A beautiful mind meets free software: game theory, competition and cooperation

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Russel Crowe, playing John Forbes Nash Junior (aka John Nash) in Ron Howards' motion picture *A beautiful mind*, claims that Adam Smith's theory that "in competition, individual ambition serves the common good" is incomplete, and that "the best result will come from everybody in the group doing what's best for himself and the group". Adam Smith's motto synthesizes pretty well what happens in the competition-driven proprietary software development market, whereas Nash's adds the cooperation that is so common even among competitors in free software markets. Every commercial free software developer tries to obtain its edge by developing better software, thus contributing to the software pool that even its competitors will be able to build upon. I.e., every free software developer does what's best for himself, and the group, so the best outcome is achieved. The paper shows how the GNU General Public License (or GNU GPL or simply GPL) licensing model can be economically favorable to developers over proprietary and even Berkeley Software Distribution (BSD)-like licenses.

Key words: Adam Smith. Competition. Cooperation. Game theory.

1 Introduction

John Nash's life was the inspiration for the motion picture *A beautiful mind*, by Ron Howard. Nash (WIKIPEDIA, 2006b), a mathematician, won the Nobel award on economic sciences in 1994, in part because of his work on game theory, a branch of mathematics that uses formal models to study incentive structures, with applications on not only economics, but also evolutionary biology, political science, military strategy, international relation and many others.

The idea for this paper first came up watching a scene from the movie that starts with Nash and three friends at a bar. A gorgeous blond girl with four brunette friends enters, and the friends start debating how they're going to approach them. One of them says they should each one try his best, citing Adam Smith: "In competition, individual ambition serves the common good". Nash has the insight for a revolution in governing dynamics, as the movie calls it, and explains that, if they all go for the blond, they block each other, and none of them gets her. Worse, when they go for the brunettes, another rejection will ensue, because nobody likes to be second choice. However, if they each go for one brunette at first, they don't get in each other's way and don't insult the girls, so they win. "Adam Smith needs revision", he says, because "the best result will come from everybody in the group doing what's best for himself, and the group".

This scene is based on one of the most-widely-known contributions by Nash to game theory, the theory of Nash equilibrium, described in section 2. It also introduces some basic concepts on game theory such as the prisoners' dilemma and the tragedy of the commons. In section 3, we related these game theory concepts with those of software development and licensing models, showing that development under the GPL can be more favorable than proprietary or BSD-like licenses.

2 Game theory

Rational and selfish players are one of the fundamental principles behind game theory (MCCAIN, 1999; TUROCY; STENGEL, 2001; WIKIPEDIA, 2006a). This science branch studies the behavior of players in real-life situations, seeking to explain it with formal models of costs and benefits for the players, in which each player attempts to optimize its payoff. Interestingly, even though real-life players aren't always entirely selfish or rational, such formal models often apply to as disparate situations as economic competition and biological evolution, in which the market or nature, respectively, tend to reward players for the intelligence behind their behavior. The models are useful to reason about strategies, enabling players themselves to make better decisions more easily.

2.1 Prisoner's dilemma

One of the most well-known examples of game theory in action is the prisoner's dilemma (WIKIPEDIA, 2006c), in which two burglars are caught near a crime scene. The police know they committed a crime, but have no evidence, other than a concealed weapon, that they can use in court, and the weapon wouldn't get them convicted for the burglary. In order to get a conviction, the policy offers each of the burglars a deal: if one confesses and testifies against the other, he can go free, and the other will likely go to jail for 15 years. The catch: they cannot talk to each other, and if both of them agree and testify against each other, each one will likely stay in prison for ten years. If none of them agrees to the deal they will likely go to jail for one year each, because of the concealed weapon. Each one must decide how to proceed all by himself.

If both of them act in a rational and selfish way, they will both conclude that the best choice is

		Bob	*
	Jail time	confess	deny
Al	confess	10\10	0\15
*	deny	15\0	1\1

Board 1: Prisoner's dilemma

Source: The author.

to agree to confess and testify against each other. Consider, for example, the prisoner whose payoffs are depicted after the slashes, whose choices are represented by columns in the table. The 0 jail time on the rightmost column is less than 1, should the other prisoner choose to deny, and the ten-years jail time is less than 15 should the other confess, so confessing is a dominant strategy. Since the table is symmetric, it is dominant for both, and they both end up confessing, achieving the worst possible result for the group, a total of 20 years of jail time.

If they could communicate and define a joint cooperative strategy, and if they could trust each other to implement it, they might be able to achieve a better result for both. Since they can't cooperate, and they act in a selfish way, they end up far worse off.

