results from one of our classroom experiments (Table 1) indicate that the usual offer is much greater than 1. Moreover, any low offers that are made are rejected a large proportion of the time. The literature on ultimatum games reports similar results. Henrich, 2000 [9] compares ultimatum game behavior between the Machiguenga of the Peruvian Amazon and people in many other places, including Los Angeles. He finds that the Machiguenga behave *very* differently from their Western counterparts. They make and accept much lower offers, usually around fifteen percent of the total available. Across various other countries,

however, results are pretty robust at offers of between forty and fifty percent. [9, p. 977]

Why do people choose nothing over something? There are a number of possible explanations. An obvious and intuitive explanation is that people value fairness and equity over small personal gains. Suppose the first player proposes to keep \$9.90. In this situation it only costs the second player \$0.10 to punish the first player for being a jerk. In my opinion, and clearly in many other people's, \$0.10 is a small price to pay for such a privilege.

2.3 Conclusion

To sum up: game theorists build simplified models of complex decision-making behavior in an attempt to better understand the world. The decision-making process that a game theorist goes through when he is actually presented with a choice is probably not so different from that of a regular person. Each of us, when we have to make a decision, tries to weigh the pros and cons of each alternative. For smaller decisions it is likely that this process is very quick, possibly even unnoticeable. For large decisions, however, it is very useful to structure and analyze the decision-making process. There are certainly areas where, collectively, we are making sub-optimal decisions. Learning why can only get us closer to fixing the problems.

3 Games in the Classroom

Game theory is typically taught in a lecture environment. A lecture on game theory may or may not engage the listener, but a game, with real payoffs, is more likely to keep an audience interested, and may even increase learning.⁴ Charles Holt's 1999 paper "Teaching Economics with Classroom Experiments" [10] supports the idea that playing games substantially aids the teaching and learning of game theory. An instructor must consider, however, the fact that when games are actually played, they can take up a lot of classroom time. Though the material readily lends itself to classroom interactions, the tradeoffs of

⁴Harbaugh, 2003 [8] takes a light-hearted look at the merits of engagement and entertainment.

time and effort may not result in much additional learning. If the costs associated with playing games in classrooms (lecture time lost, among other things) could be reduced, then playing games in class, and the presumed associated gains in learning, would become more feasible.

Instructors can and do play games in classrooms. One option is to “play” a game at the chalkboard, perhaps between two individuals or between small groups of students. Alternatively, packets can be handed out with instructions and blanks for choices. Each of these options has disadvantages; the possibility of a superior option is the impetus for this project.

Playing a game in a classroom is fine, but it will by its very nature only engage some fraction of the students in the class. Nevertheless, such an experience will probably increase the value of a lecture on game theory. A system where each student gets to play would be preferred, but the class time used in such an exercise will likely be large. Games where every student is involved are not very feasible.

Playing a fill-in-the-blank game where students make choices on paper involves a significant delay between playing the game and reporting results. In many of the games we are interested in it is important to preserve anonymity for the players, so the instructor must collect the choice packets and laboriously tally and record each player’s decision and the payout they should receive. Sometimes we can simply have students tally each others choices and assess payoffs that way; Bill Harbaugh uses this technique when he performs the experiment described in Niederle and Vesterlund, 2005 [12].

Speed is of the essence. Charles Holt, a long-time researcher in the field of experimental economics, writes about how it is difficult to keep the audience’s attention:

With a principles class of 24, it took less than 25 minutes to read instructions and complete five periods, which left plenty of time for discussion. For a larger class, you could conduct the period 1 game for several rows, the period 2 game for several other rows, and the period 3 repetition for the remaining rows. With more than about 80 students, it is better to bring some people to the front of the classroom and let the others watch. Speed is important to prevent the audience from losing interest. Specifically, in very large classes, time can be saved by

using fewer participants and treatments. [11, p. 231]

It is difficult to involve everyone without the time required becoming unfeasible. This is one of the problems that moving the system to handheld computers solves; we can involve everyone and still keep the time required reasonable. Another significant advantage of a computerized system is that results can be tallied very quickly. After each round of play the players may be presented with a table showing their previous choices and the payoffs that resulted.

