Crafty

Dynamic vendor pricing in computer role-playing games.

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ABSTRACT

In traditional computer role-playing games (CRPGs), vendors are merchants who trade with players. Until now, these games have used vendors with static pricing or extremely simple pricing models, and this has hindered player immersion. In an effort to solve this problem, we present *Crafty*, a tool allowing developers to easily implement dynamic pricing mechanics for their games' vendors. *Crafty* studies player demand and chooses prices so as to maximise the profit. It thus allows CRPGs to be populated by vendors with intelligence, personality and intent, while requiring minimal effort by developers. Play-testing results show that players perceive such vendors more as fellow characters than as vending machines, improving the experience of the role-play.

1. BACKGROUND

Non-player characters (NPCs) serve four main roles in a CRPG: combat opponents, allies, dialogue partners and vendors. The first three of these roles, while still not perfect, have been well researched and many libraries and tools are available to help implement such characters in rich and believable ways. Good A.I. for vendors, however, is severely lacking.

An extensive study of RPG players[3] found that there are eight key factors that must exist in any role-playing game for it to be satisfying, and three of these – a requirement for strategic thinking, competition and mental challenge – relate to the intelligence of NPCs as opponents. While combat is the most obvious platform for competition, trade is also a strategic element that can benefit from an intelligent adversary. However, as trading games, most CRPGs have unsophisticated gameplay that has developed little from the early days of the genre. Surveying recent titles of all game genres, we have identified three prominent models: 1) static pricing, 2) inflationary pricing, and 3) free markets.

Static pricing is the most common model used. Vendors have fixed prices and trade at those values for the entire duration of the game, regardless of what the player does. In terms of both character and gameplay, static vendors are dull. They operate mechanically and show no intelligence or personality. A common game dynamic that arises from this model is *junk harvesting*. For realism, many modern CRPGs contain a wealth of junk items that have no use to the player but can often be sold for a small amount of money. Players can amass significant wealth by collecting and selling this junk. The result of this dynamic is hyper-deflation, making all purchase decisions meaningless.

To counteract this problem, some games have introduced economies with inflationary pressure. For example, *Age of Empires II: the Age of Kings* allows players to buy and sell three of the game's resources for gold. As one player purchases a resource, both the buying and selling prices for that resource increase for all players. Similarly, as resources are sold, the prices decrease. This model offers more entertaining game-play, considering the opportunities that competition for shared resources can give to a game[5]. However, an issue with unchecked inflation is that popular goods are priced out of the market. Valuable consumables are only ever bought and not sold, so their prices will continue to increase until no-one is able to afford them. When implemented in *Counter-Strike Source* this system yielded a number of complaints about players essentially being punished for using their favourite weapon[2].

In massively-multiplayer games such as *Eve Online* the vendor problem has been addressed by abolishing vendors and giving the players complete control. Players produce their own resources and trade amongst themselves, setting prices as they see fit on an open market. From a role-play perspective, this is an excellent solution. No A.I.-controlled NPC is going to be as convincing a vendor as another self-interested player. From a game-play perspective it also eliminates the free-money loopholes and creates a sophisticated trading system. The disadvantages are that it requires a large number of players to maintain, and that it takes control of the economy out of the designer's hands. For some players it can also make trading too serious and full-time. Players who cannot make the investment to infiltrate the cartels that control the market are left out in the cold.

2. CRAFTY

To solve these problems, we need a tool that (a) provides the illusion of intelligent vendor characters, and (b) provides interesting trading gameplay. To gain wide usage it should also be easy to integrate into the existing code-base of a game and should provide designers with a simple set of parameters which provide a rich design-space.

We present *Crafty*, a tool that developers can use with their game engines to store and control vendor pricing and product data. It provides a library of economic models for determining the prices at which to sell items to and purchase items from the player. Each model is parameterised to allow the creation of a variety of vendor characters, making them greedy, generous, conservative, experimental, or highly reactive. The tool is implemented as a C++ class library to allow for easy integration with new and existing code-bases.

Crafty provides three models for dynamic price control: *linear*, *geometric* and *trend*. The first two of these are simple inflationary models as discussed above. The linear model responds to any sale or purchase by increasing or decreasing the price by a fixed amount. The geometric model works similarly to the linear model, except prices are scaled by a fixed rate, so that price fluctuations are proportional to the total value. The third is a more complex model which attempts to estimate the demand curve for each product and set prices to maximise profits, as follows.