2.2 Tragedy of the commons

Another well-known situation described in game theory is the tragedy of the commons. Commoners use a field to graze cattle, in such a way that the costs to maintain the graze are shared, but value from the cattle, being individual property, is enjoyed by each individual owner.

Since costs are shared by all commoners, they effectively divide the costs of maintaining the graze; since per-cattle value is obtained by its owner alone, the payoff model is such that there's an incentive to increase the number of cattle each commoner owns. Since this increases value for the individual while sharing the cost with all other commoners, it's a dominant strategy that all commoners will tend to follow, thus overusing the common resource to the point of depleting it.

*	Cattle	Value-cost
	n	$k_p n - k_{c_N} \frac{n}{N}$
	$n \quad 1$	$k_p n \quad 1 - k_{c_N \ 1} \frac{n \quad 1}{N \quad 1}$

Board 2: Tragedy of the commons

Source: The author.

The solution to avoid this tragedy is a credible commitment from all commoners to avoid overuse. Such agreements may be self-imposed, such as the Kyoto Protocol, or externally-imposed, such as regulations established by a government over its citizens.

2.3 Nash equilibrium

Not all games can be solved with dominant strategies alone. Going back to the bar scene at the movie, but simplifying it for two players, a single gorgeous blond and two brunettes, we can find a single dominant strategy, even if weakly dominant:

		Male 1	*
	Gets a girl	Brunette 1	Blond
Male 2	Brunette 2	1\1	1\1
*	Blond	1\1	0\0

Board 3: Nash equilibrium

Source: The author.

Going for the blond is dominated by going for the brunette because the payoff for the brunette is greater than or equal to that for the blond, regardless of what the other player plays. This is the insight that Nash's character had at the bar, but it clearly doesn't go as far as the Nash equilibrium theory.

Nash equilibrium is a generalization of dominant strategies, defined as a strategy for each

player such that no single player can increase its payoff by changing only its own strategy. It does indeed cover the solution for the game that the character proposes, but it leaves out the two other Nash equilibriums present in this game, namely, one of them goes for the blond and the others go for brunettes.

Oddly enough, a more accurate modeling of the situation, in which getting the gorgeous blond yields a higher payoff than getting one of the brunettes, leads to two Nash equilibriums that do not match the solution proposed in the movie:

		Male 1	
	Gets a girl, weighted	Brunette 1	Blond
Male 2	Brunette 2	1\1	1\2
	Blond	2\1	0\0

Board 4: Nash equilibrium with maximin problem-solving strategy

Source: The author.

The direct use of the maximin problem-solving strategy that consists in choosing the move that maximizes the lowest possible outcome for the move, leads to the solution in which everybody goes for a brunette, but if the players could cooperate by agreeing on only one of them going for the blond, they could reach a Pareto optimum. This depends on the players' willingness to trust each other to remain faithful to the agreement. Without cooperation or credible commitment, each one would reason that they're better off going for the brunette to avoid the worst-case result.

3 Software development

Software used to be distributed along with computers in the early days of the computer industry. Years later, vendors began to believe they could obtain an edge by not distributing the source code along with the binary programs that accompanied computers they sold. A software industry was then formed around the idea of selling licenses to programs that didn't permit them to be studied, modified, inspected, improved or distributed. In fact, such licenses would even impose restrictions on the execution of the programs. The free software movement started as a reaction against the ongoing trend of licensing more and more software under proprietary terms.

Proprietary software vendors seek a competitive edge by denying users the freedoms to run, study, distribute and improve the licensed software or works derived from it, most often also denying them access to the source code needed to exercise several of these freedoms. Since they consider the source code a trade secret, it is very difficult for them to cooperate. In fact, this very alleged need for secrecy of the source code is their attempt to minimize losses to competitors, requiring any entrants in the market to duplicate all of the effort other competitors have already gone through to get their product to market. But while such secrecy may have been originally regarded as a means to minimize losses to competitors, thus increasing their potential payoff, is it really the case that it maximizes the payoffs? Setting back a competitor does not necessarily lead to an increase in a player's payoff. Nevertheless, proprietary software vendors appear to work under Adam Smith's motto, "Individual ambition serves the common good", a non-cooperative behavior that leads the prisoners to jail for the longest time in the prisoners' dilemma.