For the reasons I have outlined, Bill Harbaugh approached me about developing a system that would involve every student in a hands-on, in-class game theory experience.

4 Writing EconGames

4.1 Overview

I have been able to write EconGames by making use of a several pieces of open source software that have been created by many generous developers from around the world. Without the tools that the open source community has provided, developing an application like this would be very expensive, if not impossible.

EconGames is written in the dynamic programming language Ruby⁵. In particular, the Ruby on Rails⁶ framework has made writing a complex web application much easier than it would otherwise have been. Data are stored using the MySQL⁷ relational database. Finally, the application is served using Lighttpd⁸.

I developed EconGames on Mac OS X, especially because of that system's Unix / BSD underpinnings. Ruby on Rails will run easily on any Linux / Unix system, though a persistent user could probably make it work on Microsoft Windows. I used the great text editor

⁵See <http://www.ruby-lang.org> or <http://www.ruby-doc.org>. For a comprehensive introduction to the language read *Programming Ruby* [13].

⁶See <http://www.rubyonrails.org>.

⁷See <http://www.mysql.com>.

⁸See <http://www.lighttpd.net>.

TextMate⁹ to write and edit the code.

I also stored, saved, and backed-up the project in a remote repository using the Subversion¹⁰ version control system. Subversion has been one of the most useful tools I have worked with on the project: it makes developing much easier by allowing me to isolate, compare, and rollback changes that I have made to the code. It also allows me to quickly install the code on a new machine and to easily keep the code up to date on several different machines. As more people become involved in the development of EconGames this tool will become even more useful.

4.2 Reinventing the Wheel?

This is not the first time that someone in the field of Economics has attempted to streamline games in the classroom. Over the last several years, Charles Holt of the University of Virginia has been developing a web site that allows instructors to play games or perform experiments with their classes. This system is called the VeconLab Software¹¹.

Veconlab has had a lot of development time put into it. It boasts roughly forty different experiments and games and allows any instructor to use it over the internet. It has limitations, however, which is why Harbaugh is interested in developing his own software.

In particular, Veconlab is proprietary. One cannot add games or change existing behavior. Additionally, the data stored in Veconlab is somewhat fragile, easily overwritten if the instructor begins a new game.

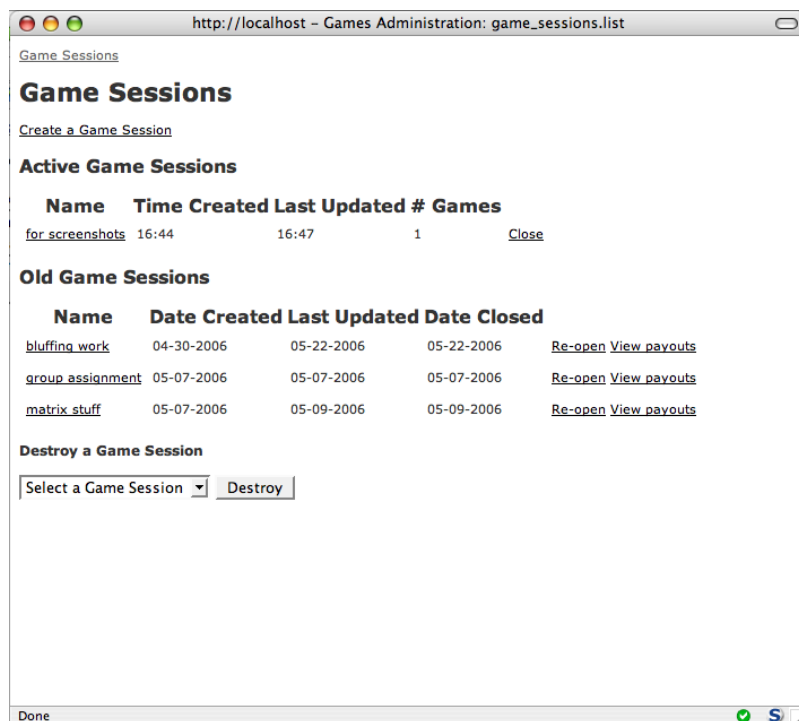
Holt's Veconlab software is far more mature than I could hope to achieve in such a short time. I developed a base, however, that deals with some of the limiting factors of Veconlab. The range of games that Veconlab includes is impressive — I hope that in the future EconGames will allow instructors such choice.