2.1 Trend model

The trend model was designed to address the weakness of inflationary models: the tendency for prices to increase until the product is no longer worth buying. Rather than increasing or decreasing prices arbitrarily, it attempts to model a rational agent who sets his prices to maximise his profit. This model studies the transaction history of an item, and estimates player demand for it in order to find the optimal, most profitable price at which to offer the item for sale.

We assume that each product has a base price P_{base} which represents its production cost. This must be artificially introduced, as in a game environment, items can be created or destroyed by the game engine at no cost, and if this fact is reflected in a game, it will remind the player that he is dealing with an artificial environment[1]. For any transaction, the profit margin p is given by

$$p = P_{sell} - P_{base} \quad \text{or} \quad p = P_{base} - P_{buy}$$

for vendor sales and purchases, respectively. P_{buy} indicates the price at which the vendor will buy a product and P_{sell} the price at which they sell it.

To maximise a vendor's profit we need to estimate the demand functions $Q_{buy}(P)$ and $Q_{sell}(P)$ which indicate how much of a product the vendor is likely to buy or sell at a given price P. These demand functions give an estimate of the expected transactions per minute of gameplay.

For each product we keep a *demand schedule*, recording the profit margin p and number of transactions per minute q at each price point. Separate tables are kept for sales and purchases. Linear regression is used to fit a straight line to this set of data, providing an estimate of our linear demand functions Q_{buy} and Q_{sell} in terms of the profit margin p.

Profit will be maximised at the midpoint of the linear demand curve, that is, the midpoint of the interval bounded by the two axes[4], as in Figure 1. This is because the rectangle bounded by this midpoint and the origin will have the maximum area of any rectangle under the curve, representing the maximum total expected profit. The profit margin corresponding to this midpoint is half the p-intercept, or:

$$p = -\frac{b}{2m}$$

where m is the gradient and b is the q-intercept. The trend model uses this optimal profit margin as a positive and negative offset from P_{base} to compute the official vendor purchase and sale prices respectively.

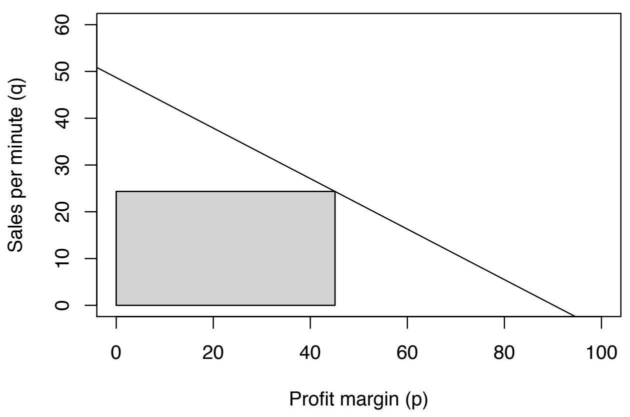

Figure 1: Optimal profit margin at the midpoint of the interval between $p = 0$ and the p-intercept of the demand curve. The rectangle represents the total expected profit.

2.1.1 *The demand schedule*

The demand schedule is a list of all previous sales and purchases with prices attached, windowed with a time cut-off provided by the designer. In some circumstances, it is not possible to obtain meaningful regression calculations for the demand curves. The set of data may be insufficiently populated, or it may not regress to a usable demand curve due to unusual market activity. In such cases *Crafty* reverts to a back-up model: one of the simpler models, as chosen by the designer. When sufficient data have been collected to allow a meaningful regression calculation for both the purchase and sale prices, the trend model again takes over.

3. PLAY-TESTING

Play-testing was performed by 13 people on *Choria*[6], a simple multiplayer CRPG. Three versions of the game were played: one unmodified, one using *Crafty*'s geometric model, and one using *Crafty*'s trend model to determine vendor prices. We did not use the linear model as vendors in *Choria* sell many items with a wide variety of base prices, which would make price changes disproportionate. In all three versions of the game, players were instructed to stockpile as much gold as possible.

We sought data illustrating the extent to which the modification of vendors influenced players' trade behaviour, as well as their opinions of the intelligence, intent, and ultimately characterisation of vendors who utilised a dynamic pricing mechanic, compared to their static counterparts.