BSD-like licenses (those based on or similar to the modified BSD license, without the advertising clause) impose attribution as the single requirement: sharing the code is considered good, cooperation is welcome, and reusing the code even in proprietary software is acceptable, as long as the authors of the original software are acknowledged. Although there is economic incentive to

contribute code back instead of maintaining forks with proprietary improvements, the reasoning that led to keeping additions proprietary may remain, turning such potential contributors into free riders, with a potential outcome similar to the depletion scenario in the tragedy of the commons: the more free riders there are, the fewer contributors there are to improve the common code base.

A credible commitment to steer people away from the free-riding temptation is the GPL, that grants the four freedoms to anyone who receives the software, enabling people to distribute modified copies of the software only if they use the same license, thus extending the freedoms to users of the improved software. By forbidding any third party from turning the software proprietary, the license prevents the creation of proprietary forks. Furthermore, even if a potential contributor chooses to not contribute her changes to the maintainer of the original project, any third party that obtains the modified software may choose to merge the changes upstream. Therefore, most competitors tend to choose to short-circuit this process and contribute the changes themselves, such that they get the credit and goodwill from it. It's still a very competitive marketplace, but competition is enriched with a significant amount of cooperation. As developers contribute their changes to the common code base, all of them get better grounds to build upon, reducing waste of resources, increasing economic efficiency and enabling each vendor to differentiate from others to better serve their chosen market niche starting from a better code base. As Nash's character put it, "The best result will come from everybody in the group doing what's best for himself, and the group".

I believe the GPL is the credible commitment that leads to cooperation and to the best outcome, so let me try to show why. Consider a number of vendors competing for a market niche of a given size, at a given time. Assume that, in this marketplace snapshot, they all offer products, developed from scratch, that are functionally equivalent, but are offered under different licensing terms. Further assume that some of them choose to use proprietary licensing terms, some use a BSD-like license, and some use the GPL.

We can reason that, since the software products are essentially equivalent, the cost to develop them should have been essentially the same, and the market will not concentrate around any single vendor; rather, each vendor should get an essentially identical fraction of the market. Since the market is divided equally, income from this product is the same for all vendors, so those with lower costs will get the highest payoffs.

License	Proprietary	BSD-like	GPL
Costs	$\frac{k}{1}$	$\frac{k}{n_b}$	$\frac{k}{n_g}$

*

Board 5: Cost to develop them should have been essentially the same

Source: The author.

Proprietary vendors tend to not cooperate, and thus incur the entire development costs K by themselves. free software vendors can cooperate, thus dividing their costs among the several vendors n_b and n_g, thus reducing the amount each one has to fork over to get the product ready, even in the presence of redundant efforts. The more contributors there are, the better off free software vendors end up, since the lower their individual costs tend to be.

So far, BSD-like and GPL appear to be equally advantageous, the balance pending to whatever community is bigger. However, since software licensed under BSD-like terms can be relicensed under any other license, the BSD vendors may actually help reduce the costs incurred by proprietary and GPL vendors, since both categories can choose

to reuse BSD software in their products. I.e., the fact that GPL code can use BSD code, but not the other way around, implies that n_g ? n_b and therefore the economic balance tends to favor GPL vendors.

It is true that the scenario above relies on a number of strong assumptions, but I do believe it can be generalized. One of the most critical assumptions is the fact that we're looking at a snapshot of a new marketplace. If we add dynamics to it, we have to factor in many other aspects, such as networking effects, compatibility issues and several others taken into account in (POLANSKI, 2005; JOHNSON, 2002).

A common objection to this model, that is actually not true, is that free software will tend to shrink the total market value, since any entrant vendor can start by taking the existing code base and taking it as a product to market for a nearly-zero cost. Consider than one such vendor won't have any distinguishing feature to increase its market share, other than the low price tag. Acting in a selfish and rational manner, it won't set the cost to zero, but rather right below the price exercised by other vendors, that do incur actual costs to maintain the software. If multiple such vendors try this trick, they may actually succeed in driving the price down to zero, but this would tend to take the real software maintainers out of the market, leaving these entrants in a situation in which they have to do the actual work to satisfy their contractual obligations toward their customers. If they fail and go out of the market as well, the higher-paid competitors get a chance of getting contracts again, if they haven't completely moved on; worst case, customers might end up having to hire individuals or new companies to do the work, increasing the market value again. The bottom line is that bargaining theory will lead the market to an equilibrium in which vendors get for their work an amount they consider reasonable, and customers pay a reasonable amount for such work.

Final considerations

Choosing the GPL can be the best choice not only for software users, for working against the formation of monopolies and unfair pricing; it can also be a dominant strategy, in the game-theoretical sense, for software developers and vendors, enabling them to share development costs and to achieve a better overall economic efficiency while still being fairly paid for their services.

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