⁹See <http://www.macromates.com>.

¹⁰See <http://subversion.tigris.org>.

¹¹Holt's software can be accessed at <http://veconlab.econ.virginia.edu/admin.htm>. More information can be found at his home page (<http://www.people.virginia.edu/~cah2k/>).

Figure 2: EconGames: List of Game Sessions



4.3 Screenshots

I include here several screenshots of the EconGames system in action. A hands on demonstration would surely be more useful, but I cannot yet install the software in the paper this thesis is written on. Perhaps in the future. [14]

When the instructor enters the **admin** area of the software's web interface, he is greeted by a login page which quickly gives way to a list of the current game sessions (Figure 2). This list also includes the ability to add a new game session. A game session, as I have defined it, is a set of games which will be played by the same group of players at the same time.

After creating or selecting a game session, the user is shown a status screen for the game session. In this example (Figure 3), I have already added a couple of games to the session. Games are quite configurable (Figure 4), with many options to change the way

Figure 3: EconGames: Details of a Game Session

Game Sessions > for screenshots

Details for GameSession for screenshots

Stats
Games 2
Players 2

Games

[Add a Game](#)

Number	Name	Type	Rounds	Players	Configured?	Started?	Complete?	
1	Prisoner's Dilemma	Matrix Game	4	2	yes	yes	no	Results Export Data
2	Rock Paper Scissors	Bluffing Game	3	2	yes	no	no	Configure Remove

Players

[Payouts for all players](#)

Name	IP	Time Logged In	Last Move	
Sean	127.0.0.1	05-22-06 @ 16:47	1176 minutes ago	remove payouts
Other Sean	127.0.0.3	05-22-06 @ 16:47	1176 minutes ago	remove payouts

Inactive Players

Name	IP	Time Logged In	Last Move
------	----	----------------	-----------

Done

they are played. Finally, the results page (Figure 5) shows how a short game's results can be inspected or projected and shown to the players.

My development environment (Figure 6) is easy on the eyes, highly organized, and easy to navigate. TextMate has many handy features built in, many of which are visible in the screenshot.