Different vendors were given different *Crafty* options in an attempt to imitate certain behavioural traits. In order to simulate varying levels of greed, we changed the proportional difference between vendors' purchase and sale prices. A generous vendor sold products for 1.5 times the price at which he purchased them, while a greedy vendor charged 3 times the price. We also tried to imitate a trait of vendors

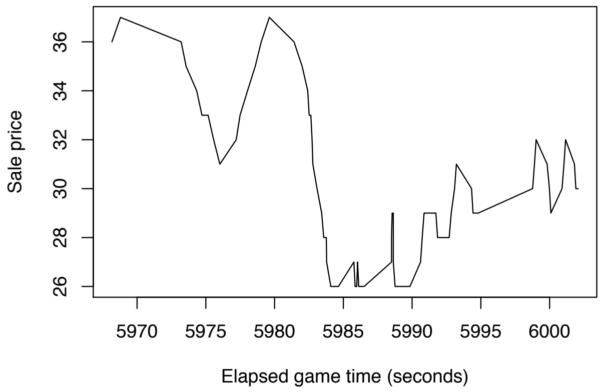

Figure 2: Sale price of health potions during the trend model play-test. Initially, the geometric model is being used as the backup model. From 5985 seconds onwards, the trend model is being used.

being highly reactive and erratic, such that they potentially changed their prices by a substantial amount very quickly, compared to a conservative vendor, who only changed prices by small amounts at once, if at all.

3.1 Results

3.1.1 Character and Intent

Players were asked to rate their perception of vendors from 0 to 10: whether they saw them more as tools to provide trading mechanics to the player (0), or rather as characters in the game world (10). Vendors in the geometric model averaged 1.86 points higher than unmodified version (std. dev. 1.95), and 2.50 points in the trend model (std. dev. 1.87). A paired t-Test shows that both dynamic models yielded significantly higher ratings for than the static model ($p < 0.025$ in both cases) but shows no significant difference between the two dynamic models.

When asked to qualitatively describe the vendors' intent, players found the geometric model easier to understand than the trend model. They reported that the former was predictable and gave them the opportunity to time their transactions and shop around to find a good offer. Prices fluctuated in large waves as market trends movevd between players preferring to buy or sell items. An example can be seen in the first half of Figure 2, which illustrates the smooth, predictable changes of prices during the play-testing.

In the trend model, players couldn't identify the system used to determine prices. Many could see that early prices followed the geometric model but would later begin to oscillate around a seemingly arbitrary value. An example of this can be seen in the second half of Figure 2, which shows the more erratic nature of the trend model. Prices remain close to a steadily increasing value, suggesting increased demand for the product. Players felt they could not rely on vendors, and had to be more careful about their transactions. They shopped around, waited for good prices and sometimes traded with vendors for profit. Vendor unpredictability also made players more averse to trading. Nevertheless, most players correctly speculated that vendors had an overarching intent to make as much money as possible.

When asked to assign character traits to vendors, the level of greed with which they were programmed was identified by players quite easily: vendors with large differences between purchase and sale prices were labeled as "greedy" and "unfriendly", while vendors with small price differences were called "reasonable" and "friendly". Other traits were not identified as frequently, but some players labeled vendors who changed their prices significantly as "fickle", "unreliable" and "erratic", while vendors who only made small adjustments were called "sane" and "familiar".

3.1.2 Game enjoyment

Players were asked to enumerate their enjoyment of each version of the game, from 0 to 10. Players rated the game with the geometric model an average of 1.29 points higher than the unmodified game (std. dev. 1.11). Players rated the game with the trend model 2.00 points higher than the unmodified game (std. dev. 1.26). A paired t-Test shows that both the geometric and trend models resulted in significantly higher enjoyment ratings than the static model ($p < 0.025$ in both cases) but shows no statistically significant difference between the two dynamic models.

4. CONCLUSION

Playtesters felt that the use of *Crafty* made vendors act more like the characters they were supposed to be portraying in the role-play. By trying to maximise their profits within constraints that were carefully chosen to ensure competitiveness, vendors were believable as greedy merchants, while promoting competitive trade between players. This, in turn, caused players to instinctively play their part as a customer in a fashion in line with their own characters; an unexpected result. They tried to make improvements while limiting their losses, and sometimes traded with vendors for profit. They considered their transactions more carefully and viewed vendors with a moderate level of suspicion. This shows that by increasing the realism of vendor trade behaviour with respect to the role-play, the corresponding player behaviour will follow suit, making their experience more consistent with the likely behaviour of their character in the fantasy.

5. REFERENCES

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