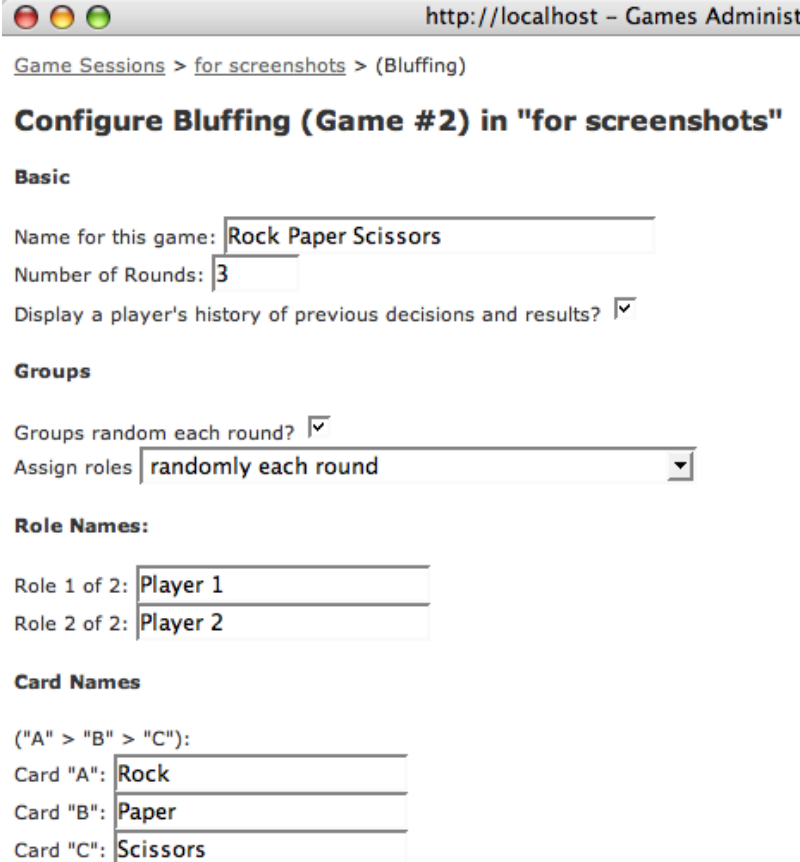
4.4 Documentation

Ruby was designed for code readability. Writing code is not terribly difficult in most languages, but the ability to read another programmer's code is the sign of a well-designed language. I, and a growing number of others, think that Ruby is such a language. It also includes a function for generating nicely formatted and easily navigable html pages from the code itself, called RDoc¹².

In writing the code for the EconGames project, my aim has been that my heir will easily

¹²See <http://rdoc.sourceforge.net> for more information.

Figure 4: EconGames: Configuring a Game



The screenshot shows a web browser window titled "http://localhost - Games Administ". The breadcrumb navigation is "Game Sessions > for screenshots > (Bluffing)". The main heading is "Configure Bluffing (Game #2) in 'for screenshots'".

Basic

Name for this game:

Number of Rounds:

Display a player's history of previous decisions and results?

Groups

Groups random each round?

Assign roles

Role Names:

Role 1 of 2:

Role 2 of 2:

Card Names

("A" > "B" > "C"):

Card "A":

Card "B":

Card "C":

Figure 5: EconGames: Results of a (Very) Short Game

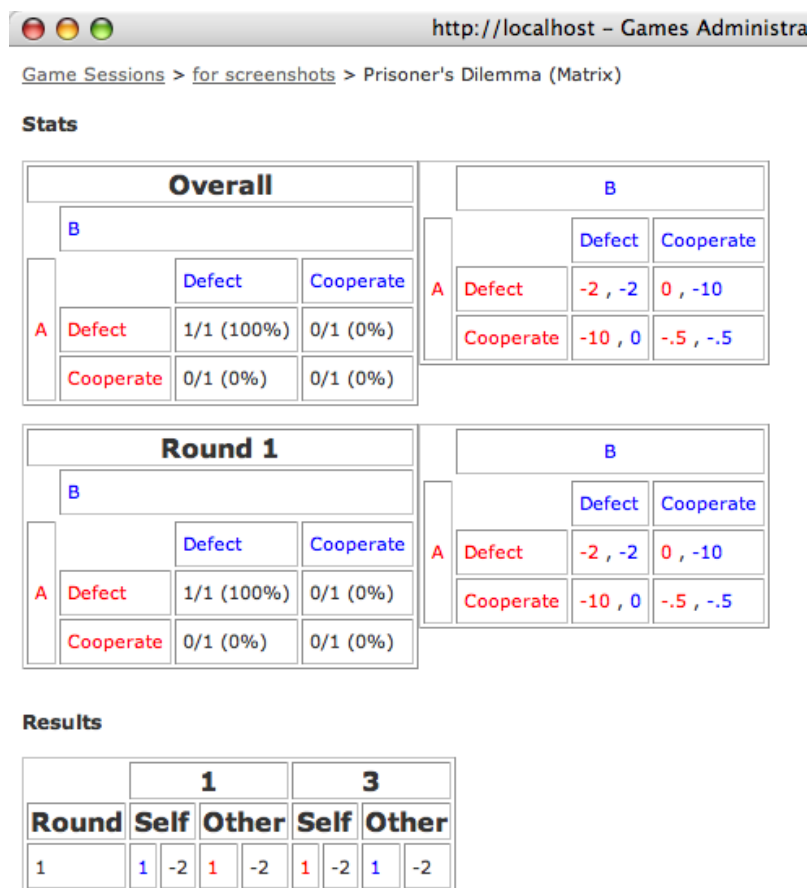


Figure 6: TextMate: Developing EconGames

```

1 class Games::BaseController < ApplicationController
2   ADMIN_AREAS = [:configure, :configuration, :results, :export]
3   before_filter :login_required, :only => ADMIN_AREAS
4   before_filter :player_required, :except => ADMIN_AREAS
5   before_filter :current, :except => ADMIN_AREAS
6   helper "games/base"-
7   layout :layout_logic-
8
9   # This method is here so that empty index methods don't have to be-
10  # defined in each game.-
11  def index-
12  end
13
14  # Load in basic data for game-specific configuration screen.-
15  #
16  # If you want to add to this then insert a method in your game's controller:-
17  #
18  # def configure-
19  #   # stuff you want to do-
20  #   super-
21  # end-
22  def configure-
23    @game = params[:game] ? params[:game] : Game.find(params[:id])
24    if @game.started?-
25      flash[:notice] = "Can't configure a game that has already started.-"
26      redirect_to :controller => "/admin/game_sessions", :action => 'show', :id => @game.g
27    end
28    @roles = {"randomly each round" => "random",-
29             "randomly once, then rotate each round" => "rotate",-
30             "randomly once, then stay the same each round" => "same"}-
31    render :template => "games/base/configure"-
32  end

```

be able to understand how things work. For many of the methods implemented in my code, documentation is not necessary. The code is simple, short, and self explanatory. As much as possible, the method name describes exactly what it does. Where the code is complex and in need of explanation, I have included comments that describe its function.

As with any reasonably sized code base, it will take a newcomer some time to learn how things work together. Ruby and Rails, however, combine to reduce these startup costs significantly. I am confident that the next programmer to work on this project will find it fairly easy to figure out.

4.5 The Future

Several things have not been implemented, due to lack of time, but are certainly possible and should happen in the future. One significant feature would be to allow anyone interested to set up and play games over the internet or possibly even on their own server. Additionally, to allow people to view results or play games against saved choices from previous sessions. Finally, and obviously, to add more games to the system.

4.6 How it Has Been Used

The EconGames system I have developed has been used and tested at various stages of its development in actual economics classrooms. In Winter 2006, various matrix games and some ultimatum games were played over several sessions in an honors introductory microeconomics course. More recently, in Spring 2006, the application was used more heavily. It was used in one session of the introductory microeconomics discussion sections to introduce the students to the Prisoner's Dilemma. This larger use saw mixed results — some sessions went very well, while others suffered from technical or teaching difficulties. Overall, I learned a lot, and I think the students did too. The system was also used several times in Bill Harbaugh's experimental economics class; the students there were exposed to various matrix games, including the Prisoner's Dilemma, ultimatum games, and bluffing games. Next year, there are plans for the continued use of the EconGames system in introductory micro courses and possibly in an introductory game theory course.

In addition to being used as a teaching aid, the EconGames system is being used to collect data for research purposes. In particular, data from matrix games is being used by University of Oregon Ph.D. student Nicholas Muller. Undergraduate David Yaffe has used the system to collect data on decisions in bluffing games for his honors thesis in Economics. Another Ph.D. student, Dan Burghart, plans to develop a game with this framework for his own research. Finally, Bill Harbaugh will continue to use the system as a teaching aid and to develop it for further uses.

5 Conclusion

As I've worked on EconGames I have learned a lot, in several areas:

When I started working on the system I had only a few months of Ruby and Rails experience. I had used Subversion and done a little bit of programming at my other job, but I hadn't yet completed any large projects. In the course of the project, I developed skills that have definitely increased my job opportunities. My experience as a programmer,

when combined with my studies in economics and mathematics, have qualified me for a job as a research assistant at the Federal Reserve Board. I might have been qualified if I hadn't had this experience, but my application wouldn't have been quite so good.

I didn't think of Bill Harbaugh as my client, but in many ways that is what he was. He gave me a set of specifications and I worked to meet them. When something was not possible I explained why and suggested alternatives. We worked together to make the system do what he wanted. It has been fun working with Bill and others as I developed the software, making and fixing mistakes, squashing bugs, and adding features. I enjoy working with others in this way — it's fun and challenging to make a computer do something that someone wants it to do.

Finally, I've learned something about teaching. Seeing this software used in classrooms has given me another perspective on what professors do. I may end up in a teaching position at some point, and this experience furthers my belief that I would like it just fine.

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